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EXPANDING AND ACCELERATING THE DEPLOYMENT AND USE OF CARBON CAPTURE, UTILIZATION, AND SEQUESTRATION

HEARING

BEFORE THE

COMMITTEE ON ENVIRONMENT AND PUBLIC WORKS UNITED STATES SENATE

ONE HUNDRED FIFTEENTH CONGRESS

FIRST SESSION

SEPTEMBER 13, 2017

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EXPANDING AND ACCELERATING THE DEPLOYMENT AND USE OF CARBON CAPTURE, UTILIZATION, AND SEQUESTRATION

WEDNESDAY, SEPTEMBER 13, 2017

U.S. SENATE,
COMMITTEE ON ENVIRONMENT AND PUBLIC WORKS,
Washington, DC.

The committee met, pursuant to notice, at 10:04 a.m. in room 406, Dirksen Senate Office Building, Hon. John Barrasso (chairman of the committee) presiding.

Present: Senators Barrasso, Carper, Inhofe, Capito, Boozman, Fischer, Rounds, Ernst, Sullivan, Whitehouse, Merkley, Gillibrand, Booker, Markey, Duckworth, and Harris.

OPENING STATEMENT OF HON. JOHN BARRASSO, U.S. SENATOR FROM THE STATE OF WYOMING

Senator BARRASSO. Good morning. I call this hearing to order.

Today we are here to discuss promising technologies that both advance environmental aims and support continued use of our abundant energy resources. Those technologies are known as carbon capture, utilization, and sequestration, or CCUS.

In Wyoming we have tremendous coal, natural gas, and oil resources. These resources fuel our State's economy. CCUS presents a win-win opportunity. Here is the concept. Instead of releasing the carbon dioxide into the atmosphere when we combust fossil fuels, CCUS allows us to turn the carbon dioxide into a useful commodity. Through this technology, carbon dioxide is captured, where the fuel is burned, such as a power plant, and then transported, used, and ultimately stored.

One key use for this carbon captured dioxide is enhanced oil recovery. Enhanced oil recovery operations, also known as EOR, are operations that use carbon dioxide, and they have been around for more than 40 years in the United States. CO_2 is injected into wells that otherwise economically couldn't produce oil. By capturing the carbon dioxide, we have an opportunity to increase the supply of carbon dioxide available for enhanced oil recovery and produce oil that otherwise could not have been harvested.

The colored map on this area show all of the oil basins where carbon dioxide-enabled enhanced oil recovery could be further used. As you can see, there are areas all over the United States.

CCUS and enhanced oil recovery should play an important role in a truly all-of-the-above energy policy. With CO_2 enabled oil recovery, we do have a win-win situation; we have the potential to make it economical, to extract more than 60 billion barrels of oil in this Country. And in producing the oil, billions of tons of carbon dioxide would then be stored, which would lead to a significant decrease in carbon dioxide emissions into the atmosphere.

The International Energy Agency estimates that the technology could enable the storage of 140 billion tons of carbon dioxide in oil reservoirs all around the world. The Clean Air Task Force recently reported that using carbon dioxide captured through CCUS "can result in a 63 percent net reduction in carbon dioxide emissions for every barrel of oil produced." This is an impressive number and one that should grab all of our members' attention.

America is currently a leader in CCUS technology, and we want to keep it that way. Use of fossil fuels globally is projected to increase over time. The U.S. Energy Information Administration predicts global increases in coal use through 2040. Encouraging American innovation is the right approach to continuing American leadership, leadership in the development of technologies to lower the emissions associated with fossil fuel use. Through American leadership we create opportunities to export our innovations around the world.

My colleagues on both sides of the aisle recognize the critical role that CCUS can play in our future. This Congress, Senator Capito, Senator Whitehouse, and I were original cosponsors of bipartisan legislation introduced by Senator Heitkamp known as the FUTURE Act, or the Furthering carbon capture, Utilization, Technology, Underground storage, and Reduced Emissions Act. The FUTURE Act extends and expands tax credits for facilities with CCUS technologies, and I am proud to say the bill now has over 24 bipartisan cosponsors.

This Committee has an opportunity to complement the FUTURE Act through our efforts by reviewing statutes and regulations that impact carbon capture, utilization, and storage. Now is the time to see what more we could do to encourage and remove impediments to the use and deployment of CCUS. We need to make sure our laws and regulations accelerate, not hinder, our environmental goals.

I look forward to working with members of the Committee in a bipartisan way to examine how we can expand and accelerate CCUS deployment and use. When we do that, we promote American leadership in technology innovation, increase our energy security, and improve our environment.

I would now like to invite the Ranking Member for his testimony.

OPENING STATEMENT OF HON. THOMAS R. CARPER, U.S. SENATOR FROM THE STATE OF DELAWARE

Senator CARPER. Thanks, Mr. Chairman.

You know, we never say, I want to work in a partisan way; we always say we want to work in a bipartisan way. We oftentimes work in a partisan way, but we always say we want to work in a bipartisan way, and this is one where we can work in a bipartisan way.

Ironically, one of the first people I ever talked with about clean coal technology was Robert Byrd, who was from my native State of West Virginia for many years. He was not born there, but certainly grew up there and served them forever. I had breakfast this morning with Ann Barth, who for many years was a State director. One of the things we talked about was the efforts going on in West Virginia to try to diversify the economy and she gave me encouraging reports. So this is rather timely, and I am channeling Robert Byrd this morning as we convene, Mr. Chairman, for this hearing.

I want to say to our witnesses, good to see you all. We welcome you to this important hearing and we welcome your efforts to help enable us to work in a bipartisan way.

It is refreshing to have a hearing that looks at solutions to climate change, as opposed to a hearing that fuels the debate over the science of climate change. And I believe one of the most important roles for our Government, and my colleagues have heard me say this more than a few times, is not to create jobs, but to create a nurturing environment for job creation.

Another critical role is to help protect public health and try to ensure that all Americans can pursue life, liberty, and happiness; and luckily the two are not mutually exclusive.

I spent the early years of my life growing up in communities in West Virginia whose economies depended largely on coal, and for a short time I was the son of a coal miner. Many years later I am now a U.S. Senator who is privileged to represent the lowest lying State in our Nation, that is Delaware. But I haven't entirely forgotten my roots.

I have long believed that the deployment of technologies that allow us to burn coal and electric power generation in a much cleaner way, with significant reduction in emissions, can be a real win-win for coal communities, for manufacturing, and for our climate.

Today our Country is in the midst of a clean energy revolution, as we know. Didn't happen by accident. Over the last 8 years, starting with the Recovery Act, the Federal Government has provided economic incentives and environmental targets to encourage investments in clean energy.

As a result, $507 billion have been invested in the clean energy sector over the past 10 years and our Country is a leader today in exporting clean air and clean energy technology. Thanks in part to these investments in clean energy and energy efficiency, American consumers are paying less for energy today and jobs are being created here at home to produce these clean energy technologies.

Following 8 years of smart economic and environmental policies, America has largely rebounded from one of the greatest economic downturns in our history, the Great Recession. Until last week, we have enjoyed lower energy costs at the meter and the pump for consumers, and we implemented clean air protections that protect public health and our climate, while adding some 16 million jobs over the past 6 years. Not too shabby when compared to the 6-years that preceded it.

However, as we know, not all of our communities have felt the benefits of the clean energy economic boom. Too many of our manufacturing plants remain dormant in States across the Country, and a number of them can be found in my State of West Virginia and my current home State of Delaware, and the States of all of us, I suspect, all around this table. In addition, many of our coal mines and coal-fired utilities are continuing the decades long trend of closing or reducing production.

Investments in carbon capture and storage can help slow or reverse this trend. These investments can lead to good paying American jobs in engineering and design, as well as manufacturing, installing and operating technology that is made in America and sold all over the world. Investments in this technology are also critical if we are going to meet our long-term climate goals.

But just as with other coal-related technologies, the barriers to carbon capture and storage are largely financial, not environmental. Investors have shied away from expensive large-scale carbon capture projects in part because energy prices are low, and this Country has struggled to put a price on carbon usage. The reluctance of investors to invest is not because we require that sequestered carbon stays sequestered, or that these operations meet other basic and important environmental requirements.

Walking away from climate and clean air protections has only compounded the problem. As a result, we are well on the way of ceding the economic opportunities of carbon capture technology to other countries, such as China, which only hurts the very communities that our President and I think all of us want most to help.

So, in closing, let me reiterate that we don't need to scrap our environmental standards to provide a nurturing environment for American innovation and economic investment in carbon sequestration technologies. They are not mutually exclusive.

With that, we welcome our witnesses. We look forward to hearing from you and having a robust conversation. Thank you all.

[The prepared statement of Senator Carper follows:]

Opening Statement of Senator Tom Carper
EPW Full Committee Oversight Hearing on "Expanding and Accelerating the Deployment and Use of Carbon Capture, Utilization, and Sequestration"
September 13, 2017

Mr. Chairman, thank you for convening this hearing today, and thank you to our witnesses for joining us.

It is refreshing to have a hearing that looks at solutions to climate change, as opposed to a hearing that fuels the debate over the science of climate change.

I believe one of the most important roles for government is to create a nurturing environment for job creation and job preservation. Another critical role is to help protect public health and try to ensure that all Americans can pursue life, liberty and happiness. Luckily, these two are not mutually exclusive.

I spent the early years of my life growing up in communities in West Virginia whose economies depended largely on coal. For a short time, I was the son of a coal miner. Many years later, I am now a U.S. Senator who is privileged to represent the lowest-lying state in our nation; however, I haven't entirely forgotten my roots.

I have long believed that the deployment of technologies that allow us to burn coal in electric power generation in a much cleaner way with significant reductions in emissions can be a real win-win for coal communities, for manufacturing and for our climate.

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As a result, $507 billion dollars have been invested in the clean energy sector over the past ten years, and our country is a leader in exporting clean air and clean energy technology.

Thanks in part to these investments in clean energy and energy efficiency, American consumers are paying less for energy today, and jobs are being created here at home to produce these clean energy technologies.

Following eight years of smart economic and environmental policies, America has largely rebounded from one of the greatest economic downturns in our history. Until last week, we've enjoyed lowered energy costs at the meter and the pump for consumers, and we've implemented clean air protections that protect public health and our climate, all while adding 16 million jobs over the past six years. Not too shabby when compared to the six years that preceded it.

However, as we know, not all of our communities have felt the benefits of this clean-energy economic boom. Too many of our manufacturing plants remain dormant. In fact, a number of them can be found in my home state of Delaware, as well as in the states of many of us who are members of this committee. In addition, many of our coal mines and coal-fired utility plants are continuing the decades-long trend of closing or reducing production.

Investments in carbon capture and storage can help slow or reverse this trend. These investments can lead to good paying American jobs in engineering and design, as well as in manufacturing, installing and operating technology that is made in America and sold all over the world. Investments in this technology are also critical if we are going to meet our long-term climate goals.

But, just as with other coal-related technologies, the barriers to carbon capture and storage are largely financial –not environmental.

Investors have shied away from expensive, large-scale carbon capture projects, in part, because energy prices are low, and this country has struggled to put a price on carbon usage. The reluctance of investors to invest is not because we require that sequestered carbon stay sequestered or that these operations meet other basic and important environmental requirements.

Walking away from climate and clean air protections has only compounded the problem. As a result, we are well on the way to ceding the economic opportunities of carbon capture technology to other countries, such as China, which only hurts the very communities that our President says he wants to help the most.

In closing, let me reiterate that we don't need to scrap our environmental standards to provide a nurturing environment for American innovation and economic investment in carbon sequestration technologies. They are not mutually exclusive.

With that said, I look forward to hearing from our witnesses on how we might be able to work together to create a win-win situation. America could us a few of those right now!

Senator BARRASSO. Thank you very much, Senator Carper.

We have, to testify today, Dr. Julio Friedmann, who is the Distinguished Associate of the Energy Futures Initiative; Mr. David Greeson, who is the Vice President of Development for NRG Energy; and, in addition, we have Mr. Matt Fry, who is the Policy Advisor of the Office of the Wyoming Governor, Matt Mead.

Before turning to you, Mr. Fry, I just want to point out that Mr. Fry has a distinguished career in the natural resource field, spanning approximately 20 years, including time in the private and public sectors. He served as a staff biologist at the Wyoming Game and Fish Department before assuming his current role in Governor Mead's office as a policy advisor.

Mr. Fry has a Bachelor of Science degree in biology, with a minor in chemistry, and a Masters in Natural Resource Law from the University of Denver in the Sturm School of Law.

While he is a native of Virginia, we are glad he has chosen to make Cheyenne his home. His work in Governor Mead's office includes management of the Wyoming Pipeline Corridor Initiative. The Initiative is a first of its kind endeavor by a State to encourage and facilitate the development of a CO_2 pipeline corridor.

I commend Mr. Fry for his leadership on this Initiative and look forward to his testimony.

I remind all of the witnesses that your full written testimony will be made part of the official hearing record, so please try to keep your statements to 5 minutes; that way we might have time for questions. We look forward to hearing your testimony.

Mr. FRY.

STATEMENT OF MATT FRY, POLICY ADVISOR, OFFICE OF GOVERNOR MATT MEAD

Mr. FRY. Good morning, Mr. Chairman, members of the Committee. Appreciate the opportunity to talk with you all this morning about CCUS.

Mr. Chairman, as you are well aware, Wyoming is heavily dependent upon the development of fossil fuels. Coal, oil, natural gas are responsible for approximately 65 percent of our State's revenue. A number of factors in recent years have led to the decline in these industries. As a result, State coffers have shrunk and our citizens find it more and more difficult to obtain stable, profitable employment. In order to address these issues, Governor Mead has spearheaded a number of initiatives, with carbon capture, utilization, and storage, or CCUS, playing a major role.

The deployment of CCUS technology is of great importance not only to Wyoming, but to the Nation as a whole. CCUS provides us with the opportunity to treat CO_2 as a valuable commodity, rather than an end-product with no value. However, there are substantial challenges associated with its implementation. We recognize these challenges and are working diligently to manage them head-on.

Development of infrastructure requires myriad regulatory review processes and approvals. The most costly and time-consuming of these regulatory processes is the one dictated by the National Environmental Policy Act, or NEPA. NEPA analyses historically were completed in relatively short timeframes and at acceptable costs. Unfortunately, in recent years they have evolved in such a way that they may now take upwards of a decade and tens of millions of dollars to complete. From a project proponent's perspective, this drawn out process creates a number of problems, which I have illustrated in my written testimony.

So I am not here this morning to suggest that NEPA be abolished or even significantly amended. NEPA is meant to function merely as a procedural law, which requires that impacts of a proposed action and alternative actions be disclosed for the purposes of informing a decision. The fundamental basis of the law has eroded, which has led NEPA to be utilized in a prescriptive manner, and to a large extent it has become a tool to either defend or inform litigation. I suggest we take a step back and return the process to its original intent.

While this recommendation sounds simplistic, the reality is that it will require a significant paradigm shift, as well as cultural changes. Reversing the inertia of NEPA's current course will require significant leadership, and I submit that this Committee is eminently qualified to undertake and accomplish this goal.

Additionally, I suggest a foundational change to the NEPA process. NEPA requires a specific sequence of actions to reach a final decision. It has been my experience that far too many resources are devoted to these formal steps and not nearly enough work is done on the front end of these projects in order to build a strong base.

There are a number of agency activities that occur behind the scenes to prepare for the NEPA process. Unfortunately, Federal agencies don't effectively reach out to other entities that are oftentimes much more knowledgeable and may have far greater insight into potential constraints that inevitably lead to delays. Adding this outreach on the front end will undoubtedly reduce time and resources required to reach a decision.

In Wyoming, we are actively developing a project that exemplifies this effort to build a strong foundation in order to minimize future analysis requirements. We call it the Wyoming Pipeline Corridor Initiative, or WPCI. WPCI is a sound strategy to streamline the NEPA process for pipeline infrastructure without compromising the integrity of the Act or its processes. While developing this project proposal, we coordinated with industry, local State and Federal agencies, non-governmental organizations, individuals that have intimate knowledge of the lands within our borders, and other authorities with experience in the CO_2 -EOR industry.

One of the primary purposes of the pipeline network is to connect oil fields suitable for EOR with CO_2 sources. Once we complete our EAS and authorization is approved, companies will be able to build their infrastructure within the corridors and reduce time and reduce costs, as will have already dedicated State resources to completing the bulk of the NEPA analysis.

I provided a third description of the WPCI and all of its benefits in my written testimony, but to highlight just a few: WPCI will spur the development of up to 1.8 billion barrels of oil, while potentially storing 20 trillion cubic feet of CO_2 ; WPCI will provide a large number of jobs for those building, maintaining, and operating pipelines and EOR fields; and WPCI provides a balanced approach of natural resource utilization and environmental conservation.

We currently are anxiously awaiting the approval from BLM to begin our NEPA process and, once finalized, WPCI can serve as a model that could be followed by any States interested in streamlining the NEPA work.

Once again, I appreciate the opportunity to present this testimony today, and I would be happy to answer any questions. Thank you.

[The prepared statement of Mr. Fry follows:]

Testimony of Matt Fry
Policy Advisor to Wyoming Governor Matt Mead

Before the U.S. Senate Committee on Environment and Public Works

September 13, 2017

Mr. Chairman and Members of the Committee,

I appreciate the opportunity to testify before the Committee today. My name is Matt Fry and I serve as a Natural Resource Policy Advisor to Wyoming Governor Matt Mead. I have worked in the natural resource management and planning fields, both public and private sectors, for approximately 20 years. I look forward to relating the challenges and opportunities associated with regulatory processes required for carbon capture, utilization and storage (CCUS) deployment, and specifically carbon dioxide (CO_2) transport and the necessary development of pipeline infrastructure.

Wyoming is heavily dependent upon the development of fossil fuels. Coal, oil, and natural gas are responsible for approximately 65% of our state's revenue. A number of factors in recent years have led to the decline of these industries. As a result, state coffers have shrunk and our citizens find it more and more difficult to obtain stable, profitable employment. While we are not here to debate the merits of climate change, the reality is that regulations to reduce climate impacts have had an effect on Wyoming. In order to address this issue, while preserving our economy, Governor Mead has spearheaded a number of initiatives, with CCUS playing a major role.

The deployment of CCUS technology is of great importance not only to Wyoming, but to the nation as a whole. CCUS provides us with the opportunity to treat CO_2 as a valuable commodity, rather than an end product with no value. However, there are substantial challenges associated with its implementation. These include rigorous and costly regulatory processes, lack of federal and state policies that incentivize CCUS, minimal financial certainty for prospective project developers, and a number of other factors that we may not have time to discuss today. Under the leadership of Governor Mead, we recognize these challenges, and are working diligently to address them head-on. The State of Wyoming does not have all of the answers, but based on our work, I do believe we can present several opportunities to reduce regulatory challenges.

Regulatory Challenges

Development of infrastructure projects requires myriad regulatory review processes and approvals. A typical pipeline project in a single western state, with mixed federal, state, and privately owned lands may require upwards of 30 reviews, permits, and approvals from federal, state, and local authorities. If a proposed project were to cross multiple states, this number would increase accordingly. While the combination of these regulatory reviews is onerous, they are all required by various laws and regulations.

Many of these regulatory processes are not difficult to complete, but some are tremendously rigorous. Without question, the most costly and time consuming of these regulatory processes is the one dictated by the National Environmental Policy Act (NEPA). NEPA analyses historically were completed in relatively short timeframes and at acceptable costs. Unfortunately, in recent years, they have evolved in such a way that they may now take upwards of a decade and tens of millions of dollars to complete. From a project proponent's perspective, this drawn out process creates a number of problems. One of the most significant challenges is commodity price instability. Markets are dynamic, which means a proponent may propose a pipeline project at a particular commodity price and as the NEPA process proceeds, that price may change drastically. This adversely affects the original economics and potentially undermines the viability of projects, including CO_2 pipelines and projects that reduce carbon emissions and provide additional environmental benefits.

As an example, Denbury Resources submitted a right-of-way (ROW) application for the Riley Ridge to Natrona Pipeline project in February 2013. This project is intended to transport CO_2 from a source in western Wyoming to an interconnect facility in central Wyoming, for the purposes of use in enhanced oil recovery (EOR). At the time of their application, oil prices were approximately $105/barrel. After 4 ½ years of NEPA review, and with a current oil price of roughly $45/barrel, the Draft Environmental Impact Statement (EIS) has not yet been released for public comment. While there are a number of reasons for this, the reality is that this timeline has significantly delayed implementation of this project at significant cost to the project proponent, and the state and federal governments that stand to benefit from anticipated revenues from taxes and oil royalties.

Regulatory Solutions

I am not here this morning to suggest that NEPA be abolished, or even significantly amended. As you are aware, the National Environmental Policy Act of 1969 was enacted to fulfill a specific set of purposes, as described below:

- *Sec. 2 [42 USC § 4321]. The purposes of this Act are: To declare a national policy which will encourage productive and enjoyable harmony between man and his environment; to promote efforts which will prevent or eliminate damage to the environment and biosphere and stimulate the health and welfare of man; to enrich the understanding of the ecological systems and natural resources important to the Nation; and to establish a Council on Environmental Quality.*

To fulfill its purposes, NEPA is meant to function merely as a procedural law, which requires that impacts of a proposed action, and alternative actions, be disclosed for the purposes of informing a decision. This fundamental basis of the law has eroded, which has led to NEPA being utilized in a prescriptive manner and to a large extent it has become a tool to either defend or inform litigation. I suggest that we take a step back and look at the enabling legislation that created NEPA and return the process to its original intent. I do not believe that we need to reinvent the wheel, rather I think we just need to make it round again. While this recommendation sounds simplistic, the reality is that it will require a significant paradigm shift as well as cultural changes. Reversing the inertia of NEPA's current course will require significant leadership, and I submit that this committee is eminently qualified to undertake and accomplish this goal.

Additionally, I suggest a foundational change to the NEPA process, which could either be achieved by legislative action, or through informal agency actions (e.g. manual updates, internal memoranda, etc.). NEPA requires a specific sequence of actions in order to reach a final decision. This process is initiated by a Notice of Intent and Scoping, then the Draft EIS is released for public comments. After comment review and edits, agencies release the Final EIS, and finally the Record of Decision and Agency Action. It has been my experience that far too many resources are devoted to these steps and not nearly enough work is done on the front end of projects in order to build a strong base. To illustrate my point, none of us want to live in a house that was built on a weak, structurally deficient foundation. This inevitably leads to schedule delays and increased costs on the back end. The same can be said for the NEPA process and the resulting environmental analysis.

There are a number of agency activities that occur behind the scenes to prepare for the NEPA process, one of which is "internal scoping". This is where agency personnel work together internally to gather data, develop schedules, and generally inform themselves of the project similar to how the public informs the process during public scoping. Unfortunately, federal agencies do not effectively reach out to other entities that are often times much more knowledgeable and may have far greater insight into potential constraints that inevitably lead to delays. There are limitations to how this outreach can occur, which are dictated by federal law, however, adding this step on the front end will undoubtedly reduce the time and resources required to reach a decision.

In Wyoming, we are actively developing a project that exemplifies this effort to build a strong foundation in order to minimize future analysis requirements. Similar to the previously mentioned example, we have witnessed a substantial number of projects that have been delayed by NEPA. As CO_2 regulations, oil prices, and our knowledge of EOR potential in Wyoming increased we decided that it would be tremendously beneficial to our economy, the companies that choose to operate within our state, and our potential to manage carbon emissions to develop what we call the Wyoming Pipeline Corridor Initiative (WPCI). While formalizing this project proposal, we have coordinated with industry; local, state, and federal agencies; non-governmental organizations; individuals that have intimate knowledge of lands within our borders; and other authorities with experience in the CO_2-EOR industry and its associated infrastructure demands.

Wyoming Pipeline Corridor Initiative

WPCI is a sound strategy to streamline the NEPA process for pipeline infrastructure, without compromising the integrity of the Act or its process. The WPCI is a component of Governor Mead's energy strategy for the State of Wyoming (http://energy.wyo.gov) and it is our goal to obtain federal authorization for an intrastate pipeline network (see attached). One of the primary purposes of the pipeline network is to connect existing oil fields suitable for EOR with CO_2 sources. The CO_2 will be injected into existing, often "played-out" oil fields, thereby increasing oil production beyond conventional recovery methods with little additional surface disturbance while ensuring safe and permanent geologic storage of CO_2 in the process. Once we complete our EIS and the authorization is approved, companies will be able to build their infrastructure within the corridors in reduced time and at reduced costs, as we will have already dedicated our resources to completing the bulk of the NEPA analysis. Additionally, we hope to solve the ever present question associated with CO_2-EOR, which is who expends resources first -- the developers of capture facilities or those who develop pipeline infrastructure. In this case it will be the State of Wyoming laying the groundwork for pipeline infrastructure.

We have designed WPCI as a pipeline corridor network of 25 segments, approximately 1,983 miles in length, and wholly within the State of Wyoming. Approximately 1,150 miles (58%) of the network is expected to be located on Federal Lands, with 708 miles (62% of the federal land mileage) located in corridors designated or proposed in Bureau of Land Management (BLM) Resource Management Plans (RMP). Over 90 percent of WPCI parallels existing pipelines. The Right of Way (ROW) widths will vary between 200 – 300 feet and be sufficient to accommodate a number of pipelines of varying types.

Some of the benefits that will result from WPCI are:

- An estimated 500 existing oil reservoirs in Wyoming are potential EOR candidates with an estimated production of up to 1.8 billion barrels of oil, based on current technologies. Additionally, 20 trillion cubic feet of CO_2 could be stored as a result of this enhanced development.
- The WPCI will provide a large number of jobs for those building, maintaining, and operating pipelines and EOR fields. These jobs would likely be in Wyoming communities which have recently experienced significant declines in energy-related employment. The University of Wyoming, School of Energy Resources, estimates that 188 jobs are supported for every million barrels of incremental oil production, or 6.7 jobs per million cubic feet/day of purchased CO_2.
- Additional production of oil, gas, and liquids from EOR will generate significant royalties and taxes for federal, state, and local governments.
- The WPCI provides a balanced approach of natural resource utilization and environmental conservation.
- Performing the environmental analysis for the WPCI will alleviate many of the challenges associated with conducting environmental analyses for individual pipeline projects, which is currently a significant barrier to infrastructure expansion. Individual projects proposed in the WPCI corridors will undergo environmental analysis, but in a shortened timeframe and at reduced costs to proponents, due to the robust NEPA analysis that will be completed to authorize WPCI.
- The WPCI will be located almost entirely within existing ROW corridors, designated in BLM RMPs and/or adjacent to existing pipeline infrastructure. This will minimize the proliferation of linear disturbances; and reduce impacts to wildlife and their habitats, culturally significant properties, and other sensitive resources.

- A sufficiently wide ROW corridor will provide for future location of product pipelines (oil, gas, liquids, etc.) with minimal additional environmental analysis needed and encourage colocation of new pipelines.
- EOR will occur primarily in established oil fields in Wyoming which have historical disturbance, extending the field's life and providing an opportunity to improve its reclamation status at the end of its productive life.

To date, we have worked on baseline development of WPCI for approximately 4 years. We have produced and allowed stakeholder review of corridor mapping, a Plan of Development, and baseline impact analyses. We are now anxiously awaiting the approval from the Bureau of Land Management (BLM) to begin the NEPA process. Once finalized, WPCI will be a model that can be followed by any states interested in streamlining NEPA work.

CO_2 – EOR Working Group

In addition to the work outlined previously, Governor Mead has sponsored or co-sponsored several additional initiatives for the support of CCUS and CO_2-EOR. In 2015, Governor Mead and Montana Governor Bullock, acting as Chair and Vice-Chair of the Western Governors' Association, released a Policy Resolution for Enhanced Oil Recovery (see attached). As a result of that resolution, and the interest it received, they subsequently co-convened a multi-state, CO_2-EOR Working Group. Our Working Group is comprised of 14 states, and growing, with bipartisan leadership and we are working toward development of policies that incentivize deployment of CCUS technologies.

To date, we have released three reports that describe potential carbon capture incentives, recommendations to streamline and finance pipeline development, and potential opportunities to address market and grid challenges associated with CCUS. Links to these reports are provided below:

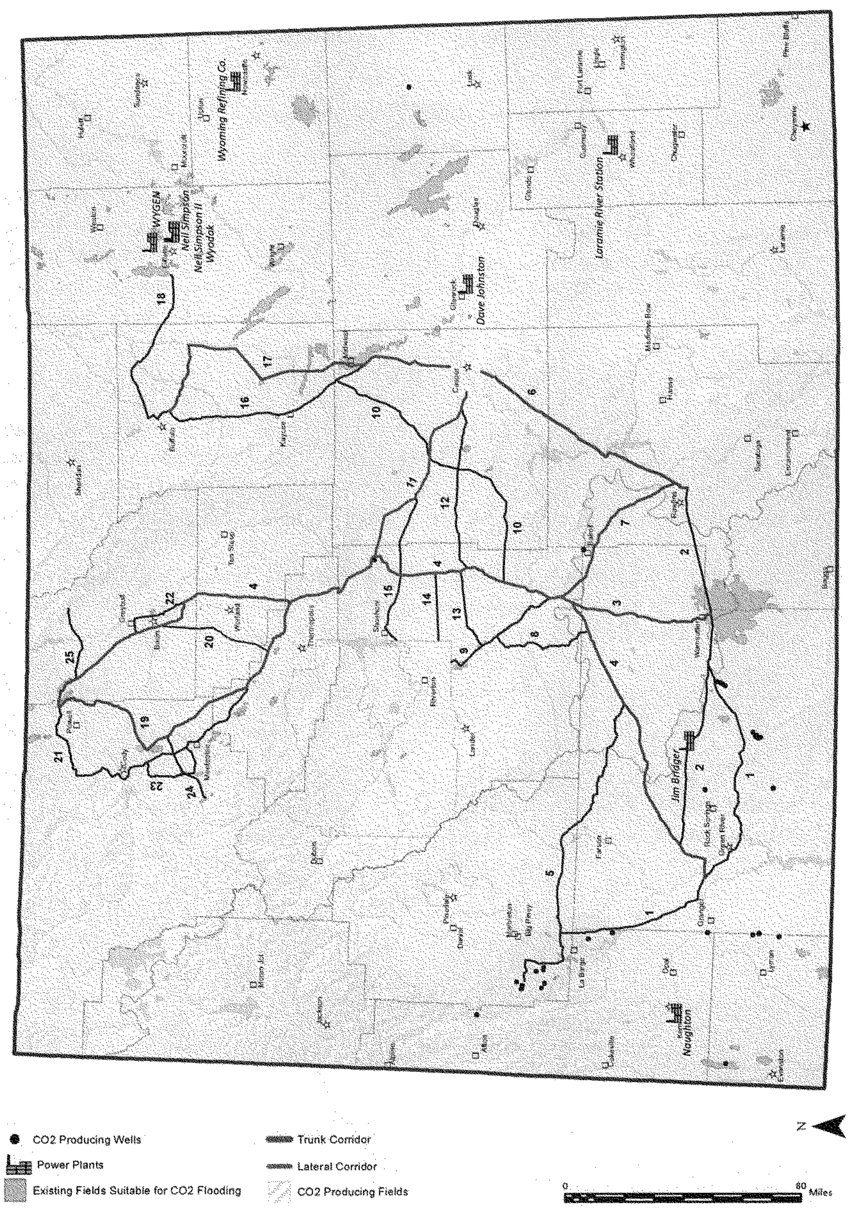
- *Putting the Puzzle Together: State and Federal Policy Drivers for Growing America's Carbon Capture and CO_2-EOR Industry* http://www.betterenergy.org/EORpolicy

- 21st Century Energy Infrastructure: Policy Recommendations for American CO_2 Pipeline Networks http://www.betterenergy.org/American_CO2_Pipeline_Infrastructure

- *Electricity Market Design and Carbon Capture Technology: The Opportunities and the Challenges* http://www.betterenergy.org/publications/electricity-market-design-and-carbon-capture-technology

Finally, we have supported legislative efforts to further deploy CCUS technology. We believe that legislation to extend and improve 45Q tax credits is essential for further deployment of the carbon capture industry. These tax credits will further bolster deployment, by providing added financial certainty that currently does not exist. The resulting symbiotic relationship of regulatory and financial certainty will in the end lead to our desired results of continued development of fossil fuels, with added storage of CO_2, and more stable and diverse economies.

Once again, I appreciate the opportunity to present this testimony today, and I am happy to answer any questions. Thank you.


WYGEN
Neil Simpson
Neil Simpson II
Wyodak
Wyoming Refining Co.
Dave Johnston
Laramie River Station
Jim Bridger
Naughton
CO2 Producing Wells
Power Plants
Existing Fields Suitable for CO2 Flooding
Trunk Corridor
Lateral Corridor
CO2 Producing Fields
0
80 Miles

WESTERN GOVERNORS' ASSOCIATION

Western Governors' Association
Policy Resolution 2015-06

Enhanced Oil Recovery

A. **BACKGROUND**

1. Enhanced oil recovery (EOR), using carbon dioxide (CO_2), when performed appropriately and responsibly offers a safe and commercially proven method of domestic oil production. The U.S. oil and gas industry, which pioneered the CO_2 EOR process in West Texas in 1972, is the world leader. Over four decades, the EOR industry has captured, transported, and injected large volumes of CO_2 for oil recovery with no major accidents, serious injuries or fatalities reported.

2. The CO_2 EOR process works by injecting CO_2 obtained from natural and anthropogenic sources into existing oil fields – often referred to as "brownfields" – to free up additional crude trapped in rock formations. This CO_2 "flooding" can result in recovery of about twenty percent of the original oil in place.[1] CO_2 flooding utilizes existing assets to recover significant additional resources stimulating the economy and minimizing surface disturbance that new exploration and development projects necessarily entail. In addition, many areas favorable for CO_2 application exist where new or continued significant drilling activity is unlikely to occur at a meaningful scale for years, if ever.

3. As of 2013, EOR using CO_2 produced approximately 280,000 barrels of domestic oil per day, or four percent of U.S. crude oil production.[2]

4. America has an estimated 21.4 billion barrels of oil, requiring 8.9 billion metric tons of CO_2, that could be economically recovered with today's EOR technologies. With advances in technology, 63.3 billion barrels of oil, requiring 16.2 billion metric tons of CO2, could be economically recovered, which is roughly double current U.S. proven reserves[3].

5. EOR enhances our nation's energy and fiscal security by reducing dependence on foreign oil, often imported from unstable and hostile regimes. It allows reduction of our trade deficit by keeping dollars now spent on oil imports here at home and at work in the U.S. economy.

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[1] National Energy Technology Laboratory – *Untapped Domestic Energy Supply and Long Term Carbon Storage Solution*
[2] Energy Information Administration – Annual Energy Outlook 2015
[3] U.S. Department of Energy, National Energy Technology Laboratory

6. Coal and oil production and utilization and other industrial processes are a vital component of many western states' economies. EOR provides a long-term path for continued low-carbon production and use of our nation's coal and oil resources and presents an opportunity for state and local governments to stimulate economic activity and realize additional revenue at a time when most governments face significant fiscal challenges.

7. CO_2 is currently limited in availability from high-volume sources needed for EOR – natural sources will not close a supply gap projected to grow. Further, CO_2 capture and pipeline transport capacity to oil fields is not sufficient.

8. CO_2 capture equipment, installed on a broad range of industrial processes, has the potential to supply significant volumes of CO_2 to the EOR industry enabling the U.S. to achieve significant net carbon reductions through the sequestration of CO_2.[4]

9. The U.S. has the opportunity to provide global leadership in carbon capture research and technology development, hydrocarbon recovery and geologic storage research and technologies, manufacturing, engineering and other services.

B. GOVERNORS' POLICY STATEMENT

1. In recognition of the environmental and economic benefits of EOR, Western Governors support policies and incentives that advance investment in EOR projects, infrastructure, technology and research.

2. Western Governors support efforts to increase the awareness of the many benefits CO_2 EOR.

3. In order to expand deployment of CO_2 capture at power plants and other industrial sources, the President and Congress should enact federal incentives to increase CO_2 supply available for the oil industry to purchase and use in EOR. Federal incentives have the potential to leverage private and state investment, harness the ingenuity of entrepreneurs and capitalize on billions of dollars' worth of DOE-sponsored research and development to enable new commercial carbon capture and pipeline projects.

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[4] As of 2014, approximately 13.6 million metric tons of CO2 was captured that would otherwise be released into the atmosphere has been sequestered as a result of EOR (U.S. Department of Energy – Quadrennial Energy Review). Over the life of a project, for every 2.5 barrels of oil produced, it is estimated that a typical commercial EOR project can safely prevent one metric ton of CO_2 from entering the atmosphere (Kuuskraa, Godec, Dipietro – Energy Procedia). Further, the volume that could be captured and sequestered from industrial facilities and power plants to support economically recoverable EOR reserves could be 8.9 to 16.2 billion metric tons of CO_2. This is equal to the total U.S. CO_2 production from fossil fuel electricity generation for approximately 4 to 8 years (EPA 2015 Green House Gas Inventory).

4. Federal policies aimed to limit CO_2 emissions should promote, and not impede, development and deployment of CO_2 capture and commoditization. Federal regulations should allow states to create programs tailored to individual state needs, industries and economies and recognize CO_2 sequestration that results from EOR in meeting federal regulatory objectives. As such, EPA should abide by principles already established by the Agency in its regulations promulgated to ensure the long-term storage of CO_2 in different geologic formations.

C. GOVERNORS' MANAGEMENT DIRECTIVE

1. The Governors direct the WGA staff, where appropriate, to work with EPA and other federal agencies, Congressional committees of jurisdiction, and the Executive Branch to achieve the objectives of this resolution including funding, subject to the appropriation process, based on a prioritization of needs.

2. Additionally the Governors direct the WGA staff to develop, as appropriate and timely, detailed annual work plans to advance the policy positions and goals contained in this resolution. Those work plans shall be presented to, and approved by, Western Governors prior to implementation. WGA staff shall keep the Governors informed, on a regular basis, of their progress in implementing approved annual work plans.

Western Governors enact new policy resolutions and amend existing resolutions on a bi-annual basis. Please consult westgov.org/policies for the most current copy of a resolution and a list of all current WGA policy resolutions.

Senate Environment and Public Works Committee
hearing entitled, "Expanding and Accelerating the Deployment and Use of Carbon Capture, Utilization, and Sequestration,"
Wednesday, September 13, 2017
Questions for the Record for Mr. Matthew Fry

Chairman Barrasso:

1. *Please list all the federal environmental statutes and regulations that you have evaluated in developing the Wyoming Pipeline Corridor Initiative. Which requirements do you anticipate will be most burdensome in the development of CO_2 pipelines? Are there process-related reforms that would ease those burdens while maintaining environmental protection?*

Response:

While developing the Wyoming Pipeline Corridor Initiative (WPCI), I have evaluated the following federal environmental statutes and regulations:

- The National Environmental Policy Act of 1962 - 42 U.S.C. 4321 et seq.
- Mineral Leasing Act of 1920, Section 28 – 30 U.S.C 185
- Antiquities Act of 1906 – 16 U.S.C. Section 431-433
- Archaeological Resources Public Protection Act of 1979 – 16 U.S.C. Section 470aa
- Endangered Species Act of 1973 – 16 U.S.C. 1531 et seq.
- Federal Land Policy and Management Act – 43 U.S.C 1701
- Federal Highway Administration – 23 CFR Part 645 Subpart B23, U.S.C. Sections 116, 123
- U.S. Army Corps of Engineers; Section 404 of the Clean Water Act of 1972 – 40 CFR 122-123, 33 U.S.C. Section 1344; 33 CFR Parts 323, 325
- Bureau of Alcohol, Tobacco and Firearms; Section 1102(a) of the Organized Crime Control Act of 1970 – 18 U.S.C. Section 841-848; 27 CFR Part 181
- Advisory Council on Historic Preservation; Section 106 National Historic Preservation Act – 36 CFR Part 800, 16 U.S.C. 470
- BLM Manual 9011.1, Guidelines for Conducting Chemical Pest Control Program

There may be additional federal regulatory requirements as we move further into the process of authorizing WPCI. The WPCI will also fall under the regulatory authority of various state and local statutes, regulations, and planning requirements.

The National Environmental Policy Act (NEPA) requirements will be the most burdensome in development of CO2 pipelines, where a federal nexus exists that triggers the Act. However, when WPCI is completed, other states could follow our example to develop corridor systems of their own, thus streamlining project level NEPA in their own states. Where there are no NEPA requirements (e.g. no federal lands), the requirements of the National Historic Preservation Act or Section 404 of the Clean Water Act may create the greatest challenges, although not nearly as great as NEPA. If Government entities and project developers begin to better plan their project footprints and public outreach, they will likely expedite their authorization timing substantially. One possible procedural reform may be required pre-scoping of projects. This could require a concerted effort to gain input from affected federal, state, and local agencies, directly impacted landowners, and the general public on potential project routing constraints. This early planning should better inform project development so that the steps of the formal NEPA process will be streamlined.

2. *In your written testimony, you said that projects in Wyoming have been hampered by the National Environmental Policy Act (NEPA) process. Could you elaborate on those examples? Would the changes outlined in your answer above address those challenges?*

Response:

I provided an example of the Denbury Pipeline in my written testimony. I believe that better outreach and constraints analysis could have reduced the timeframe required to develop their NEPA analysis. As a specific example, BLM conducts "scoping meetings" as their mechanism to provide and gain information from interested parties about projects. Four scoping meetings were held in different Wyoming towns on consecutive days. According to the Scoping Report, a total of 30 individuals attended these meetings. The proposed pipeline is approximately 250 miles in length. I suggest that a concerted effort for better outreach and utilizing better forums could inform project design in a way that minimizes challenges on the back end.

3. *The Wyoming Pipeline Corridor Initiative seeks to streamline environmental review by performing a NEPA analysis on a corridor-wide basis, thereby reducing the amount of time required for the environmental review of each individual CO_2 pipeline segment. What do you see as the main barriers to other states performing similar corridor-wide environmental analyses? Could the federal government provide better assistance to states that might be considering replicating Wyoming's efforts?*

Response:

I do not believe there are any true barriers for other states to complete a corridor system, similar to WPCI. However, there will be challenges that they must overcome. First, adequate experienced staff, technology, and NEPA analyses are costly. Any funding assistance that can be provided will be extremely beneficial. Also, as I mentioned, this project is an "out-of-the-box" approach to infrastructure development. Undertaking a project this large and different has apparently been daunting to the Bureau of Land Management (BLM). As a result, I have had and continue to have difficulty moving WPCI along through their administrative process. Anything the federal government can do to motivate BLM, and other agencies, to prioritize completion of projects like WPCI will be tremendously useful.

<u>Senator Sullivan:</u>

4. *I have been exploring ways we could broadly reform NEPA to ensure that environmental reviews are competed in 2 to 3 years and not 10. Do you think that the United States would see a marked increase of pipelines and facilities like the Petra Nova project if NEPA were amended to bring it back within its original confines—a set of procedural requirements ensure that the environmental effects of projects are considered and shared with the public?*

Response:

I think we would see development of more projects if NEPA analyses were completed within their original confines. First, more foundational and functional analyses would greatly reduce the costs of NEPA. Additionally, reducing the time it takes to actually complete the NEPA process provides an additional level of financial certainty for project proponents. While market forecasts have their limitations, it is likely more beneficial for financiers to use 2-3 year market forecasts, rather than 10 year forecasts.

a. *In your testimony you reference the judicial and regulatory inertia that has made NEPA less of an environmental policy, but instead a tool for delay and litigation. In your experience, how has NEPA in its current form delayed or stopped environmentally sound and economically beneficial infrastructure?*

Response:

I believe that NEPA, in its current form stretches too broadly and is more focused on the development of a "litigation proof" administrative record, rather than a true impacts analysis. There needs to be a substantive discussion amongst all those interested in environmental analyses to determine how far the zone of impact from a project truly reaches. Unfortunately, as NEPA documents reach farther from project footprints, the power of their analyses reduces accordingly. This has resulted in significant increases in time/costs and greater ambiguity in the impacts disclosed.

b. *I recently introduced a bill S. 1756 the Rebuild America Now Act which among other provisions would modernize NEPA and codify certain principles the administration has been pursuing via CEQ regulations. Most of our current streamlining of environmental reviews have focused only on specific titles of the U.S. Code, e.g., title 23, but have not included all infrastructure projects, such as pipelines, mines, and energy projects. Given your experiences how valuable is it for us to look at NEPA changes that go beyond purely transportation projects?*

Response:

I believe that all of these projects have similar NEPA challenges. Accordingly, to include pipelines in the broader infrastructure discussion would be tremendously beneficial.

Senator Whitehouse:

CO2 Pipelines

5. *At the hearing, witnesses agreed that a major hurdle for CCUS projects is capital financing and upfront costs. It was also discussed that CO_2 pipeline infrastructure build-out is needed to facilitate the transport of CO_2 for reuse and to improve the financing of projects.*

    a. *What specific federal policies would facilitate the construction of CO_2 pipelines?*

Response:

As you mention, policies that provide greater financial certainty will greatly influence construction of CO2 pipelines. Passage of 45Q legislation will provide a powerful incentive on this front. Additionally, policies that streamline regulatory approvals, without reducing their quantitative value, will also facilitate infrastructure development. A more efficient and effective NEPA process, in geographic regions that require them, would be advantageous. In all regions of the country, a concerted, proactive planning process to develop and site pipeline corridors would reduce the back end challenges of pipeline development.

    b. *Is it true that a majority of new pipelines could be built within existing interstate pipeline corridors? Or will CO_2 pipeline infrastructure build-out occur in areas that will require extensive NEPA requirements?*

Response:

Unfortunately, most new pipelines cannot be built within existing pipeline corridors. There has been one large scale effort by federal agencies to develop interstate pipeline corridors. Under Section 368 of the 2005 Energy Policy Act, the Departments of Interior and Energy developed the West Wide Energy Corridor (WWEC). While fundamentally the WWEC was a good idea, it was completed without adequate outreach to identify functional corridors. Additionally, the scale of the analysis was too coarse. As a result, the WWEC has limited utility. If there is not a broader effort to administratively authorize corridors, similar to Wyoming's WPCI, extensive NEPA will be required for each individual pipeline project.

Senator BARRASSO. Thank you so much for your testimony.
Mr. GREESON.

STATEMENT OF DAVID GREESON, VICE PRESIDENT OF DEVELOPMENT, NRG ENERGY

Mr. GREESON. Thank you, Chairman Barrasso and Ranking Member Carper, and Committee members. My name is David Greeson. I am Vice President of Development for NRG Energy. I am based in Houston, Texas, where I have spent the last 7 years developing the world's largest carbon capture system attached to a power plant. The project is called Petra Nova, and I am happy to report that it came online on time and on budget thanks to a lot of hard work by NRG and our partners, JX and Hilcorp.

As I appear before you today, this $1 billion project is capturing 5,000 tons per day of CO_2 , which is the equivalent of taking 350,000 cars off the highways of the U.S. And it is doing it without increasing the cost of electricity to consumers in Texas. We achieved this success despite numerous challenges that come with deploying the first-of-a-kind technology. The biggest hurdle was, and remains, the up-front capital cost. And I will refer you to my written testimony for a discussion of what the industry is doing to reduce those costs.

But I would like to take this opportunity to thank Congress and particularly the members of this Committee who have supported DOE's efforts to address the up-front costs, such as the Clean Coal Power Initiative, which funded $190 million of our $1 billion project. DOE's grant and the participation of the DOE was essential to the success of our project.

I would like to also thank the members of this Committee that are supporting the 45Q program improvements. We feel like this change to the program will help level the playing field between carbon capture and other low carbon technologies such as wind and solar.

But up-front cost was not our only obstacle. We also faced a number of licensing and permitting challenges, as well. For example, during the financing of the project, we had to deal with confusion in the industry over whether EPA's Class VI versus Class II injection well standards would apply. If Class VI had applied to our project, it would have added over $100 million to the cost of this project; a huge sum.

Thankfully, EPA eventually issued a guidance paper that clarified the Class II standard, that we have used for over 40 years in the U.S. and has served us very well, will continue to be the standard.

But a much bigger concern was the NSR rules of the Clean Air Act. They caused us a great deal of heartache and ultimately cost a lot of dollars to circumnavigate. Carbon capture systems need steam, and when considering our options to provide steam, it would seem logical that we would take that steam from the boiler, since it is already making a lot of steam for electric purposes, but modifying the boiler to provide that steam can cause a lot of permitting problems. You see, our coal plant is 35 years old. It has a complete suite of environmental controls already, for NOx, SOx, particulate, and mercury, and has an exemplary environmental performance record.

Nevertheless, control technologies have evolved over the years, and these older systems may not be sufficient to pass a New Source Review. So, if we had made modifications to the boiler to provide steam to carbon capture, we might have triggered the need for a New Source Review, and we are not sure that all of the systems on the plant would have been up to the New Source Review standard.

Since the cost and schedule impacts of a New Source Review were just not knowable in advance, it was impossible for us to build a project plan based on any path forward that relied on New Source Review, so we decided to go a different way. We supplied the steam through a $100 million cogeneration system. This system also provided electricity, so there were some offsets to this up-front cost, but in the end the up-front cost was substantial and it hurt the project economics.

So it was a shame that we missed the opportunity to save money by sourcing steam from the boiler. But an idea that might preserve that option for future carbon capture projects would be to provide an NSR exemption for the existing plant systems when the project being permitted is a new emission control system. In this way, the truly new facilities would be fully vetted through the permitting process without putting risk on the systems that are already permitted and running.

You know, it is ironic that the New Source Review rules are meant to improve air quality, but in practice they actually discourage plant owners from considering major improvements, including environmental improvements.

In the first 8 months of operation, we have injected almost 1 million tons of CO_2 into the oil field, and that CO_2 would have otherwise been emitted to the atmosphere.

For the next projects, capital costs will continue to be a barrier to entry and be the largest barrier to entry, and I can assure you that the industry is working on those. But environmental rules can and do hinder the deployment of future systems.

Thank you, and I look forward to the Q&A.

[The prepared statement of Mr. Greeson follows:]

Testimony of David Greeson
NRG Energy
Petra Nova project

Written Testimony of David Greeson
Vice President, Development
NRG Energy, Inc.

My name is David Greeson, Vice President of Development for NRG Energy, Inc. I have 36 years of experience in the electric power industry in both regulated utilities and independent power companies. I have developed 5 major power projects in the U.S. that total more than $3 billion of investment including the $1 billion Petra Nova Carbon Capture and Enhance Oil Recovery project that I'll be speaking about today.

The Petra Nova project began as an initiative by NRG to find a way to de-carbonize our coal-fired generation fleet and do so without increasing the cost of electricity. When we began this project in 2009, there were good reasons to believe that policies were coming that would make it difficult for coal-fired power plants without carbon capture to continue to deliver the value that our customers and shareholders had come to expect.

Everything we do at NRG is subject to competition. We are not a utility with captive customers, rather we must win each customer on a competitive, best-value basis compared to their other choices. Therefore, the final design of the Petra Nova project was guided by two constraints:

- The project could not increase the cost to produce electricity from the host coal unit or negatively impact its ability to participate in the competitive Texas electric market.
- Enhanced oil recovery (EOR) was (and is still today) the only known way to simultaneously (a) handle significant volumes of CO_2 to be captured from the coal-fired power plant and (2) create a revenue stream that could off-set the cost of building and operating carbon capture absent a price on carbon emissions.

Today, after seven years of diligent work by NRG, our partners, and our contractors, the plant is on-line capturing more than 5,000 tons per day of CO_2 which is the equivalent of taking 350,000 cars off of the road. Thanks to a lot of planning, preparation, and persistence I'm proud to report that the project was on-time and on-budget which is an amazing accomplishment for a first of its kind deployment of a technology at full commercial scale. The plant is operating as designed which means that we now have a coal-fired power plant that has the same carbon footprint as a natural gas-fired unit.

As you can see from slide 5 in the attachment to this testimony, the project is really five projects in one:

1. Design and build the facilities needed to interface with the host coal-fired plant in a way that did not impact its cost or its operations.
2. Install a carbon capture technology that had never been built at this scale before and had many design improvements that were not in the one-tenth scale unit built several years earlier.
3. Obtain rights of way and construct an 81-mile CO_2 pipeline without the power to condemn or expropriate private property.
4. Prepare a legacy oil field that had been in production since the 1930s for CO_2 operations by finding and plugging virtually all the existing wells, drilling about 300 new wells, and installing two large processing plants on the surface to handle the new oil production.
5. Re-establish a pipeline link to the crude oil market since the previous facilities had been abandoned years ago.

Testimony of David Greeson
NRG Energy
Petra Nova project

The carbon capture system starts by pre-treating the flue gas by cooling it and removing any remaining trace amounts of sulfur in a vessel called the quencher. Next, treated flue gas is blown upward through the 340 foot tall absorber tower where the CO_2 comes into contact with a liquid solvent and dissolves into the solvent. The solvent, now laden with CO_2, is pumped to a closed vessel where it is heated by steam which causes the CO_2 to come out of solution as a pure gas. Now segregated, CO_2 is compressed and transported down an 81-mile pipeline where it is injected into the oil field. I've included a picture of the Petra Nova CCS facility in the attachment.

Once the CO_2 arrives at the oil field it is injected into the oil-bearing formation where it acts as a solvent, dissolving into the otherwise unrecoverable oil and lowering its viscosity. This viscosity change allows stubborn oil that is clinging to the surface of the rock in the reservoir to flow freely to wells to be recovered. At the surface, the oil-water-CO_2 mixture is separated and the oil is sold to the market. The produced water is re-injected into the oil formation and the recovered CO_2 is recompressed and likewise re-injected. With each cycle of injecting and producing fluids, a portion of the CO_2 remains in the oil formation permanently and as a result, all the injected CO_2 is ultimately sequestered in the formation.

NRG considers itself very fortunate to have great partners in this project, beginning with the US DOE in 2010 when we finalized the grant agreement. Hilcorp joined the project in 2011 as our oil field operator and designer/operator of the enhanced oil recovery system. JX Nippon Oil and Gas Exploration, which is the largest oil company in Japan, became NRG's 50-50 partner in 2014 after a year and a half of working on the project pro bono. And finally, the Japanese Government through its Japanese Bank for International Cooperation (JBIC) and Nippon Export and Investment Insurance agencies (NEXI) made a limited recourse loan to the project to complete the capital requirements.

The project has been in full commercial operations for 8 months now. I am pleased to report that all systems are working well and oil production is rising sharply. In December of 2016 just 8 months ago this oil field was producing less than 300 barrels of oil per day. Today, it is producing more than 4,000 barrels per day.

Please keep in mind that NRG's power plant does not pay for any of the cost of carbon capture and enhanced oil recovery. Even the steam and power needed by the carbon capture system is provided by Petra Nova's own captive cogeneration system (as I'll discuss in more detail below, we elected to build a dedicated cogeneration system due to Clean Air Act New Source Review concerns).

NSR Discussion

Carbon capture systems need steam. The logical best place to supply that steam is to modify the coal plant and extract the amount of steam that is needed. However, in cases where a company is looking to install a carbon capture system onto an existing unit, this may not be the best approach. Environmental control technology continues to progress and New Source Review (NSR) rules can trigger a requirement to bring older control systems up to modern standards, thereby adding significant costs for minimal environmental benefit.

Ironically, while the NSR rules are meant to improve air quality, in practice they actually discourage plant owners from considering major improvements – including environmental improvements.

Testimony of David Greeson
NRG Energy
Petra Nova project

The host coal unit ultimately selected for the Petra Nova project was NRG's Parish Unit 8. This 640MW unit has a complete suite of environmental controls: low sulfur fuel, low NOx burners, Selective Catalytic Reduction system (SCR) for NOx control, bag house for particulates, Activated Carbon Injection (ACI) for mercury control, and a 1982 vintage flue gas desulfurization system (FGD) for SOx control. Unit 8 is an excellent environmental performing unit nevertheless, it is a 35 year old plant and control technologies have incrementally improved since Unit 8's systems were installed.

As we put the project together, we had to make decisions and set directions that would play out over several years with costly implications if those directions had to change. Despite Unit 8's relatively modern controls and stellar environmental performance, the NSR process would have subjected NRG to the possibility of expensive modifications. Since Petra Nova would have to bear the cost and schedule risk of such modifications and since the economics of carbon capture were already extremely challenged, we were forced to find an approach that avoided the possibility of an NSR.

We believe modest changes to the NSR rules could help achieve the intent of the program. Congress should consider changes that would incentivize more CCS rather than discourage these investments. Such changes could preserve the ability for the coal-fired unit to continue to provide safe, reliable, and economic electricity to the market, without imposing unnecessary risks and capital costs. Such changes should allow: (1) an exemption from the NSR process for all existing plant systems when a new emissions control system is being added, (2) an NSR exemption for changes in operations designed to provide parasitic load (e.g. increased fuel burns) that do not increase emissions or which can be off-set by use of system-wide or facility-wide emissions netting, including shutdowns or curtailments at other facilities, (3) longer time periods for contemporaneous netting (e.g., 10 years versus 5 years), and (3) broader exclusions for modifications to the host coal unit for efficiency improvements.

In the end, because of the existing NSR rules, we elected to build a stand-alone gas-fired cogeneration system at a cost of about $100 million to provide steam and electricity for the Petra Nova project. While the upfront cost was substantial and hurt project economics, it was at least partially off-set by (a) the ability to sell excess electricity in the Texas electric market and (b) the efficiency of the cogeneration system to allow us to save some money to help pay for the system.

I look expectantly to the future of CCS in the U.S. as we continue to lead the world. The U.S. is blessed with plenty of mature oil fields amenable to CO_2-EOR. Furthermore, a significant amount of the nation's coal-fired generation fleet is still young enough to warrant the investment needed for coal to take its place in the sustainable energy future. Unfortunately, upfront capital costs remains a major hurdle and federal subsidies to wind and solar (clean coal's competitors) further stack the deck against CCS, but there is reason for optimism. Congress is considering measures to bring parity to low carbon technologies through changes in the 45Q incentive program. Also, the industry is doing its part by continuing to find ways to reduce the cost to build amine systems like the Petra Nova project. We also have exciting innovations in membranes that are now out of the lab and are being tested in small field trials. And finally, new formulations of solvents may be commercially ready in 3-5 years that could significantly reduce the size of the capture system and thereby reduce the cost.

Thank you.

Testimony of David Greeson
NRG Energy
Petra Nova project

nrg | JX

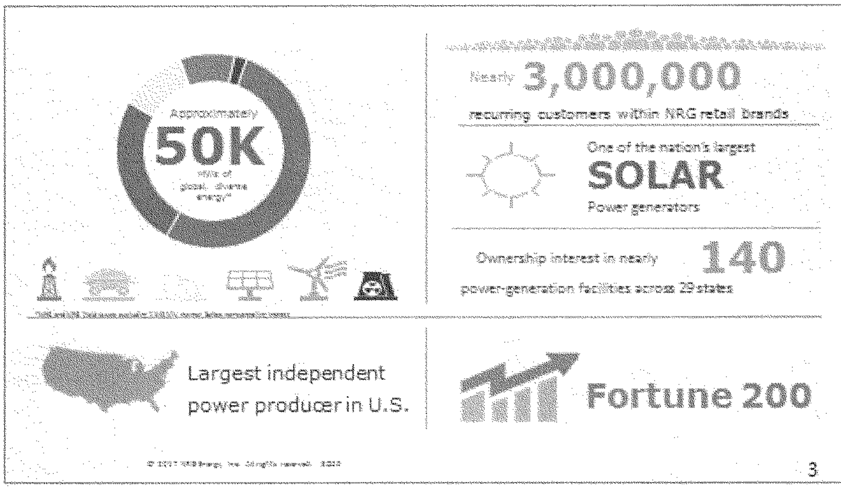
PETRA NOVA Carbon Capture

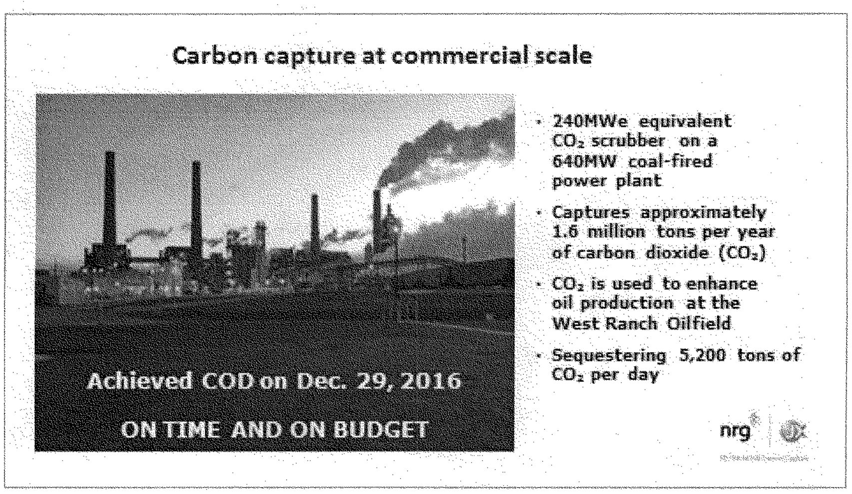
Safe harbor statement

This presentation contains forward-looking statements within the meaning of Section 27A of the Securities Act of 1933 and Section 21E of the Securities Exchange Act of 1934. Forward-looking statements are subject to certain risks, uncertainties and assumptions and typically can be identified by the use of words such as "expect," "estimate," "should," "anticipate," "forecast," "plan," "guidance," "believe" and similar terms. Such forward-looking statements include our future growth and financial performance, Company operations, developments in renewables, and project development. Although NRG believes that its expectations are reasonable, it can give no assurance that these expectations will prove to have been correct, and actual results may vary materially. Factors that could cause actual results to differ materially from those contemplated above include, among others, general economic conditions, hazards customary in the power industry, weather conditions, competition in wholesale and retail power markets, the volatility of energy and fuel prices, failure of customers to perform under contracts, changes in the wholesale and retail power markets, changes in government regulation of markets and of environmental emissions, the condition of capital markets generally, our ability to access capital markets, unanticipated outages at our generation facilities, adverse results in current and future litigation, failure to identify or successfully implement acquisitions and repowerings, the inability to implement value enhancing improvements to plant operations and companywide processes, our ability to realize value through our commercial operations strategy, and our ability maintain successful partnering relationships.

NRG undertakes no obligation to update or revise any forward-looking statements, whether as a result of new information, future events or otherwise, except as required by law. The foregoing review of factors that could cause NRG's actual results to differ materially from those contemplated in the forward-looking statements included in this Investor Presentation should be considered in connection with information regarding risks and uncertainties that may affect NRG's future results included in NRG's filings with the Securities and Exchange Commission at www.sec.gov. Statements made in connection with the exchange offer are not subject to the safe harbor protections provided to forward-looking statements under Private Securities Litigation Reform Act.

Testimony of David Greeson
NRG Energy
Petra Nova project





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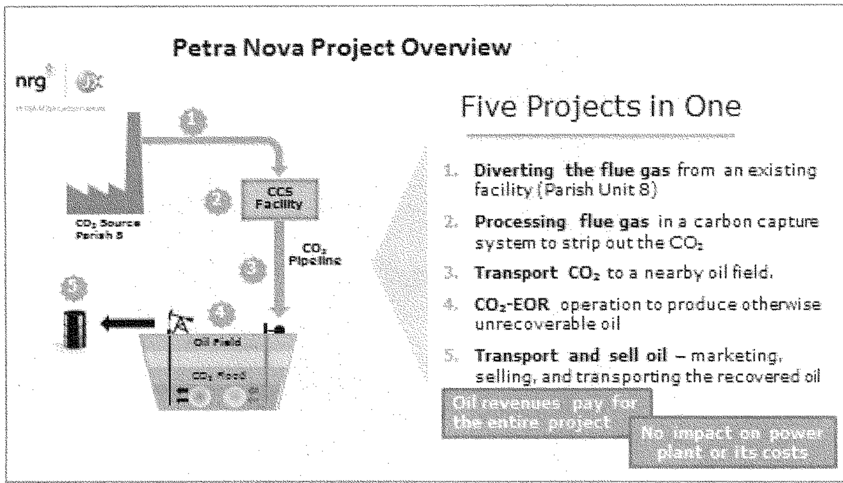

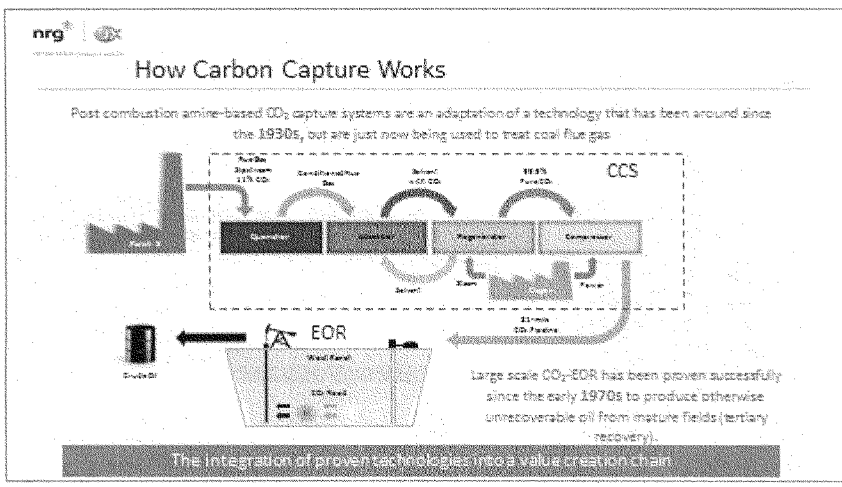

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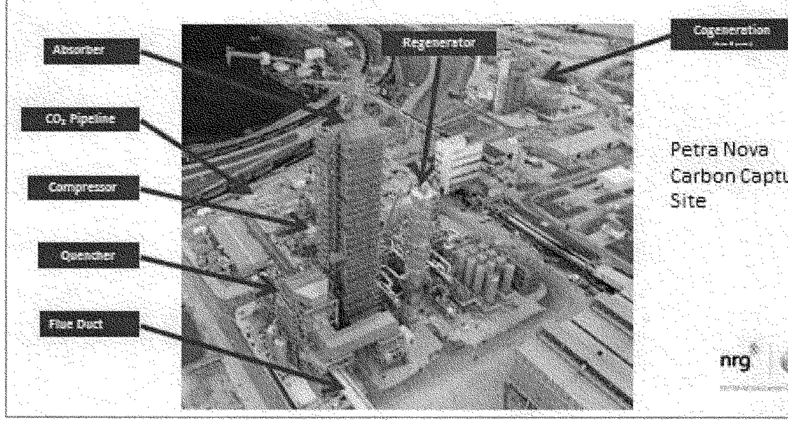
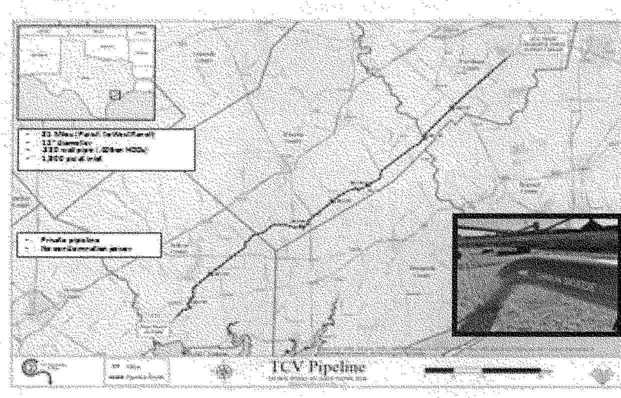
Carbon Capture System Site Layout



Petra Nova Carbon Capture Site

CO2 Pipeline Route



Flat terrain and flat topography through agricultural area

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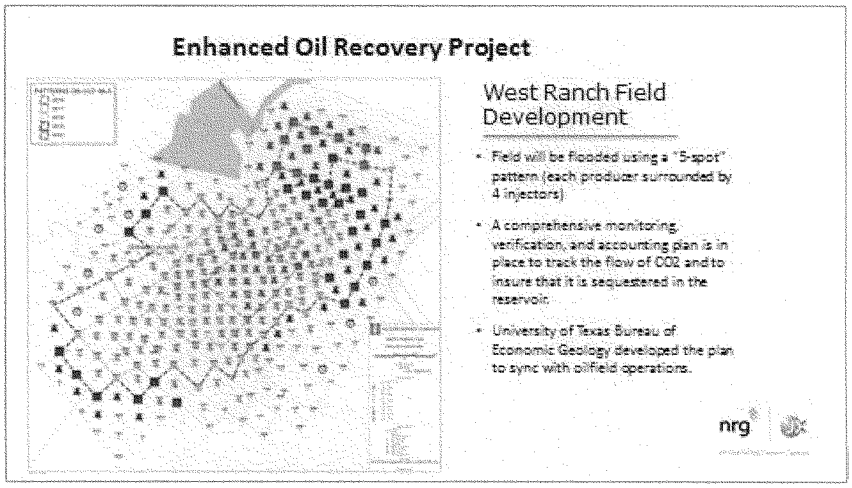
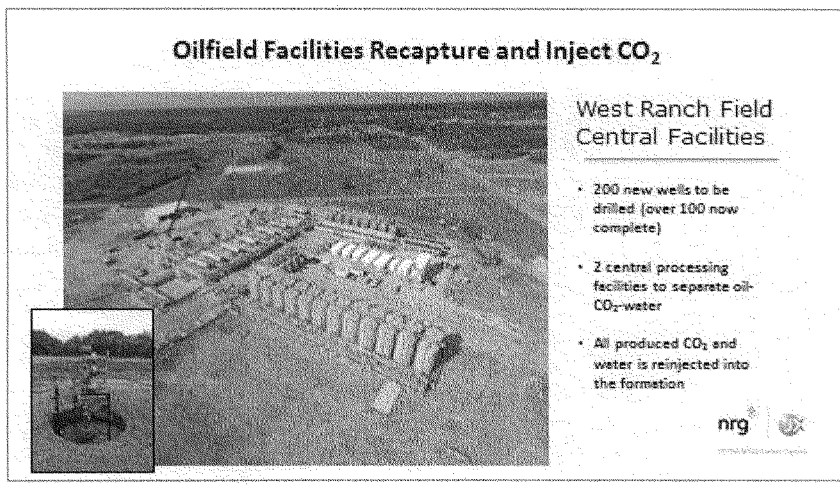
Petra Nova project





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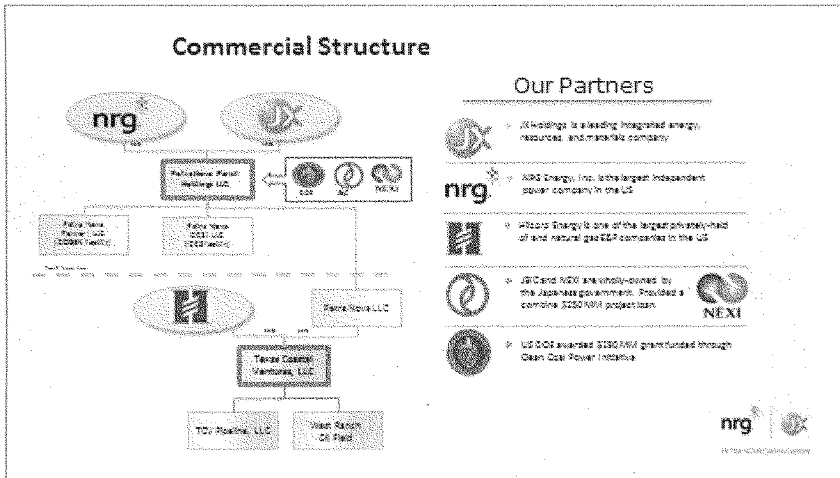

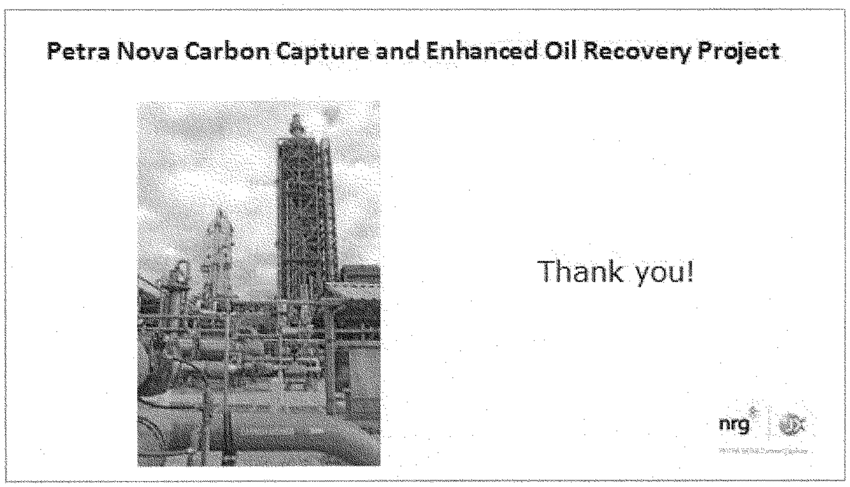

Senate Environment and Public Works Committee
hearing entitled, "Expanding and Accelerating the Deployment and Use of Carbon Capture, Utilization, and Sequestration,"
Wednesday, September 13, 2017
Questions for the Record for Mr. David Greeson

Chairman Barrasso:

1. During the hearing, all witnesses agreed that financing is a key impediment to CCUS deployment. Do you believe it is important to examine ways to lessen regulatory barriers that might hold back the full deployment of these technologies at the same time as the federal government examines financing issues?

    a. Yes, lessening regulatory barriers could help reduce the administrative cost of CCUS and reduce the time needed to deploy these projects.

2. Do you agree that 45Q tax credit expansion is an effective way of producing an additional revenue stream for CCUS projects?

    a. Yes, I believe the proposed changes to the 45Q program will lead to new CCUS projects.

3. Do you agree with Mr. Fry's testimony that development of additional CO_2 pipeline infrastructure is essential for maximizing the use of enhanced oil recovery (EOR) in the United States? Would additional CO_2 pipeline infrastructure support the continued future deployment of EOR as well as other potential commercial uses of CO_2? If so, what can the federal government do to streamline the regulatory approval processes for CO_2 pipelines?

    a. I agree with Mr. Fry that pipeline infrastructure connecting CO_2 sources (power plants and certain large industrials) with CO_2 sinks large enough to safely store meaningful volumes of CO_2 (enhanced oil recovery projects) is essential to wide-spread deployment of CCUS in the U.S. The federal government should enact policies that requires existing rights of ways such as rail roads and highways be made available to CO_2 pipelines to not only lower costs, but to also minimize disturbing new lands.

4. Your written testimony states that "modest changes to NSR rules could help achieve the intent of the program." You suggest four policy approaches: (1) "an exemption from the NSR process for all existing plant systems when a new emissions control system is being added"; (2) "an NSR exemption for changes in operations designed to provide parasitic load (e.g. increased fuel burns) that do not increase emissions or which can be off-set by use of system-wide or facility-wide emissions netting, including shutdowns or curtailments at other facilities"; (3) "longer time periods for contemporaneous netting (e.g., 10 years versus 5 years)"; and (4) "broader exclusions for modifications to the host coal unit for efficiency improvements." Can you elaborate on how each of the four

proposed changes to New Source Review (NSR) would address the challenges you outlined in your testimony?

a. The NSR rules are difficult to apply with any certainty for industry, regulators, and public stakeholders. It is not uncommon for an NSR determination to be made through a public hearing process, a permit issued, and the subject facility to be in operation for years only to have a decision in an unrelated court case cast uncertainty on the facility's permit. Greater clarity on Congressional intent for the NSR is needed. We believe that the possible changes to the NSR program that, when woven together, would help reduce regulatory uncertainty and lead to more investment in environmental improvement:
    i. (1) Exemption for installation of new emissions controls – Many owners of coal-fired plants, including NRG, are looking for ways to make our plants competitive in the low carbon energy market of the future. For example, there are some really exciting new membrane technologies that might best be integrated into the bag house systems at our plants; however such a modification to the existing controls system and the method of operation of the power plant could be viewed as triggering an NSR. **It should be clear in the Clean Air Act that the addition of certain categories of environmental control systems and the applicable changes in the methods of operation operating do not trigger NSR.**
    ii. (2) Changes in operations to supply CCUS parasitic load – in many air permits for power plants a "heat input limit" is established. This is unfortunate in that technology continues to improve and in a 30+ year old plant it may be possible to upgrade combustion systems and the turbine/generator in a way that might largely offsets the parasitic load of a carbon capture system. Further, power plant owners should have the ability to net emissions across all their units in an air shed or at the very least all the units at a common facility. **It should be clear in the Clean Air Act that efficiency improvements and the applicable heat input increases do not trigger NSR – especially if the increases can be netted with reduced operations at other company facilities in the same air shed.** State and Federal environmental agencies have a long history of relying on air quality models to demonstrate air quality improvements when considering multiple sources in an air shed, the same philosophy could be applied to determine NSR is not applicable (e.g., emissions netting across multiple units and facilities).
    iii. (3) Longer netting period – In the power industry, the ability to net emissions with reductions in operations is allowed on a 5-year look-back basis. Other industries are allowed a 10-year look-back. Given the amount of time it takes to plan, engineer, finance, and construct a carbon capture system, we believe it is appropriate to for the power industry to have a 10-year netting period as well. For example, if a carbon capture plant is being considered, you might keep a unit operating longer than the market conditions would support just to ensure that the closure of the plant falls within the netting window. In other words, a longer netting window

allows operators more flexibility to close older plants – especially when new investment is in planning. **It should be clear in the Clean Air Act that the power industry can use a 10-year netting period.**

iv. (4) Broader exclusions for efficiency improvements – There are exclusions in the NSR program for routine repairs. These exclusions should be extended to include any maintenance and life extension modifications made to a generating unit that is retrofitted with a carbon capture system. Carbon capture systems are very expensive and take years to develop. Even so, installing a carbon capture system could be worth the investment if both the power plant and the carbon capture system can be counted on to operate for many years to come. **It should be clear in the Clean Air Act that modernizations and life extending maintenance done in connection with the installation of a carbon capture system does not trigger NSR.**

5. An August 2017 report from the Department of Energy entitled, "Staff Report to the Secretary on Electricity Markets and Reliability," concluded that "uncertainty stemming from NSR creates an unnecessary burden that discourages rather than encourages installation of CO_2 emission control equipment and investments in efficiency because of the additional expenditures and delays associated with the permitting process."[1] Beyond CCUS retrofits, do you agree that NSR also discourages other types of projects that would reduce emissions of pollutants? For example, can NSR deter efficiency projects? If so, do you have recommendations to ameliorate those issues and ensure that the intent of NSR, which is to reduce emissions, is carried out?

    a. I have personally worked on an efficiency improvement project that was cancelled because NSR rules would have required the installation of costly and unnecessary equipment that more than off-set the economic benefits of the efficiency project. As I stated earlier, many NSR lawsuits happen years after permits are issued, investments are made, and plants have been operating for years.

6. Please list all the federal environmental rules you had to comply with and permits you had to receive in the design and construction of the Petra Nova facility. Aside from the Clean Air Act requirements regarding NSR that you mentioned in your written testimony, which rules are the most burdensome? Are there process-related reforms that would ease burdens while maintaining environmental protection?

    a. Federal rules and permits (note that some are administered by the State):
        i. Air Permit modification for coal-fired power plant – altering the existing coal unit's permit to a dual-stack configuration

[1] The report is available at https://energy.gov/downloads/download-staff-report-secretary-electricity-markets-and-reliability

ii. Air Permits for carbon capture and cogeneration – three total permits for authority to construct the cogeneration system and the carbon capture unit
iii. Air Permit – Title V operating permit for the cogeneration and the carbon capture unit
iv. Wastewater permit – for treated wastewater to be returned to the lake
v. Storm water permit – for proper treatment and discharge of storm water
vi. Section 404 permit – COE permit for certain portions of the pipeline
vii. Section 10 permit – COE permit for certain portions of the pipeline
viii. UIC Class II injection permits – for CO_2 injection wells in the enhanced oil recovery project in the oil field

b. Aside from compliance with the Clean Air Act, the most burdensome Federal approvals to obtain were from the NEPA process and the Corps of Engineers. The requirements and procedures themselves were not overly burdensome, however the long delays in receiving a final decision from the agencies caused many problems for our financing and construction.
c. In both cases, Congress should consider what actions are needed to shorten the process.

Senator Sullivan:

7. It took your company seven years to complete the Petra Nova Carbon Capture and Enhance Oil Recovery project and I agree it is impressive that you did so on time. It has long been my belief that the U.S. regulatory process is a burden to most energy developers, even those who sought to build an innovative facility designed to minimize carbon output, we heard a similar narrative from Mr. Fry in reference to NEPA. Could you outline a few of the permitting and NEPA requirements that you encountered personally that were counterproductive, duplicative, or unnecessary?

    a. NEPA – The rules and guidance on what constitutes an "impact" are well known and, as good stewards of our shareholder's money, we were careful to design the capture system, the pipeline, and the oil field operations in a way that had no unmitigated impacts. It took us 16 months and over $1 million to get the various agencies involved in the NEPA review to concur that we in fact had no impacts.
    b. Corps of Engineers – We needed a number of permits, consents, and acknowledgements from the COE, which were all ultimately granted. In working with the Corps it seemed to us that they lacked the personnel to respond in a timely manner.

Senator Whitehouse:

CO2 Pipelines

8. At the hearing, witnesses agreed that a major hurdle for CCUS projects is capital financing and upfront costs. It was also discussed that CO_2 pipeline infrastructure build-out is needed to facilitate the transport of CO_2 for reuse and to improve the financing of projects.

a. What specific federal policies would facilitate the construction of CO_2 pipelines?
    - The federal government should enact policies that require existing rights of ways such as rail roads and highways be made available to CO_2 pipelines to not only lower costs, but to also minimize disturbing new lands and the time it takes to build this infrastructure.

b. Is it true that a majority of new pipelines could be built within existing interstate pipeline corridors? Or will CO_2 pipeline infrastructure build-out occur in areas that will require extensive NEPA requirements?
    - The CO_2 pipeline in the Petra Nova project was smaller than the large diameter pipes likely to be used for long-distance interstate pipelines. That said, our pipeline was co-located in the same right of way with other pipelines, electric transmission lines, and railroads for over 95% of the 81-mile length. Based on our experience we would answer that these pipelines can be built in the same right of way. I note however that impact on previously undisturbed lands is not the only aspect of a project that could trigger the need for an agency to conduct a NEPA mandated review. So even if a pipeline is located within an existing right of way, a NEPA review could be triggered by other factors.

Senator BARRASSO. Thank you very much, Mr. Greeson.
Mr. FRIEDMANN.

STATEMENT OF S. JULIO FRIEDMANN, CEO, CARBON WRANGLER LLC

Mr. FRIEDMANN. Thank you, Mr. Chairman. Thank you, Ranking Member Carper and all the members of the Committee. My name is Julio Friedmann. Thank you for inviting my testimony. I am the CEO of Carbon Wrangler, LLC. Until recently, I served as the Senior Advisor for Energy Innovation at the Lawrence Livermore National Laboratory, one of the DOE's 17 national labs. From 2013 to 2016, I served in two capacities in the Obama administration at the Department of Energy, first as the Deputy Assistant Secretary for Clean Coal and Carbon Management and, second, as the Principal Deputy Assistant Secretary for the Office of Fossil Energy. I have worked for something like 17 years on clean energy technology deployment and development, focusing my work on CCUS, mostly from my position at the National Lab.

Clean energy demand continues to grow worldwide, with an investment of nearly $400 billion in 2015 and 2016. Many governments see investment in this technology as important to transforming energy markets and claim the additional benefits from those investments, for example, stronger heavy industry sector, maintaining and growing jobs, avoiding the health consequences of pollution, a number of other things. In a global clean energy market, the U.S. is considering how to best invest in the power, transportation, and industrial energy sectors as they change nationally and globally.

In this context, carbon capture, use, and storage, CCUS, remains a critically important and under-supported sector in the clean energy industry. CCUS includes carbon capture and storage, CO_2 enhanced oil recovery, which was mentioned by the Chairman, CO_2 conversion and use, and even carbon removal from the atmosphere. These different pathways provide real commercial and environmental opportunities for companies, communities, and governments.

Recent progress on CCUS is profound. Today there are 16 commercial plants operational worldwide, including Mr. Greeson's plant at Petra Nova. Six more are planned, with 22 expected to be operating in 2020. These include power and industrial projects, new build and retrofits, some for CO_2 -EOR, some for saline storage mostly in North America. A third of them are in North America. Costs have come down, performance has gone up, and new technologies have been born that show that CCUS can be cost competitive today with other clean energy technologies in many markets. In some sectors like heavy industry, CCUS is the only available option today.

Importantly, the challenges CCUS faces in deployment are neither fundamentally technical nor regulatory. Rather, it is that today there is no policy or set of policies in place that make it possible to finance a project. There is a gap between project costs and market prices, and tariffs that prevent private capital from flowing into projects. This greatly limits deployment. While there are many potential pathways for providing policy support, there is no market for CCUS absent such policies. These will severely limit the number of projects, the scale of the projects, and the availability of private capital to build and deploy CCUS. It is worth noting that of the $2.2 trillion that flowed into the clean energy deployment sector worldwide, according to the Global CCS Institute, less than 1 percent of that money, less than 1 percent went into CCS.

You have my testimony. It speaks volubly about the prices and the costs for carbon capture and storage, where these projects are going, and how it can be applied in the power and industrial sector. It is worth noting that if there were pipelines in place right now and some straightforward policies, we could capture 44 million tons of carbon dioxide for very, very low cost today from pure streams of CO_2 in the industrial sector.

But I want to focus the rest of my time on the finance question. As I mentioned earlier, CCUS is competitive on a purely levelized cost of electricity basis with many, many clean power options. Whether it is applied to power, industrial sectors, or not, it is not possible to obtain the financing for the commercial projects today. Just can't do it. This is chiefly because it is not possible to recoup the investment.

Many clean energy technologies in the United States and elsewhere, such as wind and solar, rightly benefit from policy support. These include renewable portfolio standards which mandate a fraction of generation; investment and production tax credits, the ITCs and PTCs; feed-in tariffs, which are guaranteed price supports, common in Europe; development mandates, such as the Chinese government says when they say we are going to build 200,000 megawatts of wind; and many other policies.

For many years in the U.S. and other countries, policies like this closed the financing gap for those clean energy technologies. That created markets for those clean energy and have led to growth and jobs. None of this is contested.

CCUS projects have no access to these policies. If they did, the size of those policies for other clean energy investments, such as the ITC, the PTC, et cetera, would be large enough to close that financing gap. The lack of policies that support financing limit the flow of private capital to CCUS projects. Similarly, they limit the corporate R&D, which is necessary to get dramatic price drops through deployment and activation. It limits VC financing in startups. It limits the development of human capital. It limits the supply chains that would go into these industries. Many ministries in many countries, including the United States, have called for policy parody to close the financing gap and to help create a vibrant CCUS market.

I look forward to your questions and comments. Thank you for the opportunity to testify.

[The prepared statement of Mr. Friedmann follows:]

Senate Environment & Public Works Committee
Expanding and Accelerating the Deployment and Use of Carbon Capture, Utilization, and Sequestration

Dr. S. Julio Friedmann, CarbonWrangler LLC
Written Testimony

Thank you for inviting my testimony. My name is Julio Friedmann, the CEO of Carbon Wrangler. Until recently, I served as the Senior Advisor for Energy Innovation at the Lawrence Livermore National Laboratory. From 2013 to early 2016, I served as the Principal Deputy Assistant Secretary for the Office of Fossil Energy at the US Department of Energy. I have worked for a total of 17 years on clean energy technology development and deployment focusing my work on CCUS, mostly from my positions at Lawrence Livermore National Laboratory.

Clean energy demand continues to grow worldwide, with investment of nearly $400B in 2015 and 2016. Many governments see investment in clean energy technology development and deployment as part of their strategy to remain globally competitive in transforming energy markets, and claim additional benefits from those investments (e.g., stronger heavy industrial sector, maintaining and growing jobs, and avoid the health consequences of pollution). In a global clean energy market, US is considering how best to invest in the power, transportation, and industrial energy sectors as they change nationally and globally.

In this context, carbon capture, use and storage (CCUS) remains a critically important and under-supported sector in the clean energy industry. CCUS includes carbon capture and storage (CCS), CO_2 enhanced oil recovery (EOR), CO_2 conversion and use (CO2U), and even carbon removal technology (so called negative emissions approaches, which pull CO_2 from the air and oceans). These different pathways provide real commercial and environmental opportunities for companies, communities, and governments.

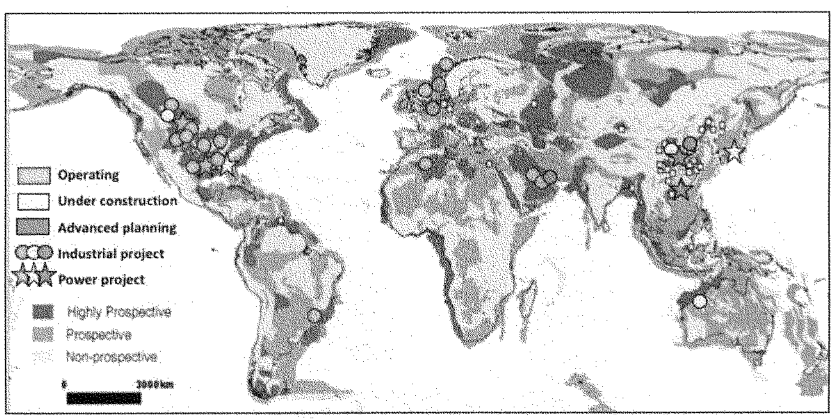

Figure 1: Operating and soon to be operating CCUS projects world-wide. Over one third of these are in North America.

Recent progress in CCUS is profound. Today, 16 commercial plants operate worldwide, and with six more planned, 22 will be operating by 2020 (Figure 1). These include power and industrial projects, new build and retrofits, and both CO_2-EOR and saline storage, with over a third in North America. Costs have come down, performance has improved, and new technologies have been born that show that CCUS can be cost competitive today with many clean energy technologies in many markets. In some sectors, like heavy industry, CCUS is the only option available at scale today.

Importantly, the challenges CCUS faces in deployment are neither fundamentally technical nor regulatory. Rather, it is that today there is no policy or set of policies in place that make it possible to finance CCUS projects. There is a gap between project costs and market prices and tariffs that prevent private capital from flowing into projects. This greatly limits deployments. While there are many potential pathways to providing policy support (see below), there is no market for CCUS absent these policies, which will severely limit the number of projects, the scale of projects, and availability of private capital to CCUS deployment. It is worth noting that of the $2.2 trillion that flowed into clean energy deployment world-wide, less than 1% went to CCUS.

Current Project Review

As noted, over 16 projects are operating in the world today, with 6 more coming online by 2020. Together, these will inject 40 million tons of CO_2 underground – like pulling 8 million cars off the road. The overwhelming majority of these projects have been completed on time and on budget, and have a successful high-capacity operating history.

In addition to these projects, there are a few additional noteworthy projects for the Committee's consideration.

PetraNova[1]: NRG, in partnership with JX Nippon and Hilcorp Energy Company, retrofit the W.A. Parish power plant near Houston, TX. Roughly 1.6 Million tons are captured by the liquid solvent technology, provided by Mitsubishi Heavy Industries, and stored during enhanced oil recovery. The project came in on time and on budget. The operators and partners say that a second project at the same site could be done for roughly 20% lower cost.

Port Arthur[2] **and Quest**[3]: These two industrial projects capture and store CO_2 which is a byproduct of converting methane to hydrogen. This produces very low-cost, zero-carbon hydrogen – the cheapest in the world so far. The Air Products project at Port Arthur stores the CO_2 through EOR. Shell's project at Quest stores in a saline formation.

China: Many CCUS projects are moving forward quickly in China. Dr. James Wood's testimony will explain this in some detail. However, it is worth noting that 3 large commercial projects are coming on line in the next four years, and that the Chinese Academy of Sciences has tasked a new research institute in Shanghai[4] for the sole purpose of CO_2 conversion to useful products.

NetPower Pilot Plant: NetPower[5] is a North Carolina based company that uses "Allam cycle" combustion – oxygen-fired natural gas turbines that use supercritical CO_2 as both the

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[1] http://www.globalccsinstitute.com/projects/petra-nova-carbon-capture-project
[2] http://www.globalccsinstitute.com/projects/air-products-steam-methane-reformer-eor-project
[3] http://www.globalccsinstitute.com/projects/quest
[4] http://english.sari.cas.cn/
[5] http://www.netpower.com

working fluid and mass to the turbine. The NetPower system has the same cost as a natural gas power block, has a physical footprint, and requires no water for cooling (in some configurations, the plant produces water). A pilot demonstration[6] near Houston has finished construction and begun component testing - it should be operational in fall 2017, with Exelon, Chicago Bridge and Iron, and Toshiba as commercial partners.

Climeworks Direct Air Capture Plant[7]: A small Swiss company, Climeworks, has created the first commercial, for-profit project that captures CO2 directly from the air. They capture and sell 900 tons/year of CO_2 to an organic greenhouse. This technology is mass-producible, scalable, and robust.

Carbon removal power plant: Climeworks is partnering with Reykjavik Energy in Iceland and Lawrence Livermore National Laboratory to make the world's first power plant with less-than-zero carbon emissions. Based at the Hellisheidi Geothermal Power Station[8], Climeworks is installing their direct-air capture system. CO_2 drawn from the air will then be injected into the deep basaltic rocks below the plant, part of the CarbFix project[9]. US participation will include LLNL work on the monitoring and validation of the CO_2 injection as well as the life-cycle analysis of the carbon footprint. Already, the project has paying customers.

Carbon Recycling International's Renewable Methanol Plant[10]: Also in Iceland, Carbon Recycling International has built and operated a plant that converts CO_2 to methanol, a chemical feedstock and transportation fuel. Using clean electricity from the Svartsengi geothermal power station, they make hydrogen from water and combine the renewable hydrogen with CO_2 to make methanol. This fuel is sold to ferries in Europe, which use the methanol to power fuel cells.

NOTE: The increased availability of low-cost, distributed clean power and heat helps to create new industries like Carbon Recycling International that convert CO_2 to products. Part of the likely market value of these products is the low carbon footprint. If so, then the demand for clean energy will grow as these companies gain market share – part of a new carbon economy.

Power Applications: Range of Costs and comparisons to other technologies

CCUS has many applications, including power, heavy industry (see below), and achieving negative emissions. While commonly considered a "coal" power sector technology (where it would be most valuable in reducing emissions), it can also be applied to biomass, natural gas, biogas, and even fuel cell power systems. Perhaps surprisingly, the CCUS power costs are competitive today on an unsubsidized cost basis with many other technology options (Figure 2). On an unsubsidized basis for the levelized cost of electricity (LCOE)[11], power from gas, coal, or biomass is cheaper than offshore wind, new nuclear power, rooftop solar PV, concentrating solar, and community solar PV with batteries in many US markets.

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[6] https://www.forbes.com/sites/christopherhelman/2017/02/21/revolutionary-power-plant-captures-all-its-carbon-emissions-at-no-extra-cost/#5db22e3d402d
[7] http://www.climeworks.com/
[8] http://www.onpower.is/about-us
[9] https://www.or.is/english/carbfix-project
[10] http://carbonrecycling.is/
[11] Lazard, 2016. Levelized cost of electricity analysis - version 10.0. https://www.lazard.com/perspective/levelized-cost-of-energy-analysis-100/

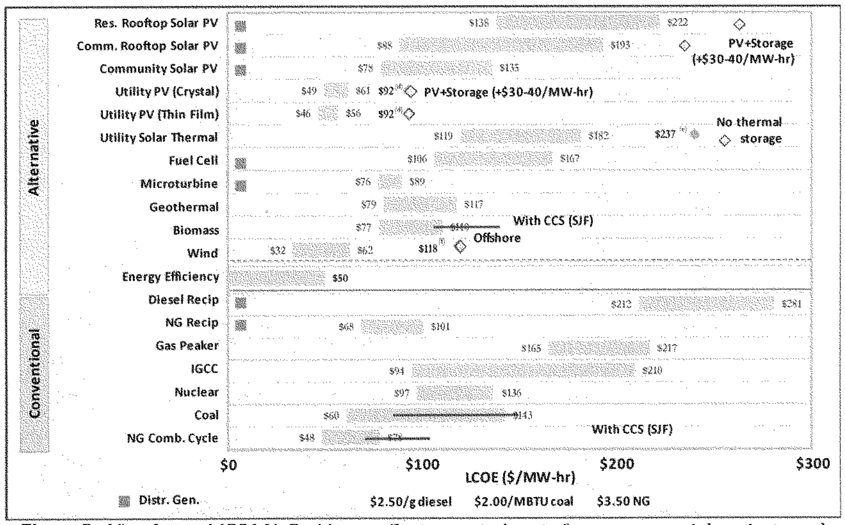

Figure 2: After Lazard (2016). Red bars reflect reported costs from commercial projects and price estimates based on DOE and NETL reports on existing technology in the market today.

Today, post-combustion retrofits on a supercritical coal plant using amine-based solvents is possible and in some cases the lowest cost pathway to decarbonization. For example, the PetraNova plant described above reduced 90% of the emissions from one unit without derating or decline in power output. Importantly, opportunities for cost reduction are major even with the same kit – CCUS coal plant operators in the US and Canada have publically stated that they could reduce costs by 20% redoing the same plant, and that the 4th plant would achieve 40-50% cost savings relative to the first.

Industrial CCUS in the US

Many heavy industries, representing 20% of global emissions, lack other options to decarbonize. Cement, steel, refining (and biorefining), chemicals, and glass making are particularly difficult cases. For cement and steel making, much of the emissions are a direct consequence of fabrication chemistry. For such systems, CCUS is the only available option.[12]

In many cases, though, by-product CO_2 is highly-concentrated (e.g., for ethanol, biodiesel, fertilizer production, natural gas sweetening, refining, and petrochemicals). These can be captured and stored at relatively modest cost. In the US, the all-in-cost of CCS, including polishing, compression, transport, and storage, is less than $30/ton CO_2 – in some cases less than $20. ***Over 43M tons/year could be stored at this low cost.*** [13]

For this reason, perhaps unsurprisingly, most CCUS projects around the world are industrial projects. These include Emirates Steel (the first ultra-low C metallurgical plant), the Uthmaniyah refinery in Saudi Arabia, the Quest upgrader project in Alberta, the ADM ethanol plant in Decatur, Illinois, and the Air Products plant in Port Arthur, TX.

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[12] Global CCS Institute, 2016, Understanding Industrial CCS Hubs and Clusters, 2016

[13] www.betterenergy.org/American_CO2_Pipeline_Infrastructure

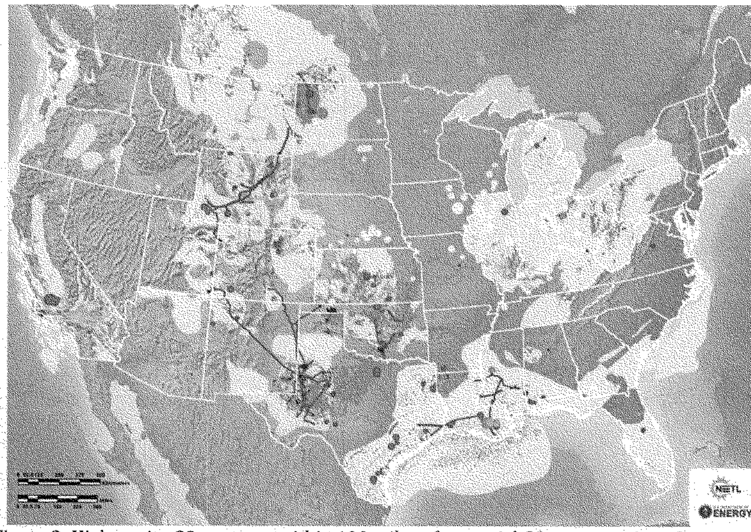

Figure 3: High-purity CO_2 sources within 100 miles of potential CO_2 storage sites. Green areas represent oil fields; light beige areas represent saline formations for storage. Yellow dots = ethanol plants, purple dots = fertilizer plants, red = petrochemicals plants, orange = oil and gas refineries.

Finance gaps and policy options

As stated above, CCUS is competitive on a pure levelized cost basis with many clean power options. However, whether CCUS is applied to power, industrial or other sectors, it is not possible to obtain financing for commercial projects. This is chiefly because it is not possible to recoup a private investment given today's policy frameworks.

Many other clean energy technologies (such as wind or solar) rightly benefit from policy support. These include renewable portfolio standards (mandating a fraction of generation), investment and production tax credits (ITCs and PTCs) which provide cash back to developers and operators, feed-in tariffs (guaranteed price supports, common in Europe), development mandates (e.g., 200,000 MW wind construction as mandated by the Chinese Govt), and others. For many years in the US and other countries, policies like this closed the gap for financing projects, and developers could recuperate their investments and pay back loans given the financial security of such policies. That created markets for clean energy, and jobs, supply chains, and wealth reaction accompanied those specific policy decisions.

CCUS projects have no access to these policies[14]. If they did, the size of these policies for other clean energy investments would large enough to close the financing gap (see Lazard[15]

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[14] Global CCS Institute, 2016, The Global Status of CCS, Summary Report

[15] Lazard, 2016. Levelized cost of electricity analysis - version 10.0. https://www.lazard.com/perspective/levelized-cost-of-energy-analysis-100/

and fig. 2 above). Lack of policies that support financing limit the flow of private capital into CCUS projects. Similarly, they limit corporate R&D investment, limit VC financing of start-ups, and limit the human capital and supply chains that come from projects. Many ministries in many countries, including the US, have called for "policy parity" to close the financing gap and help create a vibrant CCUS market.[14,16]

Ultimately, lack of financing and a CCUS market will disadvantage US companies in the global marketplace. Substantial investments in R&D and projects from the governments of Japan, China, Germany, Canada, Norway and Saudi Arabia have supported companies and projects that can take advantage of emerging CCUS markets. If the US does not create markets for CCUS companies and projects in the US, then wealth and job creation will flow to other countries.

Final thoughts

We are at the edge of a new carbon economy – one that harnesses innovation and entrepreneurship to create new products, companies, and wealth through capturing and converting fugitive carbon into value-added products. Global carbon constraints in the market will convert to product value in ways that are hard to predict, but as part of an inexorable and inevitable trend. The global economy will increasingly value low-carbon products, including goods manufactured in the US with a reduced CO_2 footprint. CCUS provides a low-cost pathway to both greater global competitiveness for US companies and for revitalizing industrial base of the US through investment and innovation. That pathway is ready for deployment today.

New policies are required to help create markets for projects, vendors, operators, and energy services in a new carbon economy - ones that can be supported through conventional financial investors that would accelerate the development and deployment of these novel technologies and industries.

[16] Carbon Sequestration Leadership Forum, November 2015. "6th Meeting of the Carbon Sequestration Leadership Forum (CSLF) Ministers: Moving Beyond the First Wave of CCS Demonstration" http://www.cslforum.org/publications/documents/CSLF_Communique.pdf

Senate Environment and Public Works Committee
hearing entitled, "Expanding and Accelerating the Deployment and Use of Carbon Capture, Utilization, and Sequestration,"
Wednesday, September 13, 2017
Questions for the Record for Dr. Julio Friedmann

Chairman Barrasso:

1. In your testimony, you said that "the regulatory issues would be the next thing that people would look at" after closing the financing gap for CCUS. At the hearing, you stated that you have heard from multiple industry stakeholders that New Source Review (NSR) under the Clean Air Act could discourage retrofits of facilities with CCUS technology. Do you agree that we should examine these claims in more detail? Is it possible that NSR reform could help to expand deployment of CCUS technology?

New Source Review (NSR) is a complex topic with deep jurisprudence. I do not have an opinion as to whether or not claims and concerns regarding uncertainty in NSR vis-à-vis potential CCUS projects are merited. As I and other witnesses maintained, the primary obstacle to CCUS deployment is up-front capital costs and financing, not uncertainty surrounding NSR.

That said, one of the main benefits of a successful CCUS project is the overt reduction in emissions from an existing source. If operators are reluctant to undertake CCUS due to uncertainties around triggering NSR, then some sort of alternative or reformed process should be considered to clarify the existing rules, ideally in a way that continues strong controls for criteria pollutants while facilitating CCUS retrofits.

2. How do public-private research partnerships, such as those through the National Carbon Capture Center, accelerate the deployment of clean energy technologies like CCUS? Is there more that the federal government could do to encourage this collaboration?

At present, public-private partnerships are essential to accelerating the deployment of CCUS and other clean energy technologies. By sharing risks, responsibilities, and costs, projects (especially large scale-pilots, demonstration projects, and pre-commercial testbeds) can provide critically important technical information, develop experience, build human capital, and add confidence to evolving markets and investors. The National Carbon Capture Center is an excellent example of this, and has served many US companies who are developing technologies as well as providing standardized information to potential operators and investors. The same will likely prove true for the CO2 Utilization testbed being built in Gillette, WY at the Integrated Test Center.

The Federal government could indeed do more to encourage public-private partnerships for CCUS in general, and the NCCC in particular:

- ***Create additional programs that award more testbeds through competitive solicitation.*** *Potential examples could include a test-bed and standards facility for CO2-based cement and aggregate, a National field facility for geological storage experiments and standards (as was* *proposed years ago for Teapot Dome), a public-private facility aimed at water harvesting from fossil fuel combustion systems, and a National algae growth and processing facility.*

- *The NCCC is currently configured to test pre-combustion (mostly solvent-based), post-combustion, and fuel-cell technologies for both coal and natural gas.* ***The natural gas test bed could be expanded*** *to include novel turbine designs (like NetPower's Allam Cycle system) and larger post-combustion gas capture programs (including larger sorbent and membrane systems).*
- *Programs like CarbonSAFE could be expanded to build a broader public-private partnership system.* ***For example, a subset of SAFE projects could be sites to explore the creation of new CO2 utilities****. These would have jurisdiction to raise rate-payer funds to pay for pipelines, and also to cover liability and monitoring issues (as well as consider primacy for Class VI wells for CO2 injection under the EPA's underground injection control statutes).*

3. In your testimony, you said that there is an "educational and informational barrier" that CCUS researchers and supporters like yourself face all the time. What steps could overcome these educational and informational barriers and bring CCUS to the forefront of 21st century energy discussions?

There are no simple answers to this challenge. Fundamentally, explaining CCUS to people involves showing folks what it is and gaining familiarity (my experience has been that detailed discussions of chemistry, hydrology, geomechanics, etc. don't help much).

Since these facilities are typically far from population centers and transit thoroughfares, gaining familiarity is a challenge. Few folks visit, and many sites are neither telegenic nor dynamic.

Over the years, many groups (e.g., Univ. Texas Bureau of Economic Geology) have developed curricula, training modules, K-12 experimental sets, etc. to help communicate this topic. Many companies and NGOs have developed short videos, children's books, and fact sheets. These do not seem to have made much progress in public communication.

A few ideas come to mind, some of which are within the purview of the Federal Govt:

- ***Study tours****: Visits to multiple facilities, including field projects and national Labs, and featuring presentations by experts (often from local universities), have seemed to make progress. These could be for PUC and PSC commissioners, state and federal officials, regulators, investors, and media leaders. Ideally, such study tours could be regular and recurring, with partial federal support (e.g., from DOE).*
- ***Roadshow****: The inverse of a study tour, a group of experts travel from place to place with professionally developed information, media, presentations, etc. to spend a day locally providing education and insight. Stops for a roadshow could include state capitals, major universities (especially land-grant universities), and industrial centers (e.g. Houston, Detroit) and engage business and civic leaders directly.*
- ***High-profile platforms****: National and international events like Davos, National Party Committee meetings, G20, CERA week, and others could provide platforms to educate decision makers on what's known about CCUS, including its benefits and economic role.*

Senator Whitehouse:

Ocean Capture Technology

4. Dr. Friedmann, at the hearing, you mentioned there are eight organizations working on removing carbon directly from the oceans.
    a. What are the names and locations of these organizations?
    b. How do these different technologies work?
    c. How might federal support help to commercialize these technologies?

These are those organizations and companies who have worked on direct ocean capture (DOC) and have developed technology to extract CO2 from seawater. There may be others as well -- these are the main approaches I am aware of.*

- ***Lawrence Livermore National Lab**: LLNL has developed tiny capsules (about 0.1 mm across) made of gas-permeable plastic and containing CO2 solvents. When placed in seawater, they rapidly draw CO2 from the brine into the microcapsules. When these are taken from seawater and/or heated, they release the absorbed CO2.*
- ***Arizona State Univ**: This is a gas-permable membrane (sheet or spiral-wound) that operates with a small pressure gradient. It can dissolve CO2 into brines (e.g., to feed algae) or draw CO2 from them.*
- ***X** (formerly Google X, part of Alphabet): The core technology is a desalination reverse-osmosis membrane which separates brine from water as well as CO2. Originally, it was explored as part of the "seafuels" project, also known as Foghorn. The goal was to create fuels from the ocean at competitive prices. The tech has not yet moved to that price, so the project was shelved.*
- ***Naval Research Lab**: The NRL was looking at ways to extract Co2 from sea water as feedstocks to jet fuels while ocean bound. The core technology is alkalinity swing – they create acids by making protons electrolytically, which leads both to bicarbonate/ carbonate production and hydrogen generation).*

**Note: This does not include approaches such as ocean iron fertilization or ocean liming, which do not directly draw CO2 from seawater and involve adding materials to the ocean.*

Today, there are no formal federal programs that support separation of CO2 from the ocean. This limits what is possible in terms of commercial co-investment and small business support, and limits the rate and variety of innovation.

CO2 Pipelines

5. At the hearing, witnesses agreed that a major hurdle for CCUS projects is capital financing and upfront costs. It was also discussed that CO_2 pipeline infrastructure build-out is needed to facilitate the transport of CO_2 for reuse and to improve the financing of projects.
    a. What specific federal policies would facilitate the construction of CO_2 pipelines?

A number of policies could facilitate CO2 pipeline construction. The key issue is up-front capital cost, so any facilitating policy must manage that risk directly.

First, the creation of a substantial "production tax credit" for CO2 storage (like the FUTURE Act) would provide enough financial incentive for pipeline developers to take construction capital risks. Other kinds of tax provisions, such as a large refundable ITC for pipeline construction or private activity bonds, would help. Second, grants to developers would suffice – these could be given through new programs at the DOE, Dept. of Transportation, or as block-grants to states. Third, creating new CO2 utilities would provide new authorities for utility commissions to gather rate-payer funds to finance pipelines, much as some natural gas pipelines are financed today.

b. Is it true that a majority of new pipelines could be built within existing interstate pipeline corridors? Or will CO_2 pipeline infrastructure build-out occur in areas that will require extensive NEPA requirements?

It is highly likely that the majority of new pipelines would attempt construction within existing pipeline corridors and rights of way. This is for permitting and logistical simplicity. However, some very good sites are not along existing pathways, and would face risks in aggregating land rights and fairways. In some cases, Federal funds would be involved, and may require NEPA regardless.

Senator BARRASSO. Well, thank you to all three of you for your very interesting testimony. We will have some time for members to ask questions now, so I appreciate your willingness to participate in this.

I am proud to say, Mr. Fry, that our home State of Wyoming is already a leading promoter of CO_2 pipeline development, with the Wyoming Pipeline Corridor Initiative that you outlined. This proposes developing a network of CO_2 pipelines connecting oil fields with CO_2 sources, both manmade and natural, within Wyoming.

In my opening statement, I showed a chart that showed many areas across the Country that could benefit from similar efforts. Are there things that the Federal Government could do? We just heard from Dr. Friedmann, who I thought eloquently talked about some of the problems that were out there. Are there things, Mr. Fry, that you think we could do to make it easier for other States to replicate what you are doing in Wyoming?

Mr. FRY. Well, thank you, Mr. Chairman. Yes, I believe there are. As Dr. Friedmann mentioned, the opportunity to move forward with 45Q legislation provides that financial incentive that we are looking at. But as far as a regulatory incentive, the discussion that I made in regards to up-front planning is probably key in this instance, so if States outside of Wyoming took the initiative to focus on where they could capture the CO_2 and where they could inject it, be it either in EOR fields or in saline formations, I think they could be ahead of the curve substantially.

Senator BARRASSO. And your testimony mentions that CCUS provides us with the opportunity to treat carbon dioxide as a valuable commodity when it is used in conjunction with the enhanced oil recoveries you just mentioned. Do you think that the use of CO_2 for enhanced oil recovery is a more powerful incentive to develop projects like this and decrease CO_2 emission, compared to, say, extensive more regulations on the energy industry?

Mr. FRY. Yes, sir, I believe it is. It seems like project proponents typically are more open to letting the market drive something like this than they are being dictated by regulations. So I agree 100 percent that is the way to go.

Senator BARRASSO. Mr. Greeson, can you explain some of the benefits of retrofitting plants with CCUS to produce cleaner energy? And what can CCUS provide that other clean energy technologies such as wind and solar can't?

Mr. GREESON. Sure, thank you, Chairman Barrasso. The benefits of retrofit are that is where the bulk of the emissions that everybody is trying to address is coming from now. It is not new plants, because there are very few new coal plants being proposed or developed, at least in the U.S. It is possible to do carbon capture on a greenfield plant, and do it even less expensively than you could on a retrofit, but the bulk of the emissions we are trying to address these days are on retrofitted opportunities. And then with the design that we ended up with, and thanks to the difficulties of navigating New Source Review, we ended up with a stand-alone cogeneration facility to supply steam and electricity to the cogen, to the carbon capture.

Our plant actually increased the number of clean megawatt hours being produced at this plant, rather than using some of the load at the plant for parasitic loads. So, yes, it definitely improves the emissions profile. The coal plant that we have attached our carbon capture system to has the same carbon footprint as a gas-fired combined cycle.

Senator BARRASSO. Mr. Fry, could you elaborate on some of the specific obstacles that the National Environmental Policy Act, or NEPA, presents when companies try to build CO_2 pipelines?

Mr. FRY. I think the greatest challenges it presents would be time constraints, as well as financial constraints when a company comes in to develop a project that may take them 10 years to finalize their NEPA document, at which point the market could have changed drastically and they may no longer have an economically viable project. So time is a big concern.

Senator BARRASSO. As you mentioned with time being a big concern, what are some improvements that could be made to preserve the goals of NEPA and facilitate quicker development of the pipelines?

Mr. FRY. From my perspective, if people would follow the model that we are laying down in Wyoming as far as up-front planning, so they can build that strong foundation, they would have a lot less constraints to challenge their project and the future of their NEPA analysis.

Senator BARRASSO. And then, Mr. Greeson, my final question, you stated that there are certain regulatory requirements that dissuade companies from installing the CCUS technology. Can you explain how New Source Review, which is required by the Clean Air Act, actually dissuades companies from installing technology that would decrease emissions in certain areas?

Mr. GREESON. Certainly. So, many of the retrofit opportunities are in plants that are old and depreciated, and there are certain triggers under the Clean Air Act that would trigger a New Source Review, including the size of the investment that you are about to make versus the book value of the host unit. So many of these units are already very well depreciated and so an investment the size of $1 billion, per se, would trigger a New Source Review, and that is, as I mentioned in my testimony, pretty risky for the host coal unit. So it makes it a very gut-wrenching decision to make to go that way.

Senator BARRASSO. Thank you.

Senator CARPER.

Senator CARPER. Let me just ask my dear Democratic colleagues. Anybody in a hurry to go to another hearing or something you need to rush off to? If you do, I will yield my time to you initially. Anybody?

I have no questions.

[Laughter.]

Senator CARPER. No, actually, I do.

Julio Friedmann, that is an interesting combination of names. How did you get to be a Julio?

Mr. FRIEDMANN. I was a birthday present, sir.

Senator CARPER. OK. Thank you.

[Laughter.]

Senator CARPER. Whatever.

Mr. FRIEDMANN. My mom is Columbian, my father is Venezuelan, and they met in the Catskills in Grossinger's Hotel.

Senator CARPER. Well, that would explain it.

[Laughter.]

Senator CARPER. More people should meet there.

I want to give you just a moment to respond to the claims made by one or two of our other witnesses that we need to make changes in environmental regulations in order to grow the use of this technology, which we all seem to support. I believe, as I have said, there are real benefits to CCUS. I also believe that we need to deploy it in a manner that doesn't create additional environmental problems while solving carbon dioxide emissions.

In your opinion, are the biggest hurdles holding back the use of this technology are they financial in nature or do they deal more with environmental permitting?

Mr. FRIEDMANN. It has been my experience and is strongly my opinion that the primary barriers are financing barriers. It is not possible to get a loan to build a CCS plant because you can't get your money back. And it is not possible to get an equity investor for a CCS plant because you can't get your money back. If we had clean energy portfolio standards, instead of renewable portfolio standards, it would be possible to get rate recovery for utilities. We do not have access to those mechanisms.

If there was something like 45Q, where you could have sufficiently large investment and production tax credits, that would be enough to close the financing gap. The regulatory issues would be the next thing that people would look at, but the first thing they would look at, like Mr. Greeson said, is the up-front capital cost and the financing.

Senator CARPER. You were very straightforward, but just tell us what do we need to do? Just say it again. I want us to listen. What do we need to do in order to provide for a more level playing field for this technology?

Mr. FRIEDMANN. Fundamentally, we want to close the financing gap. So, today, if you wanted to retrofit a plant, like the NRG Petra Nova guys have done, you need to raise capital, you need to discount that capital over some period of time. You have to have a finance raise; you need an internal rate of return. If you can't get the IRR, you can't get the project. So you need to close that financing gap.

Depending on how you calculate it, the production tax credit for wind today is about $60 a ton for CO_2 abatement. That would be large enough. The amounts of money that have been proposed for 45Q would be enough to launch a whole bunch of projects in the industrial sector and in the power sector for gas, as well as coal. You just need to close that financing gap.

Senator CARPER. I just want to say very briefly, Mr. Fry, Mr. Greeson, do you approve this message?

Mr. GREESON. I largely approve whatever Julio says.

Senator CARPER. OK, thank you.

Mr. Fry.

Mr. FRY. I agree the financing gap is a huge challenge, and afterwards we could certainly work on expediting the environmental issues.

Senator CARPER. All right.

Mr. Friedmann, Julio Friedmann, ever since President Trump announced that the U.S. would exit from the Paris agreements, I have been concerned that America will cede, as I said in my opening statement, cede opportunities to lead the world in technological innovation that could both fight climate change and create manufacturing jobs right here in the USA. Do you share my concerns? And would you further discuss the policies that you believe the U.S. should pursue to bridge the financial gaps with the CCUS, unless you think you have already done that? You may have done that in answer to my last question.

Mr. FRIEDMANN. In response to your question, the fundamental fact of the Paris Agreement is 197 countries have agreed that carbon matters. That means there is no market anywhere in the world where carbon is not an issue. There is no market anywhere in the world where carbon is not an issue. That creates opportunities for U.S. technology export. In fact, today the United States is an unambiguous global leader in carbon capture, utilization, and storage.

If we do not continue to press for an innovation agenda, if we do not continue to deploy plants, we will lose that advantage to other countries that are making substantial investments along these lines, notably, China, Japan, and Germany, and Canada.

Senator CARPER. And Canada?

Mr. FRIEDMANN. Canada is actually, is in fact the technology that is deployed on the smaller version of David Greeson's plant up at Boundary Dam, that is Canadian technology, Cansolv, and the largest saline aquifer storage project in the world today is up in Canada as well, it is the Shell Quest Project.

Senator CARPER. OK, thanks.

Mr. Greeson, you testified that NRG's Petra Nova's project was on budget and on time with the current environmental protections in place. Is that correct, yes or no? Is that correct?

Mr. GREESON. Yes, our project was on time and on budget, yes.

Senator CARPER. Good. Thanks. In your written testimony you mention this project started in 2009 because NRG felt that we would have Federal regulations in place that would constrain carbon emissions from power plants. If you would, just answer briefly. Do you believe that NRG would make the same decisions today, based on this Administration's policies to roll back all regulations dealing with climate change and carbon pollution?

Mr. GREESON. So, we are hearing from our customers. We are a competitive retail electric provider. We sell everything we sell under competitive market structures. We do not have rate base to put off cost onto, so everything we do we do because we are trying to make our product more attractive to our customers.

Right now, our customers are asking for lower carbon products, and so the current status of the Administration almost doesn't matter. We looked at what our customers are demanding, and that is what we try to provide.

Senator CARPER. Do you believe that NRG would make the same decisions today based on this Administration's policies?

Mr. GREESON. So——

Senator CARPER. If you would just say yes or no, then we will go on.

Mr. GREESON. So the question—there are so many factors that go into making the decision. Definitely, the Administration's position would be one of those factors that we would consider.

Senator CARPER. All right, thanks.

Thanks very much.

Senator BARRASSO. Thank you, Senator Carper.

Senator INHOFE.

Senator INHOFE. Thank you. Thank you, Mr. Chairman. You know, this is kind of interesting because there are so many areas here where we are in agreement. That isn't always true in this Committee.

Now, you folks are all experts in these areas and, of course, we are not up here, but we are going to be wanting to make decisions, wanting to make changes so that we can accomplish some of the goals that we are talking about. So essentially, we are talking about three steps: first, the captured technology separates some CO_2 from gases produced in electricity generation; second, purified, compressed, and all of that; and, finally, the CO_2 is injected into underground reservoir for use in other purposes.

Now, as the Chairman pointed out in his opening remarks, this does have great opportunities, opportunities that you have talked about in your testimony, Mr. Greeson. But there also is the problem of NRS. I was chairman of this Committee at the time that we went through this and, yes, it is ironic that was set up in order to make things come out cleaner, and it didn't work out that way.

Now, when you are looking at opportunities you have, we need to start talking about a legislative fix that we can do. We can do it maybe through NRS; we can do it a number of different ways. I know you outlined a few things, but have you gone into a lot of detail on this as to what we at this side of the table could do to resolve the problem that we are here meeting on today and to enhance our production?

Mr. GREESON. Thank you, Senator. I did not go into detail in my testimony. We can certainly provide more detail.

Senator INHOFE. I think you referred to your written testimony. Did you get more detail there?

Mr. GREESON. There is a little more detail there talking about the steps that can be taken to make the NSR process less of a deterrent to a major capital improvement in environmental performance, yes.

Senator INHOFE. Right. Now, you had several operations. You only used this in one area. What was the reason for that? Why were you able to face the risks that were posed by NSR in that one area and not the rest of some of your other operations?

Mr. GREESON. So, the design of this carbon capture system, it only touches the host coal unit right before the exhaust stream goes up the chimney. So, because of that, the carbon capture system itself was not considered an addition to the host coal unit; it has a separate air permit for the carbon capture system. So, in that way we did not have to face NSR on the host coal unit.

Senator INHOFE. I see. All right. Well, you know, in my State of Oklahoma we are doing this right now. It is Chaparral. I have been to their operations. One is in the northeastern part of the State and one in the northwestern part of the State.

Have you ever thought about what kind of a figure we would be looking at if we resolved that problem and were able to utilize this enhanced system?

Mr. GREESON. So, every project and every plant is different. I can tell you for our project that we probably could have spent $50 million less if we had been able to take steam from the host coal unit.

Senator INHOFE. That is interesting. How are things in Houston right now?

Mr. GREESON. Drying out.

Senator INHOFE. Yes. Well, that is good. That is good.

Mr. GREESON. Drying out. We are getting there.

Senator INHOFE. Mr. Fry, you know, we are interested in doing the same things that you have been doing. Do you have any specific advice for us to accomplish the successes that you have achieved in Wyoming?

Mr. FRY. I would suggest that if you all have opportunities to find CO_2 sources and places to inject it, whether it be EOR, saline, start planning now. Look at where you could route pipelines with the minimal amount of constraints. And I realize that you have a different Federal land status than we do in Wyoming, but I think you would follow those same steps to plan ahead and make your process a lot easier.

Senator INHOFE. Thank you. That is very helpful.

Thank you, Mr. Chairman.

Senator BARRASSO. Thank you very much.

Senator WHITEHOUSE.

Senator WHITEHOUSE. Thank you, Chairman. First, let me thank you and Senator Capito for cosponsoring the bill that is kind of at the heart of today's hearing. I would hope that other colleagues on the Committee would look at it and consider cosponsoring it as well. We are up to 25 cosponsors, which is a terrific number, but it is certainly not enough to convince the majority leader that he can get over a 60-vote threshold. So to the extent that I don't want to run too many more Democrats onto it because I don't want to get too far out of balance, to the extent that we can get more Republican cosponsors, I think that could move the project forward.

I also want to say that I have been to Saskatchewan Boundary Dam and I have been to Shenandoah, Iowa, where they are growing algae with the waste exhaust from ethanol plants, so I have seen this technology in action; I know that it is tangible and real. And everywhere I have gone I have also been told what Dr. Friedmann and Mr. Greeson have told us, which is that it is really hard to find a revenue stream to pay for the sequestered or captured carbon.

I want to emphasize Mr. Greeson's testimony that enhanced oil recovery was and is still today the only known way to create a revenue stream that could offset the cost of building and operating carbon capture right now. That is how Saskatchewan works. It is near an oil field, so you can do EOR. But there is an enormous amount of capacity out there and capability and technology to do this that isn't going to be located near an oil field, and at this point that is being shackled, smothered by this problem.

One of the things that we are seeing emerging is recognition of a cost of carbon, which implies that there should either be a payment for reductions in carbon emissions or a price on carbon emissions. And, Mr. Greeson, you mentioned that absent a price on carbon emissions, this is a problem, so presumably a price on carbon emissions would help create a revenue stream. Is that correct?

Mr. GREESON. That is correct, sir.

Senator WHITEHOUSE. It would facilitate market and industry getting together and trying to come up with ways to take advantage of that price on carbon emissions, correct?

Mr. GREESON. That is correct. Any opportunity to create a revenue stream is going to help.

Senator WHITEHOUSE. And, Mr. Friedmann, the heart of your testimony about the different ways that government, through specialized government programs, can help, isn't it true that the fundamental problem here is that there is no way to be compensated for reducing carbon, presently, without either a price on carbon or a benefit for carbon emission reductions? Correct?

Mr. FRIEDMANN. Correct.

Senator WHITEHOUSE. So, you know, one thing that is interesting to me is that if you get away from Congress, into courts and into administrative agencies, which are forums in which facts tend to have to be factual and economics tend to have to be real and false and misleading statements tend to be punished, you see a really strong and, in fact, inevitable move toward a social cost of carbon.

Three circuit courts of appeal, everyone that have looked at the question, have either approved or required administrative agencies to adopt a social cost of carbon. District courts, over and over, have approved or required a social cost of carbon repeatedly. Mining expansions have been stopped because the applications did not include a social cost of carbon. FERC has been instructed to consider a social cost of carbon in pipeline hearings.

The National Highway Transportation Safety Administration has been instructed to use a social cost of carbon and told that it cannot be zero. The Department of Energy was affirmed in considering a social cost of carbon with respect to commercial refrigeration. Indeed, the court said, yes, that kind of has to happen. New York, Minnesota, and Colorado public utility or public service commissions have adopted social cost of carbon. The Illinois State legislature has adopted the social cost of carbon.

It is now a commonplace for U.S. corporations and for major investors to bake an internal social cost of carbon into their decisions.

Mr. Friedmann, do you think that is a sensible move on the part of these courts, these administrative agencies, and these corporations?

Mr. FRIEDMANN. It is simply a market reality. They are trying to manage the carbon risks and how the market values those carbon risks. Every multinational oil company that I know of carries a social cost of carbon and an operational cost of carbon for their investment planning, and they won't build a unit unless it can have a strong internal rate of return given a high cost of carbon.

Senator WHITEHOUSE. So, I would suggest if it is good enough for the oil industry itself, it might, at some point before too long, be good enough for Congress to consider.

Mr. Chairman, I would love, if it works, to have a second round to ask Mr. Friedmann a particular question. We have dealt mostly with atmospheric CO_2 with technologies that relate to extracting the CO_2 load from our oceans, which are dramatically acidifying as a result of the CO_2 load.

Senator BARRASSO. Certainly.

Senator ROUNDS.

Senator ROUNDS. Thank you, Mr. Chairman.

Mr. Fry, I would like to begin with you. First of all, the Wyoming pipeline corridor takes a significant step forward streamlining the NEPA process for pipeline infrastructure. How do you envision the Wyoming process becoming integrated in an overly complicated and complex Federal process, and how do you see the Wyoming process perhaps serving as a model for the Federal system?

Mr. FRY. Sir, our expectation is that we will develop this project and work through the Federal agencies with a final product of an environmental impact statement. And after we are completed with that, companies could come in and build within this corridor system at a reduced environmental analysis that would probably be an environmental analysis. So we are hoping to cover the bulk of the EIS and the environmental impacts, and then they would come in just to do a lesser analysis, as well as their surveys for specific resources.

Senator ROUNDS. OK.

Mr. Greeson, you indicated that the biggest challenge you have is the original or the capital costs involved in creating the projects up front. At the same time, you also indicated that, as I understand it, with regards to the costs, you specifically pointed out the fact that the NSR, the current process in place really placed a burden on the company who was trying to capture the carbon. It made it more difficult because in doing so the existing rules would perhaps have included an additional cost to upgrade an existing plant, which the vast majority of the plants in the United States are older plants. Fair enough?

Mr. GREESON. Fair enough.

Senator ROUNDS. So it made it more difficult for you to actually take advantage of an opportunity here to capture carbon in the way that your company analyzed that process.

Mr. GREESON. Yes, Senator.

Senator ROUNDS. OK.

Mr. Friedmann, would you agree that the approach that Mr. Greeson has expressed and the concern that his company clearly looked at with regard to the NSR in its current format could be improved upon? Or at least in your analysis or as you have looked at this, would it be fair to say that if there was a way to take these older plants and to allow them to be able to be integrated into some sort of a CCUS process, that there would be a value there to taking a second look at the current rules in place at the Federal level to allow more certainty as to what their costs would be to upgrade that plant?

Mr. FRIEDMANN. I am in no way, shape, or form an expert on New Source Review and regulatory issues associated with it. What I feel comfortable saying is that I have heard the same concerns that Mr. Greeson has expressed by many other power producers, that they are considering projects and would like to do projects, but they are concerned about the potential triggering of New Source Review and how it will affect the project process.

Senator ROUNDS. Thank you.

I think as we look at this from differing points of view, there is a discussion about the social cost of carbon, which is a discussion as to if there is a desire to reduce the total amount of carbon within the atmosphere that is being released, there are two ways to approach it. No. 1, you can simply say, well, we are going to add a cost to anybody who creates carbon within the atmosphere or, No. 2, we can look at, as has been suggested here, that there are positive attributes that we can take that carbon and use it for a positive way in which to actually add additional power or additional resources to our energy portfolio.

It seems to me that there is more logic in not increasing the cost of energy by adding a social cost of carbon to the creation of energy, but, rather, looking at, in particular, this particular process that you all are discussing today, CCUS, in particular with being able to produce more energy at this time.

It would appear that there is a suggestion that there is a divergency here, and I guess I am just curious. It seems to me that we ought to be focusing on how we create more using the existing resources we have, rather than simply saying let's add a cost to the cost for the consumer in the first place up front.

It looks to me, Mr. Greeson, like your company has tried to address this by saying let's take this carbon and make it a value or give it a value, as opposed to calling it a cost. Would you care to comment on the difference between the two approaches?

Mr. GREESON. Well, Senator, clearly, because we are a competitive electric retail company, raising cost is not an option for us because others would simply undercut us and get the business. So, as I mentioned in my testimony, we found a way, using enhanced oil recovery coupled with carbon capture, to not increase the cost of electricity, and yet we are reducing by 1.6 million tons a year the emissions from the host power plant. So we kind of were able to run the circuit and get everybody something in this project.

Senator ROUNDS. My time has expired, but at the same time what you are saying is if we were to take a look at the NSR rules in place today, there may very well be other companies out there who might very well be able to accomplish the same thing if there was certainty, so that they knew that if they did upgrade an existing facility to take advantage of CCUS, that we might very well be able to capture more carbon and do it in an efficient manner and actually add value, as opposed to costing those consumers more money.

Mr. GREESON. Yes, I would agree. If you can solve the biggest problem, which is the up-front capital, then you have to attack the next reasons why people wouldn't adopt this technology, and NSR would be one of those reasons.

Senator ROUNDS. Thank you.

Thank you, Mr. Chairman.

Senator BARRASSO. Thank you, Senator Rounds.

Senator HARRIS. Thank you.

Dr. Friedmann, thank you for your work at Lawrence Livermore. It is certainly a jewel of California and, dare I say, the Nation, so thank you for your work there.

Some would say that a price on carbon via cap and trade or a carbon tax, or any other mechanism, would help, but that ultimately wind and solar are often cheaper than CCS and have fewer smog-forming pollutants and other impacts to communities. What would be your perspective on that, in terms of that being one of the reasons why CCUS needs subsidies?

Mr. FRIEDMANN. I would have three specific responses to that. First of all, what you said is only true in some markets; it is not universally true. Across the United States, resources vary in terms of solar and wind. The costs of power vary dramatically. So what may work well in one State or one region is not actually universally true, and that is also true internationally.

The second thing I would say is that a straight levelized cost of electricity basis, which has its own flaws, it does not include the cost of transmission buildout and it doesn't include resilience and all these other sorts of things, just on that basis alone CCS is cost competitive with a boatload of clean energy technologies, including offshore wind, including rooftop and residential solar in a bunch of markets.

What is not possible, though, is to finance those projects. Those other projects actually can recoup through a renewable portfolio standard or through the investment or production tax credit, they can recoup the capital investments. I know of at least three companies that scrubbed really hard looking to see if they could finance a CCS project, and they said, nope, we are going to do solar, wind, and gas, because that is what we can do today.

The third thing that I would say is that I simply don't think of this at all as an either-or question. We absolutely need more solar and wind. I don't think that is debated. In fact, the supports and subsidies which we have put in place to enable those technologies have created new industries, supported jobs, made America a technology leader, all that stuff.

We are still not reducing our emissions anywhere near quickly enough. We are far, we are far, far away from a satisfactory trajectory. And if you actually look at the emissions gap report from the United Nations, we are not even on the current policy trajectory for 2010; we are on the baseline worst business as usual scenario. We are emitting 53 billion tons of greenhouse gas emissions every year.

So I simply think that we need to do more. We need an innovation agenda; we need a deployment agenda. And, in fact, CCS is required as part of the mix, along with efficiency, along with nuclear, along with solar, along with wind, along with electric vehicles, along with biofuels. We actually need all of the above.

Senator HARRIS. So you make a very persuasive point. Why, then, do you believe have we not developed financial incentives and investment in this method?

Mr. FRIEDMANN. I think there are two issues which come back. The first is that the financing for CCS projects is lumpy. David has had to live through this. At some point or another, someone has to write a billion dollar check, and that makes it hard to pull the financing together. You can actually deploy much smaller wind and solar projects without taking the same financing risk. And that has created, among other things, a distributed energy renaissance in this Country that has its own benefits associated with it. You can't really do that with CCS; you need the large central application. In fact, that is its primary use and benefit.

The second is one that I grapple with all the time. Everyone knows what a windmill is. Everyone knows what a solar panel is. Everybody knows what a gas turbine and a nuclear plant is. It is very, very hard to communicate what CCS is to people. And so even for people who care about this topic, even people who are enthusiastic about climate change, there is an educational and informational barrier that comes with it.

There are other reasons as well. I am happy to talk to you offline and give you a much wider description.

Senator HARRIS. That would be helpful, if we are going to pursue anything as a Committee. It would be good to predict the obstacles.

Tell me, in your work in this area, have you done an analysis? You have mentioned, but have you done an analysis of what we would look at in terms of, if there were such an investment, what it would do in terms of job creation for the Country?

Mr. FRIEDMANN. Actually, I worked with Dan Kammen on this a number of years ago in which we looked at the job creation associated with it. I don't have the numbers now, I am happy to followup with you, but it is substantial.

There are two dimensions to this that I think are also important. One of them is it is not just job creation, which is real, but it is also job sustainment. This is particularly important to the unions, which are looking at a number of their jobs going away associated with the industry. But the other is actually because you are dealing with these large centralized facilities, you don't just create jobs or sustain jobs, you actually create and sustain communities; that whole communities that are at risk actually get sustained through CCS.

Senator HARRIS. Can you give me just a couple of examples of the sustainable jobs that this would create? What type of job are we talking about?

Mr. FRIEDMANN. Any number of things. Let's just do quickly, anybody building and operating the plant. I think there is well over 1,000 jobs associated with the Petra Nova project and there are 54 or some number of full-time employees who are working on that site. They are high-paying jobs; they are good jobs. GE has stopped doing research on CCS because they didn't see a market opportunity, but they were looking at an export technology market as large as their wind export technology market that is thousands and thousands of jobs.

You are talking about boilermakers, heavy equipment manufacturers, and all of the equipment that comes with that; the people who make compressors, the people who make pipelines, the people who make control systems, and, of course, all of the people who support those people.

Senator HARRIS. Thank you.

Thank you.

Senator BARRASSO. Thank you, Senator Harris.

Senator ERNST.

Senator ERNST. Thank you, and thank you to our witnesses for being here today.

Like many of my colleagues here on the Committee, I believe that an all-of-the-above energy approach is the most effective way to create jobs, promote energy independence, and ensure that our households and businesses have reliable and affordable electricity. Perhaps no State is better in leading the way or setting an example of this approach than Iowa, my home State. Largely a result of our State policies and community engagement, I am proud to say that Iowa now has one of the Nation's most diverse energy mixes, with wind now providing nearly 40 percent of our electricity.

And to give you an idea of how quickly this diversification has taken place, in 2008, 76 percent of our electricity came from coal; and just recently, 2016, now about 47 percent of our electricity comes from coal. And I would encourage other States to look to Iowa as an example of the successful application of an all-of-the-above energy approach.

Dr. Friedmann, in your testimony, you touched on biomass being a possible application for carbon capture, utilization, and sequestration. Iowa's energy plan, which was unveiled by our Governor, Kim Reynolds, earlier this year identifies one of our State strengths as its abundant and largely untapped biomass potential, which could be used to produce biofuels or generate electricity. And by 2030 it is projected that Iowa will lead the Nation in crop residues and manure, over 30 million metric tons, which have the potential to be used for bioenergy.

Companies are starting to invest in cellulosic technology in Iowa, such as POET's Project Liberty, near Emmetsburg. And now with DuPont's plant near Nevada, we can boast of being home to the largest cellulosic ethanol facility in the world.

Dr. Friedmann, can you elaborate on the potential for this type of biomass as an application for CCUS?

Mr. FRIEDMANN. Thank you, I am happy to. One of the first applications for CCUS is actually directly in the ethanol industry. Ethanol fermentation creates a byproduct stream of pure CO_2 . The Decatur project in Illinois is happily storing about a million tons of carbon dioxide every year into a deep saline formation, and has been doing so successfully. It is worth noting that for companies who are able to do this, they could actually cash in on that in the California low carbon fuel standard market, which actually has a metric and a methodology in which the carbon footprint for those fuels is assessed and includes carbon capture and storage. So, in fact, if those fuels were sold into the California market and CCS was applied to them, they would be benefited today at the cost of about $90 a ton they would be compensated for that.

Senator ERNST. And we would love to sell those fuels to California.

Mr. FRIEDMANN. I am happy to talk about that more.

Second, as you mentioned corn stover and crop residues, there is an opportunity for co-firing of biomass with coal plants. This is something which is relatively straightforward to do. It is hard to get large volumes in that, but in fact you can reduce the carbon footprint with that. If that plant is a CCS plant, you begin to trend into something that is called BECCS, bioenergy with CCS, which is one of the many technology pathways to get carbon removal or negative emissions. Essentially, the corn pulls the CO_2 from the air and then you put the CO_2 underground.

The Intergovernmental Panel on Climate Change and many other groups have insisted that BECCS is necessary for us to hit their climate target and, in fact, Iowa and the Midwest are excellent places to test such things.

The third thing is to think about enhanced terrestrial uptake. This is looking at things like soil carbon and increasing the richness in there. There is a meme going around right now of soil carbon farmers, and these guys actually have difficult access to the carbon market but are actually able to increase their yields. Our laboratory is actually working with Iowa State University on a project to in fact do exactly that, and look at ways to enhance terrestrial uptake.

There are other ways to go about this as well, but functionally, for example adding biochar, which is a byproduct of fast pyrolysis; and there are ways to think about combining char and char gasification with coal firing. There are many, many ways to think about combining biomass with CCS in a way that can achieve deep decarbonization.

Senator ERNST. I appreciate that very much. And it is fascinating and technology that I hope we are able to tap into and use in the very near future.

With that, my time has expired. Thank you very much, Mr. Chair.

Senator BARRASSO. Thank you, Senator Ernst.

Senator DUCKWORTH.

Senator DUCKWORTH. Thank you, Mr. Chairman, and thank you for convening this very important hearing.

Like many of my colleagues, I also support the FUTURE Act, which will provide industry with incentives they need for widespread implementation. I am a proud sponsor of CCUS because I have seen firsthand how effective this technology can be in bringing economic and environmental benefits. Decatur, Illinois, in my home State, is home to Archer Daniels Midland, a project that began capturing carbon dioxide from an ethanol production facility in April 2017. This project can capture up to 1.1 million tons of CO_2 per year, which is sequestered in a nearby deep saline rock formation.

So from power plants to industrial facilities to oil operations, there is obviously tremendous opportunities to deploy CCUS, and I believe we must invest and prioritize CCUS so that we can maintain our leadership in the energy sector, as well as realize its tremendous job growth potential.

Dr. Friedmann, can you please share the economic development potential associated with wide-scale implementation of CCUS not just here in the U.S., but also for us to sell or deploy this technology abroad as well?

Mr. FRIEDMANN. Thank you. It is clear to me that there are large opportunities for deploying CCS in the United States and in the North America market, including Canada and Mexico, which are seriously chasing CCS and looking for projects and partners. The market opportunity and the job opportunities in that are very large. I have seen a number of commercial estimates that suggest that by 2025 this could be a $6 billion market in the United States with the appropriate policy structures.

I think, however, the big opportunity is the international market. I have had the good fortune of representing our Country in negotiations and discussions with China, with India, with Japan, with Australia, with South Africa, and with many countries in Europe. They are aware that they are not going to hit their climate targets without CCS either. They are a bit reluctant to take it on up front, a bit the way that my children are reluctant to clean their room, but ultimately my children have to clean their room and these countries know that they have to do that work as well.

Right now it is still the case that the United States can develop and lead the world in deploying and marshaling that technology, and that is an export opportunity that is immense; many hundreds of billions and trillions of dollars of total revenues.

Senator DUCKWORTH. And so if we don't invest in its development here in the U.S., are other countries poised to take over should we not develop and be the ones to provide the CCS technology abroad with this market potential? If we don't do it, is somebody else going to step in and provide the service?

Mr. FRIEDMANN. Unquestionably, and a number of countries are very aggressive on that front. The most obvious is Norway. Since 1993, Norway has had a carbon tax. They are the global leaders in carbon capture technology. They have the technology center, Mongstad, which they are using to test technologies from around the world, and they have their own state-sponsored research programs and commercialization programs to get that technology out. Aker Clean Carbon and Statoil are in fact actively competing in this space.

Next in line I had mentioned Canada, and that is an important actor, but probably the one to keep an eye on, not surprisingly, as always, is China. Japan has put a lot of money into this, and, in fact, Dr. Greeson's plant is in fact using this Japanese technology, because that was the market beater at the time. But China is dumping an awful lot of money into center of excellence on everything from geological storage to material science to supercomputing, and they are fielding large projects and demonstration now for the first time ever.

XI Jinping is clearly making commitments to accelerate their current commitments beyond the Paris commitment, and CCS is one of the things that they can do. They are able to lay out tariffs, declare projects, marshal thousands of engineers at the drop of a hat, and are very much looking at this technology space for the global lead position.

Senator DUCKWORTH. So they have clarity in their national policy in investing in this technology. And I am not one to support red tape for the sake of red tape, but I think that with CCS I think there is a different challenge for businesses here in the U.S. that want to make these investments. I think we fail to send a direct signal to business indicating that we take the threat of climate change seriously, and with that we don't have a clarity in our national energy policy that would set up the goals, the support, so if we don't have a national policy the way the Chinese do, then people are going to be reluctant to get into the industry.

Mr. FRIEDMANN. If we are going to be competitive in that race, we have to run faster. And the way that you get the team to run faster is to incent them. And there are many, many different ways to do that, but you need to send that signal and you need to make it big enough so that companies will commit the capital and the staff and the human beings and all the rest of it to really make it work.

Senator DUCKWORTH. Thank you. I am out of time.

Thank you, Mr. Chairman.

Senator BARRASSO. Thank you, Senator Duckworth.

Senator CAPITO.

Senator CAPITO. Thank you, Mr. Chairman, and thank all of you here. Appreciate it. I would like to give a shout out to the ranking member on my subcommittee, Senator Whitehouse. We are both on the 45Q tax credit bill, the FUTURE Act, and my colleague from Illinois a cosponsor as well.

Dr. Friedmann, when you were questioned by the Senator from California as to the job benefits of pursuing an active CCSU or CCUS format around the Country, one of the jobs that you didn't mention, but I am sure you knew, were the coal mining jobs that are associated with keeping coal as an active energy source here in the Country. So, for a place like West Virginia, that has great meaning, so I will add that to the mix of the numerous jobs that you mentioned would be not just created, but sustained through an active CCUS commitment.

Let me ask you just a quick question, Dr. Friedmann. In your statement you mentioned, and you mentioned this orally, too, that there is 16 projects that are currently doing this and 22 that are going to be doing it by the year 2020. We know Petra Nova is one in the United States. How many of these 16 are located in the United States?

Mr. FRIEDMANN. Quite a number of them. The LaBarge project in Wyoming is one of these projects. The Air Products project in Port Arthur, Texas, actually the largest clean hydrogen project in the world, is in the United States. Plant Barry, the Enid Fertilizer Plant that actually sends the CO_2 through the company of Chaparral into Oklahoma for enhanced oil recovery. There is quite a lot.

Senator CAPITO. OK. Good. I was wondering, since you mentioned that a third in North America, I thought was that a way of saying North America, but not in this Country. But that is not the case, so thank you for that.

Mr. Greeson, you mentioned some of the regulatory burdens. We have talked a lot about the financial burdens, and that is part of the reason that 45Q, the FUTURE Act, is so important, I think. In terms of the regulatory burden, is there any way that you can approximate which one is a bigger burden to you, or was to you at Petra Nova, in the development? Was it the financial, was it the regulatory, or are they all just too melded in there together to really make a distinction?

Mr. GREESON. Thank you, Senator. Absolutely far and away the up-front capital cost was the biggest barrier. We found a number of like-minded companies that joined in with us, so we limited each company's exposure to the project. So that is how we were able to raise the capital.

But behind that, we did have to do a lot tap dancing to find a way to make this project work. One was to just have a minimal touchpoint on the existing plant so that we avoided New Source Review. But there were others. As I mentioned, the Class VI versus Class II injection well dust-up. That was real exciting at a time we were very near the end of our financing and the lenders were asking, what are you talking about an extra $100 million dollars? NEPA was also something that was, we feel like, a burden on the project with no real environmental benefit. Every aspect of this project is on disturbed lands, industrial sites, so we weren't really incrementally having any impact, but yet, because of the grant, we had to go through that. So there were a number of things like that.

Senator CAPITO. Right. Well, thank you.

Mr. Fry, I noticed in your bio that you acquired your beginning education at Davis & Elkins College in West Virginia, so very proud of that.

Mr. FRY. Yes, ma'am.

Senator CAPITO. Are you a West Virginian or a Wyomian?

Mr. FRY. I am originally from Virginia.

Senator CAPITO. Well, that is OK.

[Laughter.]

Senator CAPITO. In any event, talking about pipelines, we are having issues in West Virginia, I am sure all across the Country, obviously, about siting and permitting of pipelines. From a technological standpoint, is there a way to convert old pipelines into pipelines that can carry carbon, or do you have to have a specialized new pipeline developed, or is that a bad concept, to use an old pipeline for what is considered to be a newer technology?

Mr. FRY. So, actually, to utilize an old pipeline would be a challenge because the CO_2 is in supercritical State, which means it is under extremely high pressure. But what we have done in siting our pipeline corridors in Wyoming is followed alongside of those old pipelines, whereby we disturb less ground by following to the side in a safe manner. So there is an opportunity to use the pipeline in the corridor, but not the pipe itself.

Senator CAPITO. Is the corridor, as I understand it, just intra-State, so you are not crossing over into other States?

Mr. FRY. Yes, ma'am. It is challenging from a NEVA perspective to do internal, but when we started to think about coordinating with our neighboring States, where we would enter and leave the State, it just became too much of a challenge. So we come close to the borders, but we are not promoting going across.

Senator CAPITO. Do you consider this like a step one for you? Because I would imagine, in order to really maximize the financial benefit, being able to go outside of the State would probably be beneficial as well.

Mr. FRY. We are hoping that our model follows through in our neighboring States, then we can start opening those discussions.

Senator CAPITO. Thank you.

Mr. FRY. Thank you.

Senator BARRASSO. Thank you, Senator Capito.

Senator Whitehouse, you had some additional questions?

Senator WHITEHOUSE. Thank you, Chairman, I appreciate the courtesy.

I gave Dr. Friedmann a warning of where I would be going. We have been talking in this hearing virtually exclusive of atmospheric carbon; and obviously that is a significant problem. For as long as humankind has been on our planet, we have had atmospheric carbon dioxide concentrations between about 160 and 300 parts per million. We have now blown through 400, which humankind has never experienced; and projections are that we will crest above 500 parts per million.

So, I don't mean to deprecate the importance of atmospheric carbon dioxide hyper-concentrations, but 30 percent of that carbon dioxide has been absorbed, roughly has been absorbed chemically into the oceans, with a very, very predictable, replicable scientific chemical result, which is that the oceans acidify.

Mr. Chairman, I actually had a moment in the wee hours of the morning during one of our late sessions to perform I think the first scientific experiment ever done on the Senate floor, blowing my CO_2 -laden breath into the glass of water that the pages give us on the Senate floor with pH dye in it and showing that, in fact, just that dramatically increased the acidity of the water in the glass. So this is something that any middle school science lab could replicate, and not very debatable.

So we really need to, I think, focus a little bit on the oceans here as well, and if you could just say a few words about what you see as potential carbon load reduction technologies and prospects in our oceans. And do you agree or disagree with any of what I just said?

Mr. FRY. I 100 percent agree with everything that you just said. Ocean acidification is an often overlooked consequence of global greenhouse gas emissions and, in fact, atmospheric carbon dioxide becomes ocean carbon dioxide with negative consequences. It is already an economic burden for a number of fisheries. In particular, oyster fisheries around the Country are already adding lime to the waters because the oysters aren't growing fast enough because of the consequences of ocean acidification.

In the same way that we now face such an urgent problem that people have begun to think about pulling carbon dioxide directly out of the air, I was pleased to not only be part of, but to discover there are a large number of groups that are now looking at pulling carbon dioxide directly out of the oceans; it is called direct ocean capture.

I can identify eight different groups and companies who have developed technologies to do such things, including work that is going on at the National Laboratories. So, again, some work that was executed at Lawrence Livermore to pull carbon dioxide directly out of oceans.

This has a number of positive consequences. For me, the first order one is in fact that you reduce ocean acidification at its source. Rather than adding more stuff to the ocean, we are subtracting the problem in the first place, and that is an unambiguous benefit.

Second is the fact that when you pull carbon dioxide out of seawater, you actually create new things. Most importantly, you precipitate carbonate minerals that are commonly used in building materials. Sand, aggregate, cement, additives, all these things can actually be made by pulling carbon dioxide out of the ocean. And the costs for that today are substantive but, again, the best time to plant a tree is 20 years ago; the second best time is now. If we get on the stick with an innovation agenda, we can think about how to develop better technologies and ratchet down the costs for those kinds of operations.

Senator WHITEHOUSE. And these ocean technologies suffer from the same finance problems that the atmospheric technologies do, which is that, presently, there is no revenue stream that rewards the reduction of carbon dioxide levels in the ocean in the same way that, other than EOR, there is no revenue stream that rewards reduction of carbon dioxide levels in the atmosphere.

Mr. FRY. That is correct. Even the revenues from byproducts for things like the lime materials are nowhere near enough to close the financing gap. So projects are not being fielded and the amount of research that is being done on this topic is very small.

Senator WHITEHOUSE. Who knew hard to get investors for something where there is no prospect of a revenue stream? Thank you.

Senator BARRASSO. Well, thank you very much, Senator Whitehouse.

Thank you all for your responses.

Senator Gillibrand, whenever you are ready.

Senator GILLIBRAND. Thank you, Mr. Chairman and Mr. Ranking Member.

This hearing on carbon capture technology comes at a time when parts of our Country are seeing the devastating consequences of climate change caused by carbon emissions. My heart breaks for the people in Florida, Texas, Puerto Rico, Virgin Islands, Caribbean who are literally struggling to put the pieces of their lives back together following both Hurricane Harvey and Irma.

But as we help them to rebuild, we must also confront the reality of climate change. We cannot ignore that carbon emissions are causing our ocean temperatures to get warmer, which is fueling more powerful hurricanes. Reducing carbon emissions should be an urgent priority for this Committee, and now is exactly the time we should be talking about it.

I would also note that this is the second hearing this Committee has held on carbon capture technology. While this is an important topic that deserves our attention, I hope that we will also hold hearings on what we can do to facilitate the development of renewable technologies like wind and solar.

This Country used to be at the forefront of wind and solar technology; we invested in it. But because we haven't invested in it, a lot of the manufacturing has gone to China, our biggest competitor. And when you manufacture something, you are better poised to do next generation innovation. So we are losing a competitive space to China right now, and that has to be regained.

So if you truly believe that we should have an all-of-the-above energy strategy, then we should be talking about renewable energies as well. I have two questions for our witness Dr. Friedmann.

Dr. Friedmann, in your testimony you State the barriers to carbon capture technology are not fundamentally technical or regulatory. Could you speak more to what you mean by that?

Mr. FRIEDMANN. Carbon capture technology was first invented in 1930 and fielded in 1938. This is actually a relatively mature technology even at scale. It is used in many, many commercial operating facilities.

Carbon storage was first deployed in 1972 for the purpose of enhanced oil recovery in the Permian Basin of Texas. We have been injecting large volumes of carbon dioxide underground basically for 45 years.

These technologies are separately mature. Combined, we have been doing carbon capture and storage projects around the world for over 20 years. And, in fact, we have many projects that are operating above a million tons of year, so some of the geotechnical questions that people had concerns about have fundamentally been resolved.

The regulatory issues are not the primary barrier either. There are, I think, questions that people have about what is the appropriate degree of oversight for such things, but fundamentally, if you are going to be doing this, the gross scientific and technical consensus is you have to monitor. You have to monitor the carbon dioxide that is stored. And, in fact, that is one of the things that Hilcorp is doing at the Petra Nova project. That technology also exists, is well demonstrated, and there are dozens of companies to sell it.

So the primary issue is finance. You have to get a lot of money up front; you have to get a rate of return. Absent incentives that can close the gap for that, like we have provided for other clean energy technologies, we are not going to see deployment, we are not going to have a market.

Senator GILLIBRAND. Storage of sequestered carbon requires large areas, which you mentioned, often deep underground or in the ocean. There are legitimate questions around the challenges of identifying suitable carbon reservoirs for storage and ensuring that any potential impacts on water supplies or other disturbances to the environment are addressed before a project is constructed.

Is there any reason why carbon capture projects should be subjected to different environmental review standards or processes other than other energy projects?

Mr. FRIEDMANN. As I had said, the whole purpose of doing carbon capture and storage is in order to demonstrate the CO_2 is staying out of the atmosphere. That is the primary undertaking. So, in fact, there is some obligation to verify and validate that the carbon dioxide is remaining underground and that there are no demonstrable substantive public harm that comes from it.

It is my strong scientific opinion that the risks associated with geological storage are grossly overblown. In fact, any good storage site is going to be a good storage site. The Earth is in fact spectacularly well configured to store carbon dioxide indefinitely. But it is incumbent on operators to ensure that the carbon dioxide is in fact not reentering the atmosphere, and that requires an additional monitoring protocol.

Senator GILLIBRAND. Thank you, Mr. Chairman.

Senator BARRASSO. Thank you very much.

Senator CARPER.

Senator CARPER. Thanks, Mr. Chairman. I want to ask, for the record, to enter a report from a new organization called Global CO_2 Initiative, which is chaired by a Delawarean, a fellow named Bernard David. And he is doing some, I think, really interesting work that is relevant to what we are talking about here today.

Senator BARRASSO. Without objection.

[The referenced information follows:]

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CO_2 Utilization from "Next Generation" CO_2 Enhanced Oil Recovery Technology

Vello A. Kuuskraa[a]*, Michael L. Godec[a], Phil Dipietro[b]

[a]Advanced Resources International, Inc. 4501 Fairfax Dr., Suite 910, Arlington, VA 22203 USA

[b]U.S. Department of Energy, National Energy Technology Laboratory, 626 Cochrans Mill Road, Pittsburgh, PA 15236-0940

Abstract

CO_2-enhanced oil recovery (CO_2-EOR) has emerged as a major option for productively utilizing CO_2 emissions captured from electric power and other industrial plants. Not only can oil fields provide secure, well characterized sites for storing CO_2, they can also provide revenues to offset the costs of capturing CO_2. Though utilization of captured CO_2 emissions for enhanced oil recovery has been underway for some time, further advances in CO_2-EOR technology could significantly improve the technology's applicability as a revenue generator for CO_2 capture and a large-scale CO_2 storage option. With application of "next generation" CO_2-EOR technologies in geologically favorable settings, the volume of CO_2 stored could exceed the CO_2 content of the oil produced. The paper draws significantly on the recently completed report sponsored by the U.S. Department of Energy, National Energy Technology Laboratory (U.S. DOE/NETL) and prepared by Advanced Resources International entitled, "Improving Domestic Energy Security and Lowering CO_2 Emissions with "Next Generation" CO_2-EOR".

The paper introduces the feasibility of applying "next generation" CO_2-EOR technologies to new, challenging areas, such as to residual oil zones (ROZs) below and beyond the structural confinement of existing oil fields and to offshore oil fields. The paper provides a case study that tracks the performance and the economics of CO_2-EOR in the Permian Basin of West Texas. While much of the information in the paper is drawn from the CO_2-EOR experiences in North American oil fields, the paper also examines the CO_2 utilization and storage potential from applying "next generation" CO_2-EOR technology to the large oil fields of the world, drawing on extensions of work performed by Advanced Resources International for the IEA Greenhouse Gas R&D Programme.

The paper concludes with two key messages. First, with application of "next generation" technologies to a broader set of oil resources, the market for utilization of CO_2 for enhanced oil recovery is much larger than previously assumed. Second, the revenues from the sale of captured CO_2 emissions, along with research that reduces the costs of CO_2 capture, can greatly accelerate the time when CCS (now CCUS) can be applied at wide scale.

Keywords: CO_2-EOR; CO_2; enhanced oil recovery; CCUS; residual oil zones; ROZ; oil fields; CO_2 capture

* Corresponding author. Tel.: +703-528-8420; fax: +703-528-0439.
E-mail address: vkuuskraa@adv-res.com.

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1. Introduction

Four key questions are at the heart of gaining wide-scale acceptance for using CO_2 enhanced oil recovery (CO_2-EOR) as a major carbon management strategy; namely: (1) what is the size of the prize?; (2) could CO_2-EOR, like wind and solar, provide essentially net zero carbon energy?; (3) how much of the CO_2 used for EOR will remain securely stored?; and (4) to what extent could CO_2-EOR provide a market-driven option for CO_2 capture?

1.1. The Size of the Prize

Typically, only about a one-third of the original oil in-place in a conventional oil field is recovered with traditional primary and secondary methods. In the U.S., this leaves behind a massive, nearly 400 billion barrel target for "next generation" CO_2-EOR in existing oil fields, plus an additional 140 billion barrels in residual oil zones (ROZ) below and beyond existing oil fields, Figure 1. Worldwide, our estimate is that the "left behind" oil resource is many times larger, in excess of 5,000 billion barrels. Application of CO_2 enhanced oil recovery (CO_2-EOR) provides the economically most favorable means for recovering a significant portion of this "left behind" oil and for storing massive volumes of CO_2 captured from industrial and electric power plants.

- In the U.S., the "size of the oil prize" for "next generation" CO_2-EOR technology is 100 billion barrels of economically recoverable oil, assuming an oil price of $85 per barrel,[†] a CO_2 price of $40 per metric ton, and a return on investment hurdle of 20%, Table 1.[1,2]

- The economic CO_2 demand to recover 100 billion barrels of oil with CO_2-EOR is 33 billion metric tons, Table 1.[1,2] With natural CO_2 sources estimated at less than 3 billion metric tons, this means that the "size of the CO_2 utilization and storage prize" in the U.S. is 30 billion metric tons. This is equal to 35 years of CO_2 emissions captured from 140 GWs of coal-fired power.[3]

1.2. Carbon Neutral Oil

At a typical ratio of 1 metric ton of CO_2 injected and stored for every 2.5 barrels of oil recovered, the carbon balance of oil produced with CO_2-EOR is essentially neutral, when using CO_2 that would otherwise have been vented to the atmosphere. Under special conditions, such as gravity stable CO_2 flooding, the CO_2-EOR process can store considerably more CO_2 than the carbon content of the oil, Figure 2.

Today, a significant number of activities are underway that find and bring more oil to the surface, including exploration and drilling for conventional oil. These are activities that provide no offsets to the carbon in the produced oil. Yet, no rational official, one concerned with a country's economic well-being, its energy security, and its jobs, has called for a stop to oil exploration (except in environmentally fragile areas) as long as it is done in a safe and environmentally sound way. In addition, recently Norway's Statoil announced that it has adopted a goal of achieving 60% recovery efficiency from its offshore oil fields, without use of CO_2 injection. We are not aware of any Norwegian public officials that condemned Statoil's pursuit of efficiency and conservation of the nation's oil resources.[4]

[†]In this report, all economic value numbers are expressed in U.S. dollars.

1.3. A Closed-Loop System

The operation of a CO_2-EOR project is essentially a closed-loop system, Figure 3. Initially, about half of the injected CO_2 is trapped or dissolved in the reservoir and its fluids. The CO_2 that is produced with the oil is recycled (separated and re-injected back into the reservoir), with an increasing portion of the re-injected CO_2 trapped. At the end of a CO_2 flood, essentially all of the purchased CO_2 is stored in the reservoir when the operator closes the field at pressure.

1.4. Providing Revenues for CO_2 Capture

Finally, CO_2-EOR provides a market and revenues for the CO_2 captured from industrial and electric power plants. In the U.S. alone, we estimate that the CO_2-EOR industry could provide revenues of $1.2 trillion for CO_2 capture and delivery from fossil fuel power plants and industrial facilities. In addition, with "next generation" technology, the CO_2-EOR sector, over the course of thirty to forty years, would generate domestic economic activity equal to $8.5 trillion in the U.S. alone, Table 2. As important, 30 billion metric tons of anthropogenic CO_2 that would have otherwise been vented to the atmosphere would be permanently stored.

2. Status of CO_2-EOR

CO_2-based enhanced oil recovery, using state-of-the-art (SOA) technology, is already being implemented in the U.S., particularly in the oil fields of the Permian Basin of West Texas, the Gulf Coast and the Rockies.

- CO_2-EOR currently provides about 284,000 barrels of oil per day in the U.S., equal to 6% of U.S. crude oil production, Figure 4.[5] CO_2-EOR has been underway for several decades, starting initially in the Permian Basin and expanding to 123 CO_2-EOR projects currently installed in numerous regions of the country, Figure 5.

- In 2010, a total of 62 million metric tons of CO_2 was supplied to EOR operations in the U.S., Table 3. Approximately 20% (13 million metric tons) of this CO_2 came from industrial sources, natural gas processing plants, and hydrocarbon conversion facilities (e.g., coal gasification). By 2020, approximately 14 Mt of additional CO_2 supply will become available from large-scale integrated CCUS projects in the U.S. Department of Energy's (DOE) portfolio.[3]

- A robust network of pipelines exist in the Permian Basin that transports this CO_2 from natural CO_2 deposits and gas processing plants to the Denver City Hub, Figure 5. In addition, numerous new CO_2 pipelines have recently been placed on-line to deliver CO_2 to Gulf Coast and Rocky Mountain oil fields.[5, 6] These include Denbury's 320 mile Green Pipeline along the Gulf Coast, Occidental Petroleum's new $850 million Century natural gas/CO_2 processing plant and pipeline facilities in West Texas, and Denbury's GreenCore CO_2 pipeline linking the Lost Cabin gas processing plant and other CO_2 sources in Wyoming to Rocky Mountain oil fields, Figure 5.

3. Overview of "Next Generation" CO_2-EOR Technologies

Realizing the full benefits of utilizing CO_2 as part of a CCUS strategy requires having access to "Next Generation" CO_2-EOR technology. Before proceeding further, it is useful to address the questions - - just what constitutes "Next Generation" CO_2 enhanced oil recovery and how does it differ from the CO_2-EOR technology in use today? Briefly stated, "Next Generation" CO_2-EOR incorporates four significant changes in technology and industrial practices:

- First are a series of scientifically-based advances in currently practiced miscible and near-miscible CO_2-EOR technology, including:
  - Improved sweep efficiency and mobility control (reservoir conformance),
  - Advanced technology of reservoir surveillance (monitoring and process control),
  - More efficient contact and production of the reservoir's remaining mobile (and immobile) oil,
  - Lowering the threshold minimum miscibility pressure (MMP) for shallower, heavier oil reservoirs, and
  - Significantly increasing the volumes of CO_2 injected and efficiently used.
- Second is integrating CO_2 capture from advanced coal- and natural gas-fired electric power plants, oil refineries, hydrogen plants and coal-to-liquids (CTL) facilities with CO_2 utilization by CO_2-EOR,
- Third is application of CO_2-EOR to residual oil zones (ROZs), and
- Fourth is deployment of CO_2-EOR in offshore oil fields.

3.1. Integrating CO_2 Capture and Utilization with CO_2-EOR

To a large extent, operators of integrated gasification combined cycle (IGCC) facilities, proposed CTL plants and other carbon conversion projects have already "voted with their feet" by turning to oil fields for storing CO_2. Three such projects are:

- Southern Company's Kemper County IGCC plant, which plans to provide 1.1 to 1.5 MMt/yr to Denbury Resources for CO_2-EOR in oil fields in Louisiana and Mississippi. Integrating CO_2 capture and utilization involved formulating innovative contractual terms and alternative options for CO_2 delivery.[6]
- Summit Energy's Texas Clean Energy IGCC project, which plans to sell 3 MMt/yr for CO_2-EOR from the Permian Basin of West Texas in competition with natural sources of CO_2.[6]
- The "poster child" for integrating large-scale CO_2-EOR with CCS is the capture of 150 MMcfd (~3MMmt/yr) of CO_2 from the Northern Great Plains Gasification plant in Beulah, North Dakota and its transportation, via a 200 mile cross-border CO_2 pipeline, to two CO_2-EOR projects at the Weyburn oil field in Saskatchewan, Canada, Figure 6.[7]

3.2. Residual Oil Zone ("ROZ")

No discussion of "next generation" technology would be complete without a discussion of the major volumes of oil that exist and can be recovered with CO_2-EOR from the residual oil zone (ROZ). Residual oil zones exist in the lower portions of oil reservoirs that have been hydro-dynamically swept by the movement of water over a time period of millions of years. One may label this movement of water and its displacement of oil as "nature's waterflood". Because the "left behind" oil in the ROZ is at or near residual oil saturation, CO_2-EOR is required to re-mobilize and recover this oil.

Work by Advanced Resources and Melzer Consulting has identified 42 billion barrels of oil in-place below existing oil fields in three U.S. basins - - Permian, Big Horn and Williston. [8,9,10] Importantly, recent work by Melzer Consulting for the Research Partnership to Secure Energy for America (RPSEA) shows that the ROZ resource also occurs beyond the outlines of existing oil fields and exists as a series of areally extensive "ROZ fairways", Figure 7. Melzer Consulting and Advanced Resources estimate that about 100 billion barrels of oil in-place exists in the ROZ "fairways" of the Permian Basin alone. Based on preliminary modeling, we estimate there is 27 billion barrels of economically recoverable oil from the ROZ (below oil fields and from the ROZ "fairway"). The "CO_2 utilization and storage prize" offered by the ROZ resource is 13 billion metric tons, Table 1.

The viability of recovering oil from ROZs is already being demonstrated by a series of ROZ field projects - - at Seminole oil field by Hess, at Wasson Denver Unit by Occidental, and at Goldsmith oil field by Legado, among others. An important R&D goal for the U.S. (and the world) is establishing optimally efficient oil recovery and CO_2 storage in ROZs using miscible CO_2-EOR.

3.3. CO_2-EOR in Offshore Oil Fields

The deep, light oils common to Gulf of Mexico (GOM) offshore oil fields are amenable to miscible CO_2-EOR technology. With the continued discovery of oil fields in the deep waters of the Outer Continental Shelf (OCS), the size of this resource target continues to grow. However, the deployment of CO_2-EOR technology in offshore oil fields faces many challenges, including limited platform space for CO_2 recycling equipment, the expense of drilling new CO_2 injection wells, and the need to transport CO_2 from onshore sources to offshore platforms. While these barriers and challenges can be addressed with advances in technology, they add substantial costs to the oil recovery process. CO_2-EOR projects have been undertaken in a small handful of offshore oil fields in shallow GOM waters; however, currently none are operating. As such, the fourth "next generation" CO_2-EOR application involves undertaking the challenge of deploying innovative designs and advanced CO_2-EOR technology in offshore oil fields.

4. International CO_2-EOR and CO_2 Storage

In 2011, Advanced Resources prepared for the International Energy Agency Greenhouse Gas R&D Programme (IEAGHG) an assessment of worldwide CO_2 storage and oil recovery potential offered by CO_2-EOR. The CO_2 supplies for EOR were assumed to be primarily from power plants, cement plants and refineries with large-scale CO_2 pipelines transporting the CO_2 to geologically favorable oil fields. The study assessed 54 large world oil basins for CO_2-based enhanced oil recovery, using two complementary methodologies.[11]

- High-level, first-order assessment of CO_2-EOR and associated storage potential, using U.S. experience as the analog.
- Calibration of the above first-order basin-level estimates with detailed modeling of 47 large oil fields in 6 basins.

The study established that the "size of international oil and CO_2 utilization (and storage) price" from applying CO_2-EOR to already discovered oil fields is about 1,300 barrels of incremental oil recovery and 370 billion metric tons of CO_2, Table 4. This is equivalent to utilization (and storage) of captured CO_2 from about 2,000 GWs of coal-fired power for 35 years. Much of this demand can be met by large, existing anthropogenic CO_2 sources within distances of 800 kilometers (500 miles) of these oil basins. New anthropogenic sources, such as the large oil refineries and hydrogen plants being constructed in the Middle East and the high CO_2 content natural gas fields in the Far East, provide major opportunities for utilization of CO_2 by CO_2-EOR.

5. Permian Basin CO_2-EOR Case Study

The purpose of the Permian Basin CO_2-EOR case study is to provide the reader basic information by which to address the question: "What does a successful CO_2-EOR project look like?"

CO_2 injection into the Denver Unit of the giant Wasson (San Andres) oil field began in 1985, helping arrest the steep drop in oil production. Before the start of CO_2-EOR, oil production had declined from about 90,000 B/D to 40,000 B/D and was on pace to decline to below 1,000 B/D in the next 20 years. After the initiation of the CO_2 flood, oil production increased to about 50,000 B/D. Today, twenty four years after the start of the flood, the Denver Unit still produces at 30,000 B/D, Figure 8.

At the completion of the CO_2 flood, Oxy expects the Denver Unit to recover nearly two-thirds of the approximately 2 billion barrels of original oil in-place, with CO_2-EOR providing nearly 20% oil recovery efficiency (400 million barrels) on top of already high oil recovery efficiency from primary methods and the waterflood. In turn, the Denver Unit CO_2 flood will utilize over 100 million metric tons of CO_2.[6]

A broader look at Permian Basin CO_2-EOR projects shows that the CO_2 flood at the Wasson (Denver Unit) oil field, while exemplary, is not unique. Using an oil price of $100 per barrel, Occidental Petroleum, the largest CO_2-EOR operator in the Permian Basin, expects its CO_2-EOR projects to provide a net cash margin (before corporate taxes) of $56 per barrel, after subtraction of royalties, operating costs, CO_2 purchase and amortized capital, Figure 9. CO_2 purchase (plus recycling operations) constitutes the largest single cost item in the CO_2 flood. Even with delay between investment of capital and the production of oil, the EOR case study and the results from the other CO_2-EOR projects in the Permian Basin show that an economically favorable market exists for anthropogenic CO_2.

6. Summary

The information set forth in this paper argues that CO_2 enhanced oil recovery deserves to be a major part of a worldwide carbon management strategy. The "size of the prize" is large, the oil produced is net carbon energy, the injected CO_2 will remain stored securely, and CO_2-EOR can provide a market-driven option for accelerating CO_2 capture.

Acknowledgements

This study was sponsored by the U.S. Department of Energy, National Energy Technology Laboratory, under Contract No. DE-FE0004001.

Table 1. Impact of Applying "Next Generation" CO_2-EOR Technology to U.S. Oil Fields and ROZ "Fairways"

Resource Area	Economic Oil Recovery (BBbls)*	Demand for CO_2 (Billion Metric Tons)
More efficient recovery from "lower 48" oil fields	60	17
Alaska/offshore	7	3
Residual oil zone (below oil fields)	13	5
Residual oil zone "fairways" (preliminary)	20	8
Total	**100**	**33**

*At \$85 per barrel and \$40 per metric ton, CO_2 market price with 20 % rate of return (before tax).
Source: Advanced Resources International, Inc. (2011)

Table 2. The "Value Chain" of "Next Generation" CO_2-EOR (U.S. Only)

Revenue Recipient	Value Chain Function	Revenues Per Barrel (\$)	TOTAL* (\$ billion)
Power/Industrial Companies	Sale of CO_2 **	\$13.20	\$1,320
Federal/State Treasuries	Severance/Income Taxes	\$19.80	\$1,980
U.S. Economy	Services, Materials and Sales	\$26.50	\$2,650
Other	Private Mineral Rights	\$7.70	\$770
Oil Industry	Return of/on Capital	\$17.80	\$1,780
	Total	**\$85.00**	**\$8,500**

*Assuming 100 billion barrels of economically feasible oil recovery; oil prices of \$85 per barrel and CO_2 sales price of \$40/metric tons.
**Of the 33 billion metric ton, \$1,320 billion overall market for CO_2, anthropogenic CO_2 captured from power and other industrial plants would be 30 billion metric tons and \$1,200 billion.
Source: Advanced Resources International, Inc. (2011)

Table 3. Significant Volumes of Anthropogenic CO_2 are Already Being Injected for EOR

Location of Oil Fields	Location of CO_2 Sources	CO_2 Supply Geologic	Anthropogenic
Texas, New Mexico, Oklahoma, Utah	Geologic (CO, NM) and Gas Processing, Fertilizer Plant (TX)	1,600	190
Colorado, Wyoming	Gas Processing (Wyoming)	-	300
Mississippi	Geologic (Mississippi)	930	-
Michigan	Gas Processing (Michigan)	-	10
Oklahoma	Fertilizer Plant (Oklahoma)	-	35
Saskatchewan	Coal Gasification (North Dakota)	-	150
TOTAL (Million cfd)		**2,530**	**685**
TOTAL (Million metric tons per year)		**49**	**13**

* Source: Advanced Resources International, 2012
**MMcfd of CO_2 can be converted to million metric tons per year by first multiplying by 365 (days per year) and then dividing by 18.9 * 10^3 (Mcf per metric ton)

Table 4. Technical Oil Recovery and CO_2 Storage Potential from the Major Oil Basins of the World Using from "Next Generation"* CO_2-EOR Technology

Region	CO_2-EOR Oil Recovery (Billion Barrels)	CO_2 Storage Capacity (Billion Metric Tons)
1. Asia Pacific	47	13
2. C. & S. America	93	27
3. Europe	41	12
4. FSU	232	66
5. M. East/N. Africa	595	170
6. NA/Other	38	11
7. NA/U.S.	177	51
8. S. Africa/Antarctica	74	21
TOTAL	**1,297**	**370**

* Includes potential from discovered and undiscovered fields, but not future growth of discovered fields.
Source: IEA GHG Programme/Advanced Resources International (2009)

Fig. 1. Large Volumes Of Domestic Oil Remain "Stranded" After Traditional Recovery Operations

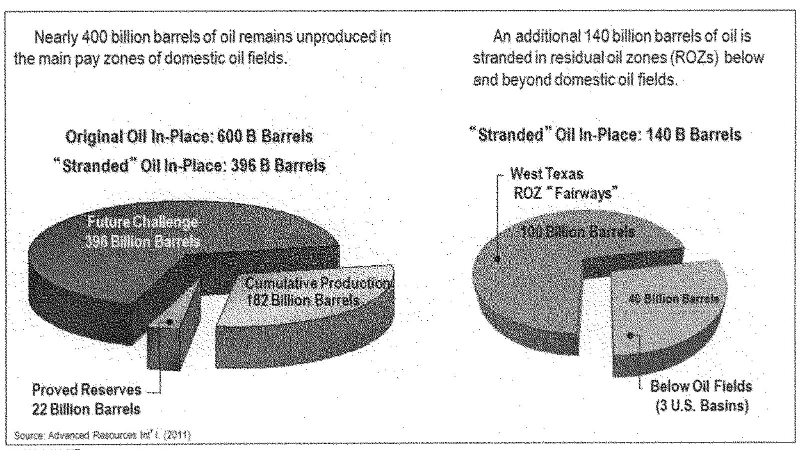

Fig. 2. Integrating CO_2-EOR and CO_2 Storage Could Increase CO_2 Storage Potential

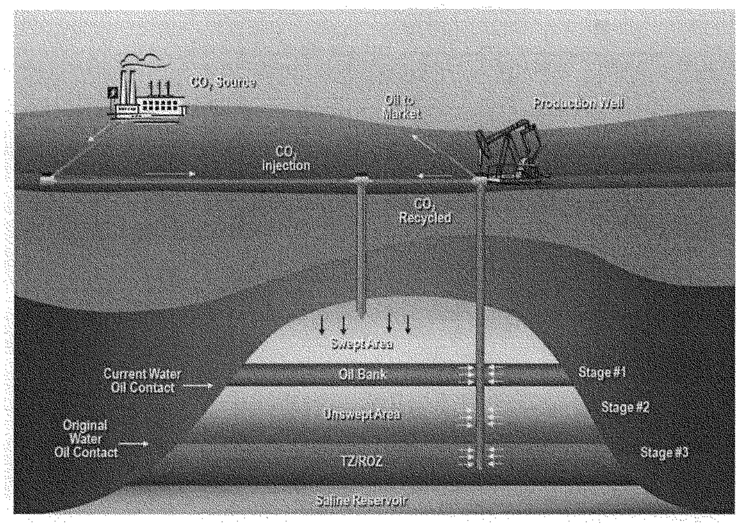

Fig. 3. CO_2-EOR Technology: A Closed-Loop System

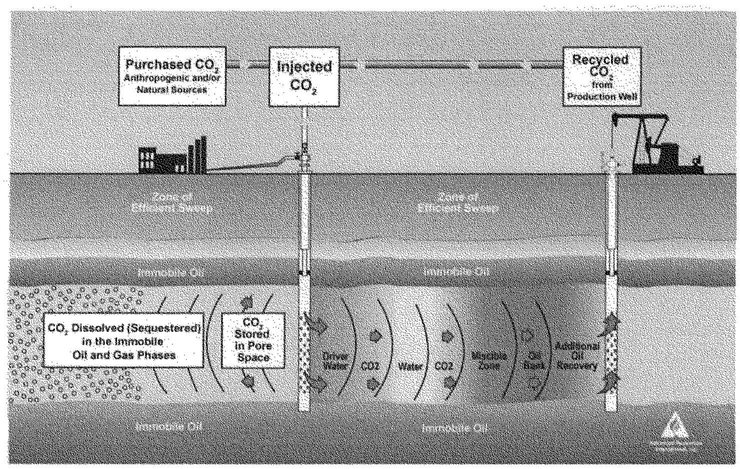

Fig. 4. Domestic Oil Production from CO_2-EOR

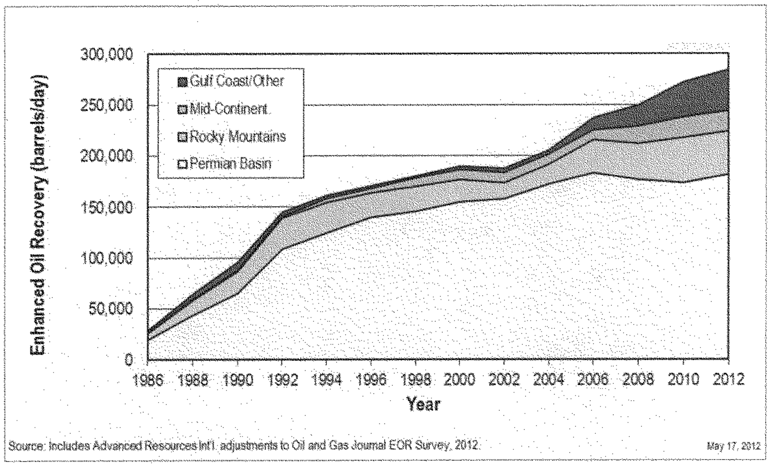

Fig. 5. U.S. CO_2-EOR Activity

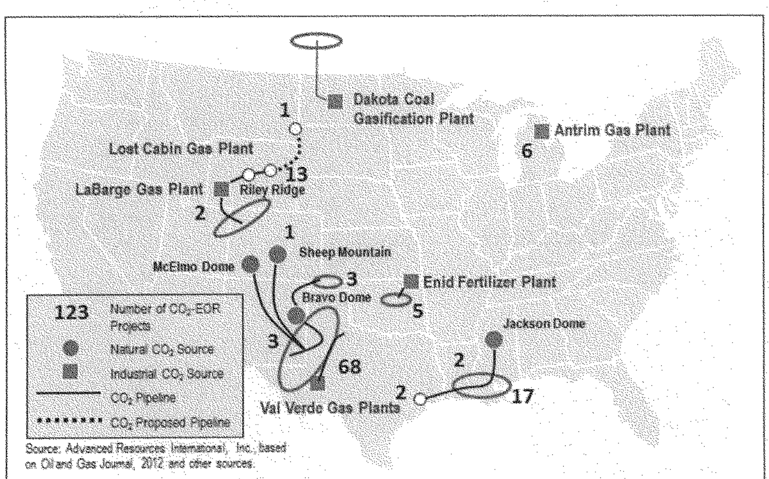

Fig. 6. "Poster Child" for Integrating CO_2-EOR and CO_2 Storage

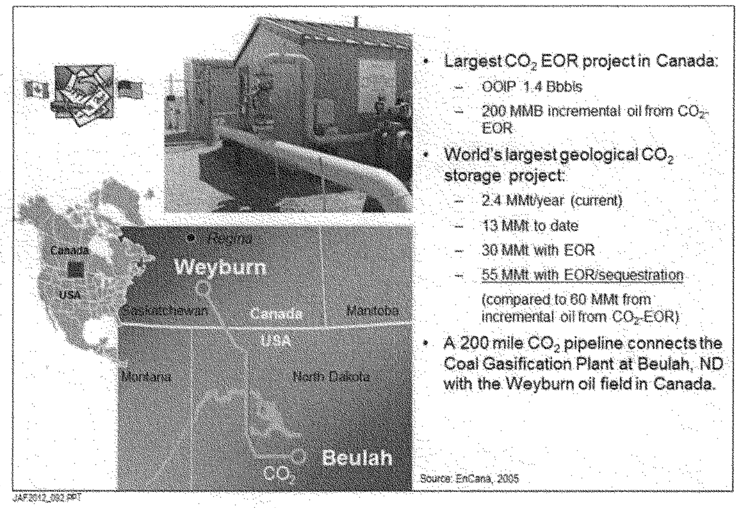

Fig. 7. Map of Permian Basin ROZ Fairways.

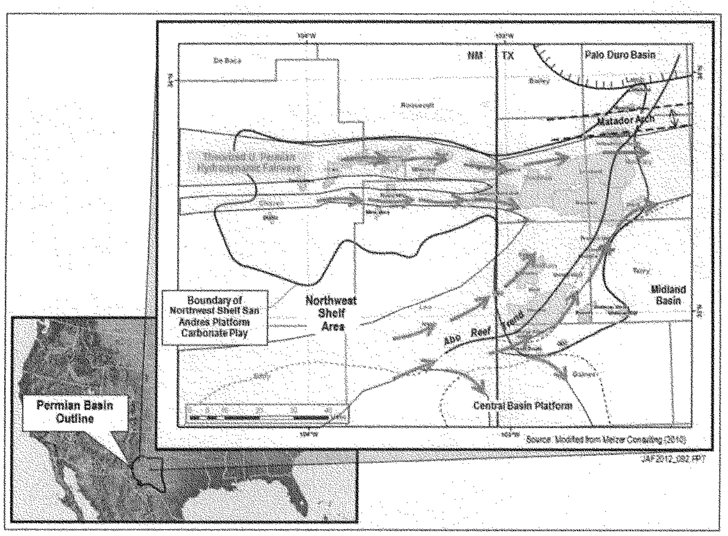

Fig. 8. CO2-EOR at Denver Unit, Wasson Oil Field.

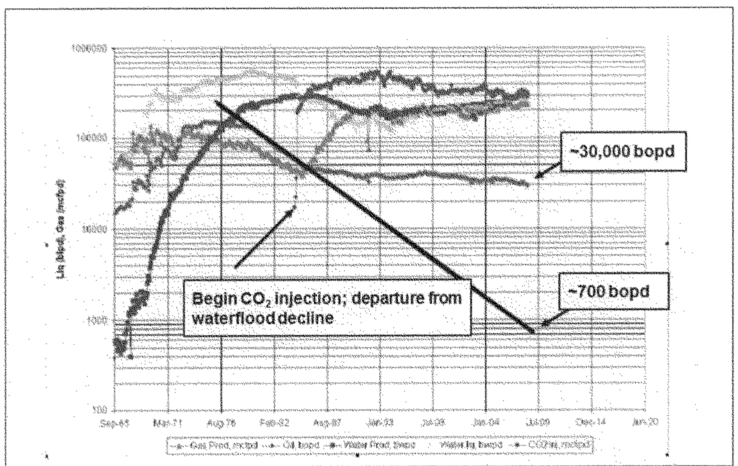

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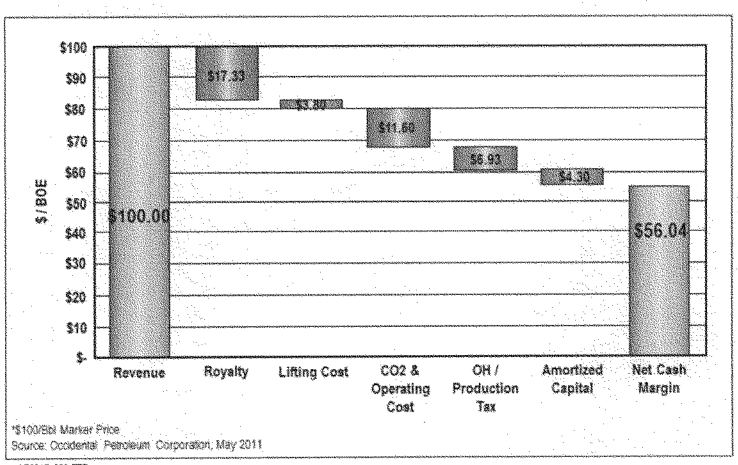
Fig. 9 Permian Basin CO2-EOR Project Cost Structure



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References

[1] Advanced Resources International, Inc. (ARI). Improving Domestic Energy Security and Lowering CO_2 Emissions with "Next Generation" CO_2-Enhanced Oil Recovery (2011), www.netl.doe.gov/energy-analyses/pubs/storing%20co2%20w%20eor_final.pdf.

[2] Advanced Resources International, "Using CO2 Enhanced Oil Recovery to Accelerate the Implementation of Carbon Capture and Storage", presentation to ARPA-E, U.S. Department of Energy, Washington, D.C., October 2011

[3] DiPietro, P., J., P. Balash, M. Wallace. A Note on Sources of CO2 Supply for Enhanced-Oil-Recovery Operations. Society of Petroleum Engineering, Economics & Management (April 2012).

[4] "Statoil Targets 60% Average Oil Recovery Rate", www.rigzone.com, August 29, 2012.

[5] Oil and Gas Journal Survey, April 2010.

[6] Various industry presentations and publications

[7] Whittaker, S. IEA GHG Weyburn-Midale CO2 Storage & Monitoring Project. Presentation at the Regional Carbon Sequestration Partnerships Annual Review (October 5, 2010), www.netl.doe.gov/publications/proceedings/10/rcsp/presentations/Tues%20am/Karen%20Cohen/Whittaker.%20WMP_Regional%20Partnership.pdf.

[8] "Technical Oil Recovery Potential from Residual Oil Zones: Permian Basin", prepared by Advanced Resources International, Inc. for the U.S. Department of Energy, Office of Fossil Energy, Office of Oil and Natural Gas, October 2005.

[9] "Technical Oil Recovery Potential from Residual Oil Zones: Big Horn Basin", prepared by Advanced Resources International, Inc. for the U.S. Department of Energy, Office of Fossil Energy, Office of Oil and Natural Gas, February 2006.

[10] "Technical Oil Recovery Potential from Residual Oil Zones: Williston Basin", prepared by Advanced Resources International, Inc. for the U.S. Department of Energy, Office of Fossil Energy, Office of Oil and Natural Gas, February 2006.

[11] "CO_2 Storage In Depleted Oilfields: Global Application Criteria For Carbon Dioxide Enhanced Oil Recovery", IEA GHG Programme Technical Report Number 2009-12, December by Advanced Resources International, Inc.

Senator CARPER. Thank you. And built on some points made by Sheldon Whitehouse of all people.

Senator WHITEHOUSE. Astonishing.

Senator CARPER. And a word, if I could, about the Global CO_2 Initiative. It is focused on research and development, commercialization of products that reuse carbon dioxide. In other words, this Initiative is trying to find new ways to make the CO_2 captured from our coal plants valuable in the marketplace.

The roadmap for this is called the Roadmap for the Global Implementation of Carbon Utilization Technologies, and I encourage anyone interested in today's hearing to also take some time to look at the report and the work that they are doing. And we thank Bernard David and the folks that are working with him.

Thanks, Mr. Chairman.

This question has been asked a couple times now, but I am going to ask it once more. Repetition is good, as you know.

How important is carbon capture and sequestration technology for the coal industry and for assisting the U.S. in meeting our global climate goals? And, economically, how big of an opportunity are we missing if we don't capitalize on this technology?

You responded to this in waves, but I want you to do it again.

Mr. FRIEDMANN. Because of the way that you framed the question, I have the opportunity to do exactly that. In 2007, MIT released something called The Future of Coal Report. I had the good fortune of working with——

Senator CARPER. In 2007?

Mr. FRIEDMANN. In 2007.

Senator CARPER. Ernie Moniz.

Mr. FRIEDMANN. Ernie Moniz——

Senator CARPER. He actually was a witness at a field hearing that I held there.

Mr. FRIEDMANN. Yes.

Senator CARPER. On this report.

Mr. FRIEDMANN. And one of the findings——

Senator CARPER. And his hair was cut just the same then as it is now.

[Laughter.]

Mr. FRIEDMANN. One of the findings of that report was that in a carbon constrained world, the market share for coal will drop dramatically without carbon capture and storage. Another finding is that if carbon capture and storage is deployed in a carbon constrained world, that in fact coal can have a bright future.

And what we have in fact seen is what those findings predicted; that the global market share for coal is beginning to drop and part of the reason why, by no means the only reason why, but part of the reason why is the carbon risk associated with those coal projects.

And even in areas where people expected long sustained growth in carbon dioxide emissions from coal plants, like in India, like in China, it is clear that the governments of those countries are taking aggressive action to limit the deployment of coal plants in part because of the carbon risks.

Senator CARPER. All right. Thank you.

Kind of a wrap up question for the whole panel. When we have a panel like this, one of the things that is very helpful is for you to help us develop consensus; and I think you are doing that today, whether you want to or not. But I want to ask each of you to just briefly tell us maybe something that you think we ought to take away from this hearing that will help further develop consensus around this issue.

Mr. Fry, who grew up in Virginia. Where in Virginia?

Mr. FRY. Staunton.

Senator CARPER. Staunton.

Mr. FRY. Yes, sir.

Senator CARPER. I know where Staunton is. Danville and Roanoke right here.

Senator WHITEHOUSE. Lived in Crozet.

Senator CARPER. Yes.

Mr. Fry, give us one great take away to help further develop this evolving consensus around this issue.

Mr. FRY. I think the greatest consensus in our discussion today is obviously the financial incentives required for CCUS. But, from my perspective, we also need to incentivize pipelines. It is a bit of a chicken and an egg scenario we have here. We have had companies come into Wyoming interested in projects, but since we don't have these pipeline infrastructure, they have gone somewhere else. So, beyond the obvious 45Q and financial issues, we need infrastructure.

Senator CARPER. All right, thank you.

Mr. Greeson.

Mr. GREESON. Like a broken record, I will say up-front capital costs and incentives to help to support financing those up-front costs. And right behind that, our project was blessed with the opportunity to pay for a pipeline as a part of the project because of the way we structured the ownership of the oil field. But that is clearly not something that is easily repeatable. Even our oil company partner said they would not repeat that model again.

So pipeline corridors will be a challenge, right behind the financing.

Senator CARPER. All right, thanks.

Last word, Dr. Friedmann, Julio Friedmann. Down by the Schoolyard.

Mr. FRIEDMANN. Thank you, Senator Carper. I think there are three points of consensus for the Committee. Two of them have already been mentioned. One of them is needing to close that financial gap through some policy option. Second is the need for pipelines and acting on pipelines. I would actually point people to the work done by the Great Plains Institute at the behest, actually, of Matt Mead and Governor Bullock in Montana to start working on pipeline infrastructure as part of a national agenda.

The third point, which hasn't been talked about as much but is also, I think, an easy point of consensus is an innovation agenda. We need to get more people at more universities, in national labs, small businesses, VCs, companies large and small working on innovation to make the performance better and the costs lower. And there are many ways to incent such things, but an innovation agenda will undergird any American competitiveness going forward, and it is a critical piece of the wainscoting.

Senator CARPER. All right, thanks.

Gentlemen, have you ever heard of the leadership being provided by Senator Heitkamp on 45Q? Are you all familiar with that?

Mr. FRIEDMANN. Yes, sir.

Senator CARPER. Do you think he is doing good work?

[Laughter.]

Mr. FRIEDMANN. I am sorry, I didn't quite hear.

Senator CARPER. Do you think she is doing good work? You are going to see her in about an hour.

Mr. FRIEDMANN. The good news is that not only is she doing good work, but all of her partners, and Senator Barrasso, the Chairman, Senator Whitehouse, Senator Capito are all doing extraordinary work with this.

Senator CARPER. I think they have me outnumbered, don't they?

Senator BARRASSO. We got you surrounded.

Senator CARPER. Maybe I should talk to Heidi.

Mr. FRIEDMANN. It is an opportunity to close that financing gap, and that is the most critical piece that needs to be done. Whether the Congress adopts it or not is not my business, that is your business, but some sort of policy structure like that is necessary to achieve liftoff. And if we are going to score, we need to take more shots on net.

Senator CARPER. And what did Wayne Gretzky say? They used to ask Wayne Gretzky why do you take so many shots on goal. Do you remember what he said? I missed every shot I never took. How is that? That is a good note to close on, too.

Thank you all very, very much.

Senator BARRASSO. Senator Whitehouse.

Senator WHITEHOUSE. Mr. Chairman, I just wanted to ask your permission to have Dr. Friedmann answer about the eight technologies that he described in the oceans as a question for the record so that we can get that into the record of the Committee.

Senator BARRASSO. Absolutely.

Senator WHITEHOUSE. And if that is OK with you, then I will proceed on that basis with Dr. Friedmann.

And I thank the entire panel for their testimony.

Senator BARRASSO. Thank you very much, Senator Whitehouse.

And, of course, other members of the Committee may submit written questions. The hearing is going to stay open for 2 weeks, but I would ask you to respond in appropriate time to those written questions, as well as the one just brought forward by Senator Whitehouse.

I appreciate all of you being here today. I thought it was a very productive hearing, very important information. I want to thank each and every one of you.

This hearing is adjourned.

[Whereupon, at 11:37 a.m. the Committee was adjourned.]

[Additional material submitted for the record follows.]

BLUEGREEN ALLIANCE

CREATING GOOD JOBS, A CLEAN ENVIRONMENT, AND A FAIR AND THRIVING ECONOMY

September 26, 2017

The Honorable John Barrasso
Chairman
U.S. Senate Committee on Environment and Public Works
410 Dirksen Senate Office Building
Washington, D.C. 20510

The Honorable Thomas R. Carper
Ranking Member
U.S. Senate Committee on Environment and Public Works
456 Dirksen Senate Office Building
Washington, D.C. 20510

RE: Expanding and Accelerating the Deployment and Use of Carbon Capture, Utilization, and Sequestration

Dear Chairman Barrasso and Ranking Member Carper:

As a coalition of the nation's largest labor unions and environmental groups, collectively representing millions of members and supporters, we write to express support for your committee's efforts to address the deployment and use of carbon capture, utilization, and sequestration.

Carbon capture and sequestration (CCS) is a rapidly growing technology that has potential to create economic benefits for multiple industries while significantly reducing carbon dioxide (CO_2) emissions. According to the Intergovernmental Panel on Climate Change (IPCC), the world will not be able to achieve its goal of limiting global surface temperature rise to 2 degrees Celsius without carbon capture. The IPCC further concluded that without CCS, the costs of mitigating climate change could increase by 138 percent, an investment estimated to total $2 trillion over the next 40 years.

Industrial facilities, in particular, are huge sources of carbon emissions, and very few solutions exist beyond carbon capture technologies to reign in these emissions. According to the EPA, currently, direct emissions from industrial activities account for 21 percent of annual U.S. GHG emissions—totaling 6,587 $MMTCO_2e$ annually. While these numbers are projected to decrease slightly, they will remain a large share of U.S. emissions in the future. Carbon capture is necessary to limit emissions from industrial activities because for many manufacturing processes, there are few alternatives for controlling emissions. Industrial facilities are the easiest, lowest cost targets for deploying CCS technologies, since they often produce pure streams of carbon dioxide that can be easily captured. Recent DOE investments in the industrial sector have stored 12 million metric tons of CO_2 safely and effectively. However, current federal incentives for CCS do not apply to industrial facilities, so CCS is not being used to its fullest potential in the sector.

Industrial facilities that capture and sell CO_2 will reduce their emissions while also gaining an extra revenue stream, creating jobs in their company as well as downstream industries and suppliers. The economic benefit of this would encourage more carbon producers to capture their emissions, and could result in reduction of stationary source CO_2 emissions from current levels. Adoption of CCS also means that we can find more effective ways to safely utilize CO_2 emissions in ways that do not damage the environment. CO_2 is already used in some industrial processes, and has the potential to shift from a burden to a valuable commodity in the future as research into safe carbon utilization advances. One example of a potential use is bio-refining. Micro-algae are incredibly efficient at processing CO_2, and some have been engineered to create biofuels and other useful chemicals. There is also research into converting CO_2 into advanced chemicals and materials, including concrete.

Federal investment and incentives are necessary to provide short-term financing and encourage industrial CO_2 producers to build the infrastructure for and invest in CCS. One major barrier is a lack of incentive for industrial facilities to implement CCS. The quickest and most effective way to encourage the rapid deployment of CCS for industrial uses is extending and expanding the 45Q tax credit, which is provided to facilities that implement CCS technologies. This tax credit recently expired, and it only covers facilities that produce over 500,000 tons of carbon per year, which rules out major carbon producers like ethanol and other industrial facilities. The 45Q credit should be expanded to include more types of facilities, and incentives must be increased, especially for industrial facilities that sequester captured emissions.

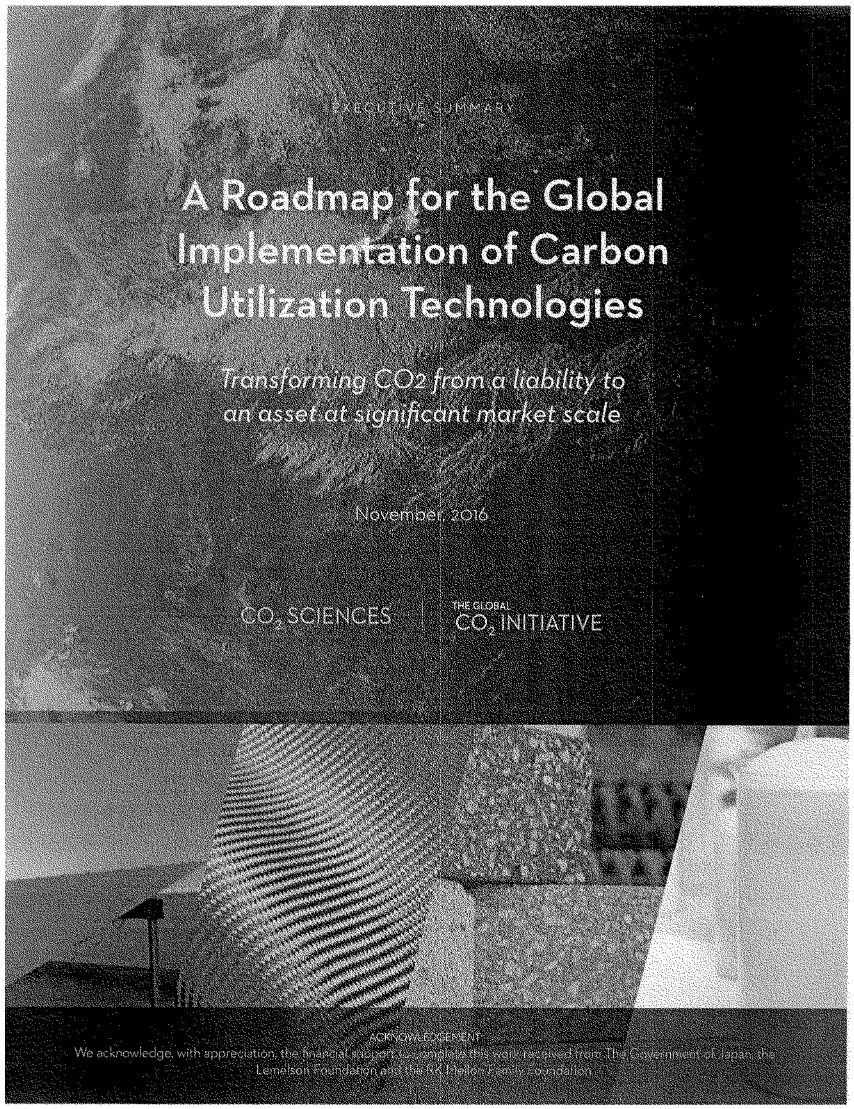
Federal efforts in this space should also consider the infrastructure associated with carbon capture. Right now, there are over 4,500 miles of carbon dioxide pipelines. Approximately 30 million metric tons of CO_2 are produced at industrial facilities within 50 miles of a CO_2 pipeline. However, to fully utilize CCS, several large corridors for pipelines from industrial regions like the Midwest and the Gulf Coast, to locations where the carbon can be sequestered or otherwise beneficially used, need to be built. Expanding this pipeline infrastructure is a win-win solution for all involved. It could drive billions of dollars of capital investment, stimulate economic activity, and support thousands of quality jobs in construction, manufacturing, and related fields.

We thank you for considering this important topic and urge you take our recommendations into consideration.

Sincerely,

Kimberly Glas

Kim Glas
Executive Director
BlueGreen Alliance


EXECUTIVE SUMMARY
A Roadmap for the Global Implementation of Carbon Utilization Technologies
Transforming CO2 from a liability to an asset at significant market scale
November, 2016
CO2 SCIENCES
THE GLOBAL CO2 INITIATIVE
ACKNOWLEDGEMENT
We acknowledge, with appreciation, the financial support to complete this work received from The Government of Japan, the Lemelson Foundation and the RK Mellon Family Foundation.

Executive Summary

The Global CO_2 Initiative (GCI) and CO_2 Sciences

The Global CO_2 Initiative (GCI) focuses on funding research, development and commercialization of products that reuse CO_2. These products have the potential to reduce global annual carbon dioxide emissions by as much as ten percent.

The GCI, announced in January 2016 at the World Economic Forum in Davos, aims to drive substantial economically based change by developing and harnessing market demand for products that capture and reuse CO_2. CO_2 Sciences, Inc., GCI's non-profit, is structured to aggressively catalyze innovative research in carbon capture and use through grants to qualified applicants worldwide totaling $400 million over the next ten years.

To carry out its mission, CO_2 Sciences is developing a "toolkit" of capabilities and expertise (Figure 1) to assess market opportunities in the carbon-based products industry (CBPI), evaluate time horizons for short and long term opportunities, and identify a roadmap for implementation.

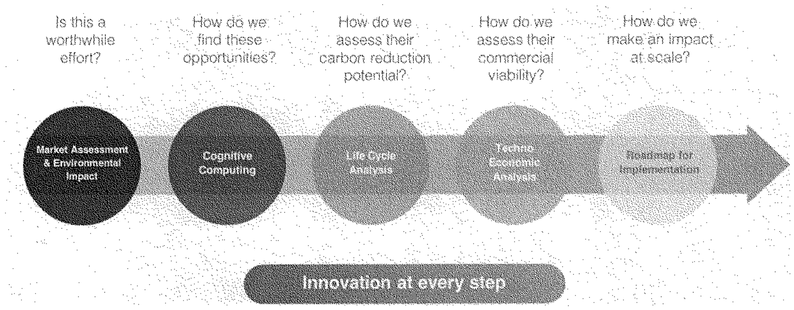


Figure1: CO_2 Sciences Toolkit: Developing capabilities to advance CBPI

To date, we have completed a Market Assessment and Roadmap for Global Technology Implementation. This document provides a summary of the results of our market assessment study (released earlier this year) and, in greater detail, the results of work to develop a roadmap for global implementation of CBPI. We conclude with recommendations for strategic actions.

Market Assessment - A briefing

CO_2 Sciences commissioned an independent study to conduct a detailed assessment of the global market opportunity for CO_2-based products. The study identified a large number of potential products and used the following criteria to focus on 25 of them:

1. **Environmental Impact**
    a. CO_2 potential: total amount of CO_2 that can be captured
    b. Permanence: length of time before the captured CO_2 is released
2. **Economic Impact**

a. Willingness to pay: maximum price of CO_2 that can be paid while keeping a given product competitive
b. Ease of Implementation: capital requirements, regulatory and market channel barriers

The 25 products shown in Figure 2 span seven categories:

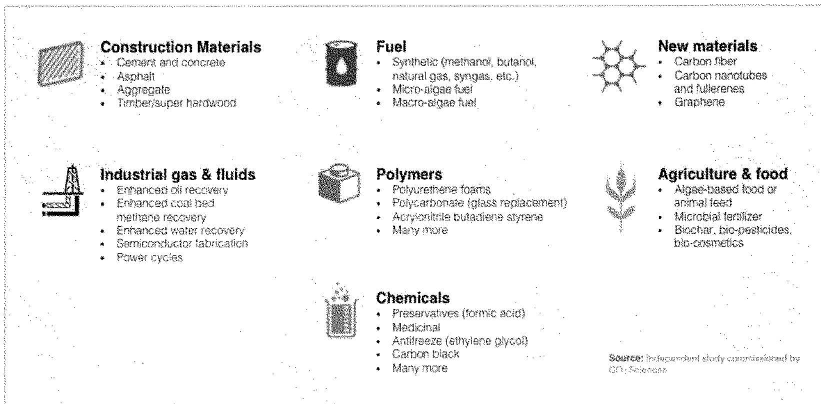


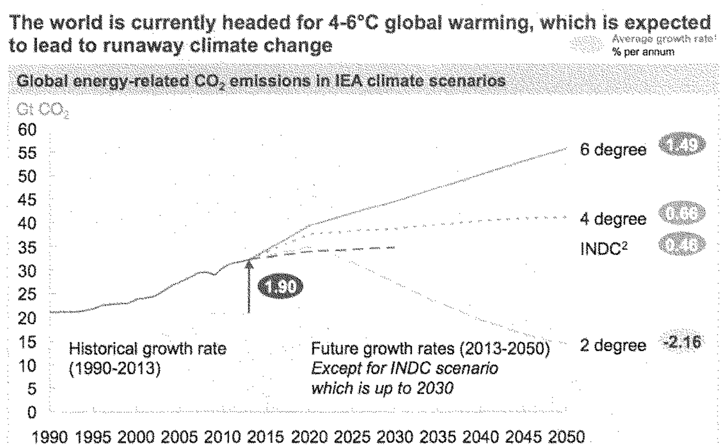
Figure 2: Examples of products that can be made from CO_2

The assessment included a bottom-up analysis for each of these seven categories and concluded that:

> CBPI can significantly contribute to reducing carbon emissions. Our initial estimate is that over 10% of annual CO_2 emissions can be captured in these products.
>
> These products represent an annual revenue opportunity of $800 billion to $1.1 trillion.

Background: Confronting an urgent challenge

The significant reduction of carbon emissions into the environment is crucial to averting a global climatological, economic, environmental and political catastrophe. While renewable power generation and a number of adaptation options can help with CO_2 reduction, experts agree that carbon negative technologies are needed to keep temperature increases below 2°C (Figure 3).



1 Historical (1990-2013); Future scenarios (2013-2050) except for the INDC scenario which is up to 2030
2 Intended Nationally-Determined Contributions to CO_2 emission reductions for COP21
SOURCE: IEA (2014), CO_2 Emissions from Fuel Combustion; IEA (2015) World Technology Perspectives; IEA (2015) World Energy Outlook Special Report on Energy and Climate Change

Figure 3: Negative carbon emission rates are needed to limit temperature increase to 2°C.

CBPI represents a major carbon reduction technology that, prior to the GCI, has not received attention nor been explored in any comprehensive fashion. As shown in Figure 4, CBPI can cover 15-20% of the projected gap between the 2°C goal and use of all currently identified solutions.

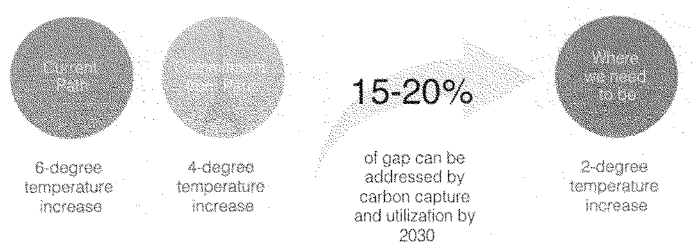


Figure 4: CBPI can play a significant role in addressing gap to achieve a 2° future

Identifying and forecasting market opportunity

Technology pathways assessment

We have identified and analyzed 180 developers who, worldwide, are actively engaged in CBPI and, ultimately, in the development of CO_2-based products. A database of CBPI developers was compiled from multiple sources. These entities include start-ups, mid-sized companies, corporations, consortia and research institutes.

Following in depth technology assessment, we defined six markets or product clusters (Figure 5) based on the number of active developers, conversion technology pathways and targeted end products:

1. **Chemical Intermediates** (such as Methanol, Syngas and Formic acid)
2. **Fuels** (such as Methane and Liquid fuels)
3. **Building materials** (such as Concrete and Aggregates)
4. **Algae** (processed separately to create biofuels or food additives)
5. **Polymers** (such as polycarbonates, polyurethane and PHA)
6. **Novel materials** (such as carbon fiber)

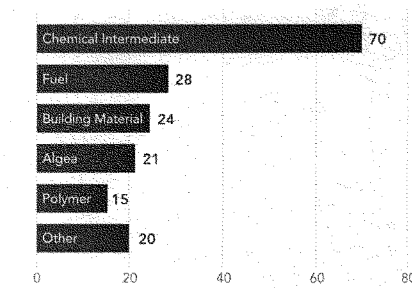


Figure 5: Number of active developers by end-product market cluster

Four markets are recommended for funding and investment

For each product or product category, we applied a Technology Readiness Level (TRL) of 1 (least) to 9 (most) to determine the relative stage of development and create a framework for expected time-to-market. We also used standardized rubrics to better quantify the mitigation potential and technology fit of each market. As a result, four markets were recommended for further analysis as shown in Figure 6. Algae and novel materials will not be part of the roadmap development as they will not significantly impact markets before 2030.

The roadmap analysis focused on eight categories within these four markets:

1. Chemical Intermediates: Methanol
2. Chemical Intermediates: Syngas
3. Chemical Intermediates: Formic acid
4. Fuels: Methane
5. Fuels: Liquid fuels
6. Building materials: Concrete
7. Building materials: Aggregates
8. Polymers

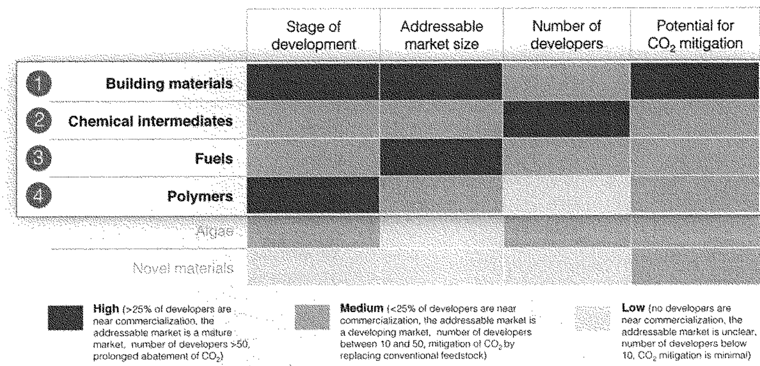


Figure 6. Markets that offer the best opportunities for support and investment

Market sizing

The study estimated the 2015 market size and compound annual growth rates (CAGR) for each of the eight categories within the four markets. The findings were based on existing proprietary research and secondary information from annual reports, published market studies and industry publications. Figure 7 indicates the methodology used in assessing markets.

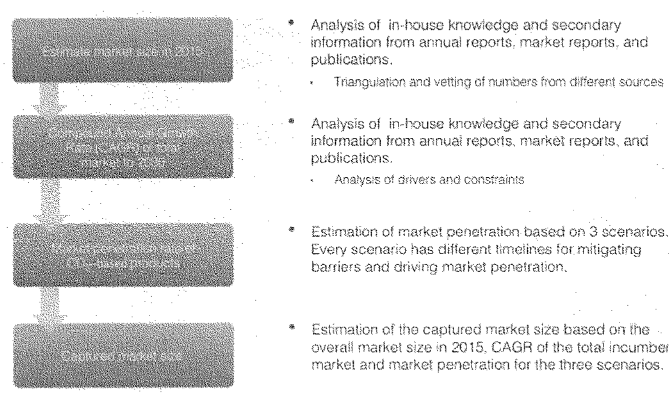


Figure 7. The methodology we used in assessing CBPI markets

We then projected each product's market penetration rate based on three scenarios:

- **Best case:** Strategic actions are taken that remove barriers at earliest possible opportunity.
- **Optimistic:** Strategic actions are taken to mitigate barriers.
- **Pessimistic:** Status quo is maintained.

Each of the eight categories has a timeline for mitigating technology, policy and business barriers and driving market penetration. The study then estimated addressable market size by five-year milestones (2020, 2025 and 2030). Figure 8 presents an example of that analysis showing the potential for one building material market segment (concrete curing) to absorb CO_2 over the next 15 years. Similar analysis was conducted for the remaining seven categories.

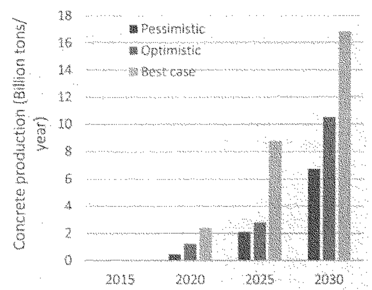


Figure 8: Estimated growth of CBPI concrete curing market through 2030

Drivers and barriers

Different market forces influence near term and long term potential of the different market segments. Market **drivers** include:

- The Paris agreement sets global goals for reducing CO_2 emissions and establishes a system to support national governments in doing so. These agreements entered into force in early November 2016.
- The drive toward a carbon-neutral economy and less dependence on oil.

Working against these drivers are **barriers** including:

- **Lack of coherent government funding strategies to support CBPI technologies.**
- **Lack of access to facilities** to scale-up CBPI technologies.
- **Lack of access to feedstocks** – for hydrogen, CO_2 and renewable energy.
- **Cost: CBPI must compete** with conventional feedstock and bio-based feedstocks, which are often lower in cost.

In general, these drivers and barriers can be examined by considering the respective roles of **Technology, Market and Policy.**

In some cases, technology may be the largest barrier while, in others, the largest barrier may be policy. Figure 9 illustrates the relative influence (1 low to 5 high) of policy, technology and market on the development of different products. For example, policy has a greater impact on the development and market penetration of fuels than on polymers.

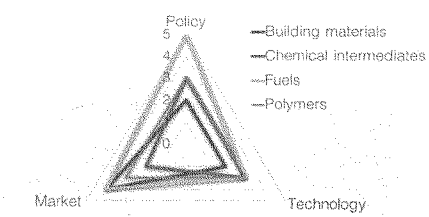


Fig. 9 Relative influence of the dimensions on different CO_2- based products

Recommendations for Strategic Actions

Consideration of the drivers and barriers enables us to develop the following recommendations to leverage the drivers and diminish the barriers.

Technology:

1. **Decrease the cost of CO_2 utilization: Fund research to improve catalysis for CO_2 reduction and electrolysis to produce hydrogen.**

   Research is needed to reduce the energy requirements of CO_2 catalysis and other conversion processes. A hydrogen feed is needed in the production of many CO_2-based products. To make CBPI more cost-competitive, applied research is needed in generating low cost H2 by electrolysis using renewable energy.

2. **Maximize high-potential long shots: Fund applied research on long-shot technologies and applications that have the highest CO_2 abatement potential.**

   In addition to the four markets analyzed in this work, there are early-stage CBPI technologies and applications that could offer solutions beyond 2020. One of the highest-potential technical areas in this regard is the production of carbon fiber. Figure 10 depicts a potential timeline for implementing the technology levers.

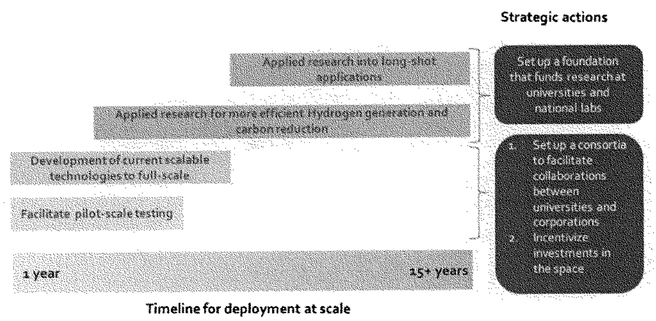


Figure 10: Potential timeline for implementing Technology levers

Market

1. **Scale up production: Make funding available to establish collaborations among research institutes, start-ups, governments and corporations for process integration of CO_2 conversion, hydrogen generation and carbon capture.**

   Consortia should be established to develop CBPI value chains, integrating carbon capture; the supply of affordable hydrogen from sources such as a chemical plant or a technology like electrolysis; access to low-cost renewable energy (such as over-capacity electricity); and physical plants for CO_2 conversion and CBPI product manufacturing.

2. **Access to Capital: Articulate and communicate the value proposition for CBPI technologies.**

As the market potential for CBPI solutions has only recently been identified by the CO_2 Sciences market assessment and global implementation roadmap, the value proposition is generally unknown by investors. Articulating and communicating the value proposition will increase the availability of capital and particularly impact investments that consider both social and financial returns. We are not implying inferior financial returns but emphasizing the double bottom line returns nature of investing in CO_2-based products. This capital will enable faster adoption and market deployment of CO_2-based products. Figure 11 depicts a potential timeline for implementing the market levers.

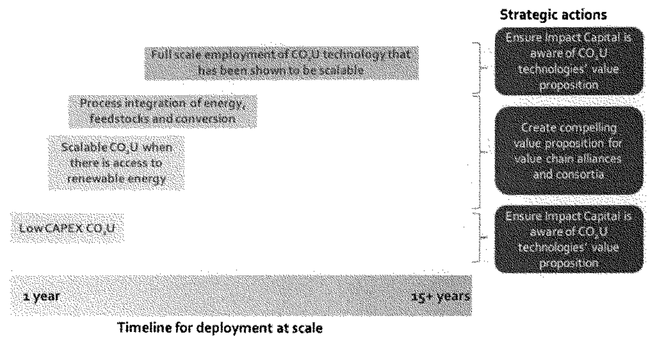


Figure 11: Potential timeline for implementing market levers

Policy

Supportive policies can help start and build markets for CBPI products. Different policies may be appropriate in different jurisdictions, depending on local circumstances. The following are policies that can play an important role in promoting CBPI products.

1. **Government and Industry support for R&D:** Support for R&D on carbon dioxide utilization is currently modest. A significant increase in funding in this area could speed deployment of CBPI technologies and yield important dividends. In December 2015, heads of state from more than 20 countries announced Mission Innovation, a pledge to double R&D on clean energy within five years. The increase in government R&D budgets offers an important opportunity to scale up R&D funding for CO_2 utilization. Support from corporations and other private funders (e.g. philanthropists) for R&D can also serve to accelerate progress on new technology creation.

2. **Carbon Price:** A price on carbon dioxide emissions, whether through an emissions trading program or tax mechanism, would provide emitters with an important incentive to cut emissions.

3. **Mandates:** Governments could mandate the use of CO_2 in certain products as a means to spur the market.

4. **Government procurement:** Government (including military) procurement can provide early market demand for emerging technologies, such as the US Navy's procurement of biofuels.

5. **Credits under regulatory and voluntary programs:** Governments could offer additional credits under existing regulatory programs tied to the use of CBPI products.

The implementation of the above cited levers will lead to significant increase in CO_2 reduction (Figure 12) and will create significant business opportunities (Figure 13).

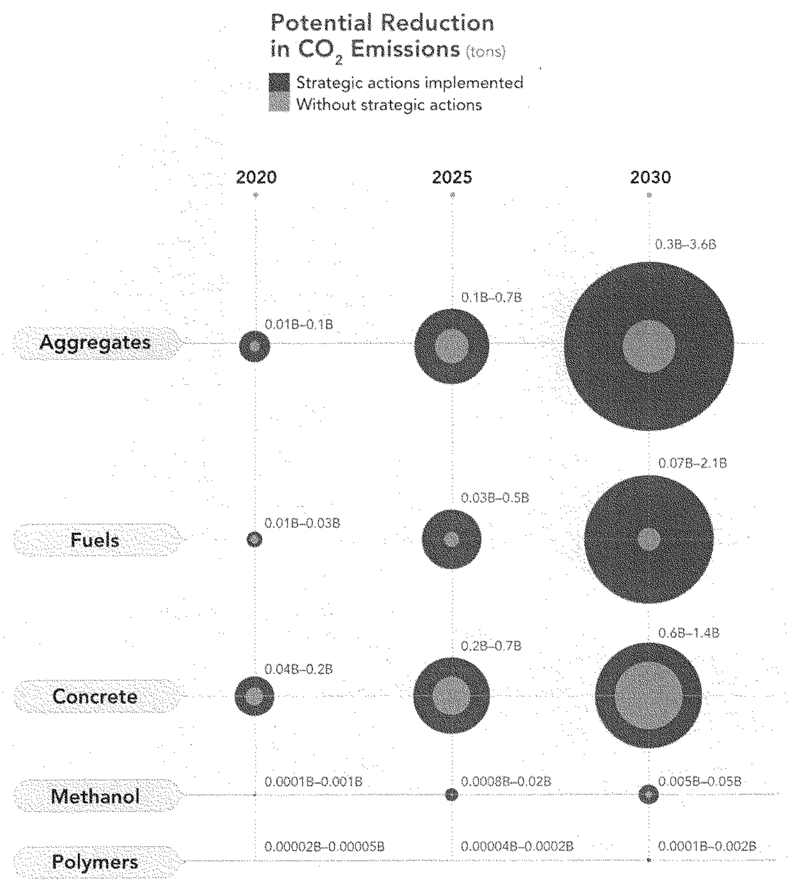


Figure 12: Potential CO_2 reduction due to implementing strategic actions

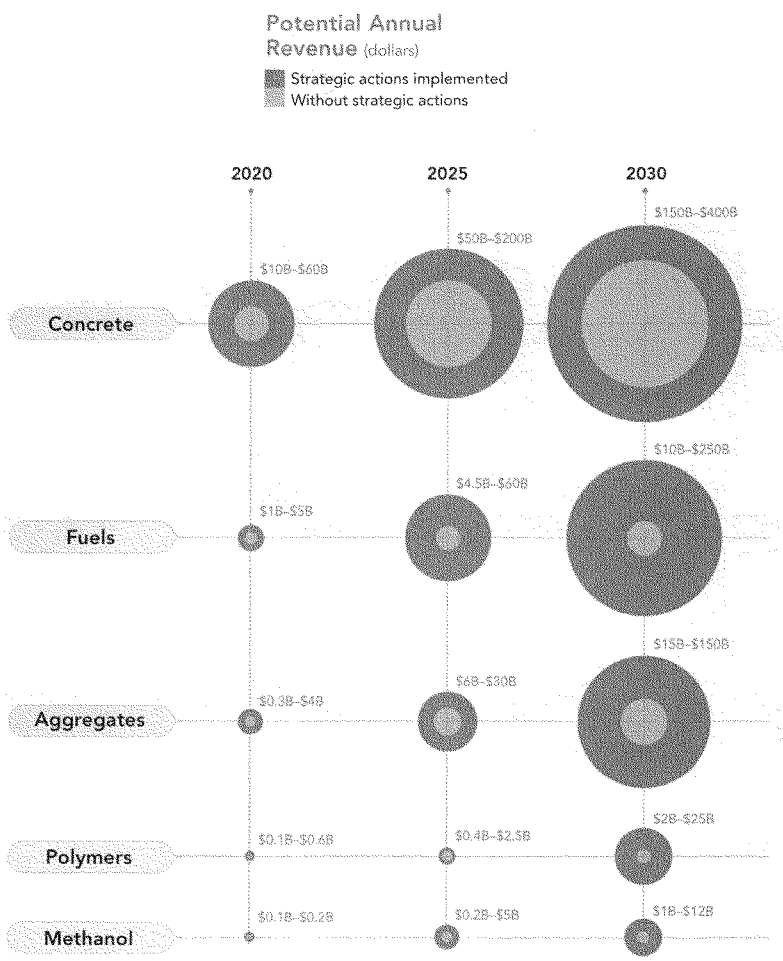


Figure 13: Potential increase in financial returns due to implementation of strategic actions

Conclusions

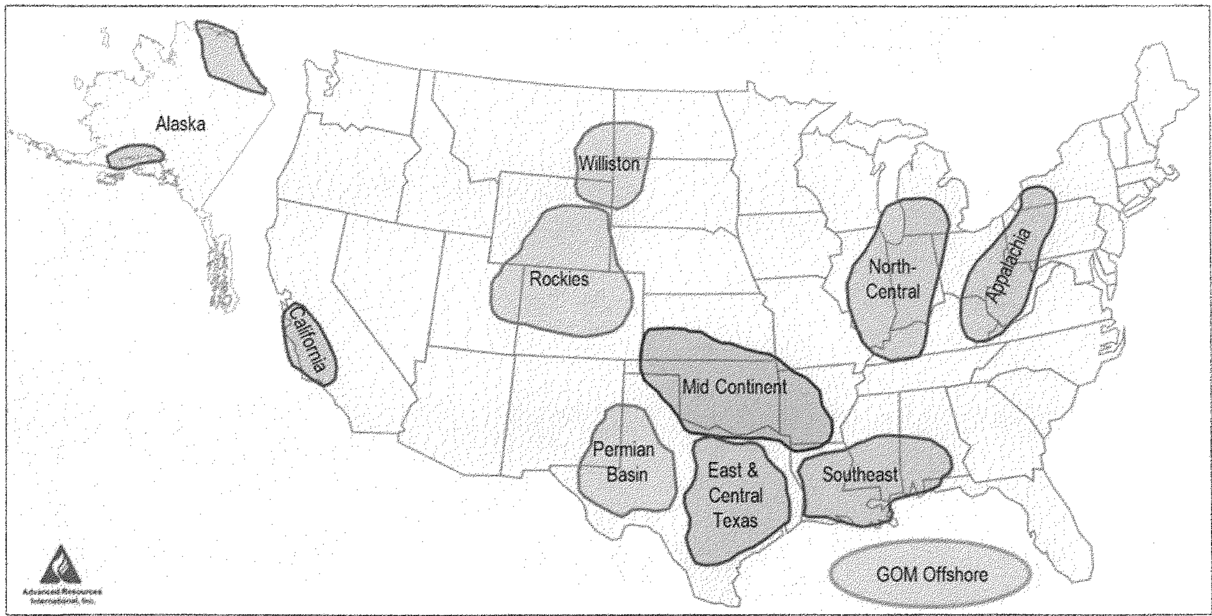
- **The Carbon Based Products Industry (CBPI), created through broad scale commercialization of products derived from CO_2, offers a huge opportunity to mitigate CO_2 emissions driven by market returns.**

- CO_2 mitigation and CBPI are critical to decrease the risks associated with climate change. CBPI utilizes CO_2 to produce valuable materials, fuels or chemicals, whereas mitigation strategies like carbon capture and storage represent only an economic cost to society.

- Over the past five years, significant progress has been made on research and development of CO_2-based products. Many technologies are proving to be scalable. There is visible momentum in four major markets: building materials, chemical intermediaries, fuels and polymers.

- Funding, incentives and prompt strategic action are necessary to move the CBPI to its full potential. At its full potential scale, our most recent global roadmap shows that the **CBPI could reach or exceed US $800 billion by 2030 and, critically, the Carbon Based Products Industry has the potential to utilize seven billion metric tons of CO_2 per year by 2030 – the equivalent of approximately 15 percent of current annual global CO_2 emissions.** The path to a 2° future depends on it.

U.S. Basins Favorable for CO_2-Enhanced Oil Recovery



Source: Advanced Resources International.

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CLEAN AIR TASK FORCE

FACT SHEET AND ANALYSIS

The Emission Reduction Benefits of Carbon Capture Utilization and Storage using CO_2 Enhanced Oil Recovery

ABOUT THE AUTHORS

Deepika Nagabhushan is a CCS Policy Associate at CATF

You can reach Deepika at dnagabhushan@catf.us or 847-505-4149.

Kurt Waltzer is the Managing Director at CATF

You can reach Kurt at kwaltzer@catf.us or 617-624-0234, ext. 292

Enhanced Oil Recovery (EOR) using industrial CO_2 provides an important way to stimulate the development of the infrastructure needed to capture and store large amounts of CO_2 consistent with decarbonizing the energy system.

According to the International Energy Agency (IEA), utilizing industrial CO_2 Enhanced Oil Recovery for the purposes of Carbon Capture Utilization and Storage (CCUS) results in a net CO_2 emissions reduction.

Based on IEA's analysis CCUS-EOR using industrial CO_2 can result in a *63% net reduction in CO_2 emissions* for every barrel of oil produced.

If we do not take advantage of CO_2 EOR, the oil may be produced by other technologies that do not reduce emissions.

According to the IEA, there is a potential to store 140 billion tons of CO_2 in oil reservoirs around the world through CO_2 EOR[1] - resulting in a net emissions reduction by 88 billion tons of CO_2. This is more than 40 times the current U.S. power sector emissions. Thus, under the right economic conditions there would be a large market-based opportunity to reduce man-made CO_2 emissions. As a result, enhanced oil recovery activity using captured anthropogenic CO_2, could significantly drive the deployment of CCUS technology & infrastructure, and help lower technology costs around the globe.

Can CO_2 EOR provide a net reduction in CO_2 emissions?

Yes. CCUS combined with EOR involves the incidental geologic trapping or storage of CO_2 that occurs as part of the oil recovery process. CO_2 is injected into mature reservoirs, where it mixes with the remaining oil, enabling it to be more easily produced, and as a result of which a portion of the CO_2 (usually about one-third to a half) is geologically trapped, permanently. The CO_2 that is not trapped is produced with the oil, recaptured, and reinjected – and the process continues until all of the CO_2 is permanently sequestered.

Over the life of the project, almost all of the CO_2 delivered to the field is stored in the geologic formation. But because EOR produces oil, which when processed or used produces emissions, the stored volume of CO_2 cannot entirely be counted as an emissions reduction. When the volume of CO_2 stored underground is greater than those emitted by the excess emissions caused by EOR activity, then the difference must be counted as a net emissions reduction benefit.

The most recent and comprehensive assessment of net storage from CO_2 EOR was developed by the IEA in 2015.[2] The study indicates that for a given volume of CO_2 delivered to an oil field or storage site, EOR can provide a 63% net emissions reduction benefit, under the reasonable assumptions outlined below.

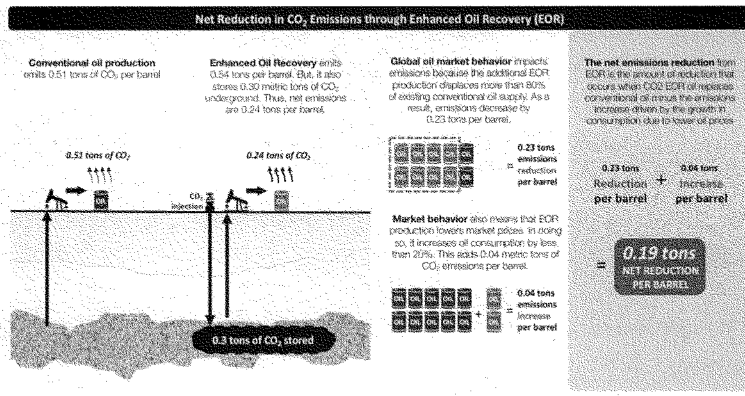

Figure 1: Net Reductions in CO_2 Emissions through Enhanced Oil Recovery (metric tons)

Figure 1 shows the benefits of CO_2 EOR in terms of CO_2 emissions reduction. The production and consumption of a typical barrel results in about half a metric ton of CO_2 being emitted to the atmosphere.

<u>But, doesn't EOR result in greater overall CO_2 emissions due to oil production?</u>

No. Producing a barrel of oil from CO_2 EOR is slightly more energy intensive than a conventional barrel of oil, with emissions of 0.54 metric tons and 0.51 metric tons of CO_2 respectively. But CO_2 EOR has the benefit of storing the 0.30 metric tons of CO_2 that was needed to produce 1 barrel of oil. After accounting for this benefit, the production and consumption of a barrel of oil from EOR contributes a net of 0.24 metric tons of CO_2 to the atmosphere.

If an EOR barrel replaced a barrel of conventionally produced oil in the market, then there would an emissions reduction of 0.27 metric tons of CO_2 per barrel (the difference between conventional oil emissions and EOR barrel emissions). In reality though, all else being equal, this 1 to 1 displacement does not occur. The new oil supply will lower the market price of oil and thus increase the demand for oil. The IEA estimates that for every 10 barrels of oil produced through CO_2 EOR, only 8 barrels of existing oil are displaced and 2 barrels are additional. The displacement of the 8 barrels (or 80% of existing supply) provides an emissions reduction benefit of 0.23 tons per EOR barrel.[3] But, the increase in consumption of the additional 2 EOR barrels (20% of existing supply) increases emissions by 0.04 tons per EOR barrel.[4] These market effects result in a net emissions reduction benefit to 0.19 metric tons of CO_2 per EOR barrel, on average.

Considering the CO_2 used for EOR is anthropogenic, i.e. captured from the power or industrial sectors and which would otherwise be released into the atmosphere, the net reduction of CO_2 is 63% per barrel of oil produced or per 0.3 tons injected (or, per any other volume of CO_2 injected).

The type of oil production that is assumed to be replaced by EOR is also a key factor in determining the net reduction in emissions. The IEA analysis found that net emission reductions could range from 47% to 150% depending on the carbon content of the oil that is assumed to be offset.[5] While a 20% increase in oil consumption driven by CO_2 EOR oil production delivers net emissions reduction, even if the consumption increased by 50% of a barrel, there would still be a net emissions reduction benefit.

<u>Are there any other emissions that might affect EOR's benefit?</u>
Yes, emissions upstream from the CO_2 EOR process can also affect the CO_2 emissions reduction benefits from using anthropogenic CO_2. But, it is important to note that the upstream emissions affect any sequestration method the same exact way. In other words, upstream emissions affect both EOR and storage in deep saline geologic reservoirs equally. Hence, it is only downstream emissions that provide the crucial "apples to apples" net emissions reductions benefit comparison.

Upstream emissions include those from coal and natural gas production, transportation of fuel, combustion and transportation of captured CO_2. But, the key emissions impact is driven by capture technology and configuration (new/retrofit/full or partial capture) used at the emitting source. For example, if we were to include in our upstream calculations a 90% capture from a retrofit on an existing coal plant using current conventional capture technology, then it would reduce the emissions reduction benefit from CO_2 EOR by 25%, due to process energy penalties and capture rates.[6] Alternatively, if we were to consider an advanced carbon capture technology such as one based on the Allam Cycle, which could reach 100% capture levels, bringing the energy penalty to minimal levels, then the reduction in the benefit from downstream CO_2 EOR would be minimal.[7]

Would the oil from depleted oil fields be produced anyway without CO_2 EOR?
Likely. The same oil that is targeted for CO_2 EOR, can be produced by other technologies and will only result in increased emissions. Oil from depleted wells will be recovered using the best available method, even if it is not CO_2 injection, if the oil prices so dictate. CO_2 EOR is effectively in competition with other EOR options outlined below. These options do not provide any climate benefit, but instead only permit and lead to increased CO_2 emissions.

Geologically-sourced CO_2 has been in use for several decades for CO_2 EOR. 75% of the CO_2 currently used for EOR is produced from natural geologic deposits. National Energy Technology Laboratory (NETL) estimates that there are an additional 3.9 billion metric tons of geologically-sourced CO_2 in the US that could be produced economically for use in EOR.[8] Because the natural-sourced CO_2 was already geologically trapped, it does not deliver a climate benefit when used for CO_2 EOR, unlike industrial-sourced CO_2.

The use of surfactants, polymers, and detergents for chemical flooding in reservoirs is another form of enhanced oil recovery. Advances in drilling such as infield drilling, horizontal drilling and fracking could also be used to extract the oil from reservoirs, which would otherwise be targets for CO_2 injection.

Methane reacts in oil fields in a manner similar to CO_2. The Norwegian oil company Statoil has been injecting methane into the North Sea for oil recovery (64 million metric tons /year) in amounts that are similar to those of CO_2 injected into the Permian Basin in Texas for EOR.[9] Methane is also regularly injected into the North Slope formation also for EOR. Although EOR is typically not the way to extract the most economic value out of methane, it is still used in some regions where either CO_2 is not available or oil-gas price arbitrage drives a preference for methane injection to produce additional oil.

Conclusion

Enhanced Oil Recovery using captured industrial CO_2 can provide a net CO_2 emissions reduction of 63% relative to the CO_2 stored, taking into account emissions from oil consumption. The combination of the existing and projected demand for EOR and the availability of industrial CO_2 offers the potential for developing the needed infrastructure to more widely deploy CCUS technology at a significant scale and to store large amounts of CO_2. Without CO_2 EOR using captured industrial (anthropogenic) CO_2, the oil will likely be produced anyway, using other methods of extraction that do not provide emissions reduction benefits.

---

[1] IEA Greenhouse Gas R&D Programme (IEA, GHG), "CO_2 Storage in Depleted Oilfields: Global Application Criteria for Carbon Dioxide Enhanced Oil Recovery, 2009/12, December 2009."

[2] International Energy Agency, "Storing CO_2 through Enhanced Oil Recovery, combining EOR with CO_2 storage (EOR+) for profit," 2015.

[3] The more precise IEA displacement estimate is 84%. Multiplying that with the difference between conventional oil and EOR oil (0.27 metric tons per bbl) results in a net benefit of 0.23 metric tons per bbl.

[4] The more precise IEA displacement estimate is 16%. Multiplying that with the emissions from one barrel of EOR oil (0.24 metric tons per bbl) results in a net increase of 0.04 metric tons per bbl.

[5] International Energy Agency, "Storing CO_2 through Enhanced Oil Recovery, combining EOR with CO_2 storage (EOR+) for profit," 2015.

[6] Calculated from spreadsheet model developed for Azzolina, et al., "How green is my oil? A detailed look at greenhouse gas accounting for CO_2-enhanced oil recovery (CO_2-EOR) sites." International Journal of Greenhouse Gas Control 51 (2016) pp. 369-379. Considering coal plant retrofit with 90% capture level, 30% energy penalty and make up power from NGCC without carbon capture (no displacement of electricity grid mix).

[7] NETPower briefing to USEA, May 25, 2016.

[8] National Energy Technology Laboratory, "Subsurface Sources of CO_2 in the Contiguous United States Volume 1: Discovered Reservoirs," March 4, 2015, DOE/NETL-2014/1637.

[9] Cavanagh, Ringrose, Statoil, ASA "Improving oil recovery and enabling CCS: a comparison of offshore gas-recycling in Europe to CCUS in North America", GHGT-12, Energy Procedia 63 (2014) 7677 – 7684.

Staff Report to the Secretary on Electricity Markets and Reliability

August 2017

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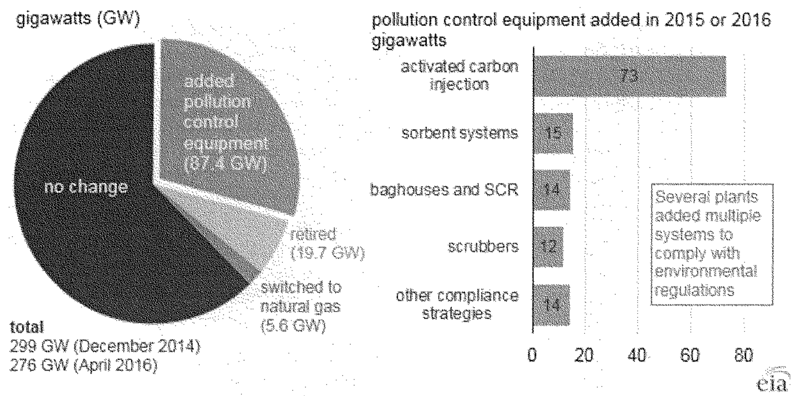
3.6.1 Coal Plants and Environmental Regulation

Existing coal-fired power plants must not only comply with all Federal requirements related to emissions and water use, wastewater treatment, and solid waste management, but also with any additional applicable state regulations.[134] Cost impacts of these regulations varied. The EPA reported that a typical coal-fueled unit with a capacity of 700 MW could incur incremental operating and maintenance costs ranging from $287 million to $351 million to install a scrubber, from $116 million to $137 million to install a selective catalytic reduction unit, and from $97 million to $114 million to install a baghouse (fabric filter). Fitch estimated the lifetime costs and reduced cash flow associated with environmental retrofits at $1,700–$1,900 per kilowatt (kW) for a 100 MW plant burning bituminous coal, as compared with a range of $1,200–$1,300/kW for a 500 MW plant.[135] These costs are on par with those of constructing a new typical (i.e., subcritical) coal plant of similar size during this same time period (averaging $1,361/kW).[136] Reported planned retirements from that time suggest that approximately 27,000 MW or 8.5 percent of 2011 coal-fired capacity was rendered uneconomic under the combination of regulatory compliance costs, little demand growth, and falling natural gas prices.[137]

The MATS rule was potentially the most expensive and immediate of the suite of pending regulations, with a compliance deadline of April 2015 (later extended to April 2016 for some plants). Further, owners of coal facilities were dealing with MATS compliance in combination with the cost of imminent additional regulations of CO_2, along with other GHGs. EIA reported that by the end of 2012, 64 percent of the U.S. coal generating capacity in the electric power sector already had the appropriate environmental control equipment (most reported using flue gas desulfurization) to comply with the MATS rule and operate past 2016; another six percent planned to add control equipment; 10 percent had announced plans to retire; and the other 20.4 percent still had to decide whether, how, and when to upgrade or retire their plants.[138]

The dominant MATS compliance strategy among coal-fired plant owners was to install activated carbon injection (Figure 3.22), which averaged a relatively modest $5.8 million per generator from 2015 to 2016. EIA estimates that "operators invested at least $6.1 billion from 2014 to 2016 to comply with MATS or other environmental regulations."[139] In its rulemaking, EPA estimated an annualized cost of $9.6 billion in 2015, declining to $7.4 billion annually in 2030.[140]

Figure 3.22. Changes in U.S. Coal Capacity, December 2014–April 2016[141]



The retrofit-or-retire decision for owners is also impacted by EPA's New Source Review (NSR) regulations that can affect owners' ability to enhance plant efficiency due to the delay, cost, and uncertainty associated with obtaining an NSR permit. The NSR permitting program requires stationary sources of air pollution—including factories, industrial boilers, and power plants—to get permits before construction starts, whether the unit is being newly built or modified.[142] This is an important concern for owners considering retrofitting an existing power plant with carbon capture equipment to reduce CO_2 emissions, or adding new components to improve operating efficiency. These upgrades could trigger the NSR requirements of the Clean Air Act because they would constitute a "physical change," or lead to a designation of the change as a "major modification," subjecting the unit to NSR permitting requirements.

The uncertainty stemming from NSR creates an unnecessary burden that discourages rather than encourages installation of CO_2 emission control equipment and investments in efficiency because of the additional expenditures and delays associated with the permitting process.[143] [144] Ironically, the uncertainty surrounding NSR requirements has led to a significant lack of investment in plant and efficiency upgrades, which would otherwise lead to more efficient power generation, benefits to grid management, and reduced environmental impacts. EPA has acknowledged these burdens and has made attempts to reform the rules to improve and streamline NSR:

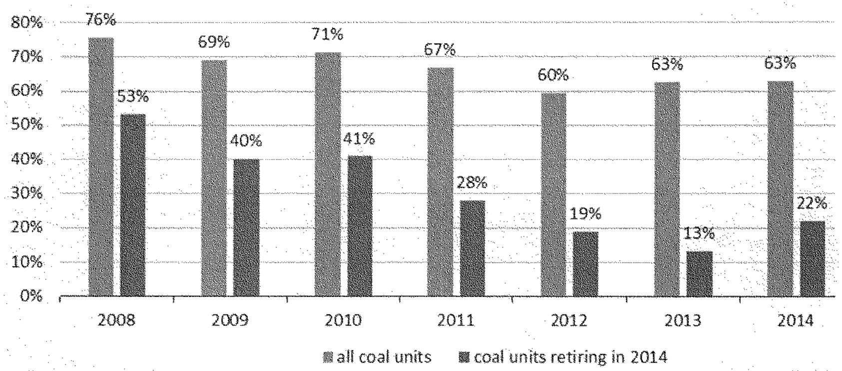
> As applied to existing power plants and refineries, EPA concludes that the NSR program has impeded or resulted in the cancellation of projects which would maintain and improve reliability, efficiency and safety of existing energy capacity. Such discouragement results in lost capacity, as well as lost opportunities to improve energy efficiency and reduce air pollution.[145]

The NSR program distinguished between "routine maintenance and repair" of existing facilities—which would be allowed—and more "substantial modification" of existing facilities, which would put the facilities over the threshold and thus require them to meet new emissions standards.

Environmentalists argued that owners of electric generation and industrial plants were building virtually new facilities from the inside out by exploiting the "routine maintenance and repair" exclusion from NSR. EPA changed its interpretation in the 1990s to a more rigorous standard, culminating in numerous enforcement-related lawsuits beginning in the late 1990s.[146]

By the late 2000s, some older coal units operating without pollution controls were no longer operating as baseload units, having operational capacity factors estimated at 47 percent to 56 percent.[147] As Figure 3.23 shows, rather than acting as baseload units at high capacity factors, these older units (with an average capacity of 109 MW) were operating at falling capacity factors. The units that retired in 2014 had an average capacity factor of 13 percent in 2013.

Figure 3.23. Average Coal Plant Capacity Factors, 2008–2014[148]



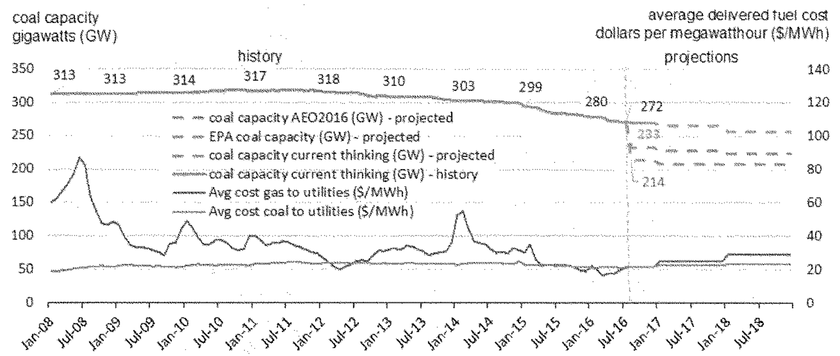
Source: EIA Form 860 and Form 923

Coal plant capacity factors generally fell from 2008 through 2014, with plants that retired in 2014 operating at much lower capacity factors than all coal plants.

Some owners delayed their retirement announcements and retrofit decisions in order to see how the regulation litigation challenges played out, in case a late court ruling made compliance unnecessary, signifying that the cost of complying with those regulations was a factor in their retirement decisions. Others delayed closing uneconomic plants to see if enough other plants retired, in hopes that the resulting shift in market dynamics and prices might render the unretired plants profitable again.[149]

Figure 3.24 shows total U.S. coal capacity from 2008 through mid-2016 and projections through mid-2018. While there was a fall in coal plant capacity in 2015 associated with the MATS compliance deadline, EIA finds that fewer coal facilities retired in 2015 and the first half of 2016 than EIA had projected ahead of the compliance deadline. Specifically, in 2015 and until the April 2016 extended MATS deadline, about 20,000 MW of coal capacity retired and another 9,000 MW of coal capacity converted to natural gas, while EIA projected 50,000 MW of retirements between 2013 and 2020, with the majority retiring in 2015 in response to MATS.[150] However, EIA's projection also included other factors that can drive retirement decisions, such as the Clean Power Plan.

Figure 3.24. Projected and Actual Coal Retirements, 2008–2018[151]



Note: Historical data derived from EIA Form 860
Source: EIA Annual Energy Outlook 2016, EIA current thinking, and Environmental Protection Agency

Fewer coal plants retired in 2015–2016 than projected.

3.6.2 Natural Gas Plants and Environmental Regulation

Because natural gas emits far less air pollution than coal-fired power plants,[152] the regulatory burden and cost to natural gas-fired power plants is much lower than for coal plants. ERCOT's December 2014 analysis estimated that the Cross-State Air Pollution Rule (CSAPR)[jj] and the Cooling Water Intake Rule would impose moderate compliance costs on natural gas-fired power plants.[153] Specifically, ERCOT estimated costs of $0.10–$2.75/MWh for CSAPR and $0.10–$0.50/MWh for the Cooling Water Intake Rule.

The large majority of natural gas plants that have retired are NGSTs, which are less efficient than the newer NGCCs.[154] From 2002 to 2016, there was a steady stream of NGST retirements, some of which may be linked to decisions about the cost effectiveness of retrofit upgrades. However, during the period 2014–2016, 23,500 MW of new natural gas capacity was added, nearly double the total natural gas capacity that was retired as part of the transition from NGST units to more efficient NGCC units.[155] NGCC plants have replaced NGST plants for baseload use and natural gas combustion turbines have been built for peak power demand.

3.6.3 Nuclear Plants and Environmental Regulation

The principal environmental regulation affecting nuclear power plants is the Cooling Water Intake Rule, which applies to all types of power plants but is most challenging for nuclear plants. A revised version of the Cooling Water Intake Rule has been in effect since 2003. The rule was promulgated to protect aquatic life. States may decide how to implement the rule, such as by requiring a nuclear (or other) plant to invest in a closed-loop cooling system to replace once-through ocean or waterway cooling. Three of the nuclear plants that have announced closures (Oyster Creek in New Jersey, Diablo Canyon in

[jj] Finalized in 2011 and effective in 2015.

7 Policy Recommendations

The April 14 memo asked staff to "not only analyze problems but also provide concrete policy recommendations and solutions." To that end, DOE staff prepared a list of recommendations below. Some actions fit squarely within DOE's authority, while others might fall to other government agencies or private organizations.

Wholesale markets: FERC should expedite its efforts with states, RTO/ISOs, and other stakeholders to improve energy price formation in centrally-organized wholesale electricity markets. After several years of fact finding and technical conferences, the record now supports energy price formation reform, such as the proposals laid out by PJM[467] and others.[468] Further, negative offers should be mitigated to the broadest extent possible.

Valuation of Essential Reliability Services (ERS): Where feasible and within its statutory authority, FERC should study and make recommendations regarding efforts to require valuation of new and existing ERS by creating fuel-neutral markets and/or regulatory mechanisms that compensate grid participants for services that are necessary to support reliable grid operations. Pricing mechanisms or regulations should be fuel and technology neutral and centered on the reliability services provided. DOE should provide technical and policy support that strengthen and accelerate these efforts.

Bulk Power System (BPS) resilience: DOE should support utility, grid operator, and consumer efforts to enhance system resilience. Transmission planning entities should conduct periodic disaster-preparedness exercises involving electric utilities, regional offices of Federal agencies, and state agencies. NERC should consider adding resilience components to its mission statement and develop a program to work with its member utilities to broaden their use of emerging ways to better incorporate resilience. RTOs and ISOs should further define criteria for resilience, identify how to include resilience in business practices, and examine resilience-related impacts of their resource mix.

Promote Research and Development (R&D) of next-generation/21st century grid reliability and resilience tools: DOE should focus R&D efforts to enhance utility, grid operator, and consumer efforts to enhance system reliability and resilience. DOE R&D opportunities include the following activities:

- Develop grid technical tools to facilitate new-generation technologies' operations to support BPS reliability (e.g., by enabling technologies to provide ERS), and maximize use of the DOE national laboratories.
- Expand cooperation on grid reliability across North America, including working with NERC to further enhance the reliability of our shared BPS through technical engagement with Mexico and Canada.
- With the National Science Foundation, sponsor the development of new open-source software for the next-generation electric grid research community.
- Focus R&D on improving VRE integration through grid modernization technologies that can increase grid operational flexibility and reliability through a variety of innovations in sensors and controls, storage technology, grid integration, and advanced power electronics. The Grid Modernization Initiative should also consider additional applications of high-performance computing for grid modeling to advance grid resilience.

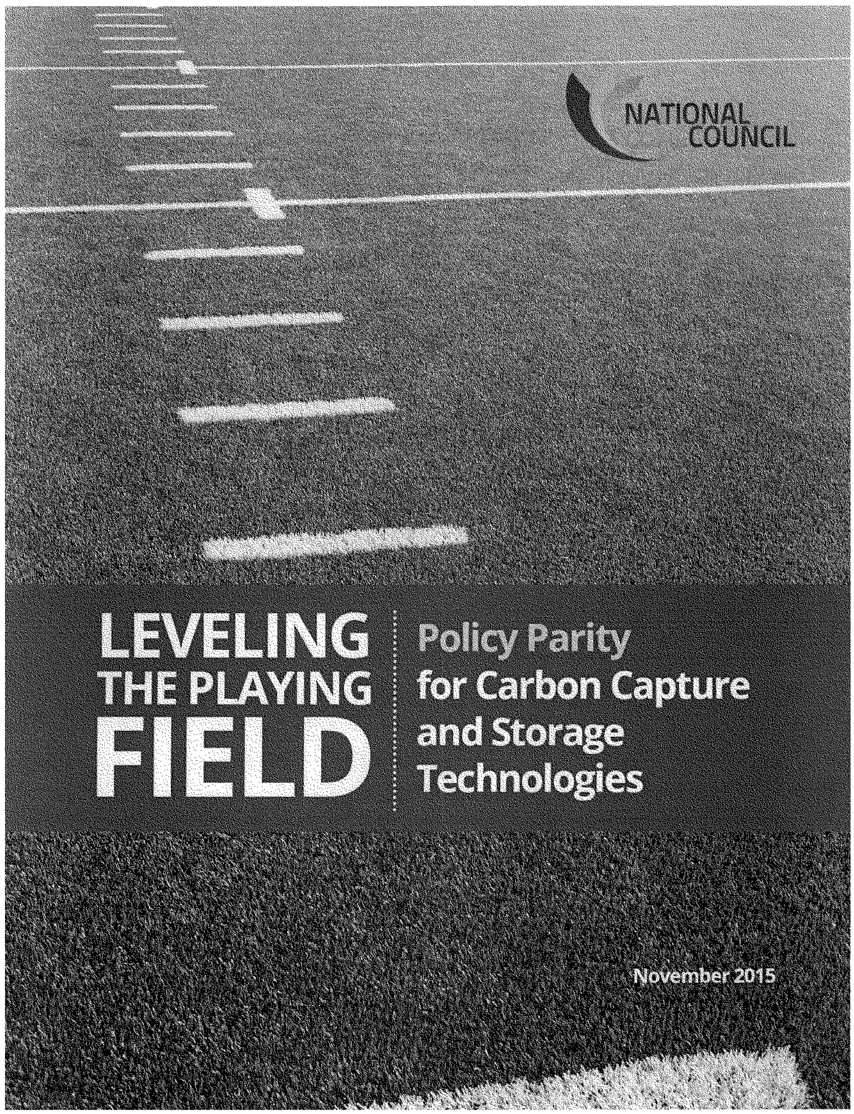
Support Federal and regional approaches to electricity workforce development and transition assistance: In partnership with other agencies and the private sector, DOE should facilitate programs and regional approaches for electricity sector workforce development. Unemployed workers nearing but not yet eligible for retirement may have difficulty retraining after careers built on specialized skills that may be in declining demand. Where possible, Federal agencies should leverage existing government, nongovernment, labor, and industry workforce consortia.

Energy dominance: Executive Order 13783 (Promoting Energy Independence and Economic Growth) outlined an approach to promote the clean and safe development of energy resources while at the same time minimizing regulatory barriers to energy production, economic growth, and job creation. The Order called for a rescission of certain energy and climate related policies, rescinded specific reports, and ordered the review of key environmental regulations. While DOE is not the main agency tasked in the Order, it should continue to prioritize energy dominance and implementing the Executive Order broadly and quickly.

Infrastructure development: DOE and related Federal agencies should accelerate and reduce costs for the licensing, relicensing, and permitting of grid infrastructure such as nuclear, hydro, coal, advanced generation technologies, and transmission. DOE should review regulatory burdens for siting and permitting for generation and gas and electricity transmission infrastructure and should take actions to accelerate the process and reduce costs. Specific reforms could include the following:

- *Hydropower*: Encourage FERC to revisit the current licensing and relicensing process and minimize regulatory burden, particularly for small projects and pumped storage.
- *Nuclear Power*: Encourage the NRC to ensure the safety of existing and new nuclear facilities without unnecessarily adding to the operating costs and economic uncertainty of nuclear energy. Revisit nuclear safety rules under a risk-based approach.
- *Coal Generation*: Encourage EPA to allow coal-fired power plants to improve efficiency and reliability without triggering new regulatory approvals and associated costs. In a regulatory environment that would allow for improvement of the existing fleet, DOE should pursue a targeted R&D portfolio aiming at increasing efficiency.

Electric-gas coordination: Utilities, states, FERC, and DOE should support increased coordination between the electric and natural gas industries to address potential reliability and resilience concerns associated with organizational and infrastructure differences. DOE and FERC should support well-functioning commodity markets for natural gas by expeditiously processing liquefied natural gas export and cross-border natural gas pipeline applications.


NATIONAL COUNCIL
LEVELING THE PLAYING FIELD
Policy Parity for Carbon Capture and Storage Technologies
November 2015

LEVELING THE PLAYING FIELD
Policy Parity for Carbon Capture and Storage Technologies

NCC CHAIR
Jeff Wallace, Southern Company Services (retired)

COAL POLICY COMMITTEE CHAIR
Fredrick D. Palmer, Peabody Energy (retired)

STUDY CHAIR
Glenn Kellow, Peabody Energy

TECHNICAL CHAIR & LEAD AUTHOR
Fred Eames, Hunton & Williams

CONTRIBUTING AUTHORS
Janet Gellici, National Coal Council
Mark Menezes, Hunton & Williams
Eric Hutchins, Hunton & Williams

LEAD EDITOR
Richard Guerard, Hunton & Williams

NCC EXECUTIVE VICE PRESIDENT & CHIEF OPERATING OFFICER
Janet Gellici

The National Coal Council is a Federal Advisory Committee to the U.S. Secretary of Energy. The NCC advises, informs and makes recommendations to the Secretary on matters requested by the Secretary relating to coal or the coal industry.

Library of Congress Catalog # 201596068

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 30-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. During its 30-year history, 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.

National Coal Council
1101 Pennsylvania Ave. NW, Ste. 600 - Washington, DC 20004
(202) 756-4524 – info@NCC1.org

NATIONAL COAL COUNCIL

November 12, 2015

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 September 18, 2015, the white paper "Leveling the Playing Field: Policy Parity for Carbon Capture and Storage Technologies." The white paper's primary focus is to recommend incentives and policies that can be employed to level the playing field for deploying CCS technologies. We are pleased to have completed this work through the NCC's newly formed rapid-response initiative, ensuring that your request for guidance could be provided in advance of the COP21 meeting in late November.

The principal theme of the NCC's Leveling the Playing Field white paper is that federal policy has severely tilted the energy playing field. Existing incentives for CCS are simply too small to bridge the gap between the cost and risk of promising, but immature, CCS technologies vis-à-vis other low-carbon technology options. While the U.S. Department of Energy has stewarded a successful research and development program to spur early development of CCS technologies, insufficient overall support has hindered commercial deployment.

Other low carbon technologies have benefitted from substantial government support. The success of policy and financial incentives afforded to the renewable energy industry provides ample evidence that government support can be the critical enabler for bringing scale and speed to clean energy technology deployment.

The National Coal Council is pleased to offer a menu of options that can be employed to level the playing for CCS. These include financial incentives, regulatory improvements, and research, development and demonstration catalysts. No single incentive by itself will provide the parity needed to effectively deploy CCS technologies. The optimal mix of incentives will need to be evaluated and provided on a project-by-project basis.

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 CCS technologies. Such commitment begins with the establishment of policies and incentives to level the playing field for CCS.

Thank you for the opportunity to prepare this white paper. The Council stands ready to address any questions you may have regarding its recommendations and other contents.

Sincerely,

Jeff Wallace
NCC Chair

Glenn Kellow
NCC Study Chair

The Secretary of Energy
Washington, DC 20585

September 18, 2015

Mr. Jeffrey Wallace
Chairman, The National Coal Council, Inc.
1101 Pennsylvania Avenue, NW, 6th Floor
Washington, DC 20004

Dear Chairman Wallace:

I am writing today to request the National Coal Council (NCC) develop a white paper that focuses on incentives and policies that can be employed to level the playing field for deploying Carbon Capture and Storage (CCS) technologies.

The white paper should focus on policy parity measures that advance CCS technologies. The questions to be addressed are:

(1) What incentives and policies can be employed to level the playing field for the deployment of CCS technologies? This white paper would provide an assessment of the incentives and policies used to advance all the low-carbon technologies.

(2) What are the opportunities to remove regulatory obstacles, address market failures, adjust tax policies and utilize time-limited subsidies for clean energy technologies that could be employed to expedite and advance the deployment of CCS?

The white paper would be undertaken by the NCC's newly-formed Executive Advisory Board of the NCC. I ask that the white paper be completed before the COP21 meeting in Paris in late November.

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

LEVELING THE PLAYING FIELD
Policy Parity for Carbon Capture and Storage Technologies

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Mark Schoenfield, Jupiter Oxygen
Janet Gellici, National Coal Council

STUDY CHAIR

Glenn Kellow, Peabody Energy

TECHNICAL CHAIR & LEAD AUTHOR

Fred Eames, Hunton & Williams

CONTRIBUTING AUTHORS

Janet Gellici, National Coal Council
Mark Menezes, Hunton & Williams
Eric Hutchins, Hunton & Williams

CONTRIBUTING ADVISORS

Shannon Angielski, CURC
Shannon Banaga, Tampa Electric
Carl Bozzuto, ALSTOM Inc.
Dr. Frank Burke, Consultant
Joe Divoky, Babcock & Wilcox
Bill Elliott, Bechtel
Dave Frederick, FirstEnergy
Nina French, Clean Coal Solutions
John Kennedy, Dynegy
Jason Makansi, Pearl Street Inc.
Larry Monroe, Southern Company
Karen Obenshain, EEI
Deck Slone, Arch Coal
Pamela Tomski, Global CCS Institute
Matt Usher, American Electric Power
Steve Winberg, Battelle

LEAD EDITOR

Richard Guerard, Hunton & Williams

SCOPING TEAM MEMBERS

Not noted elsewhere for their contributions

Brad Crabtree, Great Plains Institute
David Flannery, Steptoe Johnson
Raj Gaikwad, Sargent & Lundy
Revis James, EPRI
Holly Krutka, Shenhua Group
Nancy Mohn, ALSTOM
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COAL POLICY COMMITTEE

Robert O. Agbede, Chester Engineers
Sy Ali, Clean Energy Consulting
Shannon Angielski, CURC
Richard Bajura, West Virginia University
Shannon Banaga, Tampa Electric
Janos M. Beer, Massachusetts Institute of Technology
Jacqueline F. Bird, JFBird Enterprises
Lisa Bradley, Haley & Aldrich
F. William Brownell, Esq., Hunton & Williams
Wanda Burget, Norwest Corporation
Dr. Frank Burke, Consultant
Brad Crabtree, Great Plains Institute
Christopher Curfman, Caterpillar Global Mining Division
Jack Daly, Sargent & Lundy
Joe Divoky, Babcock & Wilcox
Ted Doheny, Joy Global, Inc.
Michael D. Durham, Soap Creek Energy
John W. Eaves, Arch Coal, Inc.
George Ellis, Pennsylvania Coal Association
Alex G. Fassbender, Ecovia Corporation
Paul J. Feldman, Midwest ISO
John S. Fischer, Breakthrough Energy, LLC
David Flannery, Steptoe & Johnson PLLC
Mark Fraley, FirstEnergy Solutions Corp
Clark D. Harrison, CH2M
William Hoback, Southern Illinois Univ.
Clarence Joseph Hopf, Talen Energy
Marty Irwin, PQR Energy
Revis James, EPRI
Michael Karmis, Virginia Tech
Michael Kennedy, KY State Dept. Energy Dev.
Norman Kettenbauer, GenPower Services
John T. Long, Connemara Ltd.
Richard P. Lopriore, PSEG Fossil LLC
Jason Makansi, Pearl Street, Inc.
George McClellan, Clean Coal Solutions
Nancy Mohn, ALSTOM
Betsy Monseu, American Coal Council
Ram G. Narula
Kenneth J. Nemeth, Southern States Energy Board
Jerry J. Oliver, Global Tech Management Services
Fredrick D. Palmer, Peabody Energy (retired)
Robert M. Purgert, Energy Industries of Ohio
Dawn Santoianni, Tau Technical Communications
Mark Schoenfield, Jupiter Oxygen Corporation
Deck Slone, Arch Coal
Matt Usher, American Electric Power
Jeff Wallace, Southern Company (retired)
Gregory A. Workman, Dominion Resources

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LEVELING THE PLAYING FIELD
Policy Parity for Carbon Capture and Storage Technologies

A. Executive Summary

Federal energy and environmental policy has severely tilted the energy playing field. Secretary Moniz has requested the National Coal Council (NCC) make recommendations to level the playing field for carbon capture and storage (CCS) and provide "policy parity."

Existing incentives for CCS are simply too small to "bridge the chasm" – as the NCC put it earlier this year – between the cost and risk of promising but immature CCS technologies and other technology alternatives. While CCS is commercially deployed in some industrial sectors and technically demonstrated at electric power plants, power generation with CCS remains expensive today compared to other technologies such as natural gas combined cycle (NGCC) or heavily subsidized renewables. The U.S. Department of Energy (DOE) has stewarded a successful research and development program to spur early development of CCS technologies, but without sufficient government support and incentives, commercial CCS deployment has lagged.

Absent commercial-scale deployment, developers have no history to understand technical risks, frequency and duration of down time, and other critical factors that become known only with operation. Today, the world's first and only operating commercial-scale power plant with CCS has successfully achieved a capture rate of 80% of the plant's carbon dioxide (CO_2), but has been unable to maintain that level of performance and has been operational just 40% of the time because of technical complications.[1] With broad deployment, technological experience and confidence will rise, and costs will decline. Policy parity is essential to this progress.

Coal and other fossil fuel use will keep rising globally as the world adds, per the United Nations, three billion more people to cities in the next 40 – 50 years.[2] To achieve climate goals and address fossil emissions, the world *must* have CCS.[3] Commercializing CCS requires a level playing field.

Cross-functional experts within the NCC's working groups have rigorously assessed the incentives and policies needed to level the playing field. There is consensus among them that the recommendations in this report will bring needed advances to development and deployment of CCS technologies.

Other clean technologies have benefitted from substantial government support. In 1992 when Congress enacted the Section 45 renewable energy tax credit, the United States had less than 2,000 megawatts (MW) of installed wind generating capacity.[4] Today there are 69,471 MW of installed wind capacity.[5] Wind energy prices have dropped from more than $50 per-megawatt-hour (/MWh) in the late 1990s to less than half that cost in 2014.[6] The industry credits government policy for its success: "With a two-thirds reduction in the cost of wind energy over the last six years, the renewable production tax credit (PTC) is on track to achieving its goal of a vibrant, self-sustaining wind industry."[7]

In 2000, the U.S. had less than 4 MW of installed photovoltaic solar capacity, at an installed cost of nearly $10 per watt (/W).[8] In 2013, the U.S. had 6,000 MW of installed photovoltaic solar capacity at an average installed cost of roughly $2.75/W.[9] Today there is more than 22,700 MW of solar generating capacity overall.[10] The industry touts 2015 as a "record-breaking" year in which more than 40% of all new capacity additions are solar.[11] As with wind energy, the industry credits government policy for its success: "Since the implementation of the investment tax credit (ITC) in 2006, the cost to install solar has dropped by more than 73%."[12]

The policies that have driven these rapid deployment growth and cost reduction are a combination of Federal incentives and State renewable energy standards that mandate growing use of renewable energy. To satisfy the increasing State renewable energy generation requirements, an additional 94,000 MW of renewable energy will need to be built by 2035.

Figure A.1. Incentives for Renewable Electricity Generation Compared with Electricity Generation with CCS

Incentive	Renewables	CCS
DOE Budget (2012-2016)[13]		
FY 2016 (Requested)	$645 Million	$224 Million
FY 2015	$456 Million	$188 Million
FY 2014	$450 Million	$200 Million
FY 2013	$480 Million	$186 Million
FY 2012	$480 Million	$182 Million
Total DOE Budgets:	*$2.5 Billion*	*$980 Million (CCS Demonstration: $0)*
Tax Credits (2010-2014)[14]		
Investment Tax Credit	$2.1 Billion	$1 Billion
Production Tax Credit	$7.6 Billion	$0[15]
ARRA §1603 Grants in Lieu of Credit	$24 Billion	$0
Investment in Advanced Energy Property	$2.1 Billion	$0
Accelerated Depreciation for Energy Property	$1.5 Billion	$0
Total Revenue Cost:	*$37.3 Billion*	*$1 Billion*
Other Federal Programs		
Loan Guarantees (EPAct '05 §1703)	Yes ($13.9 billion)	Yes ($0)
Mandatory Purchase Requirement (PURPA § 210)	Yes	No
Siting and Interconnection Preferences (*e.g.*, FERC Order 792)	Yes	No
Clean Energy Credits (EPA, 111(d) Existing Power Plant Rule)	Yes	No
State Programs		
Net Metering	44 States	0 States
Renewable Energy Standards	29 States	5 States (CCS applied to standard: 0)

NOTE: DOE issued a solicitation for up to $8 billion in loan guarantees for advanced fossil energy projects on December 12, 2013. To date, no loan guarantees have been made for an advanced fossil energy project. It is unclear whether any applications have been submitted.

As Table A.1. shows, government support to launch CCS is not remotely comparable to renewables.

A decade from today, it will be agreed that the incentives which proved effective in leveling the playing field for CCS technology deployment were those which enabled project financing to occur. These fall into two categories: those which provide up-front financial support for projects, and those which assure guaranteed revenue over the life of projects.

In its January 2015 report, *Fossil Forward: Revitalizing CCS – Bringing Scale and Speed to CCS Deployment*,[16] the NCC recommended policy parity for CCS. In September, Secretary of Energy Moniz requested the NCC report on policy parity measures that would level the playing field for CCS. Among other specific recommendations, this report calls for the following:

- **Financial Incentives** – Financial incentives for CCS must be substantially increased and broadened to include incentives available to other clean energy sources. Up-front incentives that reduce risk to capital should be emphasized, and designed with a recognition – as with wind and solar in the 1990s – that CCS is an immature technology with up-front risks and high initial capital costs. Operating incentives are important to assure a steady long-term revenue stream and lessen direct costs to consumers. Both types of incentives are needed and are central to "policy parity." Among the specific recommendations are the following:

    - Establish a "contracts for differences" (CFD) structure, one permitted under Federal law, to offer developers a menu of incentives to be provided by the government for competitively selected projects. The CFD structure may be the single most important mechanism to spur CCS development and deployment, but only if the incentives underlying it are sufficient.

    - Enhance DOE grants to increase the portion of the cost assumed by DOE to address the elevated capital costs of CCS projects.

    - Provide an electricity production tax credit consistent with that for renewables.

    - Provide for investment tax credits.

    - Guarantee purchase of electricity output with CCS to assure future revenue.

    - Establish a market set-aside for CCS, similar to State renewable energy requirements, implemented Federally through the existing structure of State programs.

- **Regulatory Improvements** – A first-of-its-kind regulatory (FOAK) blueprint is needed to remove barriers to the construction and development of projects with CCS. This blueprint would be applicable to facilities for carbon capture (*e.g.*, industrial facilities such as power stations), transportation, and injection. Given its charter and expertise, DOE is central to the development of this blueprint with sister agencies, which would include such elements as:

    - Streamlining siting and other permitting requirements for facilities necessary to a CCS project, including capture facilities, pipelines, and storage facilities.

    - Addressing uncertainty created by regulations, such as New Source Review (NSR) under the Clean Air Act, that might be triggered should retrofits or other expensive changes to existing power plants be made when installing carbon capture equipment.

    - Easing the new burden faced by enhanced oil recovery (EOR) operators under the 111(d) existing power plant and 111(b) new power plant rules to facilitate the use of "regulated" CO_2.

- **Research Development & Demonstration** – DOE must be a catalyst for additional commercial-scale demonstration projects, and such projects must commence immediately. The NCC remains firm in its belief that our national objective should be 5-10 gigawatts (GW) of commercial-scale projects in operation by 2025. Projects must be in development stage promptly in order to achieve this goal. To be such a catalyst, DOE must identify for Congress a menu of incentives needed to mobilize project developers with funding mechanisms for commercial-scale CCS projects. Existing incentives have not been sufficient.

- **Communication and Collaboration** – DOE needs to assure that U.S. and global policy makers and others firmly understand both that fossil fuels will be used in coming decades to a greater extent than today, and that there is a resulting need for CCS. DOE also should initiate international collaboration to support the prompt deployment of 5-10 GW of commercial scale demonstrations in addition to U.S. deployment.

B. The Need for Carbon Capture and Storage Technologies

Meeting global CO_2 emission reduction goals requires our expeditious deployment of CO_2 technologies for fossil. That deployment will be advanced by incentives and policies to level the playing field for CCS.

The commercial deployment of a suite of carbon reduction technologies is essential to worldwide efforts to reduce CO_2. These technologies:

- Provide the most impactful opportunity to capture, use, and store a significant volume of CO_2 from fossil fuels. The technologies can be used to reduce CO_2 emissions from electric generation as well as from key industrial sectors, including cement production, iron and steel making, oil refining, and chemicals manufacturing.

- Maintain electric reliability by providing baseload generation. Baseload power is the "always on" power that enables the grid to maintain voltage, frequency, and other attributes essential to reliable power supply.

- Significantly reduce the costs of decarbonization.[17] Not including CCS as a key mitigation technology is projected to increase the overall costs of meeting CO_2 emissions goals by 70% to 138%. [18]

- Preserve the economic value of fossil fuel reserves and associated infrastructure while undertaking strong actions necessary to mitigate climate change.[19]

In January 2015, the NCC noted in its study *Fossil Forward - Revitalizing CCS* that in order to achieve CCS deployment at commercial scale, policy parity for CCS with other low carbon technologies and options is required. The NCC recommended to Secretary of Energy Moniz that DOE take a stronger position on the need for policy parity with respect to funding allocations. This white paper is presented in response to Secretary Moniz's follow-on request for recommendations on measures that can be undertaken by DOE to level the playing field for CCS and other low carbon coal technologies, providing market, operational, financial, and regulatory parity with other clean energy resources.

Reducing carbon emissions from fossil fuels can have far more impact on atmospheric CO_2 concentrations than building renewables because of the scale of emissions involved from fossil units and the direct CO_2 emissions reductions that result. By contrast, CO_2 emissions avoided through new renewable generation capacity are constrained by renewables' smaller scale, the intermittency of wind and solar generation leading to lower capacity factors, the need for fossil load-following generation, and the fact that renewables displace existing grid power even in places where the generation mix is already less carbon intensive. Policy parity is critical to achieving carbon reduction objectives by moving more quickly toward the goal of deploying affordable, low carbon technologies. Advancing CCS and carbon management technologies should be viewed not as a subsidy for coal, but as a low carbon solution.

Policy initiatives must provide positive economic signals for CCS technology deployment. Policies that disadvantage fossil fuels have had a suppressing effect on deploying CCS technologies in a world that continues and will continue to rely on fossil energy resources for many years to come.

1. Fossil Fuels Dominate in a Growing World, Today and Tomorrow

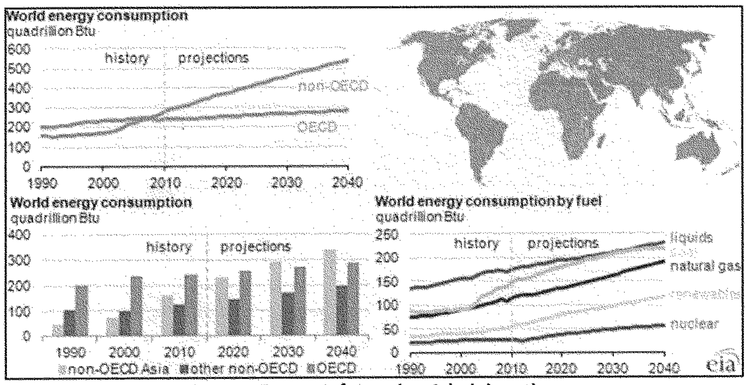
Globally, the vast majority of energy is supplied by fossil fuels. In 2014, 87% of global primary energy consumption was supplied by fossil fuels – primarily oil, followed by coal and natural gas.[20] According to the BP Statistical Review, "coal remains – by far – the most abundant fossil fuel by reserve/production ratio."[21]

The BP *Energy Outlook 2035* notes that population growth and increases in income-per-person are the key drivers behind growing demand for energy.[22] By 2035, the world's population is projected to reach 8.7 billion, which means an additional 1.6 billion people – five times the population of the United States – will need energy. Globally, gross domestic product (GDP)-per-person in 2035 is expected to be 75% higher than today, with China and India driving growth among non-OECD nations. By 2035, China and India will be the world's largest and third largest economies respectively, jointly accounting for about one-third of global population and GDP.

Primary energy consumption is projected to increase by 37% between 2013 and 2035, with virtually all of the projected growth (96%) in the non-Organisation for Economic Co-operation and Development (OECD) nations. Power generation is expected to account for an ever-increasing share of that primary energy consumption, reflecting the global trend toward increased electrification.

Globally, 44% of electricity is provided by coal. BP projects that coal will remain the dominant fuel for power generation worldwide in 2035, accounting for more than one-third of electricity production.[23] In the ASEAN region alone, according to the International Energy Agency's (IEA) recent special report on Southeast Asia, coal demand will triple between 2011 and 2035, with coal's share of power generation increasing to almost 50%.[24]

Figure B.1. World Energy Consumption: OECD vs. non-OECD



Source: Energy Information Administration

Another fossil fuel, natural gas, will also experience growth during this period. Global natural gas demand is expected to grow by 1.9% per year (2013-2035), driven by non-OECD demand of 2.5% per year. Increased usage by the power and industrial sectors will account for over 80% of total natural gas demand growth.

The foregoing emphasizes that U.S. and international policy must be built on an appreciation that coal and other fossil fuels are an indispensable – not optional – component of world energy supply for the foreseeable future.

Since fossil fuels will remain the world's dominant source of primary energy for decades to come, if we are serious about addressing CO_2 emissions from fossil fuels we must support technological solutions. As Howard J. Herzog, Senior Research Engineer at the Massachusetts Institute of Technology so emphatically states it: "There are many uncertainties with respect to global climate change, but there is one thing about which I have no doubts: we will not solve climate change by running out of fossil fuels."[25]

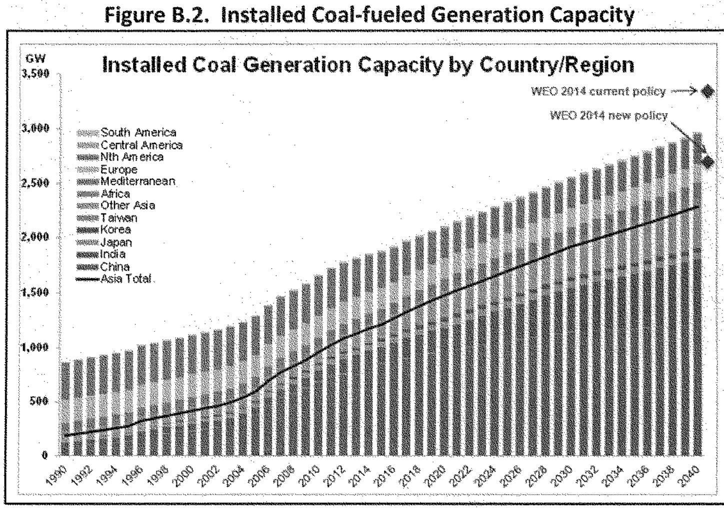
2. The Need for CO_2 Emissions Reduction Technologies

In light of the recent growth of fossil-fueled power plants in international markets, especially in non-OECD nations, achieving the goal of reducing CO_2 emissions will clearly require the deployment of CO_2 reduction technologies worldwide. Globally there are 510 coal power plant units under construction, with a further 1,874 planned; a total of 2,384 units.

China alone is bringing online an average of 500 MW of new coal capacity per week through 2030, an average of a new coal-fired plant every 7 to 10 days. The equivalent of the entire U.S. coal fleet was built between 2005-09 – more than 500 coal plants of 600 MW. From 2010 to 2013, China added the equivalent of half the U.S. coal fleet, plus another 39 GW in 2014. China is predicted to add another U.S.-worth of coal capacity over the next decade, or the equivalent of one 600 MW plant every 10 days. By 2040, its coal-fired power fleet is expected to be 50% larger than it is today and these plants typically operate for 40 years or more. Today China consumes more than 4 billion tons of coal annually, compared to less than 1 billion tons in the U.S. and 600 million tons in the European Union (EU).

China is not alone. BP's *Energy Outlook 2035* predicts that CO_2 emissions from coal use will increase in India by 360 million tons by 2035. ASEAN countries also are expected to increase coal use significantly, far outstripping projected modest coal use reductions in the U.S. and Europe.

Figure B.2. Installed Coal-fueled Generation Capacity

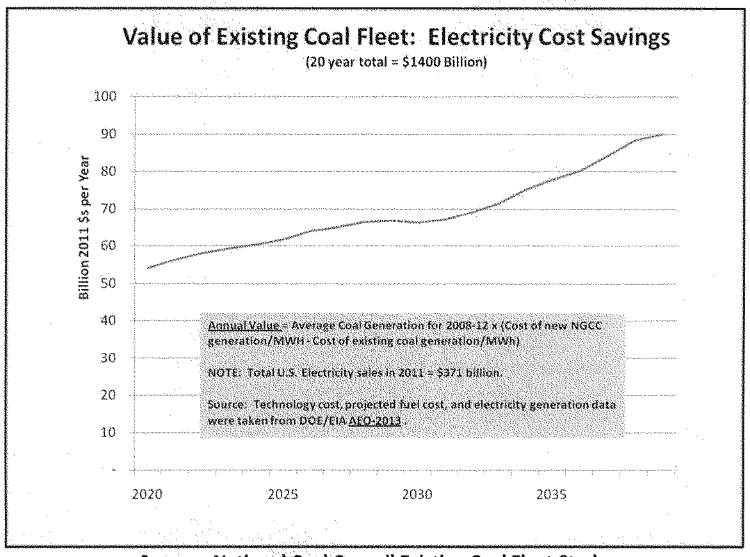


Source: World Coal Association

These recently-built fossil fuel plants, which will continue to operate over a projected lifetime of 40-60 years, as well as more mature plants still years away from retirement, constitute overwhelming evidence that CCS must be part of the path to reducing atmospheric CO_2 emissions.

Here in the United States, CO_2 reduction technology deployment will similarly be necessary to achieve CO_2 emissions reduction policy goals. Coal provided fuel for 18.5% of total U.S. energy consumption and 43% of U.S. electric power generation in 2013. In 2014, the U.S. coal fleet totaled 300 GW of capacity (28% of U.S. total generating capacity) and 1,586 million megawatt hours (MWh) of generation (39% of U.S. total).[26]

Figure B.3. Value of Existing Coal Fleet: Electricity Cost Savings



Source: National Coal Council Existing Coal Fleet Study

In analyzing the value of the existing coal fleet, the NCC calculated the cost of replacing it with another form of generation. The NCC postulated that if all coal units were replaced by natural gas power plants, it would increase the cost of electricity by over $50 billion in 2020, rising to $90 billion per year in 2040. The $50 billion increase represents a nominal 15% increase in the price of electricity which would reduce U.S. GDP and employment by about 1.5%. That 1.5% change could result in a $240 billion decline in GDP and a loss of 2 million jobs.[27]

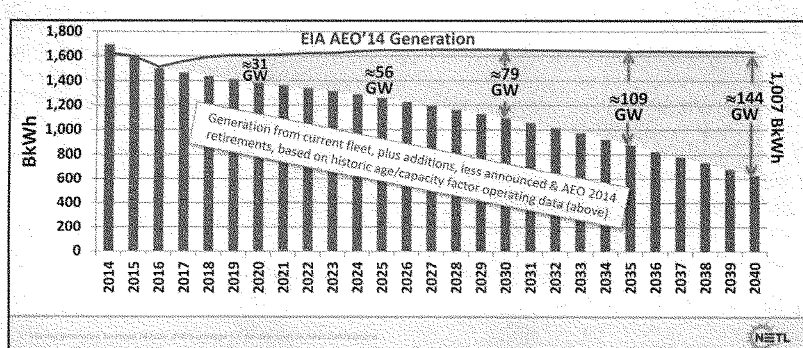
Improving the efficiency of existing power plants plays an important role in meeting environmental objectives. Improving thermal efficiency can provide two important benefits: the reduction of fuel consumption, which lowers operating costs; and the reduction of emissions, including CO_2 emissions. For example, CO_2 emissions requirements in the 111(d) existing power plant rule are based on substantial assumed improvements in power plant efficiency. However, the uncertainties created by NSR rules, their enforcement by the U.S. Environmental Protection Agency (EPA), and the prohibitive cost of administering NSR compliance have created strong disincentives to the widespread deployment of efficiency improvements.

In conjunction with increasing the efficiency of the existing fleet, there is a growing need to add new baseload generation. Power generators are increasingly retiring coal plants in an effort to achieve compliance with environmental regulations. Much of the retiring coal capacity provides baseload generation, "always on" energy critical to maintaining electric reliability. Between 1998 and 2014, baseload generation represented 72% of total U.S. electric generation; coal generation accounted for 59% of that baseload generation.[28] Baseload facilities that can generate electricity on demand 65%-90% of the time, are needed to backup intermittent renewable sources that produce electricity only about 30% of the time.

The U.S. Energy Information Administration (EIA) has projected a need for increased reliance on existing baseload coal units, rising to an average of around 74% capacity utilization in 2025 and 78% in 2040, versus a current average rate of around 60%.[29] As plants age, their capacity factors decrease. EIA's forecasts rely on coal infrastructure performing well at an unprecedented average age. Overestimation of coal unit capacity factors can result in reliability issues and underestimation of the need for replacement baseload capacity. In its analysis on this issue, DOE's National Energy Technology Laboratory (NETL) noted that this overestimation could be as large as 1,000 billion kilowatts hours (well over 100 GW capacity).[30] NETL stated that, "as the fleet deteriorates, new baseload capacity will be needed to maintain this level of generation."[31]

Figure B.4. Aging of Coal Baseload Assets

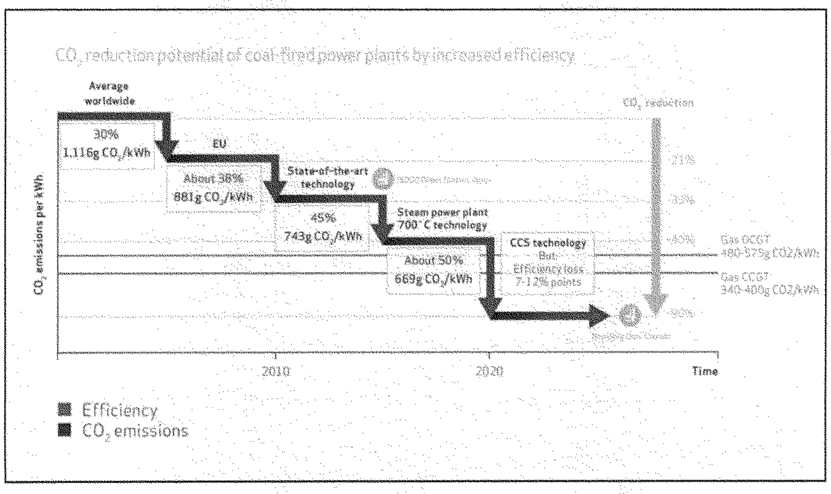
Baseload coal power generation as projected by the EIA (line) and when accounting for coal-plant capacity factors declining with age (bars). Equivalent of 144 GW of new baseload capacity projected to be needed by 2040*



Source: K. Kern, "Coal Baseload Asset Aging: Evaluating Impacts on Capacity Factors," Washington D.C., 16 June 2015

A first step in advancing CCS is to provide financial incentives for investment in state-of-the-art high efficiency, low emission (HELE) coal power plants.

Figure B.5. Potential Efficiency Improvements at Coal-Fired Power Plants

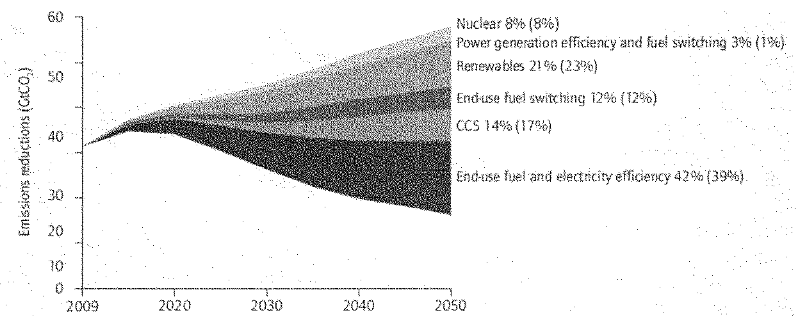


Source: VGB PowerTech 2013, World Coal Association

HELE technologies, including supercritical and ultra-supercritical/integrated gasification combined cycle plants, have significant potential to reduce CO_2 emissions through the deployment of more efficient coal power generation.[32] Moving the current average global efficiency rate of coal-fueled power to supercritical levels could deliver the equivalent environmental benefit of reducing India's CO_2 emissions to zero. The average efficiency of coal plants worldwide is 33%; state-of-the-art facilities have efficiency rates of 40%. Increasing the efficiency of coal power plants by 1% reduces CO_2 emissions by 2-3%. Many of these technologies are commercially available today and could cut 2 gigatonnes of CO_2 emissions, equivalent to India's annual CO_2 emissions.[33] In the future, these units also could be potential candidates for CCS retrofits.

A diverse set of technologies will be required to meet international GHG emissions goals. In its technology roadmap assessment, the IEA estimated that CCS would provide about 14% of the cumulative needed emissions reductions by 2050.[34] It is also important to recognize that IEA's goal assumes very significant efficiency improvements and renewables growth. If either of these does not occur at the rates projected, it is most certain that fossil fuels will fill the remaining gap, furthering increasing the need for widespread global deployment of carbon reduction technologies.

Figure B.6. Potential Emissions Reductions: Generation and Efficiency Options



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 6DS.

Source: IEA Technology Road Map

The rapid, widespread deployment of carbon reduction technologies will pay significant dividends toward achieving global greenhouse gas (GHG) objectives. We get to rapid, widespread deployment by leveling the playing field for low carbon coal technologies.

GHG objectives are a matter of government policy. If the international community wants fossil-fueled facilities operating in the coming decades to reduce CO_2 emissions, adequate government funding support is required to develop the technologies.

C. The Importance of Policy Parity For Carbon Capture and Storage Technologies

1. Defining Parity

CCS needs policies recognizing it as a still immature, not commercially available carbon reduction technology. These policies need to account both for cost factors and still uncertain technical performance risk.

In reviewing government programs below, we emphasize that two incentive programs might cost government the same amount, yet bear no comparison for "parity" sake. A $1 billion government incentive that buys market share for a mature technology said to be as cheap as competing sources[35] is not the same as a $1 billion incentive needed to deploy and test expensive, FOAK emerging technology at commercial scale. Intensified assistance is needed to develop immature CCS technologies into successful proven ones, much as policy makers provided for renewables in the 1990s. CCS will need continued assistance for years thereafter, because of the need for parity, if fossil with CCS is required to compete with mature subsidized technologies.[36]

2. The Importance of Parity

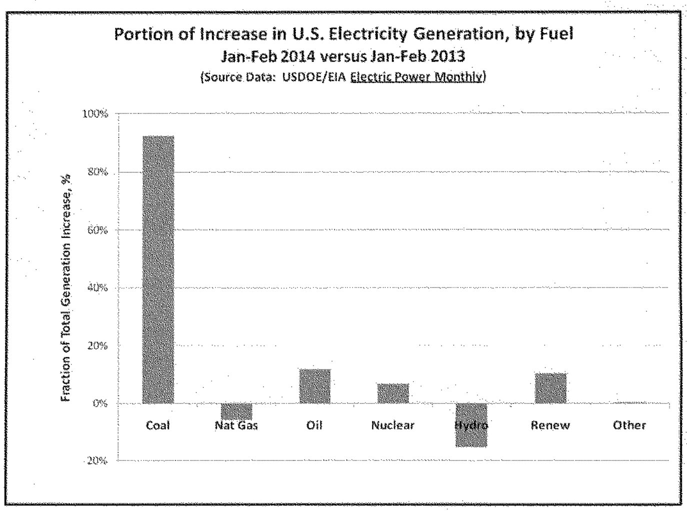
Policy parity is important to meeting the diverse set of U.S. energy policy objectives. Those objectives have consistently focused on providing a reliable, secure, and low-cost supply of energy, and in recent years have increasingly directed energy production and consumption toward environmental objectives.

CCS is essential to meeting those environmental objectives. Policy parity for CCS will have the added benefit of ensuring that we preserve other critical features of our energy system – such as fuel diversity and reliability – while we fulfill our nation's environmental obligations.

- Reliability is priority one. Reliable power is not just a matter of convenience. Electric service must be reliable to ensure the health and safety of our nation's citizens. Diversity enhances reliability.
- A diverse source of electricity provides an insurance policy against operational malfunctions and security breaches.
- Diversity also provides a hedge against monopolistic or volatile pricing of any one source of power, which is why utilities, regulators and customers advocate for diversity.
- Baseload sources are especially critical to maintaining a diverse generation portfolio that can meet environmental performance goals. The value and operating ability of intermittent renewables is greatly diminished without the backstop support of reliable "always on" generation.

Coal additionally provides enhanced energy security and reliability by virtue of its on-site storage capability, ability to be transported by various means (rail, barge and truck), and its widespread availability throughout the U.S. The value of diversity was notably highlighted during January-February 2014 when the U.S. was swept with a series of cold weather events that tested the integrity of electricity supply.[37] Wind produced only 4.7% of the nation's power during this time, while solar produced less than 0.2%. Nuclear provided only 5% of incremental year-over-year generation and hydroelectric output declined 13%. Natural gas supplies faltered and prices soared. In New England electric utilities paid more than $17.00 per million Btu for gas, while the average for the U.S. was $7.44 per million Btu, compared with normal seasonal prices of $4.41. Coal averaged $2.32 per million Btu. During the winter of 2014, coal provided 92% of the incremental increase in demand versus 2013.

Figure C.1. Coal's Cornerstone Role in Times of Challenge



Source: National Coal Council, Existing Coal Fleet Study, May 2014

Leveling the playing field in an era of increasing concern about global climate change starts with the policy imperative of recognizing that coal will continue to be a major source of electricity in the U.S. and worldwide for decades to come. Parity for low-carbon coal technologies is needed to:

- Facilitate diversity of the U.S. generation portfolio.
- Advance the use of CO_2 for EOR, providing a fully commercial, safe, and permanent path for CO_2 storage, as well as a secure and less-carbon intensive domestic source of petroleum.

- Incent the deployment of CCS technologies for use by all fossil fuels in power generation and industrial applications.

- Encourage the deployment of polygeneration and coal conversion facilities that domestically produce transportation fuels, chemicals, fertilizers, and other commodities.

- Advance environmental performance of CCS while reducing the cost of electricity by 40% compared with new coal power plants built with today's CCS technology.[38]

- Ensure that advanced baseload coal plants with CCS are available once existing baseload units are retired.

- Support compliance with environmental objectives for CO_2 reductions from existing and new power plants.

3. Parity and a Level Playing Field

CCS is the only technology that can substantially reduce CO_2emissions from "always on" baseload power generation from secure fossil resources, domestically and internationally. It is also the only technology with applicability to the existing electric generating fleet as well as industrial sources, addressing both international emission goals and the imperative of electric reliability. There can be no true parity with a one-of-a-kind technology.

The policy need at issue is to catalyze the rapid deployment of CCS to facilitate low-carbon fossil-fueled generation. For the purposes of discussion, we will discuss parity for CCS in comparison with other low-carbon energy resources – renewables – whose successful and rapidly increasing deployment in recent years is attributable to policy intervention.

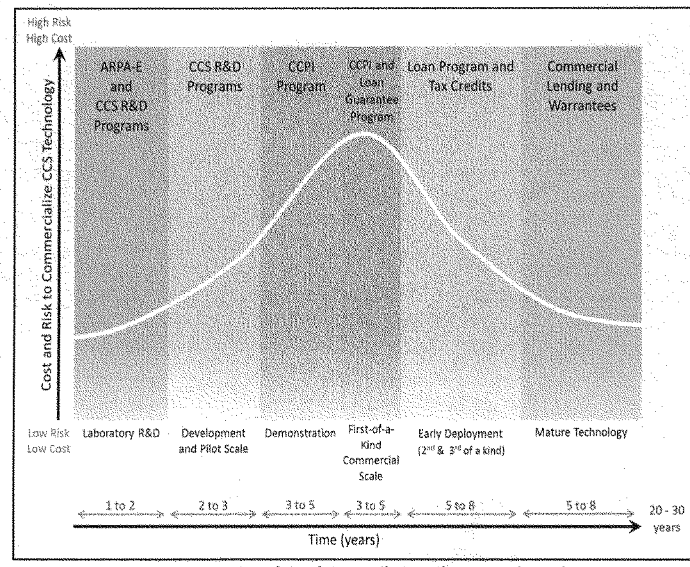
A metaphorical playing field is said to be level if no external interferences affect the ability of the players to compete fairly. Policies that disproportionately advantage one resource and erect hurdles for others impede our nation's economic and environmental objectives while imposing undue hardship on our citizens. Incentives for renewables will persist. CCS, which has greater carbon reduction significance but is not yet commercially available in the power sector, requires additional policy support in order to level the playing field.

4. Immaturity of CCS

Policymakers justify incentives on the basis that a favored technology has not yet reached maturity. Many incentives for renewables are quite recent, being employed well after those technologies achieved maturity and became commercially available. Tax credits extended to the wind and solar industries in the U.S. were intended to promote the installation of these technologies by buying down the cost of market penetration. Yet, State and Federal policies already mandate markets for wind and solar, and tax incentives subsidized compliance with those mandates.

By comparison, many carbon reduction technologies, including CCS, are in their early stages of development and are highly complex in nature, entailing significant technical and financial risk for developers and investors. The risk profiles of building a 10 MW photovoltaic facility versus a 500 MW supercritical coal power plant with CCS are significantly different. CCS systems entail much higher cost, have not been demonstrated on commercial scale in the power sector, and bind power production with back-end (*i.e.,* transportation and storage) processes that likely will be beyond the generator's fence line and control. These and other challenges unique to CCS support the need for policy incentives, which if properly designed will result in CO_2 emission reductions, even as the use of fossil fuels increases.

Figure C.2. Energy Technology Development Spectrum to Commercialize Technology



Source: National Coal Council, Fossil Forward Study

Cart-before-horse policies that appear to be mandating CCS technologies (*i.e.,* EPA's 111(d) existing power plant and 111(b) new power plant rules) will not incent CCS development or deployment. People will turn instead to mature alternatives. CCS needs policies recognizing it as a still immature, not commercially available carbon reduction technology. These policies need to account both for cost factors and still uncertain technical performance risk.

5. Unique Challenges with Carbon Capture and Storage Technology Deployment

Development and deployment of CCS technologies present numerous unique challenges as detailed in the NCC's January 2015 report for Secretary Moniz, *Fossil Forward – Revitalizing CCS.*

- Capital and operating costs for projects with CCS are more expensive than conventional technologies and carry great technological and commercial risk. Project risks include financing, permitting, public acceptance, cost overruns, schedule delays, performance, environmental compliance, operational flexibility, storage, and long-term liability.

- Pioneering FOAK projects typically include a more rigorous investment due diligence process that is conducted during the front end engineering and design study and final investment decision stages, which can significantly add time and complexity to project schedules.

- The main challenges for power generation with CCS include high cost (*e.g.*, capital and operating costs, which influence project financing), large scale integration, access to suitable storage sites and high energy requirements (called the "energy penalty") to run the capture unit, including CO_2 compression.

- Power plants or polygeneration facilities operating in deregulated electricity markets must account for additional time and complexity of negotiating power purchase agreements (PPA) and other offtake contracts (*e.g.*, CO_2, urea).

- Unlike earlier DOE-funded clean coal projects that demonstrated technologies such as SO_x or mercury control, the central technologies being demonstrated for CCS are not ancillary to power plant operation and must be fully integrated to achieve reasonable cost and performance.

- The technical risk of earlier DOE-funding demonstrations of environmental control technologies was not as great. With integrated CCS demonstrations, the central technologies must operate in order for the plant to function and to generate revenue for commercial operation. Thus, the developer has both a technological risk and a financial risk.

Acknowledging the unique attributes of the various energy resources and their associated unique challenges can help guide the crafting of policies and incentives that maximize beneficial use of our nation's fossil, nuclear, and renewable resources. An appreciation of the policy dis-parities among energy resources is also instructive.

D. The Power of Incentives and Policies

1. Policy Dis-parity Between CCS and Other Low-Carbon Energy Resources

Policy parity for CCS must be measured against other low-carbon energy resources. Earlier this year, EIA produced a report valuing subsidies and incentives provided to various forms of energy.[39] That report evaluated those subsidies targeted at energy, provided by the Federal government, and with an identifiable Federal budget impact were included. The report did not evaluate the impact of all subsidies. For example, the value of State renewable electricity mandates, which mandate that a percentage of electricity sold be produced from renewable sources, were not part of the study.

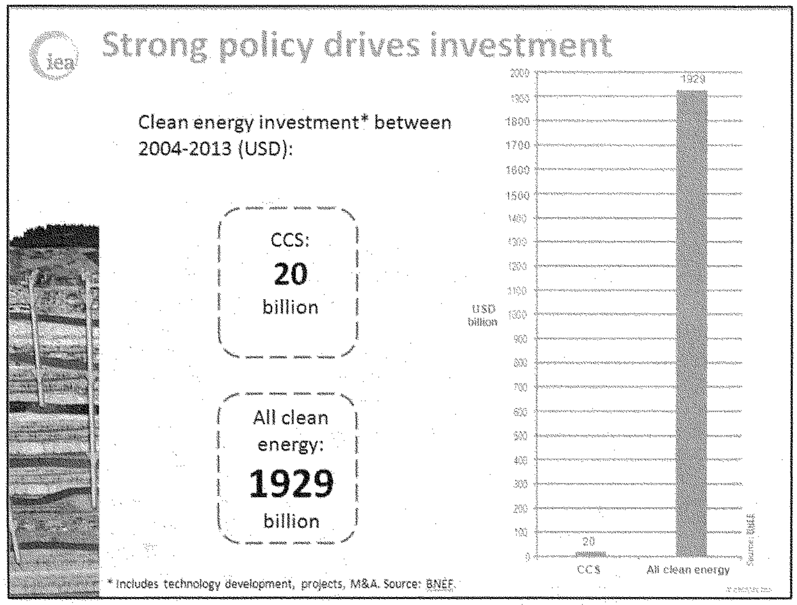
The EIA report shows the single largest recipient category of Federal energy subsidies is, by far, renewables. Confining the discussion to electricity subsidies, where renewables and coal compete (*i.e.,* screening out subsidies for vehicle fuels), in 2013 renewables received more than **12 times** the subsidies as received for coal – $13.227 billion for renewables, and just $1.085 billion for coal. EIA reported that renewables received 72% of total subsidies while coal received just 6%. Conversely, support for renewables (*i.e.*, solar, wind, biomass, geothermal, and hydro) has increased from 14.9% in 2007 vs. 72% in 2013. Support for wind alone increased from 10.7% (2007) to 37% (2013); support for solar alone increased from 0.2% (2007) to 27% (2013). Coal's share of support has declined significantly from 12.7% in 2007 to 6% in 2013.

Even these numbers do not accurately capture the extent of the dis-parity between Federal support for renewables and coal. Only $40 million of the total for coal went to a direct credit for production of electricity, and then only for coal produced from refined coal or Indian coal facilities. At the same time, renewable electricity received a direct production tax credit of $1.63 billion, more than 40 times the support provided to coal.

Moreover, the subsidy for electricity from renewables is so large that it has enabled renewable energy producers to sell into energy markets at a negative price, which in deregulated markets can have the effect of reducing market prices for non-subsidized fuels – *i.e.,* fossil and nuclear.

In March 2015, the Congressional Research Service (CRS) released a report assessing the value of energy tax credits for various fuel resources.[40] CRS notes that in 2013, the value of Federal tax-related support for the energy sector was estimated to be $23.3 billion, of which $13.4 billion (57.4%) supports renewable energy and $4.8 billion (20.4%) supports fossil fuels. In 2014, tax incentives for renewables constituted an estimated 53% of the estimated total revenue loss associated with energy tax provisions; revenue losses associated with fossil fuels-related tax incentives were 27%. The CRS report shows that in both years the investment tax credit for clean coal facilities did not exceed $200 million.

Figure D.1. Public Policy Drives Investment

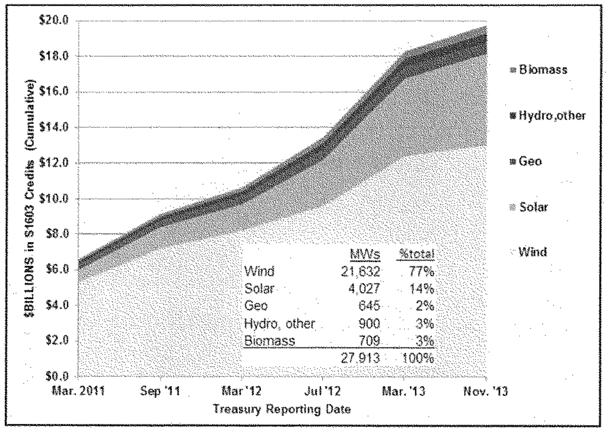


Source: Carbon Capture and Storage: Perspective from the IEA
Ellina Levina, Sydney Australia, September 2, 2014

The CRS report also notes, "While the cost of tax incentives for renewables has exceeded the cost of incentives for fossil fuels in recent years, the majority of energy produced in the United States continues to be derived from fossil fuels." In 2013, fossil fuels produced 78.5% of U.S. primary energy while renewables produced 11.4% and nuclear 10.1%.

Financial support outside typical funding mechanisms for energy has also favored renewables over other fuel sources. Funds for renewable projects under the American Recovery and Reinvestment Act (ARRA) were $20 billion versus $3.4 billion for coal.

Figure D.2. Subsidies for Renewable Project Deployment in ARRA 2009

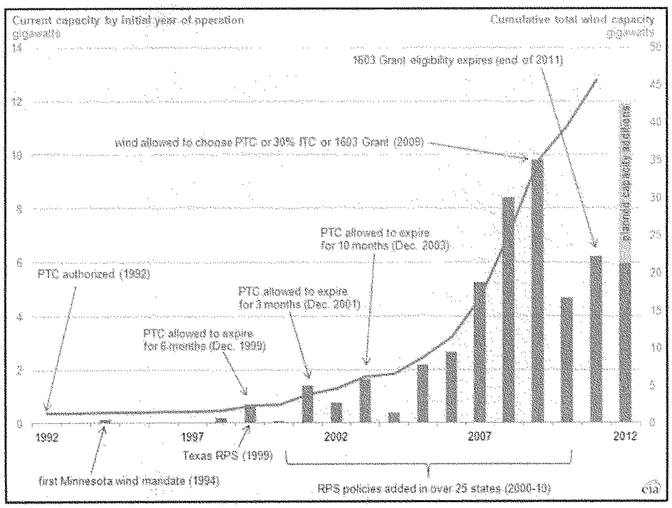


Treasury Grants (ARRA Section 1603), 2009-2013
Source: National Coal Council Fossil Forward Study

In addition to financial support, renewables have benefited significantly from regulatory mandates creating a guaranteed market for wind, solar, biomass and other alternatives to fossil and nuclear power. A Renewable Electricity Standard (RES) obligates utilities to produce a specified percentage of their electricity from renewable energy sources. The Public Utility Regulatory Policies Act (PURPA) mandates the purchase of renewable energy from qualifying facilities (QFs) of 20 MW or less. Taken together, Federal production tax credits and State RESs have successfully and quickly spurred the growth of renewable energy in the U.S. It is clear from the graphic that the combination of policy and financial incentives are effective tools that can drive scale and speed in energy technology deployment. Applying similar types of initiatives to the deployment of carbon reduction technologies for fossil fuels can be expected to yield equally impressive production results with even greater CO_2 emissions reduction benefits. Policy drove scale and speed for wind; to meet policy objectives, policy needs to do the same for CCS.

The interaction of renewables subsidies, particularly the Section 45 PTC, and market structures not only have provided revenue to renewables, but have reduced revenue to fossil and other generators, many of whom have left the market in recent years.[41] "[Midwest Independent System Operator's] [independent market monitor (IMM)] reports that in 2011 wind power generation set the wholesale price of electricity during certain times and in certain locations, at an average price of negative $20 per MWh. The IMM attributes this negatively set wind price to the availability of Federal production tax credit incentives. However, negative price offers may also be incented by the opportunity of wind power projects to sell renewable energy credits (RECs) to entities in order to comply with State RES policies."[42] In PJM, "[t]he IMM reports that an average of 935.5 MW, out of approximately 5,300 MW, of wind resources were offered at a negative price to PJM's real-time market in 2011."[43]

Figure D.3. U.S. Wind Industry: Incentives & Growth



Source: ALSTOM

Additional points of disparity between coal and renewables are evident in program funding within DOE. DOE's CCS R&D Program was launched in 1997 with $1 million in funding. Today, DOE's CCS R&D program has grown to a $200+ million annual program with a portfolio of nearly 200 projects across the CCS chain in varying stages of development. As a point of contrast, the DOE Office of Energy Efficiency and Renewable Energy has a 2014 budget of $1.9 billion, of which $775 million is in direct support of renewable energy projects.

To date, DOE's Loan Guarantee Program has issued more than $34 billion in "conditional commitments" in the form of either direct loans or loan guarantees, including $8.3 billion for a nuclear plant, $8.5 billion for automotive manufacturing and the remainder mostly to wind and solar projects. No advanced fossil projects currently have a loan guarantee. For the wind and solar loans, the mandated "subsidy cost" – the expected long-term liability cost to the Federal government that must be paid by the borrower or via congressional appropriation – was covered by the Federal government under the Loan Guarantee Program. This "coverage" is not available for CCS projects.

A commitment to leveling the playing field from these and other such dis-parities will significantly advance the quick and cost-effective deployment of low carbon coal technologies.

2. Existing Incentives for Renewables

Below is a list of the primary incentives that have encouraged growth of renewable energy production. The scope of this report is not to include every policy – Federal, State and local – to promote renewables, but only those most relevant to recommendations for policy parity.

- **Production Tax Credit (PTC)** – Section 45 of the Internal Revenue Code provides a tax credit of 1.5¢/kWh for energy produced from qualified energy resources. The credit is indexed to inflation and currently stands at 2.3¢ per-kilowatt-hour (/kWh), or $23/MWh. The credit is received for energy produced from a qualified facility for a period of 10 years after it is placed in service. First enacted as Section 1212 of the Energy Policy Act of 1992, this credit was set to expire on July 1, 1999. However, Congress has extended the credit nine times since its original enactment. Congress is again debating extension of the credit, which expired at the end of 2014, and some have called to make the credit permanent. Eligible energy resources include, among others, wind, solar, geothermal, biomass, incremental hydropower, and wave and tidal energy.[44] Wind, closed-loop biomass, geothermal, and certain other facilities receive the full 2.3¢/kWh credit. Others, including open-loop biomass, landfill gas, hydropower, and wave and tidal energy receive one-half of the full credit, rounded up to the nearest tenth-of-cent to 1.2¢/kWh. The American Wind Energy Association testified in 2013 that "without the PTC," installation of wind generation and related economic benefits and investment "would not have occurred." [45]

- **Investment Tax Credit (ITC)** – Section 48 of the Internal Revenue Code provides up to a 30% tax credit for qualified energy property. It is considered the "solar tax credit" because solar is one of the few types of energy property to which the full credit applies. The rapid expansion of solar installations that has occurred since enactment of the ITC, has been attributed to the credit.[46] Other qualified energy property receives a 10% credit.

- **Cash Payment** – ARRA Section 1603 allowed taxpayers to obtain a cash payment instead of receiving either the PTC or ITC. The facilities had to be placed in service in 2009, 2010 or 2011, unless they commenced construction during that time and placed the facility in service later (date dependent upon type of facility).

- **Loan Guarantees** – Title XVII of the Energy Policy Act of 2005 (EPAct '05) established the Section 1703 loan guarantee program for various types of energy projects that "avoid, reduce, or sequester air pollutants or anthropogenic emissions of greenhouse gases," including renewables, "advanced fossil energy technology," and "carbon capture and sequestration practices and technologies" among others. No loan guarantees have been made to fossil projects under the Section 1703 program. By contrast, loan guarantees under Section 1703 and 1705 (described below) have been issued for 18 renewable electricity production facilities totaling more than $12.8 billion, and for renewable electricity manufacturing facilities totaling nearly $1.1 billion.[47] As part of the ARRA in 2009, Congress created the Section 1705 loan guarantee program for certain renewables, under which recipients would not be required to pay the credit subsidy cost of the guarantee, further lessening their cost.

- **Mandatory Purchase Requirement –** Under PURPA enacted by Congress to address the energy shortage in the '70s, utilities are required to purchase power from "qualified facilities" (QFs). QFs can be cogeneration units, where power is used for an industrial purpose, or small power production facilities which are renewable projects of 80 MW or less. To address the overbuild of "PURPA machines" which forced utilities to buy unneeded power from QFs at "avoided costs" typically at above market rates, Congress repealed the application of the mandatory purchase obligation if the U.S. Federal Energy Regulatory Commission (FERC) found that the QFs had access to competitive electricity markets. FERC has exempted most large QFs in the organized markets but continues to grant QF status to all renewable QFs of 20 MW or less, regardless of access to markets. Furthermore, FERC allows large renewable QF projects, such as wind and solar, to be split up into 20 MW projects to be granted QF status requiring utilities to purchase the power produced whether needed or not at "avoided costs" typically higher than market rates.

- **Research and Development Funding –** DOE budgets in recent years have provided substantially more money for renewables research and development than for clean fossil, particularly coal. The FY 2016 DOE budget request of $2.7 billion for the Office of Energy Efficiency and Renewable Energy is more than all of the other applied science budgets combined. The budget request for the entire Federal government detailed approximately $7.4 billion for clean energy programs, including more than $710 million to increase the use and reduce the costs of power from solar, wind, water and geothermal energy. By contrast, the FY 2016 budget request included $560 million for fossil energy R&D, with just $224 million dedicated to CCS research.

- **Siting and Interconnection Preferences –** Renewables also have benefited from special procedures for siting, interconnection, and other approvals necessary for a project to deliver energy to the market. FERC Order No. 792, for example, provides for fast track interconnection approvals for inverter-based generators (such as solar panels) of up to 5 MW, if their capacity is no greater than the minimum load on the line to which they are connecting.

- **Clean Energy Credits –** The Clean Energy Incentive Program in EPA's final 111(d) existing power plant rule provides extra emission reduction credits for wind and solar projects that begin generation by 2021. EPA will grant one additional credit per MWh of generation from eligible wind and solar projects. Other zero or low-emission projects are not eligible for this special credit, which is limited to a total of 300 million tons. At the current carbon credit prices in California and Regional Greenhouse Gas Initiative (RGGI), the value is $3.505 billion or $1.806 billion, respectively.[48] Note that this benefit is being provided notwithstanding that renewables are already flourishing.

- **State Renewable Energy Standards –** Twenty-nine States plus the District of Columbia have binding portfolio standards mandating that a certain percentage of energy sold come from certain sources, virtually always renewable generation. They range from a 100% renewable energy mandate by 2045 recently enacted in Hawaii and a recently enacted 50% renewable energy mandates in California by 2030, to 10% mandates to be reached in 2015 in Texas, Michigan and Wisconsin. According to a 2013 study by Lawrence Berkeley National Laboratory (LBNL) (which would not reflect recent increases like those in Hawaii and California), 94 GW of new renewable energy is required by 2035 to meet State renewable energy requirements – 3-5 GW per year of additions through 2020 and 2-3 GW per year through 2035.[49] The LBNL study found these policies drove the addition of 6-13 GW of renewable energy per year in every year but one since 2008. Of this amount, 88% of the capacity additions from 1998-2012 were wind energy.[50] The study also found that 67% of non-hydro renewable capacity additions between 1998-2012 were in States with renewable energy requirements.[51] The true percentage of renewables constructed to satisfy portfolio standards may be substantially higher, as most States do not require the energy to be sourced in-State.

- **Net Metering –** A number of States provide for "net metering" under which a utility customer can receive credit on their bill for energy they produce and sell to the grid. However, the credit can amount to more than the value of the energy. Some States provide, for example, that net metering customers be paid the delivered electricity price for each kWh they sell to the grid – *i.e.,* if the delivered price is $0.10/kWh, the customer is paid that amount even though that price includes generation, transmission and distribution. A 2013 California Public Utilities Commission report found the State's net metering program would cost the State $1.1 billion per year by 2020.[52]

- **Battery Storage Incentives –** Because the sun, wind, and other non-hydro renewable resources do not provide a constant source of energy, renewable-based generation is inherently intermittent. Subsidies are now even being provided for large-scale batteries to store the subsidized electricity generated from renewable resources. These "subsidized-subsidies" come in the form of subsidies to build the batteries and even State funding to build the factories to make the batteries.[53]

House and Senate legislation introduced in 2015 has proposed additional Federal assistance for renewables.[54]

3. The Difference Between Renewables and CCS-Equipped Facilities

In addition to the tax incentives provided to renewables, the current policy landscape discourages the construction of CCS-equipped projects by failing to address the investment costs required of deploying the technology at power and industrial facilities. These costs, coupled with the increased levelized cost of electricity (LCOE) for new-build power plants with CCS, reveal how an even wider dis-parity exists than might otherwise be assumed. Although LCOE is one means of measuring the overall competitiveness of different generating technologies, its use in this comparison does not take into account all aspects of projected utilization rates and capacity values, two elements that further favor the construction of coal and other baseload resources.

According to information disseminated in conjunction with the EIA's *Annual Energy Outlook*, the LCOE values for incremental wind capacity coming online in 2020 ranges from $65.6/MWh to $81.6/MWh, depending on the quality of the resource.[55] Although these LCOE values compare favorably to NGCC facilities, the former is a non-dispatchable technology, one with just a 36% capacity factor. This means almost three times more capacity is needed when building wind as opposed to either conventional coal, advanced coal equipped with CCS, NGCC or NGCC equipped with CCS. However, equipping a conventional coal or NGCC plant with CCS technology carries significant costs.

Recognizing that LCOE values for coal-fueled power plants equipped with CCS change depending on the type of power plant (*i.e.*, subcritical or supercritical), coal rank, and the type of technology deployed, the current cost of adding carbon capture virtually prohibits widespread adoption at new and existing facilities. The Global CCS Institute recently estimated LCOE values of coal with CCS at $115-160/MWh, some 35-85% higher than a coal plant without CCS.[56] Data prepared by EIA estimates an LCOE value of $144/MWh for "advanced coal" equipped with CCS. Conventional and advanced combustion natural gas turbines also experience significant price increases once CCS is added, $141.5/MWh and $113.5/MWh, respectively.[57]

E. The Playing Field for Carbon Capture and Storage Technologies

1. Building Success

The NCC and others have performed gap analyses to define the difference between the current trajectory of CCS and what is needed to propel its progress. *Fossil Forward* reported that substantial additional financial support is needed. It described desired endpoints for each link in the CCUS chain – capture, transportation, and storage/utilization – then provided recommendations to meet those endpoints.

Fossil Forward described the desired endpoint for CO_2 capture as facilitating widespread deployment of CCS in the 2030s. In order for this to occur, CO_2 capture must be ready for commercial deployment in the decade before. The benchmark for being commercially available used in the NCC report is for a technology to have operated reliably at full commercial scale for at least one year with reasonable cost and performance so it can be commercially insurable and financeable. Today the world has only one power plant with CCS operating at commercial scale. After one year of operation, it does not exhibit the reliable performance hoped. SaskPower's Boundary Dam Unit 3, retrofitted with carbon capture through the help of government incentives, is designed to achieve a capture rate of 99% of the plant's CO_2. The plant achieved a peak-performance capture rate of approximately 80% in June 2014, but since mid-January 2015 has achieved a best capture rate of 65%. Furthermore, the plant has operated only 40% of the time in its first year because of technical complications.[58]

Reaching the desired benchmark should be the intended outcome of DOE's CCS program. Among others, the report made the following recommendations:[59]

- Have 5-10 GW of CCS demonstration projects operating in the U.S. by 2025.

- Provide budget and have a plan to fund 25-50 MW of demonstrations of second generation CO_2 capture technologies in the U.S. by 2020.

- Continue to "feed the pipeline" by sponsoring early stage R&D on transformational technologies.

- DOE's program needs to address the risk that a CCS project developer may not timely find economic CO_2 storage.

- There is a need for financing mechanisms beyond those currently available.

2. The Cost Challenge Facing CCS Projects

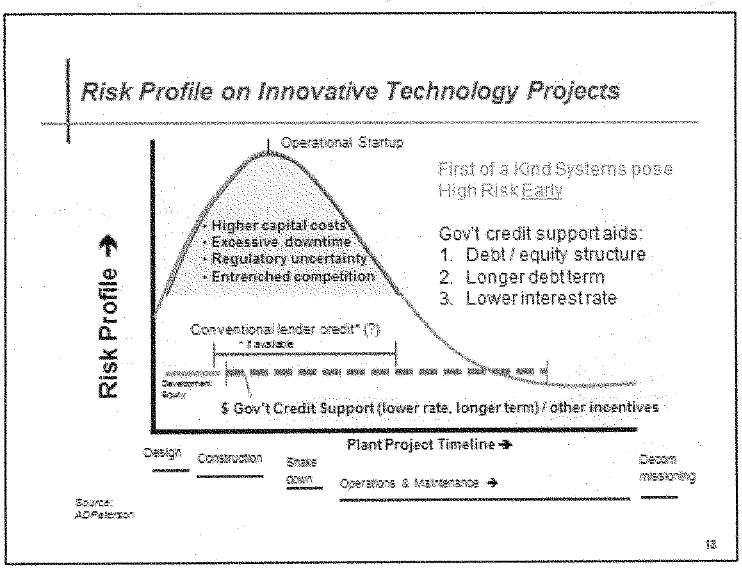
The NCC reported that a next-of-a-kind (NOAK) plant using monoethanolamine scrubbing could expect to have increased capital cost of 67% over a conventional plant without CCS. The increased cost of electricity is estimated to be 63%. The estimated cost of capturing CO_2 is \$58/ton, while the estimated cost of CO_2 avoided is \$78/ton.

NETL's Office of Program Planning and Analysis issues costing methodologies it uses to estimate the costs of developing FOAK technologies into mature, commercially viable power plants (*i.e.*, NOAK). NETL assesses the "learning curve" of various technologies necessary for power plants using CCS in determining the expected actual costs per unit output per facility.

These costs are considerably higher when compared to the average cost of output of fossil power plants including costs of operations, maintenance, and fuel. In 2013, NETL, using 2007 dollars, estimated that the cost of learning to develop and install commercially operational super-critical pulverized coal plant with CCS would be \$2,045.00/kW. By 2020, DOE predicts that Advanced Coal plants with CCS capable of dispatch to provide reliable, baseload generation will cost \$144.4/MWh.

Clearly, these recommendations and findings suggest a need for substantial financial support.

Figure E.1. Innovative Technology Risk and Cost



Source: Andrew Paterson, CCS Alliance

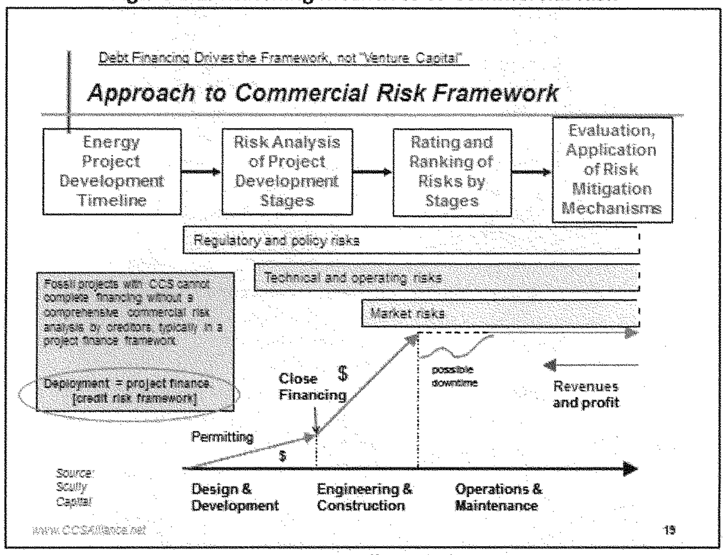
Costs of CCS can be offset by the sale of co-products. Southern Company's Kemper County facility, for example, will make and sell fertilizer from chemical streams resulting from the gasification process. It also has agreements to sell the CO_2 to oil producers for enhanced oil recovery (EOR). These revenues are significant, but not nearly sufficient to cover the capital and operating costs associated with carbon capture. Market prices for CO_2 for EOR in some areas have been above \$25/ton.[60] However, lower market prices for oil affect what oil producers can and will pay for industrial-sourced CO_2. A steady revenue stream is needed for financing industrial facilities with carbon capture. The Coal Utilization Research Council (CURC) has proposed a variable price support mechanism for the price of CO_2 pegged to the oil price, which would provide industrial CO_2 producers with a steady CO_2 income stream to make their capture projects financeable.

An often-cited issue with CO_2-EOR is that the opportunities for its deployment are not currently geographically widespread enough to present a nearby opportunity for a coal fleet scattered widely across the country. However, the estimate of the CO_2-EOR opportunity has grown substantially as detailed in research that has emerged over the past three years.[61]

CURC and the Electric Power Research Institute (EPRI) publish a periodically updated *Roadmap for Advanced Coal Technology*, including CCS.[62] The purpose of the Roadmap is to provide recommendations that will substantially drive down the cost and increase efficiencies of advanced coal technology, including CCS.

The 2015 update re-examined technology development needs in light of new factors, such as persistent low natural gas prices, GHG regulations, and increasing renewable generation. The CURC-EPRI Roadmap looked at what is needed to support development of transformational technologies that will deliver cost, efficiency, and environmental performance improvements, as well as the need for a large-scale pilot program to test technologies under real operating conditions before commercial-scale demonstration. The Roadmap identifies a need for increased Federal funding. In particular, it calls for 100% Federal financing for large pilot-scale testing of these new technologies. It also calls for the Federal government to fully fund a 50% cost share for commercial scale demonstration, a share which has not been met for any of the CCPI projects (the W.R. Parish project receiving the highest percentage at 16.7%).[63]

Figure E.2. Matching Incentives to Commercial Risk



Source: Scully Capital

DOE support and incentives to bridge the gap must be flexible to account for local differences in market structure, as well as local, technical, and financing vagaries. States are divided between those with traditional cost-of-service utility regulation, and those with deregulated markets. In areas with cost-of-service regulation, a utility proposing construction of a new power plant would be required to undergo hearings before State utility regulators to determine whether the construction of a new facility is justified in light of the alternatives, and will be cost-effective. State regulators may take into account special benefits of a facility, such as its use of in-State resources and similar factors that may benefit the State and consumers. Regardless, rates charged to consumers to pay for the facility must be "just and reasonable."

In deregulated market areas, no approval to build generation is required from rate regulators. Markets determine whether a new facility is cost-justified. Absent subsidies and mandates, such as those that apply for renewables, facilities that cannot recover their cost through rates earned in the market do not get built. In both regulated and deregulated market areas, CCS is in essence competing with new-build natural gas without CCS, a low cost option. CCS must be able to be cost competitive in both markets.

Access to a variety of financing options, taking into account both regulated and deregulated market areas and other considerations, is a recommendation that has consistently emerged over the years from meetings on CCS financing, such as those hosted by the Carbon Sequestration Leadership Forum. The rationale is quite simple. Incentives need to fit local circumstances.

3. Existing CCS and Clean Coal Incentives and Proposed Incentives

CCS and clean coal technologies currently benefit from several Federal programs and some State programs to encourage development, demonstration, and deployment. While these programs could spur CCS development if revised, enhanced, and complemented with other incentives, they are not sufficient as is (which is evident from the lack of projects resulting from them, and in some cases even lack of bids to use the incentives). These programs provide far less support than policies supporting renewables. Below is a description of the main existing incentives for CCS technologies.

- **Research and Development** – DOE's budget includes line items for both carbon capture and storage. This funding supports pilot-scale carbon capture projects as well as projects focused on storage infrastructure. However, funding for renewable research and development is regularly more than twice that spent on CCS.

- **Demonstration** – EPAct '05 authorized the Clean Coal Power Initiative (CCPI) to "advance efficiency, performance, and cost competitiveness well beyond" commercial technologies.[64] In 2009 and 2010, DOE announced a Round Three of CCPI funding for 3 CCS power plant projects: Texas Clean Energy Project (TCEP), Hydrogen Energy California Project (HECA), and W.A. Parish Post-Combustion CCS Project.[65] However, neither TCEP nor HECA have begun construction, and their DOE funding has been removed or reduced. Indeed, as of 2013, only $228 million of the $1.04 billion obligated to CCPI Round Three had been spent.[66] Notably, CCS demonstration projects have not received an appropriation since 2009.

- **FutureGen 2.0** – Utilizing $1 billion in funding made available from ARRA and additional funding from annual appropriations, the FutureGen 2.0 effort was announced on August 5, 2010 to repower Unit 4 of the Meredosia Energy Center with oxycombustion technology and to capture and sequester approximately 1 million metric tons of CO_2 per year. FutureGen has suspended operations. A case study of the project is included in Appendix 6.

- **Loan Guarantees** – EPAct '05 established a loan guarantee program for various types of energy projects that "avoid, reduce, or sequester air pollutants or anthropogenic emissions of greenhouse gases," including "advanced fossil energy technology" and "carbon capture and sequestration practices and technologies." In 2009 and again in 2013, DOE issued solicitations for coal-based power generation projects and advanced fossil energy technology with carbon capture. Although several applications were received, no clean coal project, or any fossil project, with our without CCS, has received any loan guarantee since EPAct '05 was enacted.[67]

- **Investment Tax Credits** – EPAct '05 established investment tax credits under new Sections 48A and 48B of the Internal Revenue Code for qualifying advanced coal power projects and industrial gasification facilities. These credits provide a credit of up to 15% or 20% (depending on project type), but are limited in the amount of dollars that can be provided to all projects in total. Credits have been unallocated or forfeited due to inability to meet statutory requirements for the credits.[68]

- **Carbon Sequestration Tax Credit** – Section 45Q of the Internal Revenue Code provides a \$10/ton credit for CO_2 stored through enhanced oil or gas recovery, and a \$20/ton credit for CO_2 stored in other formations. The credit is limited to 75 million tons total of sequestered CO_2 for all recipients. Due to restrictions in the credit (*e.g.,* a requirement that the taxpayer both own the industrial facility from which the CO_2 is captured, and inject the CO_2; lack of transferability of the credit), only slightly more than one-third of the credit (27,114,815 metric tons) has been claimed since its enactment in 2008.[69] Virtually none of these credits went towards CO_2 captured from electric generating facilities.

- **State Portfolio Standards** – Five States – Utah, Michigan, Ohio, West Virginia, and Massachusetts – allow electricity generated using CCS to be included in their electricity portfolio standards.[70] However, electricity generated using CCS has not been applied as part of any of these State's portfolio standards.

Numerous incentives to promote CCS research, development, demonstration and deployment have been proposed in recent years, with the pace accelerating during 2015. Appendix 2 sets forth a list of Federal incentives proposed by the Obama Administration or Congress this year.

F. Recommendations

The NCC recommends a significant ramping up of incentives to "bridge the chasm" for CCS and, per the Secretary's request, to provide policy parity. These recommendations will address the policy mismatch between actual and needed CCS technology funding, and between funding for CCS and other low-carbon energy resources.

The recommendations provide a menu of financial support options that will provide the necessary support for CCS and constitute policy parity. As with incentives for other energy resources, it is not intended that all of these incentives will be available for each project. Several of the proposed incentives should be crafted as alternatives – much as with renewables the production tax credit, investment tax credit, and cash grant programs have operated as alternatives.

No single proposed incentive should be viewed as a self-sufficient independent recommendation. A combination of support mechanisms spurred renewables development, and that is what is needed for CCS. If offering loan guarantees alone was sufficient to spur commercial CCS deployment, we would have more projects in development today.

A key recommendation is to institute a "contracts for differences" or CFD structure, available for a limited number of CCS projects, under which projects would bid for financial support making use of a combination of the proposed incentives. This structure is in use in the United Kingdom, whose program is described in Appendix 5. By way of example, a CFD structure could provide a power plant contract recipient with a CCPI grant to reduce capital cost, provide a loan guarantee to reduce borrowing cost, and make use of tax credits to reduce the cost of electricity over time. Another applicant may prefer to request variable price support for electricity, as offered in the U.K, or variable price support for CO_2 sold from the facility, in place of other incentives. The CFD structure may be the single most important mechanism to spur CCS development and deployment, but only if the incentives underlying it are sufficient.

Former Senate Energy & Natural Resources Committee Chairman Jeff Bingaman (D-NM) proposed legislation several years ago authorizing DOE to enter into up to 10 contracts for technical and financial support for CCS projects. We recommend providing the CFD structure for at least the first 5-10 GW of projects with CCS on a competitive basis. This could include projects already in the CCPI program. While several projects received limited grants and underwent substantial planning, only two are under construction and none are complete.

These options should be deployed in a manner to result in operating projects (particularly commercial demonstrations and large-scale pilots), support a diverse set of technologies in a variety of circumstances and locations, minimize Federal outlays, and minimize distortions of markets that have occurred from implementation of incentives for other low-carbon energy sources.

In its 2014 annual survey of power generators and technology developers, the Global CCS Institute found that the top three enablers for CCS projects were 1) access to direct subsidies, 2) access to viable CO_2 storage, and 3) offtake arrangements offering guaranteed prices.[71] We include proposals for each of these below. As will be apparent, many of these recommendations require congressional enactments. Appendix 2 shows interest in Congress in supporting CCS, including recently among senior congressional leaders.[72]

Financial Incentives

- **Contracts for Differences** – DOE should provide for a CFD structure under which a limited number of projects – at a minimum the first 5-10 GW of output from facilities with CCS – can receive a combination of the incentives described below.

- **Limited Guaranteed Purchase Agreements** – In order to obtain financing, a limited number of pioneering facilities with CCS should receive a guarantee that their output will be purchased. This is key to the development of an immature technology with a yet uncertain risk profile and a potential for significantly lower cost. It also is a key element in parity, as renewables have benefited from PURPA mandatory purchase requirements. This incentive should be limited in scope to cover at least the first 10 GW of output from facilities with CCS, be designed to encourage geographically diverse projects, and minimize impacts on electricity markets.

- **Market Set Aside** – True parity would entail a mandatory market set-aside, akin to State renewable energy requirements. As noted by LBNL, the vast majority of renewables construction has occurred in States with an active or impending RES. One mechanism to provide a market set aside is a "baseload allowance." Fossil technologies that deploy CCS or other immature carbon reducing technologies and meet a define carbon emissions rate while providing baseload power would be eligible for the credit. Given the importance of CCS to meeting climate goals, we recommend a Federal mechanism be explored to authorize a portion of any State-mandated RES to be met through use of qualifying low-carbon fossil baseload, similar to those in Utah, Michigan, Ohio, West Virginia, and Massachusetts.

- **Clean Energy Credits** – Fossil projects with CCS should receive credit under applicable programs for 100% of CO_2 emissions avoided by deployment of CCS. Programs that currently allocate extra clean energy credits for renewables either should make the same credit available to fossil with CCS, or the extra crediting should be removed to assure parity.

- **Tax Credits and Price Interventions** – Guaranteed purchase agreements, and the ability to attract financing that accompanies it, is only part of the equation. Facilities will not be built by entities subject to traditional utility regulation if State utility commissions determine the cost is too high. In areas with EOR opportunity, incentives could involve price support for CO_2 sales. Below are specific proposals:

  - **Production Tax Credit** – Policy makers should provide a tax credit for production of electricity with CCS equivalent to that for renewables in Section 45. Options for structuring the credit could include (a) applying the credit consistent with the lower available inflation-indexed rate in Section 45 (i.e., 1.2¢/kWh) for capture at a new facility that brings the rate of emissions to 1,400 lbs./MWh, increasing proportionately to 2.3¢/kWh as the capture and storage rate increases toward 100%; or (b) applying the full 2.3¢/kWh credit to the number of kWh dispatched, multiplied by the capture percentage.

  - **CO_2 Price Stabilization** – Establish a "variable price support" program for CO_2 sequestration under which applicants would bid to DOE for financial support payments for CO_2, tied to the market price for oil (where EOR opportunities are available). This variable price support would be used under CFD agreements.

  - **Electricity Price Stabilization** – Establish a price support program for electricity under which applicants would bid to DOE for financial support for a limited number of projects. The support would be based on the delta between the amount needed to achieve a commercial rate of return and the amount that can be earned, in the case of regulated markets, at just and reasonable rates, or in the case of deregulated markets, at projected market rates. This variable price support would be used under CFD agreements.

  - **Revise CO_2 Injection Credit** – The Section 45Q tax credit should be revised as follows:
    - Eliminate the requirement that the recipient both capture and inject the CO_2 (which may not be the case, for example, with a power plant selling CO_2 to the oil field)

    - Assure that injection that qualifies under existing verification mechanisms as sequestration is satisfactory to obtain the credit

    - Provide for transferability of the credit between parties in the capture and injection chain of custody; and

    - Increase the credit to $40/ton for beneficial reuse (*e.g.,* EOR storage) and $60/ton for other geologic storage.

- **Tax-Preferred Bonds –** A variety of activities can be funded by tax-preferred and tax-exempt bonds. Renewable projects funded by local governments and electric cooperatives may issue Clean Renewable Energy Bonds under Section 54 of the Internal Revenue Code to finance clean energy projects (those which also are covered by the Section 45 tax credit). Approaches could include extending the Section 54 approach to CCS, or qualifying CCS projects for use of exempt facility bonds issued under Section 142.

- **Master Limited Partnerships (MLPs) –** Section 7704 of the Internal Revenue Code provides that business structures receiving at least 90% of their income from "qualifying income" can be treated as master limited partnerships for tax purposes; therefore, their income will be taxed only at the individual level, rather than both the corporate and individual level. Currently neither renewables nor low-carbon fossil technologies such as CCS qualify for this treatment. If renewables are made eligible for such treatment, parity requires that CCS also qualify.[73]

- **Loan Guarantees –** As indicated above, DOE's loan guarantee program has helped renewables, but not CCS. Congress enacted a special $6 billion program to pay for the credit subsidy cost of renewables, another dis-parity with fossil deploying CCS. The loan guarantee program should be revised to provide opportunity for the same credit subsidy relief for fossil projects as has been provided to renewable projects under the Section 1705 program.

Regulatory Improvements

- **Regulatory Blueprint –** DOE must take the lead in developing a regulatory blueprint which removes barriers to the construction and development of projects with CCS. This blueprint would be applicable to facilities for carbon capture (*e.g.*, industrial facilities such as power stations), transportation, and injection. Given its charter and expertise, DOE is central to the development of this blueprint with sister agencies, which would include such elements as addressing the specific regulatory barriers below.

- **Remove Injection Barriers –** EPA's 111(d) existing power plant and 111(b) new power plant rules both provide that CO_2 from power plants regulated by the rule that is injected at oil and gas wells be reported under more stringent reporting rules than is currently required. Some CO_2 users have said this will discourage rather than encourage their use of CO_2 from these sources in the oilfield, and that associated regulatory obligations may conflict with State natural resource law. Federal policy should encourage and facilitate reuse of CO_2 from CCS operations, not discriminate against it.

- **New Source Review –** Concerns have been raised that retrofits of existing power plants to install carbon capture could trigger NSR requirements of the Clean Air Act. Such retrofits would constitute a "physical change" at the facility, and some may argue this could result in a significant net emissions increase. If we are to reduce CO_2 emissions from existing facilities in the U.S., government policy must eliminate this uncertainty in order to encourage rather than discourage installation of CO_2 emission control equipment.

- **Infrastructure Siting –** Federal policy makers should consider Federal eminent domain authority for the siting and construction of CO_2 pipelines, like the authority provided under the Natural Gas Act for natural gas pipelines could be provided. If a State does not have authority to provide for siting of a pipeline, or fails to act within a reasonable period, FERC should be available as a backstop siting and permitting authority.

- **Storage Siting –** The NCC recommends that DOE identify and certify at least one reservoir which is capable of storing a minimum of 100 million tons of CO_2 at a cost of less than $10/ton in each of the seven regions covered by DOE's Regional Carbon Sequestration Partnership program.

Research, Development and Demonstration

- **Align Research, Development, & Demonstration (RD&D) Funding With Other Fuels –** DOE needs to increase substantially the budget for RD&D funding for CCS. The CURC-EPRI Roadmap is the industry's best-supported estimate of the funding needed for CCS RD&D. Even if fully funded, the CURC-EPRI Roadmap falls short of parity with renewables RD&D. The NCC recommends fully funding CCS RD&D at a minimum as recommended in the Roadmap. That would include funding an 80% Federal cost share for early stage RD&D, 100% Federal cost share for large-scale pilots, and a fully funded 50% cost share for commercial demonstrations.[74]

Communication and Collaboration

- **Vigorously Explain Reality –** First and foremost, DOE must be a tireless advocate in all venues for recognition that fossil fuels will be used in coming decades to a greater extent than today to fuel a more populous, developed, urban world. Those who deny these facts in the name of addressing climate change not only harm fossil fuels and ambitions for improved health and quality of life, but diminish the likelihood of meaningful CO_2 emission reductions.

- **Initiate Projects Immediately –** The NCC recommends that DOE propose an international pool of funds specifically set up for the implementation of CCS demonstration projects at scale. The U.S. should initiate collaboration within the next year on 5-10 GW of international demonstration projects (in addition to the 5-10 GW of U.S.-based projects recommended earlier) advancing DOE's program objectives and promoting foreign policy interests.

G. Appendices

Appendix 1 – Abbreviations

ARRA – American Recovery and Reinvestment Act
CCPI – Clean Coal Power Initiative
CCS – Carbon Capture and Storage
CCPS – Illinois Clean Coal Portfolio Standard
CCUS – Carbon Capture Use and Storage
CFD – Contract for Differences
CO_2 – Carbon Dioxide
CRS – Congressional Research Service
CURC – Coal Utilization Research Council
DOE – U.S. Department of Energy
EIA – U.S. Energy Information Administration
EPA – U.S. Environmental Protection Agency
EOR – Enhanced Oil Recovery
EPAct '05 – Energy Policy Act of 2005 (P.L. 109-58)
EPRI – Electric Power Research Institute
EU – European Union
FERC – U.S. Federal Energy Regulatory Commission
FOAK – First-of-a-Kind (technology)
GDP – Gross Domestic Product
GHG – Greenhouse Gas
GW -- Gigawatt
HELE – High Efficiency, Low Emission
IEA – International Energy Agency
IGCC – Integrated Gasification Combined Cycle
ITC – Investment Tax Credit
kWh – Kilowatt-hour
LBNL – Lawrence Berkeley National Laboratory
LCOE – Levelized Cost of Electricity
MLP – Master Limited Partnership
MW – Megawatt
MWh – Megawatt Hours
NCC – National Coal Council
NGCC – Natural Gas Combined Cycle
NETL – DOE National Energy Technology Laboratory
NOAK – Next-of-a-Kind (technology)
NSR – New Source Review
PPA – Power Purchase Agreement
PTC – Production Tax Credit
PURPA – The Public Utility Regulatory Policies Act (P.L. 95-617)
OECD – Organisation for Economic Co-operation and Development

QF – Qualifying Facility
REC – Renewable Energy Credit
RGGI – Regional Greenhouse Gas Initiative
RES – Renewable Energy Standards
W – Watt

Appendix 2 – Federal CCS/CCUS Incentive Proposals Introduced in 2015

- **FY 2016 Budget Proposal –** The President's FY 2016 budget proposal included two tax incentives to assist CCS/CCUS:
  - A 30% investment tax credit for new and retrofitted power plants with CCS capturing at least 75% of the facility's CO_2 emissions, limited to $2 billion total for all projects. Retrofit projects must be on facilities 250 MW or greater in capacity, and must capture at least 1 million tpy. 70% percent of the credit must go to projects whose fuel source is at least 75% coal. No more than 60% of the credit can be applied to either new plants or retrofits.
  - A CO_2 sequestration tax credit of $50/ton for permanently sequestered CO_2 that is not beneficially used (*e.g.*, EOR), and a $10/ton credit for CO_2 permanently sequestered and beneficially reused. The credit would have a 20-year term. This would be a revision and expansion of the existing Section 45Q credit, which provides a $20/ton credit for non-EOR sequestration, and a $10/ton credit for EOR sequestration. That credit is an annual credit with no duration limit. However, the credit is limited to 75 million tons total for all projects.

- **Federal Legislation –** A number of bills have been introduced in the 114th Congress to provide incentives for CCS. They include the following:

  - **S. 2012 –** On July 30, 2015, the Senate Committee on Energy & Natural Resources favorably reported by a vote of 18-4 the Energy Policy Modernization Act of 2015, subsequently introduced as S. 2012. Section 3402 of the bill, offered as an amendment to the bill by Senator Joe Manchin (D-WV), would repeal the existing coal technologies program and carbon capture research and development program and establish a new coal technology RD&D program to focus DOE's efforts on development of large-scale pilot testing for CCS and other technologies "under real operational conditions and commercial scale." The amendment's funding authorization specifically would designate $285 million per year for commercial-scale demonstration between FY 2017-21. Section 3401 would list carbon capture, utilization, and storage as a specific priority of DOE's Office of Fossil Energy.

  - **S. 2089 –** On September 28, Senate Energy & Natural Resources Committee Ranking Democrat Maria Cantwell (D-WA) introduced the American Energy Innovation Act, with support from Senate Minority Leader Harry Reid (D-NV), Minority Whip Richard Durbin (D-IL), and Democratic Conference Chairman Chuck Schumer (D-NY) among others. The bill includes several provisions to support CCS. Section 2141 lists carbon capture, utilization, and storage as a specific priority of DOE's Office of Fossil Energy. Section 5011 provides a production tax credit of 1.5¢/kWh for clean energy produced, to be reduced proportionately depending on by what percentage the facility's CO_2 emission rate is below 820 lbs./MWh. Section 5012 provides a 30% investment tax credit for CCS equipment, and up to a 30% tax credit for clean technologies, depending on by what percentage their CO_2 emission rate is below 820 lbs./MWh.

- **S. 601** – On February 26, 2015, Senator Heidi Heitkamp (D-ND) introduced S. 601, the Advanced Clean Coal Technology In Our Nation Act of 2015. The Heitkamp bill provides a number of incentives for CCS and CCUS, including among other things the following:
  - Amends the EPAct '05 to broaden the purposes of DOE's existing coal technologies program, and establish a new Transformational Coal Technology research, development and demonstration program to study technologies such as chemical looping, supercritical CO_2 generation cycles, pressurized oxycombustion, and carbon utilization.
  - Establishes a new Section 48E tax credit of 30% for equipment capable of capturing, transporting and storing CO_2.
  - Establishes a Clean Energy Coal Bond program to provide tax credits for bonds issued for clean coal projects to reduce the cost of borrowing.
  - Provides accelerated (seven years) tax depreciation for certain equipment installed at coal facilities to reduce CO_2 emissions.
  - Establishes a "variable price support" program for CO_2 sequestration under which applicants would bid to DOE for financial support payments for CO_2, tied to the market price for oil (the contract price for anthropogenic CO_2 is often dependent upon the price of oil, which is not stable enough to provide sufficient future revenue stream certainty for project financing).
  - Provides $2 billion for loan guarantees specifically for CCS projects under DOE's loan guarantee program. This is 25% of the program's total funding for all energy loan guarantees.
  - Establishes a CCS risk management program under which the Secretary of Energy would competitively select up to 10 projects to receive financial and technical assistance, including indemnification for liability arising from the site.

- **H.R. 1806** – On May 20, 2015, the House of Representatives passed H.R. 1806, reauthorization of the America COMPETES Act. Among other things, this bill would amend the coal and related technologies program authorization in Section 962 of the EPAct '05 by authorizing research into chemical looping, supercritical CO_2 generation cycles, pressurized oxycombustion, and carbon utilization. The COMPETES Act also would require a study on creation of an expanded CO_2 pipeline network.

- **H.R. 2883** – On June 24, 2015, Rep. Ted Poe (R-TX) introduced the "Master Limited Partnerships Parity Act," legislation that would authorize use of the tax-preferred MLP structure for numerous types of clean energy projects, including gasification projects that capture and sequester at least 75% of CO_2 produced, and other CCS projects that capture and sequester at least 30% of CO_2 produced.

- **H.R. 3392 –** On July 29, 2015, Rep. Scott Peters (D-CA) introduced "The Carbon Capture Research and Development Act," that would amend Section 961(a) of the EPAct '05 to require the Secretary of Energy to consider the objective of 'improving the conversion, use and storage of CO_2 produced from fossil fuels' in carrying out R&D programs.

- **S. 1282 –** On May 11, 2015, Sen. Joe Manchin (D-WV) introduced legislation to make "improving the conversion, use, and storage of carbon dioxide produced from fossil fuels" a specific objective of DOE's fossil energy RD&D program.

- **S. 1283 –** On May 11, 2015, Sen. Joe Manchin (D-WV) introduced a bill to repeal the existing coal technologies program and carbon capture research and development program under the EPAct '05 and establish a new coal technology RD&D program to focus DOE's efforts on development of large-scale pilot testing for CCS and other technologies "under real operational conditions and commercial scale." It would allocate $610 million for each of fiscal years 2017 through 2020, plus $560 million for FY 2021, setting aside $285 million per year for demonstration projects. It also would repeal cost sharing for projects funded by the program.

- **S. 1285 –** On May 19, 2015, Sen. Heidi Heitkamp (D-ND) introduced the "Coal with Carbon Capture and Sequestration Act of 2015" that would authorize the Secretary of Energy to enter contracts for up to 25 years to provide 'price stabilization' support for electricity or for CO_2 captured at an electric generating facility to advance the recovery of crude oil or other purposes.

- **S. 1293 –** On Jun 9, 2015, Sen. Heidi Heitkamp (D-ND) offered legislation that would establish the Department of Energy as the lead agency for coordinating permitting at "eligible projects," including CCS and CCUS projects and other clean coal projects. The bill would require that Federal permit decisions and environmental reviews be completed within one year after a complete application is submitted.

- **S. 1656 –** On June 24, 2015, Sen. Chris Coons (D-DE) introduced the "Master Limited Partnerships Parity Act," which would authorize use of the tax-preferred master limited partnership structure for numerous types of clean energy projects, including gasification projects that capture and sequester at least 75% of CO_2 produced, and other CCS projects that capture and sequester at least 30% of CO_2 produced.

Appendix 3 – Case Study: AEP John W. Turk USC Power Plant

Issues in Electricity

Pulverized coal technologies

The issue

Coal has long been one of the lowest-cost fuels to produce electricity in the United States. Not only has coal provided consumers with reliable, affordable power, it has also spurred economic growth in areas where it is plentiful. Most coal-fired plants are located in coal-producing regions and are important sources of jobs and economic stability.

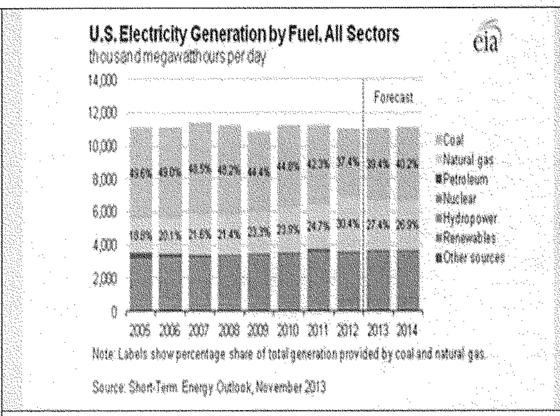
The increasing scope and stringency of environmental regulations continues to pose technical and financial challenges to the electric utility industry. These challenges are driving decisions to upgrade or retire existing coal-fired generating units, and are strongly influencing the planning of new generation projects.

Supercritical technology

In a pulverized coal (PC) plant, the coal is ground into fine particles and blown into a furnace where combustion takes place. The heat from the combustion of coal is used to generate steam to supply a steam turbine that drives a generator to make electricity.

Subcritical steam generation units operate at pressures such that water boils first and then is converted to superheated steam.

Subcritical operating conditions are generally accepted to be



Due to the improved thermodynamics of expanding higher pressure and temperature steam through the turbine, a supercritical steam generating unit is more efficient than a subcritical unit.

Ultra-supercritical technology

Ultra-supercritical (USC) steam generation currently is the most efficient technology for producing electricity fueled by pulverized coal. A USC unit operates at supercritical pressure and at advanced steam temperatures of 1,100ºF (593ºC). These temperatures and pressures enable more efficient operation of the turbine cycle. This increase in efficiency reduces fuel (coal) consumption, and thereby reduces emissions, solid waste, water use and operating costs.

2,400 pounds per square-inch gauge (psig)/1,000ºF superheated steam, with a single reheat to 1,000ºF.

At supercritical pressures, water is heated to produce superheated steam without boiling. Supercritical steam cycles typically operate at 3,600 psig, with 1,000ºF – 1,050ºF main steam and reheat steam conditions. Ultra- supercritical is a term applied to supercritical pressures and temperatures above 1100 ºF.

The 600-MW John W. Turk, Jr., Power Plant in southwestern Arkansas exemplifies our commitment to the responsible use of coal as a fuel source.

USC and AEP

Our decision to build the 600-megawatt (MW) John W. Turk, Jr., Power Plant in southwestern Arkansas exemplifies our continued commitment to the responsible use of coal as a fuel source. The Turk Plant is the first coal-fired plant AEP has built in more than two decades and represents the future of coal-based technology that we continue to advance. The Turk Plant is the only operating U.S. power plant to use ultra-supercritical technology and is among the nation's cleanest, most efficient pulverized coal plants. Turk began commercial operation in December 2012 after a variety of regulatory and legal challenges were resolved and Turk was officially dedicated in April 2013. AEP SWEPCO and the Turk Plant received several project awards in 2013:

- Edison Electric Institute's (EEI) Edison Award, the electric power industry's most prestigious honor, for the completion and commercial operation of the plant
- *Power Engineering* Magazine's "Best Coal-fired Project" for its cleaner, more efficient source of power generation and new technology, and the magazine's "Plant of the Year" award
- *Engineering News Record Texas & Louisiana* Magazine's "Best Project Winner" in the Energy/Industrial category and "Best Safety Award" winner by for its outstanding construction quality and craftsmanship, and the high-priority safety culture of site management

Helpful links

http://fossil.energy.gov

http://www.netl.doe.gov/technologies/coalpower/index.html

http://www.worldcoal.org/coal-the-environment/coal-use-the-environment/improving-efficiencies/

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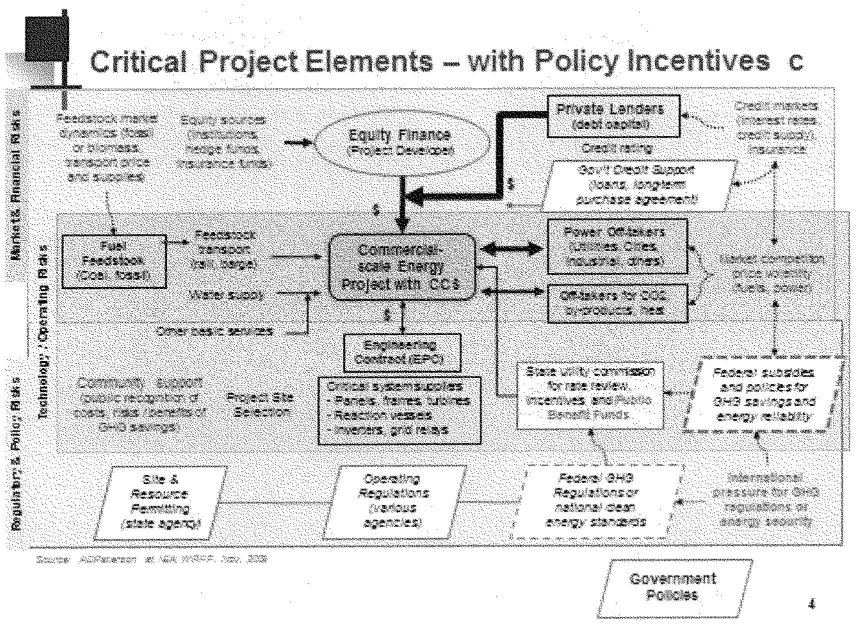
Appendix 4 – Commercial Project Financing and the Role of Incentives



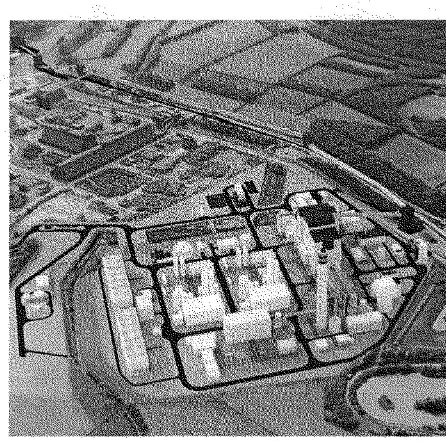
Appendix 5 – Case Study: Contracts for Differences

The UK has developed mechanisms to help low-carbon energy projects be more competitive in an open market. With huge storage potential in the North Sea and clusters of industrial CO_2 sources, the UK is well-positioned to be a leader of CCS in the European Union. While the country has set aside funding for CCS projects, the CFD mechanism could be an important source of support for large CCS projects as they come online.

CFD support low-carbon sources of energy by making investment more palatable due to reduced uncertainty about electricity pricing, while also protecting consumers from overpayment. Essentially, CFDs provide long-term price stabilization, allowing lower cost capital investment and, thus, a lower net cost to consumers. The CFD is just beginning to be used and the first set of allocations is limited to projects using onshore wind, solar PV, energy from waste with combined heat and power, and landfill gas and sewage.

CFDs require generators to sell electricity to the market as usual. However, to reduce exposure to fluctuating energy prices CFDs include a pre-determined strike price. This strike price operates against a reference wholesale market price. If the reference wholesale market price is lower than the strike price, the generator will be paid the difference between the two prices. Similarly, if the reference price is higher than the strike price the generator will have to pay back the difference.

Although CCS projects are not currently listed in the CFD allocations, future CFD allocation rounds are expected to include CCS, and two major projects are moving forward in the UK. The Peterhead Project in Aberdeenshire will capture about one million tonnes per year (Mtpa) from an existing natural gas combined-cycle plant and store it under the floor of the North Sea. The White Rose project will capture about 2 Mtpa from a new 448-MW (gross) oxy-combustion coal-fired power plant.



Appendix 6 – Case Study: FutureGen

The FutureGen 2.0 project was to demonstrate the retrofitting of an existing coal-fueled power plant with oxy-combustion technology and fully integrated CO_2 capture. All captured CO_2 was to be transported via pipeline to a deep saline geologic formation for permanent storage. Ultimately, the project did not proceed to full construction due to the DOE's decision to suspend Federal cost-sharing after concluding that there would be insufficient time to expend the project's Federal funds prior to expiration. As the project had secured all its major permits, had negotiated most commercial contracts, and was in the final phase of commercial financing, substantial policy-related lessons-learned can be drawn from it.

It is important to highlight that being a FOAK project, both with respect to the oxy-combustion technology and the fully integrated geologic storage, the State of Illinois and the Federal government took certain policy-related measures to help reduce the FOAK cost and risk down to a level that a commercial financing could bear. Inevitably, FOAK technologies require more aggressive policy-related incentives than mature CCS technologies will require. Further, in the power sector, policy-related incentives must be robustly designed to be effective in different corporate environments. That is, policy-related incentives must meet the needs of regulated utilities, merchant plants, contracted plants, and non-profit rural electric generation companies, if CCS is to effectively penetrate the coal-based generation market. Further, a robust policy framework for CCS deployment must include complementary changes to both Federal and State policies.

Policy-related lessons-learned are discussed below in the context of selected project accomplishments and challenges.

Capital Cost Buy-Downs – As a FOAK project, the capital cost buy-down provided by DOE's commitment of $1 billion dollars to the project was a necessary first step to establishing financial credibility in the marketplace. While Federal budgets are likely to be tight in coming years, the Department should consider whether larger investments in a limited number of projects versus spreading DOE funding broadly in smaller amounts would increase the likelihood of FOAK project success. CCS projects are by their very nature large capital allocations as distinct from smaller MW low carbon technologies (*e.g.*, wind and solar). However this is the balance between stable baseload power and intermittent power. Further, there is no policy parity between renewable projects and coal projects when it comes to DOE grant taxation. Many energy projects are structured as partnerships (*e.g.*, LLCs or MLPs). While DOE renewable grants are non-taxable when received by a partnership, fossil grants are taxed as income nominally resulting in a loss of approximately one-third of the grant funds. To avoid this untenable taxation, fossil projects must be structured as a C-corporation, which subsequently complicates commercial financing and increases project risk. DOE should advocate for policy parity on grant taxation.

Capital Financing Guarantees – DOE currently lacks the statutory authority to combine loan guarantees and grant funding on individual project. This is not the best use of two complementary policy tools. The Department should advocated for increased statutory authority that would allow the use of both guarantees and grants on the same project with an aggregate cap on DOE's cost exposure (*e.g.,* 80% of total capital)

Operating Cost Coverage – Operating a coal-fueled power plant with CCS, particularly when employing geologic storage, requires a mechanism to cover the increased cost of generating low-carbon power. FutureGen 2.0 was the first project to secure an investment-grade PPA under the Illinois Clean Coal Portfolio Standard (CCPS), which provided a level playing field for low carbon technologies (*i.e.,* renewables and CCS). The structure of the PPA allowed FutureGen 2.0 to engage financial markets as a long-term contracted asset. In FutureGen 2.0's case, the PPA covered the incremental cost of deep saline storage for which there is no traditional economic driver. The CCPS could serve as a model for other States. At a Federal level a substantial refundable tax credit would help offset the cost of operation for a deep saline storage site.

Power Plant Air Permitting – FutureGen 2.0 benefited from Illinois EPA's modification of the power plant's existing permit. The nature of the permit provided substantial flexibility that would have proved valuable in the early years of operating a FOAK plant. DOE, working with EPA, should consider what air permitting flexibility could be provided to other FOAK projects.

CO_2 Pipeline Permitting – The State of Illinois passed new legislation regarding the siting of CO_2 pipelines that enabled FutureGen 2.0 to receive a final pipeline permit as well as the right of eminent domain for pipeline siting. Through substantial stakeholder involvement activity, the FutureGen 2.0 project remained hopeful that the exercise of eminent domain would not be necessary; however, on most projects this policy mechanism will be required.

CO_2 Storage Rights – A remarkable project achievement was the project's ability to work with local landowners to acquire control, on a free-market basis, 100% of the necessary pore space. This success is due in part to the public community placing a high value on the job creation and the project's associated training center. On most CCS projects, it will likely be necessary to have some form of unitization or eminent domain when private property is involved. This is predominantly a State policy issue. On Federal lands, a granting of pore space rights would be necessary.

CO_2 Storage Liability – The State of Illinois passed unique legislation that required certain operator responsibility, as well as having the State taking on certain long-term stewardship and liability responsibilities. Unquestionably, this help improve the commercial financeability of the project. This landmark legislation could serve as a model for Federal or State policy.

Appendix 7 – Case Study: Government Support and a Strong Business Case Energize Boundary Dam

The Boundary Dam Power Plant in Saskatchewan, Canada has become a flagship clean energy project and has set the bar for CCS/CCUS projects around the world. The world's first-ever, large-scale, coal-fired post-combustion CO_2 capture project began operation on October 2, 2014. However, as with most first-of-its-kind energy projects CCS at Boundary Dam would never have come to fruition without the support of the Saskatchewan and Canadian governments. According to a report issued by the IEA, "Federal funding was the catalyst for converting SaskPower's clean coal power concept into a fully engineered design."

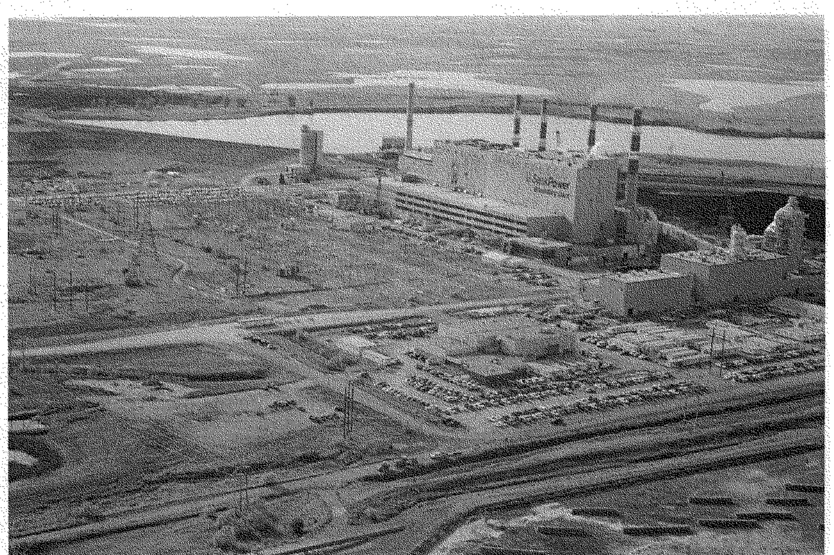
Active support from the Saskatchewan government began in 2007 to secure the Federal funding needed to support SaskPower's landmark clean coal project. The Saskatchewan government was, in part, motived by the business case made by SaskPower beyond the demonstration of coal-fired CCS. Royalties from CO_2-EOR, extending the life of an important oil field in the region, maintaining jobs in oil production, and supporting a technology to allow for Saskatchewan to continue using its vast lignite reserves in a carbon-constrained future helped support the business case.

SaskPower created the business case—and the Saskatchewan government took that case to the highest levels of government, successfully securing $240 million in Federal funding in 2008. **These funds were instrumental in completing the plant design—a critical step where similar projects have stumbled.**

This support was especially visionary because when it was provided there were no regulations in place, at either the Federal or provincial level, that required CO_2 to be captured and stored. Thus, there were also no offsets available to help support the project. Regulations were not enacted for four years after government support was committed.

CCS at Boundary Dam can be considered a joint venture between the Canadian and Saskatchewan governments and SaskPower. In addition to the financial support, the governments have been vocal on the merits of the project, both nationally and internationally. The Boundary Dam project, including the role of government in advancing the project, is a prominent example of the public-sector collaboration necessary to advance clean coal projects around the world.

Government and Business Partnership (left to right): SaskPower Board Chair Rob Pletch; the Honourable Bill Boyd, Minister Responsible for SaskPower; Saskatchewan Premier Brad Wall; the Honourable Greg Rickford, Canada's Minister of Natural Resources; and SaskPower President and CEO Robert Watson cut the ribbon at the official launch of the Boundary Dam carbon capture and storage facility. (Image credit: SaskPower)



A World's First: Boundary Dam CCS Project (Image credit: SaskPower)

[1] Mike McKinnon, *Newly Revealed SaskPower Chart Shows Capture Performance Not Improving*, GLOBAL NEWS, Nov. 2, 2015 *available at:* http://globalnews.ca/news/2313488/newly-revealed-saskpower-chart-shows-capture-performance-not-improving/.

[2] *See* Kulwant Singh, *Urban Electric Mobility Initiative* 6, UN-HABITAT, https://www.iea.org/media/workshops/2015/towardsaglobalevmarket/C.3UNHABITAT.pdf.

[3] Tony Blair, *Tony Blair Speaks on Breaking The Climate Deadlock* (Jun. 26, 2008) http://www.tonyblairoffice.org/speeches/entry/tony-blair-speaks-on-breaking-the-climate-deadlock/ ("The vast majority of new power stations in China and India will be coal-fired; not 'may be coal-fired'; will be. So developing carbon capture and storage technology is not optional, it is literally of the essence.")

[4] Lori Rugh, *American Wind Industry: Past and Future Growth* 4, AM. WIND ENERGY ASS'N *available at:* http://www.trade.gov/td/energy/AWEA%20Wind%20Power%20Presentation_Final.pdf.

[5] AM. WIND ENERGY ASS'N, *U.S. Wind Industry Third Quarter 2015 Market Report – Executive Summary* 3 (Oct. 22, 2015) *available at:* http://awea.files.cms-plus.com/FileDownloads/pdfs/3Q2015%20AWEA%20Market%20Report%20Public%20Version.pdf.

[6] Lawrence Berkeley Nat'l Lab., *2014 Wind Technologies Market Report Highlights* 4, U.S. DEP'T OF ENERGY (Aug. 2015) *available at:* http://energy.gov/sites/prod/files/2015/08/f25/2014WindTechnologiesMarketReportHighlights8-11.pdf (showing, as well, that wind prices reached a high of nearly $70/MWh in 2009, driven by increases in the cost of wind turbines).

[7] AM. WIND ENERGY ASS'N, *AWEA white paper: Renewable Production Tax Credit has driven progress and cost reductions, but the success story is not yet complete* (Sep. 10, 2015) http://www.awea.org/MediaCenter/pressrelease.aspx?ItemNumber=7877 ("The Production Tax Credit (PTC) and alternative Investment Tax Credit (ITC) have enabled private sector investments in the American workforce, domestic manufacturing, and R&D that have significantly reduced the cost of wind energy.")

[8] SOLAR ENERGY INDUS. ASS'N, *Solar Market Insight Report 2013 Year in Review*, http://www.seia.org/research-resources/solar-market-insight-report-2013-year-review.

[9] *Id.*

[10] SOLAR ENERGY INDUS. ASS'N, *Solar Industry Data: Solar Industry Breaks 20 GW Barrier – Grows 34% Over 2013*, http://www.seia.org/research-resources/solar-industry-data.

[11] *Id.*

[12] *Id.*

[13] Budgets for "Renewables" reflect funds budgeted to the Office of Energy Efficiency and Renewable Energy for the following line items: "Solar Energy," "Wind Energy," "Water Energy," and "Geothermal Technologies." Budgets for "CCS" reflect funds budgeted to the Office of Fossil Energy for the line items: "Carbon Capture" and "Carbon Storage." As noted in the chart, no funds were budgeted for CCS demonstration projects (*i.e.* CCPI). The budget for CCS does not reflect funding for technologies not under the CCS budget that have application beyond electric generation, such as oxycombustion and chemical looping. Budgets available at http://www.energy.gov/budget-performance.

[14] Molly Sherlock and Jeffrey Stupak, ENERGY TAX INCENTIVES: MEASURING VALUE ACROSS DIFFERENT TYPES OF ENERGY RESOURCES 7, Tbl. 2, CONG. RESEARCH SERV., R41953 (Mar. 19, 2015) *available at:* https://www.fas.org/sgp/crs/misc/R41953.pdf.

[15] While approximately $30 million of this credit has been claimed, we could find no evidence of the credits being claimed by power projects with CCS.

[16] NAT'L COAL COUNCIL, FOSSIL FORWARD – REVITALIZING CCS: BRINGING SCALE & SPEED TO CCS DEPLOYMENT 12 (Feb. 2015) *available at:* http://www.nationalcoalcouncil.org/studies/2015/Fossil-Forward-Revitalizing-CCS-NCC-Approved-Study.pdf.

[17] *Department of Energy Oversight: Status of Clean Coal Programs: Hearing Before the Subcomm. on Oversight and Investigations of the H. Comm. on Energy and Commerce* (Feb. 11, 2014) *available at:* http://docs.house.gov/meetings/IF/IF02/20140211/101742/HHRG-113-IF02-Wstate-KlaraS-20140211.pdf (testimony of Dr. Julio Friedmann, Deputy Assistant Sec'y for Clean Coal (now Assistant Sec'y for Fossil Energy), U.S. Dep't of Energy) ("Commercial-scale demonstrations help the industry understand and overcome start-up issues, address component integration issues, and gain the early learning commercial experience necessary to reduce technology risk and secure private financing and investment for future plants.").

[18] NAT'L COAL COUNCIL, FOSSIL FORWARD, *supra* note 16, at 12 (citing INT'L ENERGY ASSOC., Technology Roadmap: Carbon Capture and Storage 6 (2009) *available at:* http://www.iea.org/publications/freepublications/publication/CCSRoadmap2009.pdf ("Without CCS, overall costs to

halve CO_2 emissions levels by 2050 increase by 70%.") *and* INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE WORKING GROUP III, CLIMATE CHANGE 2014: MITIGATION OF CLIMATE CHANGE 60, Fig. TS-13 (2014) *available at:* http://report.mitigation2014.org/report/ipcc_wg3_ar5_full.pdf (showing a median cost increase without CCS of 138%)); *see also* INT'L ENERGY ASSOC., ENERGY TECHNOLOGY PERSPECTIVES 2012: PATHWAYS TO A CLEAN ENERGY SYSTEM 11 (2012) *available at:* http://www.iea.org/publications/freepublications/publication/ETP2012_free.pdf ("CCS is the only technology on the horizon today that would allow industrial sectors (such as iron and steel, cement and natural gas processing) to meet deep emissions reduction goals . . . . The additional investment needs in electricity that are required to meet [CO_2 reduction goals] [would add] a total extra cost of USD 2 trillion over 40 years.").

[19] INT'L ENERGY ASSOC., TECHNOLOGY ROADMAP CARBON CAPTURE AND STORAGE 8 (2013) *available at:* http://www.iea.org/publications/freepublications/publication/technologyroadmapcarboncaptureandstorage.pdf

[20] *See* BP, 2015 BP STATISTICAL REVIEW OF WORLD ENERGY 42 (June 2015) *available at:* http://www.bp.com/content/dam/bp/pdf/energy-economics/statistical-review-2015/bp-statistical-review-of-world-energy-2015-full-report.pdf.

[21] *Id.* at 43.

[22] BP, BP ENERGY OUTLOOK 2035 9-11 (Feb. 2015) *available at:* http://www.bp.com/content/dam/bp/pdf/energy-economics/energy-outlook-2015/bp-energy-outlook-2035-booklet.pdf.

[23] *Id.* at 17.

[24] INT'L ENERGY AGENCY, SOUTHEAST ASIA ENERGY OUTLOOK 2015 9 (Sep. 2013) *available at:* http://www.iea.org/publications/freepublications/publication/world-energy-outlook-special-report-on-southeast-asia-2015.html.

[25] Howard Herzog, *Pumping CO_2 underground can help fight climate change. Why is it stuck in second gear?*, THECONVERSATION.COM, Mar. 12, 2015, http://theconversation.com/pumping-co2-underground-can-help-fight-climate-change-why-is-it-stuck-in-second-gear-37572.

[26] COAL UTILIZATION RESEARCH COUNCIL and ELEC. POWER RESEARCH INST., THE CURC-EPRI ADVANCED COAL TECHNOLOGY ROADMAP 2 (July 2015) *available at:* http://media.wix.com/ugd/80262f_ada0552d0f0c47aa873df273154a4993.pdf (citing U.S. ENERGY INFO. ADMIN., *Electric Power Monthly – February 2015*, Feb. 2015.).

[27] NATIONAL COAL COUNCIL, RELIABLE & RESILIENT: THE VALUE OF OUR EXISTING COAL FLEET 23 (May 2014) *available at:* http://www.nationalcoalcouncil.org/reports/1407/NCCValueExistingCoalFleet.pdf.

[28] Ken Kern, *Coal Baseload Asset Aging, Evaluating Impacts on Capacity Factors* 3, NAT'L ENERGY TECH. LAB., June 16, 2015, http://www.eia.gov/forecasts/aeo/workinggroup/coal/pdf/Coal%20Baseload%20Asset%20Aging%20Kern%206-16-15.pdf.

[29] U.S. ENERGY INFO. ADMIN., ANNUAL ENERGY OUTLOOK 2013 42 (Apr. 2013) DOE/EIA-0383(2013) *available at*: http://www.eia.gov/forecasts/archive/aeo13/pdf/0383(2013).pdf.

[30] Memorandum from Coal and Uranium Analysis Team to John Conti, Assistant Adm'r for Energy Analysis and Jim Diefender, Dir., Office of Electricity, Coal, Nuclear, and Renewables Analysis, U.S. Energy Info. Admin., Notes from the Future Operating and Maintenance Considerations for the Existing Fleet of Coal-fired Power Plants workshop held on June 16, 2015 2, June 18, 2015 *available at:* http://www.eia.gov/forecasts/aeo/workinggroup/coal/pdf/AEO2016%20Adjunct%20CWG%20Mtg%20Minutes%20on%20Coal%20Fleet%20Aging%2016-Jun-2015%20FINAL3.pdf.

[31] *Id.*

[32] *See infra* Appendix 3 for more information on the first ultra-supercritical power plant in the United States, AEP's John W. Turk Jr., Power Plant.

[33] WORLD COAL ASSOC., A GLOBAL PLATFORM FOR ACCELERATING COAL EFFICIENCY (2014) *available at:* http://www.worldcoal.org/coal-the-environment/pace-platform-for-accelerating-coal-efficiency/.

[34] INT'L ENERGY ASSOC., TECHNOLOGY ROADMAP, *supra* note 19, at 24, Fig. 6.

[35] See, *e.g.*, Tom Randall, *Fossil Fuels Just Lost the Race Against Renewables*, BLOOMBERGBUS., Apr. 14, 2015, http://www.bloomberg.com/news/articles/2015-04-14/fossil-fuels-just-lost-the-race-against-renewables ("The price of wind and solar power continues to plummet, and is now on par or cheaper than grid electricity in many areas of the world.").

[36] Renewables proponents have argued for continuing subsidies based on the alleged latent subsidy of infrastructure geared toward fossil fuel use. *See* Kate Gordon, *Why Renewable Energy Still Needs Subsidies*, WALL ST. JOURNAL, Sep. 14, 2015, http://blogs.wsj.com/experts/2015/09/14/why-renewable-energy-still-needs-subsidies/ ("Even if they're now,

finally, cost-competitive at the point of sale, low-carbon technologies are still working with an infrastructure . . . built for a world powered by fossil fuels.")

[37] NATIONAL COAL COUNCIL, RELIABLE & RESILIENT, *supra*, note 27, at 12.

[38] CURC-EPRI ADVANCED COAL TECHNOLOGY ROADMAP, *supra* note 26, at 8.

[39] U.S. ENERGY INFO. ADMIN., *Direct Federal Financial Interventions and Subsidies in Energy in Fiscal Year 2013*, Mar. 12, 2015, http://www.eia.gov/analysis/requests/subsidy/.

[40] Molly Sherlock and Jeffrey Stupak, ENERGY TAX INCENTIVES, *supra* note 14.

[41] The effects have led to retirements of both coal and, most recently, nuclear. See, *e.g.*, Rebecca Smith, *Entergy Plans to Shut Down Pilgrim Nuclear Plant by June 2019*, WALL ST. JOURNAL, Oct. 13, 2015, http://www.wsj.com/articles/entergy-plans-to-shutdown-pilgrim-nuclear-plant-by-june-2019-1444743133 ("Entergy Corp. said Tuesday it will close its aging Pilgrim nuclear power plant in Massachusetts by mid-2019, citing low power prices, regulatory challenges and public policies that it says disadvantage nuclear plants . . . . For example, the U.S. intends to limit carbon-dioxide emissions from power plants by 2030, but Mr. Mohl said some State and Federal policies that favor clean energy specifically exclude existing nuclear plants, even though they emit no carbon.").

[42] Phillip Brown, U.S. RENEWABLE ELECTRICITY: HOW DOES WIND GENERATION IMPACT COMPETITIVE POWER MARKETS? 15, CONG. RESEARCH SERV., R42818 (Nov. 7, 2012) *available at:* https://www.fas.org/sgp/crs/misc/R42818.pdf.

[43] *Id.*

[44] A Section 45 credit also applies to refined coal and Indian coal. This credit operates differently, and is based on tons of qualified coal produced, rather than electricity produced.

[45] *Oversight of the Wind Energy Production Tax Credit: Hearing Before the Subcomm. on Energy Policy, Healthcare, and Entitlements of the H. Comm on Oversight and Gov't Reform* (Oct. 2, 2013) *available at:* https://oversight.house.gov/hearing/oversight-of-the-wind-energy-production-tax-credit/ (testimony of Rob Gramlich, Senior Vice President, Am. Wind Energy Ass'n.) ("A single incentive, the Production Tax Credit, is by far the dominant policy driver for wind energy in the US.").

[46] 26 U.S.C. § 48(a)(3)(A)(i) (applying credit to "equipment which uses solar energy to generate electricity, to heat or cool (or provide hot water for use in) a structure, or to provide solar process heat, excepting property used to generate energy for the purposes of heating a swimming pool.").

[47] U.S. DEP'T OF ENERGY, *Portfolio Projects*, http://energy.gov/lpo/portfolio-projects (last visited Nov. 10, 2015). These figures do not include loan guarantees for energy storage projects, which disproportionately aid intermittent renewable energy sources by storing energy produced but not needed (typically during off-peak hours).

[48] California price listed at $12.88/ton as of October 16, 2015 ($11.68/ton). CLIMATE POLICY INITIATIVE, *California Carbon Dashboard*, http://calcarbondash.org/. The most recent RGGI auction price is $6.02/ton. Gerald Silverman, *RGGI Carbon Prices Continue Upward Trend*, BNA.COM, Sep. 21, 2015, http://bna.com/rggi_carbon_prices_b57982058492/.

[49] Glen Barbose, *Renewable Portfolio Standards in the United States: A Status Update* 20, LAWRENCE BERKELEY NAT'L LAB., Nov. 6, 2013 *available at:* https://emp.lbl.gov/sites/all/files/rps_summit_nov_2013.pdf (presentation to the State-Federal RPS Collaborative National Summit on RPS, Washington, D.C.).

[50] *Id.* at 9.

[51] *Id.* at 8.

[52] CAL. PUB. UTIL. COMM'N, CALIFORNIA NET ENERGY METERING RATEPAYER IMPACTS EVALUATION 6 (Oct. 28, 2013) *available at:* http://www.cpuc.ca.gov/NR/rdonlyres/75573B69-D5C8-45D3-BE22-3074EAB16D87/0/NEMReport.pdf.

[53] Jerry Hirsch, *Elon Musk's growing empire is fueled by $4.9 billion in government subsidies*, L.A. TIMES, May 30, 2015, http://www.latimes.com/business/la-fi-hy-musk-subsidies-20150531-story.html.

[54] See, *e.g.*, American Energy Innovation Act, S. 2089, 114th Cong. (2015)(introduced by Sen. Maria Cantwell (D-WA), Ranking Democrat on the Senate Energy and Natural Resources Committee and cosponsored by Minority Leader Harry Reid (D-NV), Assistant Minority Leader Dick Durbin (D-IL), and Senate Democratic Conference Vice Chair Chuck Schumer (D-NY)).

[55] U.S. ENERGY INFO. ADMIN, LEVELIZED COST AND LEVELIZED AVOIDED COST OF NEW GENERATION RESOURCES IN THE ANNUAL ENERGY OUTLOOK 2015 3 (June 2015) *available at:* http://www.eia.gov/forecasts/aeo/pdf/electricity_generation.pdf.

[56] GLOBAL CCS INST., THE COSTS OF CCS AND OTHER TECHNOLOGIES – 2015 UPDATE 9, Fig. 5.2 (July 2015) *available at:* http://hub.globalccsinstitute.com/sites/default/files/publications/195008/costs-ccs-other-low-carbon-technologies-united-states-2015-update.pdf.

[57] U.S. ENERGY INFO. ADMIN, LEVELIZED COST, *supra* note 55, at 7.

[58] Mike McKinnon, *Newly Revealed SaskPower Chart, supra* note 1.

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[59] NAT'L COAL COUNCIL, FOSSIL FORWARD, *supra* note 16, at Ch. E.

[60] L. STEPHEN MELZER, *Carbon Dioxide Enhanced Oil Recovery (CO_2 EOR): Factors Involved in Adding Carbon Capture, Utilization and Storage (CCUS) to Enhanced Oil Recovery* 8, Feb. 2012 *available at:* http://neori.org/Melzer_CO2EOR_CCUS_Feb2012.pdf

[61] *See, e.g.,* John Harju and Ed Steadman, *The Energy & Environmental Research Center's Economic Case for CCUS: Reducing Capture Costs and Increasing Demand for Commodity CO_2*, ENERGY & ENV'T RESEARCH CTR., Mar. 25-27, 2014 *available at:* http://www.cslforum.org/publications/documents/seoul2014/Steadman-Workshop-Seoul0314.pdf (report for the Carbon Sequestration Leadership Forum Technical Meeting); Vello Kuuskra, *Increasing the Size of the CCUS Prize: The Potential and Economic Viability of Storing CO_2 and Producing Oil from the ROZ of the Permian Basin Greatly Enhances the CCUS Option*, ADVANCED RES. INT'L, INC., Oct. 5, 2015 *available at:* http://webcache.googleusercontent.com/search?q=cache:-aoyG6RUi08J:nortexpetroleum.org/wp-content/uploads/2015/10/Kuuskraa-Keynote-Oct_5_2015.pdf+&cd=1&hl=en&ct=clnk&gl=us (report prepared for the 2nd Biennial CO_2 for EOR as CCUS Conference).

[62] CURC-EPRI ADVANCED COAL TECHNOLOGY ROADMAP, *supra* note 26.

[63] *Id.* at 29.

[64] While Congress authorized the CCPI program with EPAct '05, Congress created the program in 2001 appropriations language. Fiscal Year 2002 Department of Interior and Related Agencies Appropriations Act, P.L. 107-63, 415 Stat. 414, 453 (2001). DOE began project solicitations for CCPI Round 1 in 2002. U.S. DEP'T OF ENERGY OFFICE OF FOSSIL ENERGY, MAJOR DEMONSTRATION PROGRAMS: PROGRAM UPDATE 2013 2-1 (Sep. 2013) DOE/FE-0565 *available at:* www.netl.doe.gov/File%20Library/Research/Coal/Reference%20Shelf/DemoPrograms-CCTUpdate2013.pdf.

[65] DOE awarded a grant in CCPI Round Two to demonstrate the Coal-Based Transport Gasifier system at what is now the Kemper Energy Facility. MAJOR DEMONSTRATION PROGRAMS, *supra* note 64, at 3-17. However, that grant was not for Kemper's CCS technology.

[66] *Id.* at 2-5, Ex. 2-5.

[67] Peter Folger and Molly Sherlock, CLEAN COAL LOAN GUARANTEES AND TAX INCENTIVES: ISSUES IN BRIEF 6, CONG. RESEARCH SERV. (Aug. 19, 2014) R43690 *available at:* https://www.fas.org/sgp/crs/misc/R43690.pdf.

[68] Congress allocated $1.25 billion for a Phase II of 48A investment tax credits. *Id.* at 7. Of that amount, the IRS allocated $1,009,436,000 to three projects in the 2009-10 first allocation, no amounts in the 2010-2011 second allocation, and $103,564,000 to one project in the third allocation; leaving unallocated $137,000,000 for qualifying advanced projects utilizing lignite. U.S. INTERNAL REVENUE SERV., Notice 2010–56, 2010-39 I.R.B. 398 (Sep. 27, 2010), *available at:* www.irs.gov/pub/irs-irbs/irb10-39.pdf, Notice 2011-62, 2011-40 I.R.B. 483 (Oct. 3, 2011), *available at:* https://www.irs.gov/pub/irs-drop/a-11-62.pdf, Notice 2013-2, 2013-2 I.R.B. 271 (Jan. 7, 2013) *available at:* www.irs.gov/pub/irs-irbs/irb13-02.pdf. The IRS recently announced that $1,104,000,000 of 48A credits were made available for reallocation due to forfeitures of previously allocated Phase I credits and unallocated Phase II credits. U.S. INTERNAL REVENUE SERV., Announcement 2015-14, 2015-10- I.R.B. 722 (Mar. 9, 2015) *available at:* https://www.irs.gov/pub/irs-irbs/irb15-10.pdf.

[69] Figure as of June 1, 2014. INTERNAL REVENUE SERV., Notice 2014-40, 2014-27 I.R.B. 100 (June 30, 2014) *available at:* https://www.irs.gov/pub/irs-irbs/irb14-27.pdf.

[70] CENT. FOR CLIMATE AND ENERGY SOLUTIONS, *Financial Incentives for CCS*, http://www.c2es.org/us-states-regions/policy-maps/ccs-financial-incentives (last visited Nov. 13, 2015).

[71] GLOBAL CCS INSTITUTE, THE GLOBAL STATUS OF CCS 2014 84, Tbl. 5.1 (Nov. 5, 2014) *available at:* http://hub.globalccsinstitute.com/sites/default/files/publications/180923/global-status-ccs-2014.pdf.

[72] *See, e.g.* S. 2089, *supra* note 54. Other recommendations can be implemented by DOE without statutory changes.

[73] Note that the House and Senate legislation that has been introduced to extend MLP status to renewables and CCS. Master Limited Partnership Parity Act of 2015, H.R. 2883 and S. 1656, 114th Cong. (2015).

[74] CURC-EPRI ADVANCED COAL TECHNOLOGY ROADMAP, *supra* note 26.

Revolution?

the weekly Standard

The astonishing promise of enhanced oil recovery

DEC 29, 2014 | By SAMUEL THERNSTROM

Just five years ago, almost no one outside the natural gas industry had heard of fracking, even though the basic technologies were not new; today, the shale gas revolution has transformed America's energy markets, with profound effects for economic growth, competitiveness, security, and environmental quality. In a nation still deeply concerned about its energy future, this extraordinary success story should prompt the question: Can we do it again?

The answer is yes—if we correctly understand both the model for innovation that shale gas exemplifies and an opportunity that now exists to emulate the shale model. That opportunity involves exploiting a technique called "enhanced oil recovery" (EOR).

Like fracking on the eve of its success, this concept is virtually unknown to most Americans, yet it rests not on pie-in-the-sky technological dreams but on the application and refinement of proven technologies that companies have been developing for decades. Like fracking, enhanced oil recovery has the potential to recover staggering quantities of hydrocarbons that were previously known but considered inaccessible. As with fracking, the primary players will be the private sector—but public policy has a crucial role to play in establishing the necessary conditions and providing the impetus for this market to take off. Most tantalizingly, enhanced oil recovery should be less controversial than fracking, because it also offers the opportunity to radically reduce greenhouse gas emissions from electric power generation (and other industries).

The shale gas revolution may have seemed to emerge out of nowhere, but it in fact represented the maturation of an industry that had been developing for decades, driven by advances in multiple technologies—hydraulic fracturing, directional drilling, and the combined-cycle natural gas power plant. In the nuance-allergic world of politics, this story is often spun either as a triumph of the free market or as proof of the power of government-funded R&D. In fact, both the government and the private sector deserve credit, and success depended in no small part on getting the relationship between the two sectors right.

Reviewing this history in a recent *National Affairs* essay, Jim Manzi identified three factors that drove the shale gas revolution: (1) America's system of property rights and pricing, which allowed innovators to reap the rewards of their work; (2) our highly skilled and competitive workforce and market for oil exploration, extraction, and associated services; and (3) government support for research, development, demonstration, and commercialization of these technologies.

As Manzi observes, we cannot know how much weight to give to the third factor—there's no way of knowing what would have happened without it—but the very companies that led the fracking revolution have been the first to acknowledge the significance of government support. It takes nothing away from the entrepreneurial geniuses who saw and pursued the potential of shale gas to acknowledge the public policy contributions to their success.

Federal support for shale gas development wasn't limited to basic research and development. It ran the gamut: early R&D support through the Eastern Shales Gas Project in 1976, a hand-off of technology to the private sector via the Gas Research Institute (a public-private institution funded by a charge on interstate gas sales), support for refinement of the technologies through further federal R&D in the 1980s, and a boost to its commercialization through tax incentives for the use of

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"unconventional gas" (as it was then called). Long after the core technologies were first developed, federal support for their refinement and commercialization continued.

Manzi's essay looks at the most important part of the equation—the revolutionary advances in technology for extracting gas from shale—but there was another element of the story that wasn't inconsequential: the combined-cycle gas turbines that turn the gas into electricity. Why do we have such efficient natural gas power plants? Because the Department of Defense invested well over a billion dollars over three decades to improve the performance of jet turbines for military aircraft—and then the Department of Energy spent millions more to apply that knowledge to power generation.

An unfortunate legacy of the Obama administration's tainted record on green energy investments has been a loss of conservative support for this model of innovation. Overreach-and-backlash may be an unavoidable dynamic in politics, but it would be a mistake to assume that this administration's missteps on energy innovation reflect inherent obstacles to success in the field.

In fact, the opportunity that enhanced oil recovery offers today is much clearer than that of shale gas in 1976, when President Ford first focused federal attention on its potential. EOR's core technologies work well, and the market is much more advanced than shale gas was in the 1970s. But a focused public push to expand the market for EOR and bring next-generation technologies forward could still have profound effects on America's energy future.

Using known and next-generation technologies and processes, enhanced oil recovery could increase domestic oil production—mostly from existing wells, not new fields—by tens of billions of barrels. Public policies to jump-start this nascent market could

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significantly enhance our energy security, improve our balance of trade, and generate tens of billions of dollars in revenue for the federal government and trillions in economic activity over the next half-century.

Equally important is the answer offered by EOR to two of the most pressing questions in energy policy: *What is the future of coal in this country, and what can the federal government do to reduce the risks of climate change?* The answer EOR offers is uniquely compelling: *Coal stays in our energy mix while almost all of its carbon gets trapped underground.*

The key to this opportunity lies in the fact that carbon dioxide is the essential ingredient in enhanced oil recovery operations. And in contrast to EPA's divisive, expensive, and likely ineffective approach to regulating carbon emissions, EOR would give American companies an opportunity to make money putting carbon dioxide underground while producing oil, making this a wealthier, more productive country with a stronger, more secure energy economy and a cleaner environment.

Drillers have long understood that they leave most of their product in the ground. As oil is pumped, the pressure underground drops and it becomes harder to extract what remains. Typically, only about one-third of the oil in a given location can be economically removed. As a result, many supposedly "depleted" wells actually still contain most of their oil—just waiting for a technology that will make it economical to extract it.

In the early 1970s, drillers in west Texas figured out how to do just that, and the remarkable secret to their success was carbon dioxide. Pumping carbon dioxide into depleted wells not only increases the pressure, it also acts as a solvent, helping to separate oil from the cavities in the rock where it is trapped and the water it is often mixed with. This process enables oil companies to extract as much as another third of a site's oil—essentially doubling a well's productivity.

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One might think that such a remarkable technology would be an overnight sensation. But in fact, we are nowhere near capitalizing upon EOR's full potential. Since the 1970s, oil companies have injected about a billion tons of carbon dioxide into "depleted" wells, producing roughly 2.5 billion barrels of oil. About 6 percent of the oil produced in America is now extracted using this technique. We know it works—but it's still a niche market.

What's holding us back? A shortage of carbon dioxide. The carbon dioxide used in EOR operations is predominantly geologic—companies tap into underground deposits and extract CO_2 for enhanced oil recovery and other commercial applications. That's how it's been done since the 1970s, but two important things have changed in recent years. Climate change has become the preeminent environmental concern, and new studies have shown that there is *much* more oil reachable through EOR than had been previously understood—so much so that geologic carbon dioxide supplies aren't nearly sufficient. If we want to get that oil, we'll have to capture carbon dioxide from industrial sources, such as coal-fired power plants.

Which brings us to the interesting place we find ourselves today: Our nation's top environmental goal is reducing carbon dioxide emissions. And one of our top energy priorities is maximizing production from domestic oil reserves. Capturing carbon dioxide from power plants and using it for EOR could produce billions of barrels of oil while simultaneously putting billions of tons of carbon dioxide underground forever. Yet policymakers are doing next to nothing to take advantage of this unique opportunity. Instead, Washington is preparing to fight a pitched legal and political battle over proposed EPA power plant regulations that will, even if implemented, make barely a dent in America's carbon emissions.

Why is so much carbon dioxide being released into the atmosphere if it's valuable? Because the costs and benefits don't quite align—yet. But Congress could easily change that. There isn't much of a market for carbon dioxide from power plants

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because the costs of capture typically exceed the market price of carbon dioxide. Oil companies might pay $30 or $40 a ton for carbon dioxide, but capturing it from a power plant can cost $80 a ton or more.

So imagine what would happen if the federal government provided a tax credit that bridged the difference—a credit, say, of $40 a ton. All of a sudden, we would have a market: Oil companies could continue to pay market prices for carbon dioxide, while utilities and other industrial sources could make money selling it to them. Instead of leaving all that oil underground while carbon continues to accumulate in the atmosphere, we could be in the business of sequestering billions of tons of carbon dioxide while producing billions more barrels of oil.

Fine, say the skeptics—but who wants to pay the cost of all those tax credits? New subsidies for energy aren't exactly popular on Capitol Hill these days. The difference, though, is that an EOR tax credit would more than pay for itself. Over time, its net effect on the Treasury would be positive to the tune of tens of billions of dollars.

Pumping a ton of carbon dioxide into a well produces roughly two-and-a-half to three barrels of oil; on average, each barrel generates $23 or so in federal and state taxes and royalties (depending on the location and price of the oil, of course). So each ton of carbon dioxide used for enhanced oil recovery would create about $58 in revenues. Even after covering the cost of a $40 per ton tax credit, the Treasury would come out ahead. And when the additional oil production is measured in the billions of barrels, the revenues—not even counting the effect of the added oil production on economic growth—would be substantial.

It's worth noting that not all sources of carbon dioxide would require that level of subsidy, but power plants are the largest potential supplier of carbon dioxide. And over time, as technology and efficiency improve, costs should come down and the need for tax incentives should as well.

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Other public policies could also make EOR more attractive, reducing the need for tax credits. Tax-free bonds, for example, would improve the economics of many EOR projects; we issue such bonds for many other privately owned pollution-control systems but not for carbon capture. Congress could grant that authority, and advocates of this concept believe it would make many EOR projects economically feasible.

The EOR industry is going to grow on its own in the coming years, but public policy could greatly increase the pace and scale of its expansion. And while the market-focused mechanisms just described would have the most immediate effect, the shale gas model suggests that continued federal support for advanced R&D might be helpful as well.

To maximize the EOR opportunity, public policies should seek to ensure that the technologies can be applied widely and that the industry and its markets mature as quickly as possible, phasing out the need for financial incentives. Achieving both of those goals depends upon the same thing: development and demonstration of next-generation EOR technologies that will increase their efficiency and expand their applicability in geologically suboptimal conditions. Federal support could speed up that process.

Right now, EOR operations are centered in west Texas in the Permian Basin, in fields with very favorable geology. Under such optimal conditions, particularly in higher quality fields, the process is efficient: For every metric ton of carbon dioxide injected, 2.5 barrels of oil are produced. To maximize the market, though, we would want companies to be able to operate in more geologically challenging settings such as the Rocky Mountains, the Mid-Continent, and second-tier Permian Basin fields. In those places, EOR is pricier and less efficient; productivity tends to fall to 2 barrels of oil per ton of carbon dioxide injected.

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How to overcome that? Even modest federal (and/or state) support for research and development and, importantly, incentives for demonstration of more efficient EOR technologies for these geologically challenging contexts could be very helpful. Will the industry get there on its own? Probably, someday—but federal funding would almost certainly accelerate that process.

The issue is not merely maximizing the geographic scope and scale of EOR operations; this is also the path to making the markets self-sufficient, which would certainly be in the public interest. More efficient next-generation EOR technologies would make carbon dioxide more productive and consequently more valuable, reducing the need for tax incentives.

For example: If oil producers in the more challenging Rockies or Gulf Coast oil fields are able to recover only two barrels of oil per metric ton of carbon dioxide, and a ton of carbon dioxide costs $40, the CO_2 cost per barrel of oil produced is $20. But next-generation technology might make it possible to recover three barrels of oil for every ton of carbon dioxide used. That would mean the industry could afford to pay $60 per ton of carbon dioxide while keeping its costs constant at $20 per barrel. And as carbon dioxide becomes more valuable, tax credits could be phased out.

If public policies can accelerate the rate at which the industry moves along that cost curve—more efficient technologies, bigger markets—the payoff will be enormous. Domestic EOR operations now produce about 300,000 barrels of oil a day, but if the market took off, they could produce 10 times that amount.

People will understandably be skeptical of these claims. They've heard too many overblown promises from energy and environmental advocates. One important attraction of this concept, however, is that it puts the private sector in the role of evaluating commercial risks and financing projects; it only costs the government money once the process is nearly complete. So if the tax credit fails, it'll fail cheaply. To earn the credit, the carbon dioxide would have to be captured and injected into an oil field; at that point, we can be pretty confident that oil is going to be produced as a result. If the assumptions about the market effect of the tax incentive turn out to be wrong and companies don't find it profitable to do EOR, there simply won't be take-up on the tax credit; net cost, nothing.

This sort of public policy decision seems categorically different from government bureaucrats placing blind (if not biased) bets on an individual company's ability to build a new plant to produce a new commercial product that has to compete in complex, ever-changing global markets, as was the case with Obama administration missteps such as Solyndra, the now-bankrupt maker of solar panels, and Fisker, the failed maker of electric cars.

Aspects of this concept are, of course, somewhat out of step with the desire for broad tax simplification and technology-neutral public policies—but given the lack of progress on those fronts, it seems unwise to hold this opportunity hostage to larger goals that may never be accomplished. And of course this is not a never-ending federal handout to a fundamentally unproductive technology, but a revenue-positive tax credit to jump-start a market that would generate trillions of dollars of new economic activity based around increased supplies of a commodity that is a linchpin of our economy.

Still, skeptics will rightly wonder why the government should be involved in something like this. The answer comes down to the fact that there is a compelling public interest at stake in two critical dimensions: Expanding EOR markets could arguably do more to improve American energy security—in both transportation and electricity-generation fuels—while simultaneously moving us closer to a zero-emissions energy system than any other single policy we could pursue. Even small-government conservatives should be willing to consider policies that leverage such significant outcomes out of limited federal interventions, particularly when the alternative is an expensive and ineffective regulatory approach to these issues.

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This last point bears emphasizing: Industrial sources of carbon dioxide such as power plants would no longer be just electric generators in this context; they would become an integral part of the oil production process. There are places in America where there's a lot of oil to be had—if we had carbon dioxide to extract it. An EOR initiative would mean that the impetus to install carbon capture on power plants would no longer be a politically contentious pollution control measure imposed by Washington; instead, it would be a profitable way to harness an essential chemical for oil production.

It's also worth noting that EOR isn't the only way carbon might be productively utilized, although it is by far the largest, most reliable near-term opportunity. But there are a number of other potential markets for carbon dioxide, ranging from water desalination (where its use could cut costs significantly) to the production of chemicals, algae bio-fuels, and other commercial products. (In fact, carbon dioxide might even be used in fracking itself.) A host of companies are exploring these prospects; in October, a $125 million factory opened in Texas that uses a cement plant's carbon dioxide to make chemicals. If an EOR initiative created a multibillion-dollar market for carbon dioxide, supported by an extensive infrastructure for capturing and transporting the gas, these other potential uses of carbon dioxide would likely benefit as well.

It might seem fanciful to imagine that utilization could possibly compare to regulation as a tool for reducing carbon emissions, but the numbers suggest otherwise.

One thing that climate and energy issues have in common: *It's all about scale.* Whether the question is carbon reduction or energy production, it only really matters if you're talking about big numbers. So let's look at the potential size of enhanced oil recovery.

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Recall that most "depleted" oil fields still contain a lot of oil. Last year, the leading consulting firm in this field, Advanced Resources International, took a fresh look at how much oil remains in major deposits in the Lower 48 where EOR might be used (and in 2014 extended their analysis, the findings of which are included here). The figures are eye-opening.

Of the 600 billion barrels originally in those reservoirs, 182 billion barrels have been produced, and another 22 billion barrels are proven reserves that can be extracted economically with existing technologies and practices. That accounts for 204 billion barrels, meaning that nearly 400 billion barrels—more than twice the total amount produced to date—are "stranded" in these oil fields.

Advanced Resources International estimates that today's EOR technologies—including the next-generation technologies that an EOR initiative could bring to market—would make an additional 85.4 billion barrels economical to extract (this assumes oil prices at or above $90 a barrel and carbon dioxide prices at or below $40 a ton).

Those figures are conservative; for one thing, every time new oil fields are discovered, these numbers increase. Also, this estimate doesn't factor in the potential to reach into "residual oil zones," where oil is typically mixed with water and unavailable through conventional means. Residual oil zones contain another 140 billion barrels of oil, some significant fraction of which might be accessible using advanced EOR technologies. And, of course, if oil prices are higher than $90 a barrel—which, despite their recent decline, remains likely in the long run—or if EOR technologies and practices improve, then even more oil will become economical to produce.

Given that America's oil consumption is just under 7 billion barrels a year and domestic production is projected to top 3.1 billion barrels in 2014, the opportunity for federal policy to unlock access to 85 billion barrels of economical oil—potentially producing as much as an additional 2 to 3 million barrels of oil per day for the next 50 years—seems worthy of serious consideration to say the least.

The EOR opportunity is much bigger than Keystone XL—and it's American oil, not Canadian tar sands. It's bigger than the Arctic National Wildlife Refuge—and it involves extracting additional oil from existing fields; even the Natural Resources Defense Council approves of enhanced oil recovery as a pragmatic alternative to drilling new fields. And it could arguably do more for decarbonization than EPA regulations, yet it remains at the margins of the national conversation about energy and climate.

So the numbers are extraordinary on the energy supply side, but what about on the carbon reduction side? Democrats aren't likely to support a policy that's just drill-baby-drill; what's in it for them? Here too the tonnage is significant—and the strategic implications for decarbonization are even greater than the numbers alone suggest.

To produce the 85 billion barrels of oil that Advanced Resources International estimates EOR could economically reach in the United States, nearly 24 billion tons of carbon dioxide would be needed. Geologic (and low-cost industrial) sources might provide as much as 3 billion tons but other industrial and agricultural sources of carbon dioxide would be needed for the remainder—21 billion tons. When carbon dioxide is used in EOR operations, an initial fraction of it (roughly a third) remains underground; the rest comes up with the oil, where it can be recaptured and reused until it is all sequestered. You could think of EOR as a sophisticated form of carbon recycling and disposal.

If the only thing an EOR initiative did was to sequester 21 billion tons of carbon dioxide, it would still merit serious consideration. But the real measure of success is in innovation: What can EOR do to drive development of carbon capture and sequestration technologies?

Because carbon dioxide emissions are cumulative (carbon dioxide accumulates in the atmosphere), climate policies can't aspire simply to bend the U.S. emissions curve a bit. Stabilizing atmospheric concentrations of carbon dioxide—at any level, on any timeframe—depends on our ability to virtually eliminate emissions from key sectors such as electric power generation, and to do it globally. Incremental reductions aren't enough; you've got to get to zero.

Naturally, incremental reductions that reflect real progress toward that goal are productive—but not all policies that reduce emissions incrementally lead to zero. Natural gas proponents like to call it a "bridge fuel," neatly sidestepping the question of what lies on the other side of the bridge or how the two ends connect. Using more gas and less coal will lower emissions, but, without carbon capture, the improvement is 50 percent at best (and probably less). So if the goal is near-zero emissions, whether the fuel is coal or gas, there's no way to get there without carbon capture and sequestration.

Given the extraordinary abundance and affordability of coal and natural gas and the enormous established infrastructure for those fuels, pragmatists recognize that there is no practical path to decarbonization that doesn't start with the assumption that the world is going to continue to burn them for the foreseeable future. Progress on decarbonization depends therefore not on dreams of a day when the world agrees to leave fossil fuels in the ground but rather on finding practical ways to put their carbon dioxide back underground through carbon capture and sequestration, not just in advanced economies but also in the developing world. The metric of success for a climate policy should not be just the tonnage of avoided annual emissions; the more important question is whether we are making decarbonization possible and practical on a global scale.

Here's the thing about carbon capture and sequestration: We know how to do it—but it's far from being a mature technology. Capturing carbon dioxide from power plants is a challenging business, and doing it on a global scale will require advanced technologies and practices, a skilled workforce, robust markets, and extensive

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infrastructure. It's a long road from here to there. We can see the technology's potential, but without a practical path to commercialization, its development will be slow.

Although basic carbon capture and sequestration technologies have been demonstrated in varying configurations for decades, companies are only just beginning to do carbon capture and sequestration at full scale on power plants (including one that just opened in Canada, and another that will open in Mississippi in 2015). That means the technology is still at the most expensive stage of the learning curve, and there is almost no market demand for it today that would drive the necessary investments in innovation.

For carbon capture and sequestration to work well enough for both developed and developing nations to use it at scale, the core technologies and their associated markets and regulations will need to be much more developed, and costs will have to come down considerably. Assessments of the technology strongly suggest that can happen—but it will require finding a way to build a lot of these facilities and their supporting infrastructure, learn how to operate them efficiently, and learn how to build better ones. What is needed most is not just more research (although there's a role for that) but rather a way to pay the cost of building carbon capture and sequestration projects today at scale—to "learn by doing"—and to create market demand for next-generation technologies.

Regardless of one's stance on climate risks, finding cost-effective ways to develop carbon capture and sequestration technologies is important. The EPA's regulatory approach won't be the death of coal, but it will bring stagnation and long-term decline for the industry. Just the threat of EPA regulations—which will persist for years as the regulatory and legal processes play out—will deter the capital investments the industry needs to move forward. Over the long run, for coal to continue to serve as one of the bedrock fuels for electric generation in America, technologies to manage its carbon emissions will be indispensable. Unfortunately, EPA's regulatory proposals look like they may do little, if anything, to drive their development, so if we want to find ways to make carbon capture and sequestration work, we'll have to think about other approaches.

Policymakers looking to advance the development of carbon capture and sequestration techniques have three basic models at their disposal.

Option 1 is to have the federal government fund demonstration projects directly. We tried that during the George W. Bush administration, which selected a project known as FutureGen to be built in Illinois. After more than a decade of delays, that project has only just broken ground, so no one is looking to build on that model. The Bush administration also created, and Obama expanded, a Clean Coal Power Initiative that has helped fund the few carbon capture and sequestration projects that are getting underway—but since it requires a 50 percent cost-share from project developers, it's still a far cry from what would be needed to make a significant number of carbon capture and sequestration projects economical. That approach costs taxpayers too much while providing project developers too little support.

Option 2 is the Obama administration's approach: EPA limits on power plant emissions. It's anyone's guess what will emerge from the legal, political, and bureaucratic battles over EPA's proposed regulations, but one thing is fairly clear. The primary effect of whatever regulations survive scrutiny will be to encourage utilities to burn more natural gas and less coal, particularly over the next 15 years. This is one of the problems with setting modest targets for emissions reductions—industry's primary incentive is to seek low-cost compliance options such as fuel-switching rather than investing in development of deep decarbonization technologies such as carbon capture and sequestration.

That provides politicians the satisfying appearance of progress—*look, we're reducing emissions!*—while doing little to move us towards commercialization of near-zero emissions technologies such as carbon capture. Policies that promote fuel-switching take us on a slightly faster path to a somewhat lower but still-high emissions plateau. If we want to get to near-zero emissions from these power plants, we'll need policies that specifically target development of carbon capture and sequestration technologies and markets.

Which brings us to option 3, enhanced oil recovery. To provide the 21 billion tons of carbon dioxide needed for EOR to reach the 85 billion barrels of economical oil, utilities would need to install carbon capture equipment on about 122 gigawatts worth of coal-fired power plants (assuming for the sake of simplicity that all the carbon dioxide came from power plants—in fact, some would come from other sources). That would mean putting carbon capture and sequestration on roughly *half of the coal plants* expected to be in operation over the next 30 years (taking anticipated plant retirements into account).

The significance of that figure can hardly be overstated. EPA regulations aren't going to put carbon capture and sequestration on half the coal fleet—not even close. Federal demonstration projects and grants certainly won't. EOR demand could generate over $800 billion in revenue from carbon dioxide sales, much of which could be invested in developing and operating the infrastructure of carbon capture and transportation. Where else is that level of investment going to come from?

EOR's revenues offer what is almost certainly the only practical path to making the investments necessary to demonstrate carbon capture and sequestration technologies at scale, build out supporting infrastructure, and develop the legal, financial, commercial, and institutional structures and relationships that would make the industry a credible option for decarbonization. And a policy push for EOR would put American companies at the forefront of another energy revolution, just as they are with fracking, with the opportunity to sell technologies and services in potentially vast global markets.

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The best evidence for EOR's potential to drive carbon capture and sequestration development is that it's doing so already, even without the benefit of strong federal support. Every new carbon capture and sequestration project underway or recently opened in North America—Southern Company's Kemper project in Mississippi, a new power plant with carbon capture and sequestration; SaskPower's Boundary Dam project retrofitting carbon capture and sequestration to an existing coal-fired power plant in Saskatchewan, Canada; and NRG Energy's newly announced W. Parish project near Houston—relies heavily on EOR revenues (as well as government grants). Because of the location of the plant, NRG is also able to take advantage of tax-free bonding of the kind that could help other EOR projects.

Having said that EOR's potential to drive carbon capture and sequestration could hardly be overstated, I should make sure that I haven't done just that. EOR is a way to instigate and pay for the development of advanced carbon capture and sequestration technologies and infrastructure, as well as the legal, governmental, and commercial structures necessary for the industry to thrive. The size of the EOR opportunity will probably increase over time. But recycling carbon into oil production and other products won't solve the carbon dioxide issue entirely. EOR markets might cover the costs of sequestering an awful lot of carbon dioxide for a long time—but not forever. Some day, policy-makers would have to revisit the question of how much they might be willing to pay to continue sequestration.

But by that time, they wouldn't be fighting a pitched battle over whether a federal agency can and should impose regulations requiring the use of an immature technology that is not yet proven on a commercial scale, where the price and performance of the technology remain uncertain and daunting. Instead, they would be making a well-informed decision about the continued use of a highly refined technology with well-understood costs and performance characteristics that is supported by an extensive, sophisticated physical and commercial infrastructure. By that point, costs of sequestration should be dramatically lower than they are today.

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We can't know how much society might value decarbonization in the future, we can only work on finding practical ways to develop tools that could do the job, recognizing that the lack of such options is the primary source of political conflict over carbon today. Instead of placing blind bets on Rube Goldberg regulatory schemes resting on creative interpretations of outdated laws and a host of farfetched assumptions, climate advocates would be asking governments to make informed choices about using proven, affordable technologies. That would be a very different conversation.

One other issue requires consideration: the emissions from burning the oil that enhanced oil recovery would produce. To many environmentalists, using carbon to produce more fossil fuels could hardly be more perverse. How does this get us ahead? This is, unfortunately, a very complex question. Let me sketch the outlines of an answer.

Emissions from transportation and from generating electricity are in a sense almost entirely separate issues. In both sectors, decarbonization using today's technologies is impractical; success depends on developing innovative technologies with far better price and performance than we have today. If we want decarbonization options for electric power, we need policies that will develop those technologies; if we want better transportation options, we need polices that target those technologies.

Enhanced oil recovery, as I have argued, is the only realistic path to developing carbon capture and sequestration technologies, which will be needed for decarbonizing electric generation. Decarbonizing transportation systems is mostly a different question—although it's worth noting that carbon capture and sequestration is also essential for low-carbon transportation options such as electrification and some alternative fuels.

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The important thing to appreciate is that the development of those transportation technologies is not going to be hindered by the production of another 60 or 80 or even 100 billion barrels of oil in the United States. Those technologies will rise or fall on their merits, and when they can compete with conventional cars and trucks and buses, they'll win; the marginal effect that EOR will have on the price and production of oil won't hinder that process.

That's a conceptual answer to the question, but some people will want to understand the math as well: Will producing more oil in America using EOR increase or decrease carbon dioxide emissions?

The long-term answer to that depends not on simple carbon-in, carbon-out arithmetic but on one's assumptions about EOR's influence on the oil and electric power markets. If one thinks of EOR's oil as *additive*—additional oil that would otherwise not be consumed—and doesn't take into account the displacement of more carbon-intensive electric power by carbon capture and sequestration, then EOR could release more carbon dioxide than it eliminates. But if you believe that oil produced by EOR will mostly *displace* imported oil, and that low-carbon electricity from carbon capture and sequestration will displace higher-carbon power—which seems likely, at least to some extent—then EOR will sequester more carbon dioxide than it produces.

To give an example of the complexity of the calculations: Critics of EOR often cite a 2009 study by Carnegie Mellon's Paulina Jaramillo (with coauthors W. Michael Griffin and Sean T. McCoy), which concluded that each ton of carbon dioxide injected in EOR operations produces oil that releases 3.7 to 4.7 tons of carbon dioxide emissions.

Sounds pretty bad, right? But that figure assumes the oil and electricity from EOR are added to what's already available; naturally, that means net emissions increase. If you incorporate the more realistic assumption that the oil and electricity produced by EOR and carbon capture and sequestration would displace other energy from the market, Jaramillo concedes that EOR reduces net emissions by about 20 percent, a figure that

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rises to 30 percent when compared with Canadian tar sands oil and new coal plants. The National Environmental Technology Laboratory (NETL) also looked at this question last year and came to similar conclusions (although their figure for EOR's additive emissions is 1.7 tons of carbon dioxide, a much lower figure than Jaramillo's).

These studies are far from perfect—answers to these questions depend on long-term projections about the behavior of oil and electricity markets during periods of significant change—but the broad picture they paint is probably not far from the mark.

Here's a simpler way to think about this question in present-day terms: A barrel of oil contains 0.43 metric tons of carbon dioxide. As mentioned previously, current EOR operations in the Permian Basin use 0.4 metric tons of carbon dioxide per barrel of oil recovered; even without taking displacement into account, that process is essentially carbon neutral. Add in the displacement of conventional oil and we are well on our way to net sequestration.

One can think of the combination of enhanced oil recovery with carbon capture and sequestration as providing low-carbon power or low-carbon-dioxide oil, or arguably both, but certainly not neither. EOR's direct effect on carbon dioxide emissions may be somewhat uncertain, but at worst it's a wash, and more likely it sequesters more carbon than it produces. What is indisputable is the progress it could provide toward the metric that matters most: EOR is the only plausible way to pay for the development of advanced carbon capture and sequestration technologies and the billions of dollars of infrastructure investments that will be necessary to make the technology a workable option for controlling carbon dioxide emissions from fossil fuels.

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Whatever one concludes about the direct sequestration question, anyone who is serious about practical decarbonization pathways cannot afford to ignore EOR. It's difficult to compare EOR's direct annual emissions reductions to the possible effects of EPA's regulatory proposals, but if our ultimate goal is a practical pathway to commercialization of carbon capture and sequestration, the potential power of markets for carbon dioxide utilization cannot be denied.

Carbon utilization is not receiving nearly the attention it deserves. We should be having a national conversation about enhanced oil recovery; instead, we are obsessed with issues that are almost trivial in comparison. The basic facts of the matter seem clear: Carbon capture and sequestration is probably indispensable to any pragmatic approach to decarbonization, and EOR appears to be the only practical way to underwrite the extensive up-front costs of developing carbon capture and sequestration technologies, infrastructure, and markets.

Using carbon capture and sequestration to enable enhanced oil recovery is the path to keeping coal in our energy economy while simultaneously achieving our environmental goals; without it, we are likely to lose both battles. The choice is between a declining-but-not-disappearing coal industry that can't invest in innovation and a thriving, productive industry that could develop effective carbon management technologies. EOR could produce tens of billions of barrels of oil in America while sequestering billions of tons of carbon dioxide and driving over $800 billion in investments in decarbonization and energy production technologies. And it would establish a different model for meeting the climate challenge: *Make decarbonization technologies affordable and productive rather than trying to make carbon-intensive energy more expensive.*

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A national enhanced oil recovery initiative wouldn't entirely protect America from the vagaries of global oil markets or fully eliminate carbon dioxide emissions from our electric power plants—but it would make genuine, important progress on both fronts, and that would be no small feat.

Samuel Thernstrom, a senior fellow at the Center for the National Interest, is the founder and executive director
of the Energy Innovation Reform Project (innovationreform.org). He participates in a bipartisan coalition that advocates for an expansion of federal incentives for enhanced oil recovery.

Web Link: http://www.weeklystandard.com/article/821866

John Kelly In, Reince Priebus Out as White House Chief of Staff

President Trump announces the latest White House shakeup with a Friday afternoon tweet.

5:40 PM, JUL 28, 2017 | By ANDREW EGGER

President Donald Trump announced the latest White House shakeup via Twitter on Friday afternoon, tweeting that John F. Kelly would replace Reince Preibus as White House chief of staff.

...

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I am pleased to inform you that I have just named General/Secretary John F Kelly as White House Chief of Staff. He is a Great American....

4:49 PM - Jul 28, 2017

19,386 24,485 92,851

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...and a Great Leader. John has also done a spectacular job at Homeland Security. He has been a true star of my Administration

4:54 PM - Jul 28, 2017

7,672 14,468 68,500

The move follows months of speculation that Priebus was not long for the job, which grew to a fever pitch when Trump took on rival Anthony Scaramucci as his communications director last week. Priebus successfully convinced Trump not to give Scaramucci a role in his administration in January.

Priebus, the former three-term chair of the Republican National Committee, struggled to bring order and unity to Trump's chaotic White House.* Priebus reportedly resigned privately on Thursday, according to sources with knowledge of Priebus' conversations with Trump.

The president has grown obsessed in recent months with White House information leaking into the press, and Scaramucci is convinced Priebus has been responsible. The new comms director viciously attacked Priebus, calling him "a f—ing paranoid schizophrenic" in a conversation with the New Yorker's Ryan Lizza.

"Oh, Bill Shine is coming in," Scaramucci said to Lizza, imitating Priebus. "Let me leak the f—-ing thing and see if I can cock-block these people the way I cock-blocked Scaramucci for six months."

Kelly, Priebus's replacement, is a retired Marine Corps general and the former commander of the U.S. Southern Command. As Secretary of Homeland Security, he has ferociously advocated for Trump's agenda, most notably by advocating for the complete construction of the U.S.-Mexican border wall within two years.

Kelly has also repeatedly demonstrated the personal loyalty Trump craves by defending the administration's conduct on television. In March, when Trump baselessly accused Barack Obama of ordering him wiretapped, Kelly said Trump must have "some convincing evidence that took place." In May, Kelly defended Trump's son-in-law Jared Kushner after it was reported that Kushner had attempted to set up a back channel to communicate with Russia.

"There's a lot of different ways to communicate, back channel publicly with other countries," Kelly said. "I don't see any issue here relative to Jared."

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