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

Wednesday, September 13, 2017

United States Senate

Committee on Environment and Public Works

Washington, D.C.

The committee met, pursuant to notice, at 10:04 a.m. in room 406, Dirksen Senate Office Building, the Honorable 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.

STATEMENT OF THE HONORABLE JOHN BARRASSO, A UNITED STATES  
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<sub>2</sub> 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 CO2 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.

[The prepared statement of Senator Barrasso follows:]

STATEMENT OF THE HONORABLE THOMAS R. CARPER, A UNITED STATES  
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 eight 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 eight 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 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 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:]

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 CO2 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 five 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 CO2 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<sub>2</sub>-EOR industry.



One of the primary purposes of the pipeline network is to connect oil fields suitable for EOR with CO2 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 CO2; 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:]

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 seven 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<sub>2</sub>, 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 eight months of operation, we have injected almost 1 million tons of CO2 into the oil field, and that CO2 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:]

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<sub>2</sub> enhanced oil recovery, which was mentioned by the Chairman, CO<sub>2</sub> 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<sub>2</sub>-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 one percent of that money, less than one 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<sub>2</sub> 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 start-ups. 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 parity 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:]

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 CO2 pipeline development, with the Wyoming Pipeline Corridor Initiative that you outlined. This proposes developing a network of CO2 pipelines connecting oil fields with CO2 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 CO2 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 CO2 for enhanced oil recovery is a more powerful incentive to develop projects like this and decrease CO2 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, yeah, 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 CO2 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. Okay. Thank you.

[Laughter.]

Senator Carper. Whatever.

Mr. Friedmann. My mom is Columbian, my father is Venezuelano, 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 CO2 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. Okay, 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. Okay, 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<sub>2</sub> from gases produced in electricity generation; secondly, purified, compressed, and all of that; and, finally, the CO<sub>2</sub> 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 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. Yeah. 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 CO2 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 towards 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, yeah, 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 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 CO2 with technologies that relate to extracting the CO2 load from our oceans, which are dramatically

acidifying as a result of the CO2 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. Okay.

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. Okay.

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. Number one, you can simply say, well, we are going to add a cost to anybody who creates carbon within the atmosphere or, number two, 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 follow up 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<sub>2</sub>. 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 benefitted 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<sub>2</sub> from the air and then you put the CO<sub>2</sub> 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 of 2017. This project can capture up to 1.1 million tons of CO<sub>2</sub> 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 CO2 through the company of Chaparral into Oklahoma for enhanced oil recovery. There is quite a lot.

Senator Capito. Okay. 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 okay.

[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 CO2 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 intrastate, 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<sub>2</sub>-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<sub>2</sub> 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 CO2 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:]

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 CO2 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 CO2 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 okay 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 two 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.]