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POLICIES TO COMMERCIALIZE CARBON CAPTURE AND STORAGE IN THE UNITED STATES

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P R O C E E D I N G S

MR. BOERSMA: Ladies and gentlemen, good morning. We're gonna get underway. Thank you for being here. Welcome to Brookings. I'm Tim Boersma. I'm the Acting Director of the Energy Security and Climate Initiative here at Brookings. We're here this morning to talk about carbon capture and sequestration technology, CCS from here onward, as I'm sure you all know.

I'm delighted to share with you that we have a number of true hard hitters where on the podium on this topic, who I'll briefly introduce to you. To my left is Sasha Mackler, who's the Vice President at Summit Power Group responsible for their work on CCS technology. Next to him, Professor Ed Rubin, who's an alumni chair professor of Environmental Engineering and Science at Carnegie Mellon. Truly one of the leading experts on this topic. We're delighted to have both these gentlemen with us. And then to my far-left, Professor John Banks, who has been a Senior Nonresident Fellow with our program at UCI for a significant number of years. Teaches at Johns Hopkins across the street in Georgetown in town, so he's a regular to our program. Delighted to have him. And he is a co-author of this study that we're here to talk about today, which looks at the status of CCS technology in the United States in particular.

So the outline for the next roughly 45 minutes, I would estimate is as follows. John and I are gonna give you a bird's eye perspective, if you will, of what we've been doing over the course of the last say five months. What the main findings of our research are, what we've done and why we've done it. And then John will get into the main findings and policy recommendations.

And after we've done that, and given you that broad overview, we're gonna turn to both our guests who are gonna give their perspectives a) on the report, but share some of their knowledge and expertise in the field. So we'll hear from them shortly.

Let me kick this off briefly with first what is CCS? I think most of you are familiar with this integrated process of capturing carbon dioxide from power stations, or industrial activities, and storing it permanently into suitable geological formations. In short the working definition that we used in our report, which by the way I should have mentioned, you can all find online on our website from this point onward.

So CCS is a climate mitigation tool, because it captures manmade carbon for the

purpose of isolating it from the atmosphere. Then the next question is why is this important. It's a low carbon technology. It can be part of a broader portfolio to address climate change. It's currently the only available technology that can significantly reduce emissions from existing energy infrastructure, offering a pathway to transitioning those fossil fuel assets into a low carbon economy.

There a number of points I want to make why we think this is important. First of all, even though not everyone is convinced, the majority of people fortunately is, climate change is a serious and real problem. A number of studies suggest we're currently (not) on the trajectory to the meet the famous two degree Celsius line. After which it becomes increasingly unpredictable, but we know that we are reaching dangerous levels of climate change at that point from then onward.

In fact, global emissions are expected to increase up to 2040 to nearly 20% above the 2012 levels. Second important reason why this is important is that fossil fuels will continue to play a major role in the global energy mix. Coal demand is expected to increase throughout the non OECD world at fairly dramatic pace. And in addition, natural gas usage is also in the OECD world, in developing world, increasing its share. And, as you all well know, burning natural gas comes with carbon emissions as well.

CCS can play a crucial role in addressing some of these consequences. It's fairly certain that expanding the share of renewable energy sources alone is not going to be sufficient to meet that two degree Celsius line. And CCS can therefore plan an important role. According to some studies, for instance, the International Energy Agency, accounting for up to 14% of cumulative emissions reductions by 2050.

A number of studies also indicate that without CCS that two degrees Celsius line that I mentioned, cannot be reached.

So finally, maybe most importantly, there's a number of major studies and scenarios, amongst others the World Bank, the IPCC, and the International Energy Agency, that suggested in the long run CCS is actually a cost effective measure to combat climate change.

So despite this apparent potential to be a carbon mitigation technology, CCS has been very modestly deployed in the electricity sector, which is the focus of our study. In fact, there's currently

only one fully operational electricity plant with CCS and there's two more under construction, so it's very modest.

Why is that? And I know that our guests will get into that in more detail, but in essence, it's because of inadequate government support and a lack of carbon policy. Without requirement to reduce emissions, you know, electricity generators are very hesitant to use the technology. And it's chiefly because of its high cost.

In particular, capturing carbon is a rather energy intensive process and without a market for carbon it doesn't really make sense to use that technology. Moreover, in order to achieve cost reductions for the technology at whole, next to R&D you'll need substantial commercial deployment of the technology. And for that in turn to happen, you need a market for carbon. So you're in this circle where this is not really moving forward.

I think it's important to note though that a market for carbon alone is not enough. If that were the sole focus, then electricity producers would likely continue what we already see happening in the United States, which is fuel switching. Switching away from coal and just building new gas fired facilities instead.

Hence, you need a broad policy framework that spurs technological refinement and addresses various uncertainties and risks of all the three components, so capture, transportation, and storage of the CCS value chain.

In our study we focused on those risks and barriers related to CCS at electricity plants in the United States and the existing policy framework to support its application. I'm gonna turn to my colleague, John Banks, now, who is gonna talk us through some of the main findings in that study.

MR. BANKS: Thanks, Tim. Contrarily to what it might look like, there isn't a CCS uniform. We're all wearing blue suits, at least we have different ties on at least anyway. Thanks, Tim. And thank you all for coming today, and also thank you to our two distinguished guests for joining us on the panel.

As Tim suggested, what I'd like to do is just give you sort of a highlight of the research that we conducted and also provide you some of the major themes and issues that emerged in our

discussions with a quite wide array of stakeholders in this field. And also give you a sense of our main conclusions and recommendations. Obviously, in these opening remarks, I won't go into great detail but just give you some of these highlights.

As Tim suggested, one of the first things we really wanted to do is to get a handle on exactly what the risks and barriers are confronting CCS. And really there is a way of categorizing these as there's really three: the financial risks, the technology risk, and climate policy uncertainty. Tim alluded to the financial risk, which really revolves around very high upfront capital costs as well as high operating costs. The later related principally to the additional energy that's used to run the capture and compression equipment that adds costs per unit of electricity produced.

The National Energy Technology Lab at DOE, in July I think, recently provided some estimates on the additional costs, and it ranges around $60.00 to $70.00 per ton captured. And that's for a range of super critical pulverized coal plants to IGCC and NGCC, natural gas combined cycle plants.

The technology risk is really the lack of experience and information we have in running captured systems, carbon capture and storage projects in an integrated fashion in a commercial and market environment. And that learning experience could show us the impact of running such systems on things like maintenance, workforce training issues, cycling, etcetera.

The last is climate policy uncertainty. And I think here, this is really one of the major messages that we heard in our discussions that we try to emphasize in this report, which essentially is that there is no market for CCS technology in the absence of a requirement to reduce CO2 emissions. And that message really came across quite strongly, and of course, you all realize that, and Tim alluded to this as well, there are other market dynamics, market conditions that affect the viability of a CCS project. Not the least of which is cheap natural gas. We heard one comment that there is really no incentive to apply a capture system to a PC plant right now, a pulverized coal plant, unless you see gas prices approaching or exceeding $10.00 per million BTU.

But I think here it's important with this lack of climate policy risk or barrier that confronts CCS, to note a couple of things. And that is that CCS is also applicable to natural gas fired power plants. And with the U.S. EIA projecting that over 70% of additional capacity being natural gas in the U.S.

through 2035 or 2040, there's gonna come a point where in the out years to meet decarbonization targets, you're either gonna have to phase out gas, or apply CCS to natural gas fired plants.

And the other note is that it is very illustrative and noteworthy, I think, to mention that of the three plants that have proceeded the farthest in the world, in North America, the SaskPower Boundary Dam plant in Canada, and the two under construction in the Unites States, Petra Nova in Texas, and the Kemper project in Mississippi, all of them are selling the captured carbon for enhanced oil recovery. That improves the economics and the viability of a CCS project, and provides a market, we'll talk a little bit more about that later on.

So those really are the three major risks and barriers confronting CCS and I think go a long way to explaining together why you see so little progress on commercializing and deploying CCS on a wide scale. So we next wanted to turn to looking at what U.S. policy is right now, what is the current framework supporting CCS and what maybe some of the gaps and weaknesses in that policy framework.

The federal government, principally through DOE, has been supporting CCS since 1997. Several states also have financial and other incentives supporting CCS. The federal government support is largely focused on the capture and the storage side. Policy has also largely focused on R&D and support for demonstration. And there are also several financial incentives, notably a loan guarantee program, as well as a variety of tax credits, investment tax credit, and a tax credit for EOR.

The Congressional Research Service recently estimated that between fiscal year 2008 and 2014 that amounted to about $6.4 billion in support. And since 2009 most of that support, a pretty large amount of it, has been in support of large scale demonstration projects, principally through Future Gen, which has now been cancelled. We can come back to that. But also the Clean Coal Power Initiative, CCPI program, which has provided grant money for several projects that are active.

But what we found in our discussions, again across a wide variety of stakeholders including a number of project developers, is that there's several pretty core weaknesses or gaps in this policy framework. Just quickly, and we'll go into some details on this, but notably that there has just been insufficient support for large scale demonstration projects. The existing financial incentives are inadequate as designed. Principally that while you have these financial incentives in place, and they may

go toward addressing the financial risk, they do not address the risk or the barrier of creating and helping create a market for CCS technology.

But most importantly, I think from our perspective, is that you really see a lack of policies on the backend that help to establish sizeable CCS markets. CCS policy in the U.S. is largely weighted toward the frontend of the policy spectrum, and policies to improve and facilitate and accelerate the innovation process. It's largely geared toward R&D. There's much less emphasis on the backend, policies to try to pull the technology into the market, namely to create a market for CCS.

And if you look at the projects that were initially awarded funding under the CCPI, the Clean Coal Power Initiative, the three that pulled out, American Electric Power, Basin Electric, and Southern Company cited the lack of ability to recover costs and uncertain market and regulatory conditions as the reasons why they pulled out. So the private sector sees this regulatory, the climate policy uncertainty as a major barrier, and is a reason for pulling back from their support.

So to conclude, what we see from this is that essentially current policy is really inadequate to spur commercialization of CCS in the U.S. R&D alone is not going to do it. Financial incentives are not going to do it. Essentially the policy framework is at the moment not capable of addressing the range of risks, the spectrum of risks that we just outlined. And so what we're looking to try to do here is to spur a conversation on what sort of policy portfolio is required for supporting CCS. That this is really a policy challenge, not a technology challenge. We need a cohesive, coherent policy package that addresses the range of risks and secondly is feasible, takes into consideration the political realities, that that policy package has to be cognizant of the political realities, try to reduce the burden on taxpayers, the government budget, and also facilitate ease of implementation.

And so we put forth, and I'll just highlight a few things here on what that policy package could look like, that takes into consideration the goal of addressing that spectrum of risks and is also politically feasible. And the first is to address the technology risk, we need some sort of off-budget funding mechanism that generates sufficient financial resources in particular for large scale demonstrations. There's no question there's widespread consensus that demonstration projects are needed in order to advance along the learning curve and help to reduce costs.

And Professor Rubin, in particular, has done studies looking at the deployment of other environmental technologies in the past and looking at the learning curves and cost reductions associated with deployment of those technologies and derived some rules of thumb for what it would take to deploy CCS. But what we're looking at is a dedicated CCS trust fund supported by either a wires charge or some sort of public good surcharge. And, again, Professor Rubin has done some work on this going back to 2008. And, in fact, there was a proposal on the Hill from Representative Bucher back in 2008, 2009 drawing on Ed's work in this area.

Essentially, this would mean establishing a dedicated trust fund for CCS with the idea the bulk of that money would be used for funding expensive large scale demonstration projects. You would apply a levy or an assessment on a per kilowatt hour basis to coal fired generation, or perhaps fossil fuel fired generation. The revenues from that would be put into the trust fund and then used for supporting CCS. And assessment or a levy, a public good surcharge, meaning you could put this levy or assessment on something outside of the electricity sector, perhaps there's been some suggestions on fossil fuel production or fossil fuel exports, for example. But the idea is that that money comes back into a trust fund that is used to support CCS.

To address financial risk we have sort of a two-pronged idea here. One is that there are modifications you can make to the existing financial incentives. Perhaps better designing the loan guarantee program addressing some of the issues that have been raised with regard to how that is implemented. And modifications to some of the existing tax credits including 45Q, which is the tax credit for enhanced delivery recovery.

And also some new mechanisms that could be considered. And there's some work being done here. I'll mention two mechanisms we think should be under special consideration. One is master limited partnerships. Senator Coons from Delaware, has proposed back in 2013 and again most recently that the master limited partnership approach be applied to not only renewables but also CCS. Essentially MLPs are a business structure that provides some tax incentives and allows a way of raising funding and accessing financial markets.

And secondly, a private activity bond. There has been some activity looking at private

activity bonds, which is essentially a revenue bond that is issued by a municipality or a local government, that also has tax benefits. The revenues from the issuance of that bond can be used for projects in the public benefit. These are used, for example, for sanitation projects and the transportation, airports, things like that. But it's another financial mechanism, another way for CCS projects to potentially access financing.

And then finally, on the sort of challenge of creating markets for technology, I don't think there's any way around not discussing the need for a federal carbon policy to create a market for CCS technology. In the course of our research discussions it became quite clear, and we heard a number of people say that markets spur development and deployment. And in fact, one project developer articulated it as some form of economy-wide push to value carbon reductions is needed to demonstrate that there's a market for the technology.

Of course the challenge is in determining how you set that carbon price. And as Tim alluded to or mentioned earlier, just because you have a price on carbon that alone may not be sufficient. Because in a low natural gas environment you may not be able to set the carbon price high enough initially to create this market. You could also do it through performance standards and the EPA's Clean Power Plan will be a way to develop some sort of implicit carbon price. But in isolation that may not be enough in a low gas price environment with no carbon price. So there may be a rationale for looking at some combination of a carbon price with performance standards in order to generate sufficient policy support to create that market.

And I'll just conclude, there are other details, and some other policy mechanisms we suggest, I just wanted to highlight those. But I think the main message here is that what we define as a need for a sort of a next generation set of policies for CCS. And the characteristic of those next generation policies is that they need to be effective. There need to be multiple policy mechanisms to address the multiple risks across a spectrum that confront CCS. And they need to be feasible. They need to be cognizant of political realities and try to facilitate ease of implementation.

I'll just paraphrase our friend and colleague, Mike Levi, from CFR who said, and I think this summarizes our view on this, that betting entirely on renewable energy or nuclear energy, or treating

all fossil fuels as the enemy, is bad. It's a dangerous path. We have to build, I think, some kind of at least minimal baseline consensus that decarbonization can offer us and help us achieve a balance in meeting environmental, energy security, and economic goals. And if we're really serious about decarbonization particularly in the long term, then we need a policy approach that leaves no low carbon megawatt hour behind. And I think a policy framework that at least allows CCS to be considered, is a way of making CCS a viable part of that kind of approach. Thanks.

MR. BOERSMA: Thanks very much, John. We're gonna turn to Professor Rubin, sharing some ideas. You've seen this report. You've been engaged with our research. We're very grateful for that, for the exchanges we've had. Love to hear your views on the reports, and also some broader takeaways you'd want to share with us.

MR. RUBIN: Happy to do that, Tim. So just a word of background, I met these two gentlemen for the first time earlier this year when they invited me to come down to a meeting of their coal taskforce. It was back in May, I think. At which CCS was one of the topics being talked about. A couple weeks later I got a phone call from John saying that they were thinking about focusing on CCS as a subject of a policy brief. I had seen a couple of policy briefs in preparing for the May meeting, they tend to be six or eight pages, and pretty tight. And I said sure I'd be happy to help talk about CCS.

And then they went off and spent the summer and I was blown over by this, I don't know if you've had a chance to see it yet, very substantive document. So I know how they spent their summer vacation. (Laughter) Bottom line is I was just enormously impressed by how much work had gone into that report, how much these two gentlemen absorbed, how thorough they were in coming to their own conclusions about a lot of things that many of us have been talking and working on for many years, but not them. As far as I know, this is the first time Brookings has poked their finger into the world of CCS. And it's very welcomed, and I think very important contribution for a couple of reasons. One is in fact that Brookings has a very strong and solid reputation. They've been in Washington a long time doing a lot of good work. And the fact that a fresh look at this topic by two people who know how to sort wheat from chaff, I think is just very refreshing and potentially very important in terms of perhaps redirecting or resuscitating the conversation around CCS. So kudos to you. My hat's off to you. I think you've done

just a fantastic job. I just wanted to make -- when they told us about the arrangements for this meeting, I said you've asked us to speak for as long as you, I figured five minutes would do it.

But I just wanted to make a couple of high-level comments, then welcome some discussion, about things that I think are particularly important that their study has done. One is to, again, focus on the importance of CCS as really an essential option for climate change. There have been basically no changes in the results of lots of studies around the world over the last 10 or 15 years as to what it would take to achieve climate stabilization goals. That is stabilizing the climate in a way that would prevent a lot of potentially unpleasant outcomes.

And there has not been a single study that has shown how you could get to those very substantial objectives without doing two things. One, requiring large emission reductions of carbon, not small reductions. So if the climate problem could be solved by a 10 or 20 percent reduction in carbon emissions, we probably would not be talking about CCS. But in a situation where addressing the climate issues requires 50, 60, 70, 80, 90 percent reductions in long-term emissions, that's a very different world than the one we're living in today dominated by fossil fuels. And if one is gonna try to move in that direction, in a way that doesn't bankrupt the world, the least cost way of doing that involves a portfolio of technologies in which CCS is basically essentially.

The computer experiments where you take away one technology at a time, find solutions except when you take away CCS. It's just not easy to get there as far as we know today. So focusing the spotlight on that and the importance of that, I think has been a very useful contribution.

The other is, again, John and Tim mentioned it as well, focusing on the fact that CCS is not just about coal. It kind of started out that way and a lot of the discussion around CCSs involved around coal, because most of the CO2 that we've seen recently has been from coal fired power plants. But that's really not the way, I think, to think about CCS going forward. I was particularly happy to see them title their report as fostering low carbon energy. That's really the way to think about CCS. It doesn't automatically fall off the lips of people who talk about low carbon, when you hear nuclear renewals, dah-dee-dah, but it needs to be put on that list. And it needs to be inserted into the conversation, because it's a low carbon energy for fossil fuels, not just coal, but increasingly natural gas. A number of us have been

talking about the importance of that in a while.

It's hard to envision, again, reaching the kinds of policy goals that we have today. State of California is an example, without also having CCS and natural gas. Natural gas alone is not, I would say a low carbon energy source. It's lower than coal, but it's still a half a ton of CO2 per megawatt hour of electricity. You can do better than that.

CCS with biomass is something that's getting increasing attention, not in the media, but in the climate modeling and policies communities looking out to mid-century and beyond the potential for having to not only remove carbon from sources, but actually find ways of removing CO2 out of the atmosphere, such as by using biomass and the magic of photosynthesis to take carbon out of the air. Using the biomass for energy and then sequestering the CO2 there with CCS.

So, again, it's something that should be thought of broadly as a low carbon strategy and I applaud them for emphasizing that point.

They pointed out, again, the barriers, when I talk about barriers to CCS, I've got one slide I've used a couple of times and it says, "policy, policy, policy." I took that cue from the real estate agency, what determines the value of your house, right? Location, location, location. You all heard that one. I think the analogy here is policy, policy, and policy. Clearly policy is related to other things. It's related to the cost and performance of technology. It's related to a whole series of legal and regulatory issues. And related to public perception and there's kind of a circle of interactions around these things that determines outcome. But without a policy driver, why on earth would you want to capture carbon?

It isn't fundamentally an environmental technology. CCS does not generate electricity. It doesn't generate anything else that people value and want. If Steve Jobs were in the business of promoting CCS, he'd had a tougher problem than with iPhones. So without a policy driver, without a requirement to solve a problem with the commons, just the way we've solved problems starting with particulate matter and smoke, and going to SO2 and NOX, without a policy driver there effectively is no substantial market for this technology. So, again, I applaud them for highlighting that, for stresses the importance of that, and for making some specific suggestions with which I certainly cannot disagree, because they're very similar to things I've been saying. And obviously they're wise and came to the same

conclusions quite independently. I was very happy to see that in their report.

Today in this country, up until a month ago, we had no policy driver at the federal level. Now there's a beginning of one. There's a new set of regulations on CO2 from power plants. But it's not the kind of national policy driver we were talking about six or seven years ago. There's still the need for that. So absent that, what to do?

I think, again, they've done just a very nice and thorough job of putting together a package of options, things that one can do both at the frontend -- the backend is basically the policy driver -- but the frontend is coming up with resources in a sustained way to both pursue R&D and develop as DOE is aggressively trying to do second and next generation technologies that are less costly, more efficient, and more readily available. But at the same time, using what we have and know now, which is quite substantial, to get it built, demonstrated, understand what new problems might arise, fix them, and drive down the cost of the technology.

That's an expensive program and that's where you basically need a billion with a B dollars per project. So, again, recommendations like I was very happy that they also thought a trust fund idea was a good idea. Basically we're looking for revenue streams that don't have to come from Congressional appropriations every year. A trust fund is one of the ways that potentially could do that, to raise the kinds of funds that are needed to put real large scale projects on the ground at the same time we're supporting longer term investments.

So, with that, I've probably exceeded my ten minutes and I'll stop and turn it over to Sasha, or whatever the next agenda item is.

MR. BOERSMA: Thanks very much for those remarks, and very kind remarks. Appreciate it. We're gonna turn to Sasha indeed, who takes a different perspective, who knows the public policy side well from the past, and knows the challenges there, but looks at this as a project developer.

MR. RUBIN: Sasha can show you his scars after the meeting.

MR. BOERSMA: Definitely. We'll turn to you, please go ahead.

MR. MACKLER: Thanks. And you know being the last speaker, you know, I'll have to think of something new to say because I really agree with everything that's been said so far.

First of all let me just say again what an excellent report this really is. The CCS community has been through a lot of ups and downs I think over the course of the last 10 to 15 years. And there's been a lot of thinking that's gone into how to promote carbon capture and how to articulate the importance of CCS. And it's really nice now, I think, to see that all sort of find its way again into one sort of synthesized report now as sort of flashback, for me, for the last decade of all the sort of ideas that I've seen been proposed, and that I've been working on myself.

Now that we're at a point, I think, where over the last few years we've seen the abandonment of an effort to get a national sort of CO2 trading program in place, and we're at a point where we're sort of starting to embark on a new regime for dealing with climate change through the Clean Air Act and at a point where I think the energy markets are really readjusting to a new reality. CCS, and the discussion around CCS we're really at a point where I think it needs to get reset. And it's nice to have this document coming from Brookings, I think, to really kind of help frame the discussion around where we've been, what are some of the best ideas out there for trying to advance carbon capture going forward, and really making the case, I think, for why it's important.

And the case for why it's important, and it's important to continue to articulate that, because a lot has changed with renewable energy technologies, with the price of fossil fuels, and it's important to always keep in mind that what we're really getting at with CCS, is deep decarbonization. How are we gonna get to these really, really deep reductions in CO2 over the medium term, and that's where carbon capture, I think, really has a very important role to play in addition to other technologies. And that's what we need to focus on when we talk about CCS.

And one of the other things I think that we should keep in mind as we sift through the idea in a report like the one that is being released today, is that this technology push and pull that's being emphasized here for CCS is not unique to CCS. These are tools that we know work, because we've seen them used in other areas. If you look at what the great successes that we've seen with renewable energy over the last decade, without a carbon price, we've seen that that has really been driven by a suite of policies that have worked together to drive down the costs of wind and solar primarily, and to drive deployment. It's been portfolio standards primarily at the state level that have created markets for the

technologies. It's been the tax code through tax policy that is very simple to access, the eligibility requirements to get the investment tax credits and the production tax credits for wind and solar are very simple. You do this, you get that.

And you combine the tax code with these mandated markets for the technologies, in some cases for the initial solar projects you actually also had loan guarantees for utility-scale solar projects. And that has really stimulated an industry. And I think that's really it's a lesson. It's not something unique that's been asked for or being sort of emphasized here for CCS. It's something that we know works. And we've used it in other areas.

And when we think about carbon capture, and when we talk about the expense and the cost of carbon capture, which is not trivial, I think it's also really important to really frame it in a cost compared to what. Because of course as it's been said by Professor Rubin and others, it's always going to be more expensive to capture CO2 from a power plant or an industrial facility, than to emit it. But if we're looking at the cost of avoiding CO2 in the long term, then we really need to compare the cost against other alternatives we have to avoid CO2.

And if you look at it in that framework, I think you will quickly discover that carbon capture and storage is actually a pretty good deal. If what you're trying to get at is not necessarily megawatts of low carbon technology, or capacity in the ground, but CO2 reductions, if we look at it in that framework, carbon capture is a pretty good deal. And we know that the cost will come down over time, because what we have right now is an engineering challenge. We know the technologies work. But we're at the very, very early stages of trying to optimize the engineering and really figure out the best ways to build these facilities. And if you look, again, at lessons in other areas of deployment, whether it's scrubbers, or whether it's renewable technologies, I mean there's a whole host of things that we've done, that we can look to for lessons. And we can see that cost will come down as we deploy.

So these are all things that I think we need to keep in mind as we think about the right framework for carbon capture as they relate to other low carbon technology options.

As a developer of carbon capture, right now Summit Power Group is developing a very large project in Texas, that's the beneficiary of a DOE grant and some federal tax credits, and we're trying

to get all the pieces of that project to be lined up so we can finance it. So it's still in the stages of financing. I can tell you that the policy framework, sort of the market and policy framework that CCS fits into today, it's a very difficult framework to actually get some projects built.

It can be said that we've been talking about carbon capture for a long time, and perhaps there's carbon capture fatigue. You know, where are the projects? But I can tell you that these are projects that we can do, that can get built. But it's really important to align the policy so that the various risks and challenges of CCS can be addressed by the various policies. So, for example, we have a 45Q tax credit that's in effect today. Which you would think would be a helpful tax credit for the development of projects. It's been compared to the production tax credit for wind, for example.

But in some pretty fundamental ways, that tax credit is very different from what is seen in other area. Number one, there's a cap on the volume of credits that's available to be used. And we're about half-way through the available credits that can be utilized by projects. And so it's not clear how many of those credits will remain for any project that decides to go forward.

And so what that means, is that a development team, or a project developer that wants to build a project can't rely on the credits in terms of the financing of the plant, in terms of a revenue stream for the plant. So they really don't do as -- you know they'll be really helpful if we build the project and there's some left, they'll be a helpful revenue stream. But if you can't rely on it, it doesn't help you build a project. Because your investors and your lenders won't give you credit for them.

So it's one way where the policy has a very nice and positive intention, but through design, and through the way it's been developed, it's not really that useful. I mean in addition you want this incentive to be scaled to actually fix the problem that's trying to be addressed. And a $10.00 per ton for EOR or a $20.00 per ton for pure storage value through the tax credit, really doesn't actually close the cost gap between capture and non-capture. So it also in and of itself is not gonna catalyze projects. That's just one example of where we have a policy but it's not really doing much to drive projects.

Just one other thought I think to really emphasize when we think about scaling CCS from where we are today to some larger industry, maybe 10 or 15 years from now, is I think we really need to focus, as has been emphasized in this report, I think very nicely, we need to focus on the markets. We

have a very robust funding program at the Department of Energy. It's really the premier group in the world funding carbon capture technologies. There's really no doubt about it. A lot of expertise there and a lot of very good work being done to bring technologies forward.

But we need to set up a market framework where these technologies and these projects actually can find a home and they're set up in a way where investors feel like they can get their money back, if they invest in these technologies. A challenge with CCS, which is something we just have to grapple with in some way, is that these are very lumpy investments. It's unfortunate that we can't really scale up the industry as we have in other areas with maybe wind and solar where you can do small projects, or smaller projects that don't take as long to build, and you can kind of grow organically.

A CCS project needs to be pretty big. And it has a high upfront capital cost. And that's just a really tough thing to swallow generally because of the technical risk. It's also a tough thing to build in today's market when we don't really see high electricity growth demand. So there's not a need for, in lot of places, big projects like the ones we're talking about. I mean CCS has the benefit where you can also retrofit existing plants, and you can kind of go at the carbon problem from the existing power plant fleet. And I think that that's actually one of the things that we'll see here in the near term is some retrofits of coal plants, if the policy regime really comes together.

So the focus on how we get the market set appropriately, so the private sector can get in there and actually try to build these things is I think a really paramount importance, if we want to try to scale the industry.

I'll stop there. But I hope there's some good things to discuss further.

MR. BOERSMA: Thanks. There certainly are. Thanks very much. Before we turn to the audience, there's two points I'd like to touch on. The first would be going into, you said markets for the carbon are needed, in certain situations we see this with the project in Canada, see it in the United States, enhanced oil recovery can play that role. But in other parts of the world enhanced oil recovery may not be an option. I wonder if you could maybe both elaborate on how you see, how you view enhanced oil recovery, EOR, as playing a role in developing this technology.

MR. RUBIN: Everything helps. But EOR alone -- well, we're also living in a different

world now than we were a year or two ago. The difference between an oil price of a hundred dollars and $45.00 or $50.00 is really very significant. And the math that you do on the benefits of selling CO2 in a hundred dollar market, are not the same as in a $50.00 market.

So EOR in this country is a very useful addition but even at a hundred dollars a barrel, EOR alone does not come close to covering the full incremental cost of a CCS system at a power plant. It can cover and reward other industrial sources which separate CO2 in a course of their natural business. And the incremental costs there might be $10.00 or $15.00 to compress it, put it in a pipeline. And that's where a lot of the anthropogenic, the manmade CO2 that's currently used today for EORs has been coming from.

But for power plants where the incremental costs is closer to $60.00 a barrel, a credit of $20.00 or $30.00 or even $40.00 a barrel still doesn't close the gap. So where does the rest come from? In the Canadian project at Boundary Dam, I assume -- not assume -- the professor in me assumes that the audience always knows very little, less than you think they might. So there was a project built in Canada in Saskatchewan. The power plant called Boundary Dam that came on line about a year ago, little over a hundred megawatts, 120 megawatts. And it was financed by a combination of revenues from EOR, which is very significant, but also grants from the Canadian government and corporate money.

Those were the three things that made that project work. Without the EOR addition, it probably would not have gone. So yes it can be important at the margin, but it still has to be package deal.

Going forward it could still be important, but if we're focused on power plants as the main source of CO2 where we need experience, we really need a much richer set of tools.

MR. MACKLER: Yes, I don't disagree with that at all. I would just say that in situations where you can link a power plant to a source of CO2 demand, for example, the largest one in our view is enhanced oil recovery in the oil industry, that's I think a very good thing. But it's not a panacea. It won't solve all your problems this linkage. It solves a lot. It helps a lot, because you're gonna be getting paid and you're gonna create a revenue stream for the CO2, which helps buy down the cost of capture.

And you're also handing the CO2 over to presumably a very sophisticated entity that

knows how to manage it, handle it, inject it, and so it reduces a lot of the complications around for the power plant operator, which may not have a strong geological team associated with that group. It reduced a lot of the challenges with respect to the storage part of this.

The U.S. Environmental Protection Agency has recently determined, which this is a very important point to keep in mind when we think about CO2 EOR, they've determined that storage can occur, and can be demonstrated in an EOR operation. And so this really clears the way commercially for the business model that we're talking about here. And it also helps reemphasize the point that I think can be lost when people talk about capturing CO2, but then producing oil. Actually this is a net climate positive thing to be doing, to be injecting CO2 into oil reservoir s.

But ultimately, what we need to do really is capture a lot more CO2 than what the oil industry can in itself absorb. So we need to think of EOR has a stepping stone to pure storage. But that stepping stone could help a lot and it could be quite large.

MR. RUBIN: And that's the way your study frames it. I thought you did a very nice job that way.

MR. MACKLER: And just one other point on EOR is that while you do see the revenue stream that comes from oil recovery helping on kind of the theoretical economics of a project, one of the challenges it introduces to a project is a new financial volatility, a new financial risk, which is not inconsequential. All of a sudden you're exposing a project that really had traditionally kind of one product power that you're selling into a power market, and the investors and the operators sort of the whole industry around that facility understands that industry, that market very well.

Now, you're introducing a very, very different market, the oil market. And a very, very different revenue stream to a project that really, really complicates the financing of a project. Oil price volatility we all know is great. And the investors that invest in oil field are not the same investors that invest in power plants.

I'm not saying this is an unresolvable issue at all, I'm just saying it's a double-edged sword going into trying to combine these things. But I think ultimately it will help drive the industry.

MR. BANKS: I would just add that, Sasha just used one the phrases, in the course of our

discussions we consistently heard phrases regarding EOR as a stepping stone, or a transitional mechanism. It certainly helps economics in the short term, but don't take your eye off the ball in the long term, which is the need to store significant volumes of CO2 permanently. And EOR should be considered as a transition mechanism not the end result.

MR. BOERSMA: Yeah. Thanks. The other issue I'd like to ask you to weigh in before we turn to the audience is one of the focuses, well maybe the key focus, that our study's taken is look at the capture side in particular. And so we've spent I think less focus looking on challenges and risks related to transportation of carbon and storing it. We highlight and acknowledge how important they are, I mean if you capture carbon, you can't store it, obviously there's no real point. But we haven't spent as much time on those two sides of the value chain. And admittedly throughout the course of our research, there been a number of folks that said, well actually you should spend a lot of time on those issues, too.

I guess the question that we grappled with is are these showstoppers? Can they be showstoppers or not? We got the sense that getting the cost down for capturing would be key first. But I'd love to hear both your thoughts on how you see those three elements in the value chain and the importance of addressing it now.

MR. RUBIN: So transport and storage, we focus on capture, because roughly 80% of the overall cost of a CCS project is on the capture side. I haven't done the math in detail, but I suspect that if you have already built and are operating a capture plant, 80% of your headaches are on the storage side, because they are new to this industry.

But let me take it in pieces starting with the transport side. There are actually a number of ways of transporting, we talk about pipelines because that looks like the most viable method. In Europe there's a lot of interest also in ships. Basically putting CO2, as you would L&G on ships take it out to North Sea and injecting it from there.

So there're a number of transport options that have been looked at. Pipelines are the most valuable. I think pipelines in the context of your work it's certainly not a totally trouble-free area. Anything to do with building any kind of infrastructure always has issues associated with it. But it is an area where there is in fact several decades of experience. Again, just in case there are any of you here

who don't know it, when the first oil crisis hit back in the 1970s and oil spiked a factor of ten over a decade or so, that's when interest in EOR really spiked. And out west there are natural domes where you can drill for CO2, just the way you can drill for oil. Very cheap to produce.

And so the oil industry started using CO2 for enhanced oil recovery back in the late 1970s and continues to this day. So we have now, and have had for decades, several thousand miles of pipelines that carry CO2, mostly in the western U.S. So there is an experience and there's an industry that understands that.

Depending on how quickly and where new CCS facilities would develop, so a lot of these might be in the Midwest and eastern part of the U.S. There might be other difficulties in siting pipelines. It kind of depends on where things are. But there's been enough look at this, I think for the technical community to feel comfortable that the way one would get started on this would be in places where this is viable. Not too many years ago, maybe it's been close to a decade now, there was a 200-mile pipeline built from North Dakota. There's a facility there that produces a lot of CO2 that's now being sent up to Canada. So these things can be done.

The regulatory issues are shared between federal and state governments. And there are some issues, but the pipeline part is probably not the front burner. The storage or sequestration side is the more problematic, because again for this industry this would be a new activity at a sizeable scale, and we still need experience in sequestering at a single site something on the order of a couple million tons. Just for scale a 500 megawatt kind of large-scale coal plant would produce three or four million tons a year of CO2 on that scale.

We don't yet have experience in one facility at that scale. We need that. But that said, there's been a lot of progress over the last five or six years on the regulatory side, so EPA now has in place a procedure for getting a permit to sequester CO2 in what's called a deep saline formation, basically something other than the EOR site. The first couple of permits have been issued under that, so there's starting to get some experience. There are still many more issues that are pending and need to be resolved. There's technical issues about things like pour space, who owns that. The U.S. is on the only country in the world where individuals and not the government owns the subsurface. So we have

more headaches, need more lawyers to resolve some of those issues.

Again, that said, there are similarities with what has gone on over the past hundred years in the oil industry. Where, again, to get rights to produce oil often involves negotiating with large collectors of stakeholders. So there are procedures there, a lot of those procedures are currently specified at the state level, and there's a patchwork now of different regulatory procedures and requirements. A number of years ago a number of us at Carnegie Mellon were involved in a study looking at whether there might be some federal legislation that could harmonize some of that activity and pull that together. So if you're looking for another project there's certainly a lot more that can be done. But really right now the bottleneck is getting the capital costs to build a capture system.

MR. BOERSMA: Thanks. You want to add anything?

MR. MACKLER: Yeah. I would just reemphasize one of the points that Ed made that we've been handling, transporting, managing, injecting CO2 for almost 40 years in this country and there's about a 4,000-mile pipeline network that exists currently in the United States. And I think, I don't have the exact number off the top of my head, but somewhere on the order of 60 to 70 million tons a year of new CO2 are injected into the Permian Basin, sort of the west Texas area. So I mean in terms of managing, there's not a sort of a technology issue around do we know how to handle large volumes of CO2. So I would agree with Ed totally that it's really on the capture side and on the storage side, and not the transportation side.

I mean there are costs associated with building pipelines and compressors that need to get factored into the economics. And the further your source is from your sink, that really starts to have an impact on the overall project viability, but it's not a question of sort of is this something that we can do at a large scale. I don't think that's something we should be worried about.

Being able to leverage the EOR industry through storage, I think is another reason for why I believe that EOR will be sort of a stepping stone to broader CCS. Because the rules are already worked out on who owns the pour space there. The EOR fields are unitized. And we know that the sink, the geological formations for where you're gonna be putting the CO2 when it's depleted oil reservoir, we know those are excellent contained sinks for CO2 because they've held hydrocarbons for hundreds of

millions of years. So we know where the weaknesses are in those sinks, because it's where we've drilled. And those are places that we can keep an eye on very carefully. And so these are -- and they're also depleted, so you don't have the same pressure issues you might have when you're injecting in a saline reservoir where sort of pressure management is one of the things we really need to keep an eye on. It's not that I don't think it can't be managed at all, it's just an emerging area we don't have a whole lot of experience in.

So taking advantage of what has been done in the oil industry, the regulations in the oil industry, the expertise that exists in the oil industry to take to CO2 just makes a whole of sense. And there's also some thinking that once the oil projects are really completed through a CO2 flood, there may even be ways to take advantage of that existing infrastructure and go to other, you know, drill beneath the oil reservoirs and find other places to put the CO2. So we can probably take advantage of the infrastructure that's been put in place to transport the existing natural CO2. So it's really something we need to build on.

MR. BOERSMA: Okay. Thanks very much. You've been very patient. Thank you for that. We're gonna turn to you now for Q&A. If you'd be so kind to introduce yourself before you ask your question. We're gonna take a couple. There's gentleman there in the alley and then gentleman in front of him. Yep.

MR. CAREW: I'm Lawrence Carew from International Energy Partnership. Sasha, is this gonna be in Paris, late next month, is this gonna be part of the topic? It should be.

MR. MACKLER: Yes. I'm fairly sure it will be. Others may know more about this. But I know that there is a large contingent of parties that are interested in seeing something done on CCS.

MR. BANKS: There was a, Ed, I don't know if you're aware of this, or you were a signatory, I saw recently that a group of 40 or 50 internationally recognized CCS experts sent a letter, sort of a formal letter to the UN FCC folks specifically asking that CCS highlighted and focused on. I saw that note, I was wondering if you were a signatory.

MR. RUBIN: Yeah. I wasn't a signatory to that one. But the U.S. Energy Association Headquarters here in town has been very active in pursuing that agenda. I suspect they will succeed in

some way.

MR. ODEY: I'm (Antoni Odey) formally with Oil Bank, just thinking about the potential interest and appetite for this technology outside of North America. I'm a little rusty on some of this stuff, but would it be right to assume that the recent problems with the European carbon market have largely undermined the incentive for this sort of thing in that part of the world?

MR. RUBIN: I'm glad you brought that up. We should have mentioned that earlier, it slipped my mind. CCS is clearly not just a U.S. or North American issue. In fact, if anything it's probably in the long term if we're gonna succeed in addressing the climate problem, it's probably as much an Asian issue, I think about China and India, potentially European issue, South America, think about where coal is used. We often tend to forget that we're enjoying in this country right now relatively low cost natural gas, the rest of the world isn't. In the rest of the world natural gas prices are high. Coal is the cheap fuel. Coal is what's gonna continue to be used.

So, again, fundamentally the situation isn't any different until there's a market for the technology, which requires a combination of some policy sticks as well as some policy carrots. Until that happens, large scale deployment is not gonna be likely. But that said, there has been for some time now a lot of activity in China on CCS technology. I think this is an area where U.S. leadership, again as it has in other environmental areas, been really rather critical. A decade ago a lot of the international interest simply wasn't there. But as a result of operations like Carbon Sequestration Leadership Forum, which DOE has instigated and a lot of the R&D, no country wants to be technologically behind. And China's actually now very aggressively in that area.

One of the questions I asked, we had a little breakfast meeting before this, a couple of decades from now who's gonna be buying whose technology? Are we gonna be buying CCS technology from China? Are they gonna be buying U.S. technology invented here? There will be potentially large markets for the technology in a future where there is a regime.

In the European context that you raised, Europe is actually using more coal now that before. My European friends have trouble talking about anything except a carbon market. I have an engineering background. I think I understand something about economics. I was delighted by the

recommendation in the report that to move something like CCS forward, a carbon market along just ain't gonna do it. The kinds of carbon prices that are politically viable today including the European prices, are still far short of what we need to do a standard. But that said, the combination of a market based system with a performance based system of some sort. It could be a portfolio standard, it could be a low carbon portfolio standard, it could be a plant level emission standard. A variety of ways of doing that, but basically ways of saying if you want to be in business, this is what you need to do.

The combination of that with a market strikes me as kind of the best policy package. Because the existence of the market overcomes one of the disincentives of performance standards. That is no incentive to improve beyond that. But if there's a market, and for a little extra money you can capture 95% instead of 90%, you might be able to more than recover that in a market. So Europe doesn't yet have a mentality of performance standards in this business. And I think that's one of the things that's inhibiting.

MR. BANKS: I think one comment here it's important to note that the UK is actually, I think put together a policy approach, a policy portfolio approach akin to what we're thinking about. They do have a number of different mechanisms that they've put in place. They do have a performance standard. They do have a mechanism for a carbon price floor. They also are looking at implementing a price stabilization scheme called a Contract for Difference, which basically guarantees an electricity plant a certain price for the sale of electricity at a plant that has CCS. So they've put together a package of four or five core policies across the spectrum to address the risks that we outlined. And I think that's kind of the thinking that we're trying to put forth here in thinking about what a policy portfolio would look like.

MR. RUBIN: That's right, John. That kind of thinking needs to get carried over to the EU level. That's what I was thinking of.

MR. MACKLER: Yeah. And I just to say a little bit more, if you look at the UK compared to the EU, there actually is much more activity in carbon capture than in the EU. And I think it is due to these efforts to kind of create a more kind of holistic framework to drive projects. And we have a project that we're working on in Scotland actually, because of that environment.

MR. BOERSMA: I'd just add very briefly that in the EU they used to be a different

approach to this. The thinking was, I think, in the EU, I think it's a good example that just putting money into it is not gonna cut it.

MR. MACKLER: Right.

MR. BOERSMA: Right. 2007 and '08, I used to work in the utilities industry in Europe, this was a big thing. The European Commission funded, I think around three and a half billion euros of 12 demonstrations projects to try to lift this off the ground. And left it there. And just throwing money at it is not gonna cut it. And that's what it shows. Because of those 12 projects, I think there's one still, which has not been killed, it's the Rotterdam project, but it hasn't reached FID either. So it's sort of still. I think the intention was there, but I think they learned that just putting money into it is not enough.

MR. MACKLER: Right.

MR. LEWIS: My name's Evan Lewis, I'm with the Program for Public Consultation at the University of Maryland. Sasha mentioned something about retrofitting current coal plants with CCS technology. And I was wondering if there was difficulties that went across plant types? Because I know some coal plants don't have any clean tech at all. Other have combined cycle, or advanced combine cycle processes to remove soot. So is there any project, or is it indifferent to the different kinds of coal plants that exist out there?

MR. MACKLER: Well there are better coal plants than others to be retrofit for sure. You know the key factors you need to really consider when you're looking at a retrofit, number one is what other pollution control equipment does that plant have. Because to actually install a CO2 capture system on a coal plant, the flue stream of that plant needs to essentially be cleaned up of everything else. Because the amines right now that we can use to capture CO2 are extremely sensitive. And you don't want them to be capturing other things, you don't want them to be poisoned by other chemicals. So this is one of the good things about a carbon capture project. At the end of the day, if you've done a carbon capture project on a coal plant, that's essentially an emissions free plant from that point forward. Because you have to take everything else out of the flue stream.

But it really helps your economics if you can find a more modern coal plant that already has those pollution control systems on them. That lowers the incremental cost of doing carbon capture.

And then of course there's also just the thermal efficiency of the plant itself. If you're looking at a real old coal plant that probably doesn't have much of a future in front of it because either it's very inefficient, it can't compete against other more modern plants in the fleet. Or it's at the end of its lifecycle. That's probably not a great candidate for a retrofit, unless it's sitting on top of an oil field that's desperate for CO2. I mean there could be special circumstances. But generally speaking you want to get the more modern, more efficient coal plants.

I don't know, Ed, if you have anything.

MR. RUBIN: Yeah. Let me just make a quick comment about that. If a retrofit is gonna be viable, the plant design matters a lot. It would be most viable at plants that are most efficient, large, and relatively new. Those things tend to go together. So plants that are small, old, and inefficient are generally not gonna be candidates.

But that said, it should not be discounted. So let me go back to what is now currently public policy at the national level, which is the Clean Power Plan that was promulgated finally a month ago for existing plants. So the objective is an average of like 32% CO2 reduction from existing fossil plants, meaning by 2030. CCS was not explicitly mentioned or named as one of the so-called building blocks for achieving that. But it is certainly an option. It's recognized as an option by EPA. It's not being broadcast as loudly as switching to natural gas and efficiency improvements, and other things.

One of my colleagues, I was the third-wheel in a study that was actually just published a couple of months ago, looking nationally at the potential for CCS to play a role in meeting not the current plan, but the proposed plan, which is what we had on the table up until a month ago, very similar though I think in nature. So this involved coupling a detailed database of every unit in the country, every power generating unit in the country with models that we've developed for DOE that look at cost and how cost vary with different plant characteristics.

And to our pleasant surprise I think, we actually found at the national level an nontrivial amount of capacity that potentially could be a candidate for CCS. And to meet a 30% standard you would do partial CCS. So you wouldn't put the technology on the entire flue gas, but only a part of it. If you envisioned a trading program, a multistate trading program, which is allowed under the Clean Plan, it

might in some cases be more economical to do 90% capture on a big plant and not have to do a bunch of other things on other plants to get the overall 30% goal.

So this is something that in fact we want to pursue in more detail. I know that DOE and others are trying to look at this as well. There could well be some drivers in there one really needs to get a handle on site specific factors and how difficult or easy it might be to physically put in a piece of technology. But that could in fact turn out to be a driver for some CCS activity in this country.

MR. BOERSMA: Thank you. More questions on this side? I saw more hands. Yeah, sorry, lady there. Lady over there in green.

MS. SCHWARTZ: Thank you so much. My name is Laura Schwartz, and I'm coming from the National Bureau of Asian Research. We've been looking at lot at these international issues, particularly as you mentioned China has been making a lot of progress on CCS and clean coal technology, as well. However, in places like Southeast Asia where energy demand is still rising, very strongly increasing coal reliance is something that we're seeing projected.

On an international scale what can be done to enable CCS and clean coal technology in places where it's gonna be more dominate going forward? Because in the United States we can do all we can, but in Southeast Asia, for example, it's going to become more and more dominate.

MR. RUBIN: My answer would be again absent a regulatory driver, which you don't have in that part of the world, you've got to come up with some clever financing mechanisms to make it worthwhile, basically to cover the difference in cost between a plant with and without CCS. I know the World Bank has been trying to do some incentives in that area. I don't know that enough money has yet been put together to pull those off. But I suspect there's a practical issue that's the kind of thing you need. The same kinds of recommendations that were made in the report that we've talked about.

MR. SIVARUM: Hi, I'm (Varun Sivaram), I'm from the Council on Foreign Relations. And thank you for a fantastic talk. Sasha, you said earlier on that we know what the technology is and now it's just a matter of solving engineering challenges. If you build more of it, costs will go down because of learning by doing. But across different parts of academia, there's a lot of excitement over fundamental breakthroughs. For example, metal organic frameworks and material science.

Dr. Rubin, in reading your work, I gathered that there's several different types of learning that go on in CCS. And it's a nonlinear process between innovation and deployment. Can you guys talk a little bit about how to get breakthroughs commercialized while you're simultaneously making current technology cheaper?

MR. RUBIN: Again, I have to start with markets, all right. In all of the case studies we've done retrospectively to see how things evolved, there was a market. So absent a market driver, there's a lot more inertia in the system, a lot more risk, you know, are we developing a technology that no one will ever want to buy.

But that said, I think you need in a market-based system you have the dynamic of push and pull with a lot of feedbacks between early experience making technologies better. Often costs go up before they come down with very new technologies. We tend to look at the learning curve a little after it starts coming down. Again, financial risk.

So without that backend pull currently in CCS, we are where we are now. Which means we have to do the best we can on the frontend with incentivizing R&D to look at these kinds of issues. The trick I think, particularly with large-scale projects, Sasha was absolutely right on target in stressing, this is big technology. This isn't like building a silicon wafer that you can get a new generation every year, or every six months. A generation of technology takes years to build, deploy, get some experience with and fix. So it's a slow system, anything at that scale is. Which means the pipeline needs to be as full as possible.

Right now the CCS pipeline is kind of emptying out. I think DOE has recognized this. Empty out in the sense that yes we still have a couple of large-scale demonstration programs. We're cheering that Sasha's program project gets off the ground and one or two others. At the very frontend, at the R&D at the university and lab level, there are people looking at MOFs and other kinds of technologies at smaller scales. The National Carbon Test Center we're looking at things like on a scale of one megawatt. But there's a big distance between one megawatt and 500 megawatts, or a 100. And that's the gap that is currently void. Largely void. Projects on the scale of 10 to 50 megawatts, which is usually the intermediate stepping stone that you need.

DOE has just funded a couple of projects to try to begin filling that void. Those are not inexpensive projects. It's not in the billion dollar class, but it's in the many tens and potentially hundreds of millions. So first recognizing the need for that and again developing the political will to fund those kinds of projects is gonna be really rather essential to start that process.

MR. MACKLER: Yeah. I just have a thought on that, because I think it's a great question, sort of the feedbacks between innovation and deployment. Where we are today with today's technology, if we're looking at the amine scrubbing systems, which I think are really probably the most likely to see greater deployment, they make the most sense with what we have today really to put on the back of a power plant, or a gas plant, or a coal plant. These are technologies that we're basically transferring from another industry. They're used widely around the world in gas processing facilities and refineries. So we know how to use these technologies. We know that they work. There's big multibillion dollar, multinational companies that sell these systems.

And so what we really need to do is take them and start to optimize them for power, which is a different application. There are definitely better technologies that will be developed for power. Whether it's an optimization and some refinements to these amine scrubbing systems. These first generation scrubbing systems. Whether it's a completely new solid (zorbent) or metal organic frameworks. But these innovations will be pulled into the market if we can establish a real vibrant marketplace for the whole system.

And what is also needed in CCS in addition to technology innovation is business model innovation. We're looking at really rethinking, I think power and oil, and financing around how these projects can get put together. And the groups that can figure this out will really help to drive the industry. And it will pull new technologies in.

We need the business case and the business model for CCS we're really at the very, very early stages of that. And I think the business model innovation, if we can sort that out with today's technologies, which will work and they will be optimized, will drive more technologies in. I mean we need that feedback.

MR. BANKS: Sorry. One comment. This is a classic example of making sure you

connect the frontend and the backend and address the risks along the innovation spectrum. So DOE does fund R&D for second generation and transformational capture technologies, as well as providing funding for improving first generation amine technologies. But the trick is not only just funding that frontend at the one megawatt and then 50 megawatts scale, pilot scale, bench scale, but also making sure you think ahead and connect that to the demonstration scale and then pushing beyond that into early commercialization and maturity. And making sure you connect all of that in a cohesive way. Because if you just spend all the money at the frontend, and then don't think about bringing it into the next stage of innovation down the road, it's not gonna go anywhere.

MR. RUBIN: And the other key ingredient in that is to keep at it. Not for a couple years, but for a couple of decades in this business. You see that very clearly. We did a study a number of years ago trying to explore the concept of radical innovation. What does radical technology innovation mean in this context? And we interviewed a lot of people in industry and government and all that specifically in the power systems area. Can you give us some specific examples of things that already happened that you would consider radical innovation?

Every example that we got was a technology that had basically incrementally improved over about 20 years. And today is viewed as radical. Think about that. Radical innovation as the sum of 20 years' of incremental innovation, things that people look down their nose, we can't just do incremental, we have to be. The world doesn't work that way. And it's not true just in the power industry. If you look at any other major industry, look at aviation, look at computers, think about your cell phones, remember those? Remember Get Smart carried the shoe phone? Decades of work generally goes into those kinds of things. And so a continued funding stream, a continued stream of bright people who want to work on these projects, self-serving comment for a university guy, right. Those are all essential ingredients of that innovation process.

MR. BOERSMA: Thanks. We'll take another question. Gentleman upfront, he's been very patient.

MR. HALPERN: Josh Halpern, Howard University. EOR has this peculiar paradox that the more efficient it is the more oil you get out by injecting CO2, the less advantage you have in injecting

the CO2 in the first place. And I wonder if there's actually an advantage if you inject CO2 from a natural gas plant?

MR. RUBIN: I thought you were gonna raise the issue of carbon emissions. What about the carbon emissions from the oil that gets burned.

MR. HALPERN: That's the point.

MR. RUBIN: Yeah. That's another issue. Yeah. That turns out to be a religious argument. In the sense that you have to know what the counterfactual is, right. What if you didn't produce that barrel of oil from EOR, if you do produce it does that mean that you are not producing another barrel from a traditional source? Or does it mean you're simply adding to the oil market? And there are a number of scenarios that one would look at.

The situation today, and Sasha is closer to this, and correct me if I'm wrong, it's getting tougher and tougher. As EOR operations continue, you would need more and more CO2 to produce a barrel of oil. The technology in use today, if you're just concerned about carbon balance, you actually wind up emitting slightly more CO2 from the oil that you would produce compared to the CO2 that you have stored to produce it. Small differences. But it depends very much on the situation.

EOR technology is also improving and should be able to reverse that arithmetic. So it depends on your outlook. It depends on what you think the value of oil. Oil is still unfortunately almost the singular fuel we use for transportation. The overall consensus I think in the community is that today given where we are in both of these technologies, the importance of EOR in reducing the cost of CCS and in avoiding potentially other kinds of new drilling operations, is a net benefit.

MR. BANKS: I'd just pick up on that last point, I mean one of the comments we heard from several different let's just say more of the environmental community stakeholders that we talked to on this question of the carbon balance, you're using CO2 to extract more fossil fuels, and what happens to your carbon lifecycle balance. And I'm picking up on Ed's last point, often what we would hear in that respect is well I would rather see the CO2 being used to extract more oil from an existing field that's already been drilled, than to extract the oil from a newer field perhaps in a more pristine area like the Artic. And we heard that sort of line argumentation we heard a number of different times from some

surprising sources.

MR. BOERSMA: Sasha, do you have thoughts on this?

MR. MACKLER: I mean nothing really to substantively add to it. If you're looking at point source emissions, power plants, smoke stacks, things like that, it's very clear the CO2 you capture from the point source, inject into the oil field, can be disposed of permanently in the oil field. And that's how we regulate today.

If you're talking about, or if you were concerned about kind of what's the net carbon impact of that activity, you really, as Ed said, you really have to then, I mean there's another environmental argument around recycling oil fields versus what's your marginal barrel of oil, what does it look like and where does it come from? It usually comes from very technically difficult things like ultra-deep water, new developments, or heavier oils that require more processing. So your marginal barrel of oil in the system probably has a higher carbon intensity and more environmental sort of risk associated with it, than an EOR barrel which comes from an area that's already been developed.

I mean these are more qualitative arguments. If you want to try to untangle the climate impact of that activity, you have to look at -- it's very difficult first of all. Because it's a global oil market with essentially a global price for oil. And presumably some sort of a global supply demand balance. So you have to look at what is that activity doing to the climate, to the next emissions, not point in oil out. That's not the climate impact. So we have to look at what's it doing to oil. And does it affect oil prices? Is it gonna be offsetting a barrel somewhere else? Or contributing to overall supply? These are difficult questions to answer.

But I think that really, in my view, the way to look

at it is if EOR is a small enough industry that it's not really impacting the global price of oil, than it's probably not gonna be impact the global supply system enough to be driving more CO2 emissions. It's probably gonna be offsetting a marginal barrel somewhere else. But this is a very difficult -- it's an area, if you're looking for another topic this is a good one. Because it's very difficult.

MR. BOERSMA: We were about to run out. (Laughter)

MR. MACKLER: Yeah.

MR. BOERSMA: Thanks very much. I regret to say that we've run out of time. I want to thank the audience first of all for your excellent questions and interesting engagement. I appreciate it. Please join me in thanking our guests for their excellent comments and contributions. (Applause)

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