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THE FUTURE OF NATURAL GAS

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P R O C E E D I N G S

MR. GOLDWYN: Ladies and gentlemen, good morning and welcome to Brookings. I'm David Goldwyn. This is my inaugural day as a non-resident senior fellow. I want to thank Straub Talbot and Charlie Ebinger for actually bringing me back to Brookings 31 years after I first started as a research assistant when I was a junior in college. So it's nice to be back.

Our topic this morning is the future of natural gas. And anyone who has seen the *New York Times* or the *Washington Post* or read any newspapers in the last six months knows this is an extremely controversial and hot topic. And so the questions that are on people's minds today range from how much resource is there and is it sustainable? Can we produce this safely or not? Is the problem hydraulic fracturing or is it drilling or is it casing? Is it what's in the fluids or is it where it goes and whether you can contain it? People are wondering about what's the potential for natural gas. Is this the bridge to a carbon free future or is it the destination? Is this a competitor to renewable or is this a complement? Can we enter a new age of using natural gas for alternative fuels and end our dependency on oil? Or is the cost structure not really viable for that?

And countries around the world, from Warsaw to Romania to China to India are also asking the same question -- what's the future of natural gas? Is this the game changer? Is this what's going to enable us to have energy security or are we ready? Do we have the right regulatory structure? And in fact, everyone is asking. I think 10 state legislatures, EPA, Interior, the secretary's Energy Advisory Board and countries around the world, both Canada and Quebec and Britain and France and Germany are all asking these questions. What do we need to know to know whether this is the path forward?

So we're really fortunate this morning to have the engineers and the physicists and the chemists of MIT launch a multidisciplinary, multiyear study on the future of natural gas. And with the integrity of MIT to look at these questions on a science basis and ask what are the challenges and what do we need to face? And so we are really lucky and it is our great fortune that MIT has done this and we are really grateful to Ernie Moniz and to Melanie Kenderdine for coming down from Boston to present this today to take a look at these questions and answer what do they know, what do we need to think about, and what are the policy choices. And after initial presentation, then we will have commentary from Phil Sharp from Resources for the Future and Jeremy Kepes from PFC Energy to look at some of the other questions. So we are grateful that you're here.

Let me introduce my good friend and colleague. And actually, Melanie and I are colleagues as well from MIT. Dr. Moniz is the Cecil and Ida Green Professor of Physics and Engineering. He's also the director of the Energy Initiative and he's also director of the Laboratory for Energy in the Environment at MIT. As he said this morning, he is a triple unpaid employee of the federal government from a distance, both PSAC, which is the President's Science Advisory Council, the Blue Ribbon Commission on America's Nuclear Future, and also -- what's the third one, Ernie? Track. All right. He has got a long career, both as a physicist but also in government as undersecretary at the Energy Department and also a deputy director at the Office of Science and Technology Policy. So we're lucky to have Ernie here.

Melanie Kenderdine has also worked in the Congress and been a senior advisor at the Energy Department, and she is a key part of the leadership team for MIT's Energy Initiative. And so the way we will work this morning is Ernie will give the overall presentation. Melanie is going to comment afterwards, and then Frankie O'Sullivan, because the supply issues are so hot today, will talk about some of the resource assessment questions and the shape of the supply curve.

So let's start there. We've got a lot of ground to cover. We will have time, of course, for questions but first it's a great privilege and honor to introduce Dr. Ernie Moniz.

MR. MONIZ: Well, thanks, David. And welcome back to the real world of post-government life. You hung in longer than I did. I also might say that we've done crazy things like kind of view the U.S. representation at a very bizarre energy ministerial in South African many years ago as you might recall.

Anyway, we appreciate this chance to present to you the results of our study. We appreciate the *New York Times* in helping with the crowd building apparently here today. So we started this, in fact, three and a half years ago as David mentioned and as I will describe it's the result of a very, very large team with many disciplines. David mentioned we're kind of the physicists and engineers but I want to add as well the very important role of several MIT economists because that's going to play a major role in terms of when we look at what really were the two questions that in some sense convinced this motley group of various disciplines to come together. One, it was the question about supply. This was three and a half years ago. This was kind of on the leading edge of the focus on the potential of shale, although some of us had through other connections frankly been looking at things like unconventional gas production for many, many years. We'll come back to that later on.

And then the question would be if the answer to that was a fairly robust supply situation, then what exactly is the role of gas particularly in response to anticipated carbon emission constraints because, you know, we often talk about gas as this bridge to the future? But, you know, it's a fossil fuel. And so when it's part of the problem and when it's part of the solution isn't entirely clear. And that is, in fact, what the quantitative analysis that we carried out addresses.

The full copy of the report, including supplementary papers, all 350 pages, you can find and download at this website. Again, I'm not going to go through. Just to say again a very, very large group, 19 members of the study group plus 10 graduate students. Very importantly, while we believe that these studies really are kind of a contact sport and so we try to keep it an internal group, but we have a very distinguished external advisory committee, in this case chaired by Mac McCarty. Phil Sharp is eligible to be a commentator today because it's the first time he hasn't chaired one of our studies. Indeed, I should add that this follows studies on the future of nuclear power, the future of coal, the future of the nuclear fuel cycle, coming the future of the grid and future of solar energy. So this is part of a series in which as David indicated our goal is to bring together rigorous technical analysis as the grounding for a set of policy recommendations. That's really what we are trying to do.

And the way we'll arrange this today is that I will kind of run through the study with the principal narrative if you like, but then I'll have my two colleagues come and drill down for a few minutes on two very key issues. One, the supply issues, particularly as they have been highlighted in the *New York Times* this week. And secondly -- that will be Frank O'Sullivan. And then Melanie Kenderdine, who led much of the electricity analysis, will come and talk about especially important the issues of what are the opportunities and realities of gas substitution for coal in a carbon constrained environment.

As you know, with this little diagram that some of you can read, gas -- the only point is that gas is roughly a third, a third, a third in the electricity industry and buildings sectors, and of course plays today a minimal role in transportation. In fact, when you see that 3 percent in transportation, don't think that that's vehicles. That's moving gas around and oil. It's gas in terms of transportation of pipelines -- in pipelines. In transportation it is a less than -- more than an order of magnitude, less than that 3 percent.

But the point is gas serves multiple sectors and that in turn requires an analysis in which you can do these kinds of cross sectoral comparisons. In that sense, this study was more complex than that of say nuclear power or coal which certainly in the United States at least largely serve just one end use.

In terms of supply, and again we'll go into some of the more specific issues later on, this is just an indication of recoverable resources globally. Two points to make here in general terms. One is we are sometimes, in the United States, our discussion does not fully understand the fact that gas resources are as concentrated even by some quantitative measures slightly more concentrated globally than is oil. And it's the Middle East and Russia that dominate. That will have some of the geopolitical implications that we'll come back to later on.

Secondly, on this particular graph we have included unconventional gas only for North America. The reason being that we believe when we started this and frankly we believe today despite the receipt EIA-AIR publication which I think was very, very helpful. But as it itself says, there's still a lot of uncertainty in terms of these unconventional resources globally. So in that sense this is an underestimate. Because if you looked at that EIA paper, for example, it suggested around 1200 TCF in China alone. So those are the two messages in terms of this picture.

We then create, and Frank can go into this in more detail, but we then create supply cost curves for all the regions of the world as input later on to our modeling of global trade in gas. But let me just give the summary -- two summary results to frame the rest of the discussion.

So this is our composite global gas supply curve again reminding you without unconventional gas outside North America. The dark blue line in the middle is the mean and you have the 10 percent and 90 percent probability curves on the side. Bottom line is there's a lot of gas in the world. You know, 9,000 TCF at $4 or less. And then you can run up the curve.

So a lot of gas at reasonable prices. In fact, important for our later discussion but also talking in the order of, you know, 4,000 to 5,000 TCF at $2 cost. And when we come back to that we will want to refer as well to this little inset that let's say a typical, in some very broad sense, LNG supply chain cost to the United States of around $4, that will come into our discussion later on on the questions of exports and imports of gas.

Okay. So that's the global picture. Now let's go to the United States. On the left again is the composite curve for the United States' supply curve. And at the mean again we're talking about, you know, 800 TCF or so at $8 or less. Notice, by the way, this is relevant to the *New York Times* article in a certain sense. And Frankie will come back to this later on. If you go to like the $4 range, you know, it isn't quite as robust. It really begins to open up as you get into the $6 to $8 range, as the right-hand curve shows, especially because of shale gas. So the right-hand curve, this is the decomposition of the mean into the various sources. And here, once you're getting into this kind of like $6 region, then you're up into the $400 TCF just in shale in the United States. Mean estimate.

So we have a set of recommendations in terms of trying to understand better. In fact, one of the issues is that we point out rather strongly that we really don't understand the basic science, if you like, of the shale plays and it is -- we have no basis on which to think that we are, or are not for that matter, optimally using this resource and we believe that a strong research program is needed.

We will come back and talk -- Frankie will come back and talk about the environmental issues of production. Let me just say for our purposes now the conclusion is that indeed there is a pretty robust gas supply outlook at moderate prices in the United States and in the world than you do have a lot of much less inexpensive gas. We are a mature gas producing region.

So with that and with those supply curves that you saw for the world, we then -- what we do is we put that into a 20-year-old hamburger machine. It's a general equilibrium model, economic model of the world, including trade between regions, interaction between sectors, et cetera. And its strength as it says is, in fact, to explore these market interactions. The limitation of this kind of model is it does not start from high fidelity, you know, engineering data. It characterizes the technologies and then looks at how the sectors and the fuels play off against each other.

There are a number of uncertainties. There's the uncertainty in the supply side. And you saw we explicitly deal with uncertainty in the supply curves. And if you want statistical analysis techniques look at our appendix. There is a great uncertainty obviously as to how greenhouse gas mitigation will or will not proceed at the policy level. There's an uncertainty about the evolution of international gas markets, and we will see that that explicitly affects U.S. gas prices and utilization. And of course, there's a big uncertainty about the development of technology over time. So again, on the website you can find all the details, the inputs. But let me just say roughly speaking on the technology side, you know, we are not assuming any magic breakthrough in any particular technology. It's like today's technology costs with reasonable evolution. So that's a general characterization of it.

And our base model also assumes that we have the current kind of market segmentation, if you like, with principal North American, European, and Far Eastern markets and we will come back again to how that might be modified in the future.

So going to some results. The -- we're going to look today -- we have three scenarios in the report. I'll look at only two of them today. One is the business as usual, no carbon policy. The second one will be the following carbon policy. It's a linear reduction in CO2 emissions in the industrial world by 50 percent to 2050. It's an honest 50 percent. No offsets or anything else of this type. So 50 percent carbon reduction accomplished through a price mechanism. The price, the economic model adjusts the price to accomplish the reduction. There is also a similar trajectory in the large emerging economies with a 20-year time delay. And there is no policy for the less developed countries. Again, like it or not, I mean, that's what we used as the basis of our model.

In the business as usual then you see here total gas utilization in the United States. The three bars are the low, median, and high supply curves. So just looking at the median supply curve, what you can see is that the usage goes up 35 trillion cubic feet or so in the United States. Also note the price goes up, of course. And this will be relevant to the discussion later on of *New York Times'* land that, you know, we're working our way up those cost curves. Indeed, in the low -- if the least optimistic supply curve were correct, as you can see here, like in 2050, you actually begin to see the gas use tail off. That's a result of working up that cost curve.

Now, what happens if we go to the price-based carbon mitigation policy? This then is what one sees. For a few decades, at least, total gas usage is not materially altered. I mean, it's slightly less but it's not that less -- that much less. And of course, the reason basically is that gas, as we'll see, plays a relatively larger role in the energy supply situation with a carbon constraint. That's the beginning of the bridge discussion to which we will be coming. Although you do note that again as you go to the middle of the century then that use is tailing off. To remember, in 2030, in the median supply situation, the cost of gas at the production point, if you like is $7.50 for MCF. The $13 is what you get with the carbon price added in, which already gives you a hint. These carbon prices are not for the faint of heart. The carbon price to accomplish this trajectory is already at $100 by 2030. It's substantially north of $200 by 2050 to accomplish this 50 percent reduction in the economy.

So this is the picture actually running out to 2100. In this case then the carbon reduction continues to 80 percent reduction to 2100, 50 percent at mid-century. And this kind of gives you the picture.

This is the U.S. power sector. First of all, demand reduction with respect to business as usual. Business as usual is the top of the curve. The hatched area is the reduction in electricity use over that time period. And as you see, it's actually electricity use goes up but only a small degree relative to business as usual. But demand reduction from business as usual as absolutely essential. I've never seen any credible response to a major climate challenge without demand reduction playing a lead role.

All right. Now, on the supply side this picture says a number of things. One is -- and it's not very complicated. Please do not consider this -- this isn't a prediction. This is understanding how the pieces work together. And of course, it depends upon the inputs. The supply curve inputs and the technology cost inputs. Right?

But the first thing that happens obviously is coal in the economic model ruthlessly is driven out of the system. It goes to 0 in 25 years in this picture. That's not a political reality check; that is an economic model consequence. Gas, in fact, essentially accounts for the entire substitution of coal over that time period. And then, of course, what happens is -- so gas is, in fact, part of the solution. But then as you keep cranking down, gas becomes part of the problem and it gets driven out of the system. You know, 20, 30 years later. The numbers again will slide depending upon your inputs. That, in fact, is the bridge to the essentially zero carbon world at least in the power sector. If I showed you the rest it still would be oil going on for transportation.

Now, in this particular run, because of the cost inputs, the pre-Fukushima cost inputs, nuclear happens to be the one that then fills up the space. But basically what you should really think is this is zero carbon and the economics of the various technologies as they compete with each other will tell you how this is shared.

Now, one piece that is worth referring to explicitly is you notice this is gas with CCS and there is no coal with CCS. And you know, often we think -- we ask the question what is the price of CO2 at which coal and CCS beats coal and pay-the-carbon price. And the answer here is rather optimistic in our inputs. If anything, we were helping coal and CCS. That crossover price was about $60. Today it would be at least $100, frankly. But let's call it 60 bucks. I told you at 2030 we already have a $100 price because that question that we asked is the wrong question.

Coal and CCS isn't competing against coal; it's competing against everything else. Natural gas provides the cost benchmark for getting the marginal ton of CO2 out of the system. In fact, with our inputs -- and for this particular picture it actually has $6.70 gas. So it's not cheap gas. It's got overly cheap carbon capture and it's got an optimistic heat rate for coal plants with capture. And it still never comes in. What you see is here's the crossover point of coal and coal with CCS, around 60 bucks. But at that point it's not beating anything else. Gas and gas CCS crosses at about $100, et cetera.

Now, if gas price went higher than what we had or the coal costs came lower, then those could flip and coal could come in. And this just again gives you kind of the notion. The numbers don't matter so much as the pattern. What you can see is coal and CCS, not surprisingly, eventually comes in if you have two conditions. Both a high carbon price and a high gas price. Those are the two things that you need. So that interplay actually is quite interesting and frankly what it tells you in the end, if you want to make the world safe for coal, what you better do is reduce the carbon capture cost by at least a factor of two.

Let me say a couple of words about the international market evolution. On the left is what you already saw for a carbon constrained world. That is the U.S. gas use, exactly what you saw before. On the right is the result in the following thought experiment. In the model now we have no trade barriers. We assume we have gone to a completely liquid, functioning, global natural gas market just with transportation corrections, which of course are much more significant than in the oil case. But that's a very different picture.

And then what happens to U.S. gas use? That's on the right. And what you see is two things. The dark blue at the bottom is imports, is net imports. On the left, that represents, you know, that's basically Canada which kind of just stays flat in our picture. On the right what you see is starting in, you know, one or two or three decades, you begin to see very substantial gas imports. It's simple arithmetic. Let's go back to the supply curve. A lot of $2, $3 gas out there in the world. Add $4 for a typical supply chain cost. Remember that trajectory of U.S. gas prices going up. You cross $6, $7, $8 and imports become competitive. That's fundamentally what it is. Although noted, especially in the 2030, 2040 timeframe, domestic production is not dramatically affected. It's just that demand goes up, and demand goes up because also prices go down. That's why we're importing it. It's to lower the prices.

In fact, we make a recommendation -- oh, and I'm sorry. Before I say that, here -- so this is kind of the picture of the -- in this global gas market. And what you see is basically Russia and the Middle East where the gas is become essentially suppliers to all the major markets. And that's where the integration is coming in with LNG obviously playing a key role.

So we, in the end, strongly recommend as a U.S. policy matter that we support the development of this kind of a global market, despite the imports, if you like, that we believe there are both economic benefits and security benefits where the security benefits are in no small part attached to the enhanced situation of key allies. In Europe, for example, and also maybe getting a little more flexibility in the Far East as China's demand goes way, way up. Now, of course, the global shale possibilities do come in.

So here is shown the recent EIA ARI numbers. And in parenthesis, if you can read it, that is current use in those countries. So in China, again, they posit the order of 1275 TCF shale gas. Today, China uses 3 TCF. In Europe, Poland, and France, it's combined around 350 TCF with very, very usage in those two countries. Germany has the big usage but no shale, and the French have decided for the moment at least that they don't want to really develop that shale.

Anyway, but on the geopolitics our big view in the end is we think that we should support the development of this kind of global market. Domestically that would mean, for one thing, not having barriers to either the import or export of LNG but obviously the United States has many other tools in terms of how global markets develop.

So with that background the issue now is we saw in that graph to 2100 the interplay of various fuels. But now we then drill down into some of the key issues about gas substituting essentially for coal and for oil the more carbon intensive fuels and especially coal.

I'm just going to set this up. Melanie is going to come back and discuss this, but this just shows the average capacity factors for various energy sources in the United States. Nuclear, of course, way up there at 90. The thing we'll emphasize here, and this will be very critical for what Melanie will discuss, we have a large fleet of natural gas combined cycle plants, highly efficient. They are used at just about 40 percent capacity factor. The possibility of getting a lot more juice out of those plants with no capital construction is a big story for substituting for coal, and I will leave the story to Melanie to tell.

I will just make comments on building -- I think I'll just skip over this quickly. Just to say that -- and this is, okay, this works. The key issue we looked at was the issue of efficiency standards in buildings based upon site efficiency standards versus full fuel cycle. So-called site versus source. Not surprisingly, one finds that there are many opportunities for net enhanced efficiency with full fuel cycle. Our recommendation in the end, and I'll just move on, is that we do recommend moving toward such full fuel cycle efficiency standards but cautioning that it's not so simple. There are significant geographical variations, climatic variations to make the full fuel cycle standards meaningful. And so this really is an area for further policy development. And needless to say, the full fuel cycle analysis also leads to substantial, like that was for water heaters, nearly a factor of three reduction in CO2 emissions with today's U.S. national electricity supply fleet.

Let me wrap up, say a few words about transportation. So now we're going to the gas-oil differential. This, again, eye test you can find in the report, but it's kind of interesting. All of these dots are looking at the West Texas intermediate oil price and the Henry Hub gas price at monthly intervals over 10 years, 20 years. Twenty years. Over 20 years. Okay? So it's a scatter plot of that. And plotted here are various -- these four lines are the various rules of thumb people use for that ratio. This, for example, is the energy equivalent ratio of 6. This is the, I don't know, the oil fuel ration of 10. Now, of course, any of these by definition is not going to be terribly accurate over time given the incredible volatility of this.

But what is kind of interesting is that in this time period, whenever the oil price has been above, you know, $75 or so, the ratio of oil to gas price has always been higher than any of the benchmarks. All the time in this period. Now, so the gas price is not being dragged up in the United States with the global oil price. Now, whether that is temporary or not we don't know, but if this certainly is a persistent trend and high oil prices that does obviously have implications for the oil-gas price spread and for the options of gas in the transportation sector.

Having said that, the payback periods -- let's talk about CNG, light duty vehicles. As you can see here, the only really attractive payback periods come when you drive 35,000 miles a year. That's the fleets. And if one can get the cost difference of the gas vehicles, let's say down into the $3,000 range, we are not in that range. In fact, the United States is an example of American exceptionalism perhaps is that we have exceptionally high costs for the price difference of gas and gasoline-powered vehicles. We strongly recommend that the regulatory structures be reexamined for this unnecessarily high difference. Get a level playing field. Even then we don't think that CNG will come in in a big way, at least not for a few more decades until the carbon price also gets very, very high to give you additional spread.

LNG long-haul trucks. I think I'll just make a long story short. That dog don't hunt. Then, despite the screwed up arrows, we also then look at -- imagine the arrows go down between those boxes. We also then talk about there's a whole bunch of pathways of gas to liquid fuels and, because the liquid fuels could tend to have some infrastructure advantages. We just note there is one -- one of these pathways is widely used today, just not for transportation. And that's methanol, which is the simplest conversion step. It's a big, global market. It is getting used more in transportation. Actually, China is moving into methanol. Methanol, if you remember, is also great for, you know, racers. Very, very high octane. Not so good on energy density.

But anyway, the bottom-line is that the methanol production cost is let's say the order of $1.50 per gallon of gasoline equivalent. There are issues with corrosion, et cetera, but the expectation is that the additional vehicle cost for tri-flexed fuel operation -- gasoline, ethanol, methanol -- is in the 100 -- plus 100, minus 50, minus 40. Jim Woolsey will say 60. We think that's a little bit on the low side. Somewhere in the $100 to $200 range is probably right. We advocate the open fuel standard, which means requiring all or some of the vehicles to have this capability as a national security issue because our view is in the end, which is like Jim Woolsey's that the issue is not oil use or oil imports per se; it's elasticity of the transportation fuel market. And this is the way to build in that and at least maybe get the ball rolling to produce the infrastructure, et cetera.

We'll just say that we do think that it's important that we start analyzing more carefully the interdependency between the gas and the electric infrastructures, particularly if the results that Melanie talks about come to pass. And I think I'm just going to end and say that on R&D we also, A, note that previous public-private partnerships -- at that time it was called GRI -- did play a significant role in moving us into the unconventional gas world and that with the demise of that -- of the GRI, which was funded by an interstate gas tariff -- there has been no substantial replacement of the natural gas R&D program which we consider somewhat ironic given the increasing prominence of gas in the energy mix and we make some recommendations about going back and restarting an R&D program.

So that's kind of the overall look. What I'm going to do now is have

Frankie spend a few minutes on drilling down into some of those issues you are looking at from the *New York Times*. And then Melanie on the electricity issues.

Frankie. (Applause)

MR. O'SULLIVAN: Thank you, Ernie.

Okay. So what I'm going to do is provide a little nuance around the supply side analysis. Earlier in the presentation, Ernie shows a breakdown of our overall U.S. supply curve. And in that -- on that graph, what you can see is that shale on average now represents some of the lowest cost gas in the United States. And that's certainly true. If you go about and have a look at where the rigs are right now you'll see that there's very little activity in the conventional place and a lot of activity in the shale place.

However, you know, our graphs kind of show an average representation of a much more complex picture. And what I'm going to speak about on this slide is that more complex picture. What we've got on the right-hand side here is a probability distribution for the performance. This is initial performance. Sorry, left. It's my right, your left. A probability distribution of the initial production rate for wells that were drilled in the Barnett play in 2009. The Barnett play is a useful play because many, many more wells have been drilled in the Barnett than elsewhere. And so the statistical analysis is more valid. But the same trend is present in all of the shale plays.

And what you can see here actually is that there is an extremely broad range in the performance of the wells. Much broader that you would expect, say for example in a conventional gas play. And what that means is that if we turn to the right and we explore the breakeven price for those wells, you can see that the mean price or the P-50 price looks something like we hear about in the media and so on. The actual spread within the play can be very, very dramatic. So for example, if we look at the

Marcellus -- because we hear a lot about the Marcellus -- you can see that a P-20 well or, you know, a higher performance well than the Marcellus, could likely breakeven at or about 200, 250. You know, obviously all of these numbers are subject to our assumptions around the cost of development, but the variance is baked in.

The mean might be around $4. But on the upside you could be $6 or $7 easily. And to be honest, the Marcellus is a reasonably tight spread. Other plays have much broader spreads. If you take the Barnett even for example, the Barnett now we're entering a phase where more of the better area has already been drilled out. And so we're seeing that the average well in the Barnett is now probably requiring about $6.50 to break even but you could have a range between $4 and $10, $11, $12 even.

And this is really the issue that's being drawn out in some of these *New York Times* articles. Individual wells can have very, very different performances, and we really don't know why. And as Ernie was saying earlier, this, you know, this shale development is really an art at the moment and not a science. As we move forward, the expectation is that technology development and so on will allow these spreads to narrow and allow operators to identify the sweet spots in the play and to drill those out. But at the moment you're seeing a lot of variation.

However, on average, these shale plays are more attractive than other alternatives. So the Marcellus on average is probably the cheapest gas to produce in the country at the moment. That isn't to say that any given well you select will be the cheapest well.

There's also a further complication to all of this and that is the fact that when you drill a gas well you may also be producing liquids. Depending on the play, you may, in fact, be producing a lot of liquids.

On this graph here, what we're essentially doing is illustrating how the breakeven price of a Marcellus gas well, an average performing Marcellus gas well, would vary from a situation where the well produced no liquids whatsoever to a situation where the well was producing about 50 barrels of condensate or liquids per thousand -- per MMCF of gas. And what you see is that with the coal liquids priced at let's say $80 per barrel, if you have a particularly wet well or a well that's yielding a lot of liquids, you can dramatically reduce the breakeven price. This dynamic is currently at play in the gas industry. So particularly in the Eagle Ford shale and in the Bakken shale, operators are trying to move their capital into those areas because the wells they were drilling there are yielding much higher liquids and they're able to drill them at much lower gas prices and still earn a healthy economic return.

Another issue that was brought up was -- in these *New York Times* articles -- was the question of sustainability in the resource space. And of course, it's an important issue. I think it's important to realize that, you know, shales have a finite resource base as well as conventional place and so on. And what we've done here is taken our analysis of the -- our analysis of the shale resource, the major shale plays at least, and projected forward the level of production you would be able to deliver from these shales, assuming drilling activity rates that were present in the plays in 2009.

And there are a couple of important points to note from that. The first is that in the Barnett shale, which is the bottom-most wedge, you will get to a point relatively soon by 2020 or perhaps even earlier, where you will have drilled out the play. You will no longer be able to extract any further production, any increases in production at least from the play. And the play will just enter into decline. Shales though have a slightly different decline characteristic to conventional gas wells. They decline slower, and so even though a shale may enter into decline, you're not able to further enhance output. You will still have a very substantial wedge of production coming from that play for a long,

long time. The question as to whether or not that production will be maintained is really dependent on what the OPEX or the operating cost is for individual operators relative to the gas price at that particular point in time.

A second point to note here, and this is very important, is that it is very easy to ramp up production from shales. Shale wells on average are a much higher performance or much higher initial production rates than a typical conventional well. And so with a given unit of capital, with a given number of rigs, for example, you can bring much more shale gas online than you can if you were drilling conventional wells. And you can see that from the very, very steep ramp up that's illustrated in this graph. The reality is that today at 1,800-odd rigs working in the U.S., this, you know, this projection may even be slightly conservative.

And then the final point that I will note is that here the Haynesville and the Marcellus should probably be flipped. When we made this projection the activity levels in the Haynesville were higher than in the Marcellus. The reality is that the economics of the Marcellus are more attractive than the Haynesville and in all likelihood will continue to be so. And so the Marcellus will really become the largest wedge among these major shale plays.

Okay. So very quickly a couple of points around the environmental issues. What I'm showing here is the -- an illustration of some of the steps involved in completing a shale well. Right now a lot of the controversy around shale production is of course linked to the fracking and the environmental consequences of fracking fluids, in particular contaminating aquifers, potable aquifers. Our analysis has really led us to the conclusion that this is not an issue. In fact, there has been no proven confirmed instance of frack fluid contaminating a potable aquifer. There are though significant issues around gas migration, shallow gas, for example, migration and drilling fluid migration into shallow aquifers, primarily due to poor cementing and well completion.

This is not a feature of shale drilling, per se. It's an issue that's inherent to all drilling activities. But because of the substantial increase in shale drilling activity, these issues have really come to the fore.

This graph, it's just a quick plot from our report. It's an illustration of the depth at which the aquifer exists in the Marcellus versus the depth at which fracking has occurred. And just a quick point. In all instances here there are several thousand feet of overburden between the shallowest frack and the deepest aquifer. And the physics, literally the physics of fluid migration under those sort of conditions are such that it is almost -- the risk is almost negligible to actual fluid making it from a frack zone to a potable aquifer.

So as I said, some of the key issues -- contamination of groundwater with drilling fluids or natural gas. Onsite surface spills. This is an important issue. Contamination of surface water due to inappropriate disposal. Again, an issue. It could be characterized as an issue to deal primarily with perhaps smaller operators who have less capability in this area. Excessive water withdrawal, not so much an issue in this part of the world, in the United States. And excessive road traffic. This is clearly an issue.

But all of these issues are manageable. I think that's the point. You know, in our report we lay out the environmental issues as challenging, certainly, but manageable. And with the right approach to regulation and coordination between industry and regulators, we believe that these issues can be addressed and that this resource can be, you know, safely tapped into the long-term.

So that's it. (Applause)

MS. KENDERDINE: Thanks. Thank you all for having us here today.

This is -- you saw Ernie earlier gave a -- showed a slide, a graph that had the capacity factors for the various generation technologies. It's important for the discussion as is this. And he mentioned we have a large NGCC fleet in the U.S. In this slide, what you're seeing are the various technologies and on the left-hand bar is the nameplate percent, nameplate capacity of U.S. total generation capacity. And on the right is the actual generation. And so what you see for natural gas, for example, it is 41 percent of our nameplate capacity. It is by a substantial amount the largest nameplate capacity we have in the U.S. Everyone thinks it's coal. That's not the case. It's gas. And but it's only generating 23 percent of our electricity. So that combined with the capacity factors that Ernie showed you earlier was a subject of interest to us in the gas study. And I'm going to talk a little bit about that today.

And Ernie talked about substitution possibilities of natural gas for gasoline and transportation and substitution of natural gas for electricity in buildings. And I'm going to talk about two substitution opportunities for natural gas with coal.

Drilling down into the numbers of the capacity factor for natural gas combined cycles of 42 percent when they're actually designed to operate at 85 percent capacity factors, and I think EIA in 2012 says 87 percent capacity factors for NGCCs. So what we wanted to do, we asked the question what would the impacts of changing the dispatch order be so that you dispatched the NGCC generation over coal generation. What would the impacts be on something like carbon emissions? And right now natural gas by and large, although it's changing, is the marginal fuel. It gets dispatched after coal. Those are old coal plants. It's less expensive overall and very old paid off coal plants. Many of them are 50 years old or more. And so NGCC capacity generation is the marginal fuel.

And so what if we just magically changed the dispatch order? What would the impacts be? And we started at a very high level. And that's what you're looking at here. And this is the scale and location on a state-by-state basis of what we call fully dispatched NGCC's potential FDNP, which I think sounds like a South American political party and radical political party. But we had to make up an acronym in order to describe what this truly was.

And you can see here the gray bar shows you the scale and the legend. I'm sorry about the colors. The colors in this and earlier slides, the really ugly colors reflect the ongoing battle between the Mac users and the PC users in the gas study. It's not really orange on the slide; it's green. That is efficient coal. Okay. I'm looking at the legend. That's efficient coal. Okay. The purple is inefficient coal and we define that by heat rate. Okay. Heat rate and pre-1987 coal plants. We picked the date when we repealed the Fuel Use Act as a date where we would look at all the new plants and efficiencies. And then the blue bar is the existing NGCC capacity operating at an 85 percent capacity factor minus the 2008 actual generation from NGCC plants. So it's kind of a made-up number but it shows you the potential surplus.

And then we plotted them on a state-by-state basis. You look at Texas and you compare the potential NGCC capacity to the inefficient coal and you could theoretically, if that was all surplus, replace almost all -- substitute almost all of the inefficient coal generation with surplus or potential surplus NGCC generation. So this is a starting point. It gives you an overview of the U.S., where you might start looking and drilling down into these numbers, which we did. And I'll show you that next. It gives you potential. And what you see here is or what is surprising to me is that the Southeast has a whole lot of inefficient coal plants and a lot of potential surplus NGCC plants. Then you look up here in the Midwest. Not a lot of NGCC generation and a whole lot of inefficient coal. Okay. So that's the first level look we took at this.

And then we modeled using an end rail model, modeled the U.S., and we modeled various regions in the country, ISO regions as well. And that model isolated what is truly surplus NGCC, taking into account congestion, imports, exports, all the things that you need or exist in order to ensure system reliability so that we can truly identify the surplus.

And what we found is that with no new generation capacity, nationwide coal generation displacement with surplus NGCC would reduce CO2 emissions from power generation by 20 percent. That's overall U.S. reducing CO2 emissions by 8 percent. I would note that that is over half of the 2020 goals for Waxman-Markey -- more than Waxman-Markey. Nevertheless, just by switching the dispatch order. Reduce mercury emissions by 33 percent. Very important right now as EPA is considering a mercury rule. And reduce NOx emissions by 32 percent and it would achieve all of this at a cost of roughly $16 per ton of CO2.

We had a symposium at MIT looking at the cost of retrofitting existing coal plants for carbon capture and sequestration and it was $50 to $70 a ton. So that gives you an idea of what that number means. And another point I would make is that the -- let me go on.

Now, the results vary by region. Of course, it depends on your generation mix. You saw the map. Some regions you have enormous opportunity; some you don't. And this is just looking at some regional impacts for mercury reduction in particular. Again, in ERCOT you get a 48 percent reduction in mercury because there's so much NGCC substitution potential. You go over here to Florida where when you look at the regional maps of CO2 emissions you get a substantial reduction. And you can do almost a one-for-one exchange in Florida, but they don't have a lot of coal generation. Okay? So you only get a 14 percent reduction in mercury emissions in Florida.

And so one of the recommendations in the study is the displacement of coal generation with NGCC generation should be pursued as the only practical option for near-term large-scale CO2 emissions reductions.

And just a story, my student and I were working to put together the language for this chapter and for this section and he had written that it is one of the lowest cost options for reducing CO2. And I said, Tommy, what are the other options? And he said, oh, there aren't any. There are no other options for large-scale CO2 emissions reductions near-term from the power sector. This is it. You can do efficiency, you know, in general, but this is really what we have right now in order to achieve large scale reductions, and you get criteria pollutant benefits as well.

I'm going to switch gears a minute. We also looked at what are the impacts on natural gas of large-scale penetration of intermittent renewable. This is wind, this is ERCOT. And what this is is this is short-term. And short-term is not what we typically think of as short-term in research terms. Short-term means that you have a requirement, say, for a renewable electricity standard that it passes right now and you have no opportunity or time to change the underlying generation technologies in your system. So it's an immediate impact. And these are -- this is a 24-hour period. Again, this is for ERCOT. In the far left over here is your base case. Okay? And again, you're seeing the Mac versus the PC fight here. The -- what you see, the wind is the orange; the coal is brown; gas peakers are light blue; and NGCC -- I mean, dark blue. The gas peakers are dark blue and NGCC is light blue.

So you see there, you see the wind, you see coal operating in a base load capacity. It's not cycling and very little peaking and a lot of NGCC use over a 24-hour period. What you do see in the NGCCs is the cycling of your NGCC plants on the tail-end of both the hours of the day.

Okay. Then you go over here where you have twice as much wind. And the impacts -- and here you can see the impacts of that win generation. Obviously, orange you see a lot of wind. On the early morning-late evening hours of the day, you see your coal plants cycling. Coal plants are not meant to cycle. That causes a lot of problems. You can read about some of it in some other work that has been done. Coal plants are not designed to cycle and they emit more CO2 and they emit more criteria pollutants. So that's what happens when you cycle coal plants that are not meant to operate that way.

The NGCC generation goes way down and your gas peakers are used a lot more. Okay. So that's the short-term impacts -- does the displacement of NGCC generation increase utilization of your operating reserves and more frequent cycling of mid-range and base load plants.

Then we also looked at this for the long-term. And I don't have the slide up here but what happens in the long-term is that, again, this is for wind. And long-term means that you have the requirement for renewables and you have an opportunity to change your base load -- your underlying generation technologies.

And in that instance, in the long term, and this is for wind again, wind assumes a base load role. You need more gas peakers but they are used less. And you reduced your conventional base load generation from nuclear coal and even NGCCs. This flips the definition of what we currently think of as base load. What your base load becomes is your intermittent renewable and gas peakers. And you don't really have a regulatory structure in place to accommodate that definition of base load. You need some way to incentivize the building of additional gas peakers that don't get used very often.

And so that's what this is. We need policy and regulatory measures to accommodate that, and we need an expansion of electric system models. We just can't look at all of this in a detailed way using existing models. And it's important for both short and long-term impacts and understanding what we're doing; an understanding, the unintended consequences of things like 20 percent renewable by 2020 on your power generation.

And then one more substitution opportunity. We looked at, and this is an industrial gas demand and what you're seeing coming up here is how much natural gas is used by industry. Thirty-five percent of natural gas use is consumed by industry. Of that, 85 percent is in manufacturing, and we spent a lot of time worrying about ammonia and fertilizers and feedstock, but really it's about boilers and process heating in the industrial sector.

And just a few words on boilers for both cogen and conventional boilers. There is a lot of discussion about that in Washington right now because of pending rules. What we did was we looked at the net present value of replacing existing natural gas boilers, which pre-1985 they're operating at 65 to 70 percent efficiency. In 2004, DOE set standards for gas boilers and those are 77 to 82 percent when in fact there are super efficient gas boilers on the market that can operate 94, 95 percent efficiency. And what we found here is that net present value, a gas boiler modification from the existing natural gas boilers to the sufficient efficient gas boilers makes a lot of economic sense to do and you get a payback period. It's a payback of 1.8 to 3 years. You get a payback very quickly.

But more importantly, and what's going on at EPA right now, is they're working. They've put out a proposed rule and withdrawn it. And I don't know where they are right now on coal boilers which really are about 66 percent of our large industrial boilers in the country today are coal-fired boilers, which I think is a little shocking. And what we did was look at existing -- retrofitting existing coal boilers to meet the MACT standard they put out, which does not allow for fuel switching. And they decided not to allow for fuel switching to gas in the MACT standard because they assumed a price of natural gas at about $10. If you go in and put today's price of natural gas and using all of their other assumptions, what you see here is that high efficiency boilers are slightly more expensive than the retrofit but you get CO2 benefits from that. But the super high efficiency boilers are less expensive and because the payback period is so robust and the difference is so great you have a negative $5 a ton carbon price. So we would hope that EPA would take an additional look at this as well.

As such, we would recommend replacing existing gas boilers. New super efficient boilers would cost effectively reduce gas demand and reduce GHG emissions. And EPA should allow fuel switching in its MACT boiler rule.

So that's it. Thank you. (Applause)

MR. GOLDWYN: Thanks to all three of you. As you can see, there's a tremendous amount of work that's been done.

We want to make sure we have time for the audience questions and for commentary from our two commentators, so let me introduce Phil Sharp, who is the president of Resources for the Future. He served 10 terms in Congress, so he understands the politics well. He's on the Advisory National Petroleum Council and as Ernie mentioned, he's been on a number of advisory councils on nuclear power and other areas. So Dr. Sharp, please join us.

Jeremy Kepes is partner and head of PFC's energy upstream and gas practice and he is also an exploration geologist by training. And so he can help comment on the upstream.

And then Ernie and Melanie, if you all want to come up, too.

Before we leave here we should really touch on four areas. A little bit on the resource, on what the potential is for demand. I want to come back on safety and exports. But maybe we'll start in that order. On the upstream we heard that the MIT study is pretty confident about the resource potential here in the U.S. both on -- contrary to some of the things we've heard in the press, doesn't seem too worried about the rapid decline rates because the ability to extract gas over a long period of time.

Jeremy, as you look at the upstream and deal a lot with companies here and overseas, do you share that view? What do you think about the upstream potential?

MR. KEPES: I think in terms of the resource estimates, as opposed to the reserve estimates and again I'm making the distinction where reserves are the economically determined volumes, I think that those numbers are good because we're not absolutely sure. But I think that range of estimates works just fine. The real issue is cost and productivity and I think some of the things that you had talked about are really the critical issues. So that's one thing.

The second thing is I think we have to be a little bit less optimistic about what happens with shale gas overseas. There's a set of issues at play here in the United States that simply do not exist yet in other locales. I'm not just talking about pro-business investment and what have you. There are a number of factors. One, we had from 2005 to 2008 very high gas prices. That allowed a degree of experimentation in technologies and the application of technology that really is holding us out well today which would never have been developed otherwise. And there's another way to say that. Right now, the economics for dry shale gas does not work in most places. One of the speakers referred to the importance of liquids. That's the critical point. Right now it's liquids that are driving shale gas drilling and activity, so that's one big issue.

Two, one thing that happened to the Barnett shale is at one point in time there were 70 different operators drilling and trying out differences in technology and applied technology. Flight variations in terms of how they did fracking. That degree of experimentation, kind of a hothouse laboratory simply does not exist in most other countries. In a lot of other countries the block size is a lot bigger. Larger companies doing this. The degree of experimentation just is not there.

Remember, it was not large companies that did this play in the U.S. They were gone. They saw it as incremental and not worth it. This was all about small companies. So as we've had large companies come back in, buy out the small companies consolidate, we may actually see the degree of innovation slow down. We may see large companies making other decisions about investment. So that actually has a negative impact.

And finally, just for people looking at this, the number of rigs that are drilling in the play is actually not a good number to look at at all as it was in the past. About 4 years ago, we had about 1,600 wells drilling gas wells. Now it's 1,000. But our production rates are much higher. So what's happened is that the type of rigs are much more complex so you really can't look at rig activity per se anymore. And that's because it's not about drilling vertical holes; it's about drilling lateral or horizontal holes. So to really predict this you have to look at what's the lateral length of these well bores. That's actually where you have to look at to make projections about efficiency gains and so on.

So again, just to come back to it, there's a lot of other countries that don't have all these positive factors at play. One of the critical factors we were talking before, if you're a landowner and if you don't get a royalty or a piece of about what's to happen in your backyard, you're not going to be for it. Right? If you're a landowner and you get a royalty you can put up with some of the activity that's about to take place on your property. If you're in France, if you're in a lot of places in Europe and other places, if you don't get a cut, you're not for it.

So again there's a number of factors at work here in the U.S. that brought about this. They don't exist together, at least not right now in a lot of other countries. So I think that's an important thing to keep in mind.

There's lots of other things we could talk about but let me stop at that point.

MR. GOLDWYN: Great. Thanks. Thanks, Jeremy. And the differential in the price of gas overseas where it's more linked to oil rather than where it is here may be another factor we should --

MR. KEPES: Huge impact.

MR. GOLDWYN: Phil, to turn to you, we heard some very optimistic things that if there are appropriate policy and regulatory changes could reduce greenhouse emissions dramatically, and we've heard about gas as really being a bridge, a somewhat long bridge but really ultimately not the destination in terms of a carbon-free economy. Based on the terrific work that RFF has done -- I'm going to slide by you for your answer --

MR. SHARP: Sure.

MR. GOLDWYN: -- I wonder if you could comment on that.

MR. SHARP: Well, just very quickly, we, like everybody else, have only been able to take sort of preliminary looks at this with models and whatnot. And what's very clear is it's not an automatic that you get great emission reductions and carbon dioxide because it depends, as Melanie was pointing out to various policies in the regulatory system whether the way you operate now or what gets substituted for what. So if it works out just normal, if you have no policies in place to force renewable or nuclear, you'll probably replace those two first with not existing nuclear but any future nuclear which is in trouble already with natural gas. And you don't replace the coal so rapidly. However, with all these rules and regulations coming down on coal and with the RPSs and what not, that remains an open season for it. But the point is, while economic, if the supply is really available, pricing in the market will make it harder for this development, not easier.

Now, that's just -- nobody thinks there's no policy in place so that's going to change. Let me just mention a couple of other -- we're actually about to start on a whole new thing we just got funding for to look at comparing the expert risks -- and that has various opinions on that -- with the public perceptions. And for example, the Marcellus, what the difference is in that and then what the impact of various regulatory systems at the state river basin and federal government level might have on that.

And that really goes to a point I want to make here. These studies done by MIT have been really important in the policy arena as well as, I think, in the marketplace and deserve very high praise in my view. And I think analysis is very important. But there's a couple very important limitations to absolutely keep in mind which they tried to articulate, which is these are not predictions. We can analyze what happened in the past pretty effectively but we are only projecting into the future. And that depends very heavily on what we allow for in the marketplace and what market decisions get made, especially in the United States. And if you go back, there was research when Melanie was at the Gas Research Institute that helped produce the understanding that you could have an economic breakthrough on this. But as Jeremy said, it really was having volatile gas prices. The willingness for a few people against all their peers telling them they were fools, to put the money in and take the risk and prove it.

So the point is though that the two big characteristics I think that are going to impact how significant this is in the future, one is how industry approaches this and the shift that Jeremy is talking about in who owns and operates and is into the big production appears to be shifting significantly at the moment as the big companies come in. Jeremy mentioned one of the potential downsides, which is they may not be as innovative, they may not decide to do it as fast because there are other opportunities that they will look at, but there are some other features that they might bring to it. I say might, which could be extremely important. And that is there are indeed departments that will very quickly be focused on how do we make these wells far more efficient than they are? How do we manage the complex more efficiently than might be done? How do we manage the communications with local communities and the politics? That means lobbying. And how do we smooth out the production because they are not likely to be quite as sensitive to, oh, my God, the price dropped for six months and we're going to pull back. They're more likely to play this out in a more productive way.

Now, that can all be positive or it may not work out. One of the most important things, if they are as proactive as some of them articulate that they are where they could be positive, and this is an if, too, is being proactive in trying to bring best practices to bear throughout the industry. In other words, help bring discipline on everybody; help engage with the policymaker. I think this remains to be seen. Is the industry going to be proactive in dealing with the kinds of technical and imprint questions that are very important to deal with?

But the second, of course, big uncertainty here is how will regulators at the state and federal government? Because they can add impediments and hurdles that make it too costly or will shape how this develops. But I don't think there's one fundamental that either one of these is going to change and that is the knowledge that this resource exists out there and exists on an economic basis is a magnet. It is a magnet to individual land owners. It is a magnet to state and federal governments and local governments that have massive revenue problems. It is a magnet to investors to make money. And it has some potential environmental benefits. So I do not think this is going to be an either/or proposition.

I would argue, too, that while what Jeremy says about developments in Europe and elsewhere, property ownership rides, regulatory systems, all these kind of things may make it harder. But let me suggest to you that if companies develop good techniques and strategies, they will move in. And if Poland thumbs their nose, as they did in a recent conference I'm told, at both Russia and as France and says we're going to go forward, you may find a bigger political push in some of these places to seize those economic benefits than you would get in the United States because here we are going to leave this more to the market regulating the environmental proposition.

SPEAKER: And China.

MR. SHARP: And China.

MR. GOLDWYN: Ernie, can I come back to you on the safety questions? Because this is, you know, there are task forces in a number of states. EPA is looking at this and a lot of the press is really worried about what do we need to do to make, you know, extraction safe? What do you think are the issues that are important to be focused on? And what do you think are the myths out there in terms of safety risks?

MR. MONIZ: Well, I think Frank detailed what's caused the problems. And so usually it's a good idea to go and solve the problems that actually exist as opposed to the ones that don't exist. So just following on what Phil said and Frank mentioned it, we feel that we just have got to, you know, raise the game in terms of requiring and furthermore requiring that the regulations be implemented on best practices for well completion and for service water management. We make some recommendations. One of them I would say is practically trivial at this point which is, you know, full transparency in terms of fracking fluids. Of more relevance is we recommend that there be mandatory regional water use and disposal plants. Now, that may lead in turn to some complication in terms of state versus EPA regulation. We are not arguing to move regulations to the EPA but we just think it's just got to be in everyone's interest to do that.

Can I just add one thing just to say something that Phil was always implying and never quite said in terms of the role of the big companies moving in, they've got very deep pockets and a very, very big interest in seeing best practices used by everybody because you know who's going to be gone after in terms of the problem. So we think that it's really the two obvious things -- well completion and we have very, very irregular standards in different states. We've got to raise them to the best practice and we need this kind of integrated water -- surface water plan.

MR. GOLDWYN: Perfect, thanks.

MR. KEPES: David, let me make a comment here, and that is there's another set of actors here that we're not talking about directly and that's actually the service sector. They're the ones actually drilling, running the casing and so on and so forth. And I don't want to talk about Macondo right now but obviously when that happened there were a number of factors at work. It's a complex situation. So what these guys are talking about also applies to who is really the service sector. Now, what could be good about larger, well capitalized companies coming in is that they may enforce a higher level of quality from the service sector because with the deep pockets you're ultimately responsible, which I think is your point.

So it's often in place like -- remember in the Marcellus, gas is not new. We've had gas and oil activity for 140 years. Right? So there are lots of mom and pop service companies that may cut corners here or there. I'm not casting any aspersions but the quality of that offering may not be what we would want. So we're going to have to be looking at that. So there is a whole group of other actors here and they range from the biggest Halliburton and Schlumberger all the way to, you know, my nephew running fat jobs off the back of his pickup truck. So there is a real quality issue and they're the ones actually on the ground.

MR. MONIZ: And if I may just add actually, in fact, Frank could give a kind of tourist report about visiting, you know, a frack site in Pennsylvania with absolutely first class operations, including piping in -- piping water, reducing truck traffic, recycling water, et cetera, et cetera. So that's the standard we need to have become regular.

MR. GOLDWYN: I want to make sure we get some time for questions for the audience. If you can keep your questions brief, why don't we take four questions in a row so that way we can get a variety of people? And we'll do one, two, three, Lou, and then the person in the back, four. Go ahead, ma'am. State your name and your affiliation. That would be helpful.

MS. AYRES: I'm Mirabelle Ayres with Lighthouse Consulting Group and I also serve on the board of directors of a Midwestern utility that has lots of those old, aging power plants.

SPEAKER: We can't hear you.

MS. AYRES: Okay.

SPEAKER: She confessed about coal plants.

MS. AYRES: Okay. My question is as follows, and it's to Ernie and Melanie and Frank. You made very compelling presentations and I found myself saying, okay, let's analyze why aren't we doing this. And I guess I have one question. The economics were compelling if you assumed some kind of a greenhouse gas reduction scheme in the U.S. And we're just not going there at this time politically. What may happen, you know, on the regulatory side will be a long and winding road. But if you could just talk about the economics, absent that what it means to rape payers.

MR. GOLDWYN: Okay. Economics that one. Second one. We'll take the second one. We'll take four in a row. This gentleman right there. Just the question.

SPEAKER: I have two questions. The first one is this. In your part about the energy source versus year and the coal in 2065 is zero, in addition to the CO2 problem what are the other measures, factors involved? And also the future sometimes is unpredictable and with human innovation could this breakthrough in coal use? And also water is a tremendous source. I think now from your answered question it seems that you have a pilot plan. Right? What's among the water source? And also, how do you do the used water disposal? And --

MR. GOLDWYN: I think those three are enough. I want to give others a chance. Breakthrough for technology in water use.

Lou, help me with a short one.

MR. POLARISI: Lou Polarisi, Eprin.

Melanie, first, what was the cost of gas when you dispatched -- when you did your dispatching rule? I mean, how far up did you get on the supply curve? I think that would be interesting. And the second thing sort of, Phil, you know, if you think about this innovation issue, which I think is fascinating, the guys in Texas, it leaps to Oklahoma, West Virginia, they have this huge landscape in which to try out ideas. And maybe the federal government ought to change its policy. Instead of use it to lose it maybe they ought to just open up lots more opportunities for people to innovate and try ideas. I think that's an interesting RFF problem because maybe we're thinking about leasing land all the wrong way.

MR. GOLDWYN: Thanks. And last the gentleman with the striped shirt all the way in the back.

MR. HANDLEY: Thank you. James Handley with the Carbon Tax Center.

SPEAKER: Can't hear. A little louder, please.

MR. HANDLEY: James Handley, Carbon Tax Center.

First of all, I'm pleased to hear the mention of the need for a carbon price in order to get displacement of coal with gas. And I'd like a little more discussion of that. And the second question I have is we're reading reports, for example, from Professor Howarth at Cornell about the amount of methane being released during the fracking process, which his estimates suggest are significant enough to negate much, if not all of the advantages of natural gas as a replacement fuel for coal. And I'd be interested in your comments about that subject.

MR. GOLDWYN: Great, thanks. All right. Prospects for this policy happening without a carbon price; prospects for innovation water management; cost of gas on dispatch and a policy for federal lands; and the Howarth Center.

SPEAKER: We can't remember all of those questions.

MS. KENDERDINE: Put it out one at a time. The need for carbon price, to Mirabelle's point or question is there is no carbon price. Politically, we don't think we'll see one for a while. The Mercury Rule, if we don't repeal the Clean Air Act, the Mercury Rule is going to drive a lot of this. Okay. So, you know, you can see you're going to have to make choices on these old, inefficient coal plants. Do you retrofit them to comply with the Mercury Rule? Or do you use a surplus NGCC capacity? And so I think that's the calculus that the utilities are going to have to make. And I dare say a lot of those old coal plants are going to go down.

MR. MONIZ: Well, in fact, let me just add to that. Of course, a bunch of coal has gone down already, about 12 gigawatts. Because we're dealing here with kind of averages but these are all distributions and there's a tale that's already getting cut off. We also forget that coal prices today are actually relatively high. And so you take the oldest, inefficient coal plants and they already in some cases have a higher marginal cost than gas. But that won't get you up the kind of ramp that we're talking about. And the fact is in the average sense the substitution that Melanie spoke about would end up being about two mils per kilowatt hour incremental cost on average. So that's just the reality. And so either you require it or you don't in a certain sense.

MS. KENDERDINE: If I could say one other thing on that, too, and we've talked a little bit about Europe. And I just got back from Hungary where, you're right, Poland is very bullish on developing their shale resources and it's actually going to cause problems in the E.U. as the E.U. develops environmental regulations and so -- and they were worried about that. But the Europeans have a price on carbon. And the Europeans are also watching what we do here on our production -- the environmental impacts of production to see how we handle it before they move forward full bore there. But the Europeans have a price on carbon. Companies here want to do business there in shale production. They need to pay attention to carbon price. And so it's important in other parts of the world even if we don't have it here.

I personally think that there is a large export market and a need here if we want to take advantage of that export market for the drilling rigs and the entire supply chain that you need to service that industry elsewhere because there aren't enough rigs around the world. That's another thing I hear everywhere I go. We don't have any shale rigs. Or the entire supply chain to produce that shale. So what we're doing here is important there and there is a carbon price elsewhere. And I think that the price of gas is around $5 in the model. Okay.

MR. MONIZ: Although that result though was driven by just legislating dispatch quite independent to the price.

MS. KENDERDINE: Right, right, right, right.

MR. GOLDWYN: Phil, do you want to talk about the federal side.

MR. SHARP: Well, just briefly I don't have a lot of knowledge except my previous experience on accessibility. Of course, the federal government is one of the largest -- is the single largest landowner in the United States and is huge, especially in the West, as well as the Outer Continental Shelf. But the question I would simply raise is we have two different kinds of questions here related to the innovation. One is where you experiment and you do pilot projects. Those can be great as part of R&D and whatnot. But what happened in shale was a broad based opportunity. The land was potentially open. The resource known to be there. All of this stuff, the question was would somebody gamble, take a risk on their limited knowledge and go for it? Now, I think it's unlikely the federal government is just going to widely open up for "do whatever you want" kind of proposition, though there might be ways in which we should be reviewing. Land policy in this country is old and needs to be revived. It's very clear, however, we appear to have made a decision. We haven't made it formally but informally we're going to go ahead with deepwater drilling even after the Macondo, and that's a very wide open proposition which suggests a changing in attitudes or politics that is much more open in this economic climate or economic development, which goes back to my other point. Anybody who imagines that we're going to shut down all of this productive possibility and shake gas has got to have their head examined politically. There are important environmental and other kinds of information issues but be careful about getting caught up in the notion, oh, well, therefore, we're not going to do this. This is a magnet. That's what tells me about Poland and Europe, too, is once proven, once done, and it needs to be done and managed well, I think it will be -- this is an unstoppable train.

SPEAKER: (inaudible) answer for my question.

MR. GOLDWYN: Yes, we are just about also out of time if you want to comment on the science of the Howarth study and the technology question.

MR. MONIZ: Look, as I said, I mean, clearly technology breakthroughs can change the time and the nature of the transition, especially in a carbon-constrained world from carbon to zero carbon. For coal, it comes down to carbon capture cost is just way too high. Incrementalism is not going to solve that problem. It's got to be new.

Nuclear, okay, let's assume, let's put Fukushima- kind of ripples aside for the moment. Frankly, recent experience in building large reactors has not been encouraging in terms of costs. One of the ideas out there is small marginal reactors. It's a completely open game whether or not the manufacturing approach to reactors will produce a different cost paradigm and make them competitive. Don't know.

Wind, solar. Solar, in particular, clearly coming down in cost very, very dramatically as far as carbon-free. But at some point, whether it's wind or solar, at a large deployment we have to not give -- we cannot run a reliable system while giving a free ride to storage and reliability of the system, et cetera. So there's a big technology space. I want to repeat. You said the future is unpredictable. We agree those were not predictions. They were a model scenario to give you a sense as to how different factors interplay. On water, let me say that the issue is not the water availability for these. You take even the Barnett, the most mature of the shale plays. What is it? A couple percent of the --

SPEAKER: One percent.

MR. MONIZ: One percent is the scale of the water requirement. It's the flow back water managing the water on the surface, cleaning it up, recycling it, having a good disposal well infrastructure which does not exist in the Marcellus. Those are the issues there.

Howarth, do you want me to do?

MS. KENDERDINE: I would say on water it's also compared to what? All of your conventional energy uses a lot of water. Okay.

MR. MONIZ: Yeah, withdrawals. Yeah.

MS. KENDERDINE: Not necessarily consumption.

MR. MONIZ: In fact, not often realized is that the largest water withdrawal activity in the country is --

SPEAKER: But in your case --

MR. MONIZ: Is for the cooling of thermal power plants.

MS. KENDERDINE: Right.

MR. MONIZ: On Howarth, the Howarth issues, we do have -- we have an appendix on it and a recommendation. First of all, the issues of the -- okay. We can see no basis on which this idea that gas is worse for us than carbon than coal, we just see absolutely no basis for that. On the fugitive emissions issue we do recommend -- we cannot understand, frankly, the numbers used but we do say that, you know, this is not well understood. We recommend that the EPA and the DOE together do a serious analysis of this, including, kind of a novelty, using real data to address this. We have some other recommendations in there as well but the other thing that we would mention is that, in fact, there's even some experience with voluntary programs, EPA for example, that there is also an economic benefit to capturing these emissions. And frankly, it's not all that hard.

So the distinction we would draw is that when you combust a fossil fuel, the CO2 goes. You can try to capture it. Very expensive, but the CO2 goes. Whereas, these other sources, like fugitive emissions, we know how to deal with them. It's a question of requiring them or having a market incentive to capture the methane and reuse it. We do recommend the study that I mentioned.

A second issue raised in that paper where we -- oh, and I should say by the way the number may be doubted because, as I say, frankly, they're not that well understood. But fugitive emissions from both gas and coal were part of the modeling that you saw. That is built into our economic model assumptions based on previous knowledge at least about emissions in production.

And the other point that's raised there is there was a recommendation to change the factor used for translating methane into CO2 equivalents as a greenhouse gas forcer. The conventional number is in the 20s, low 20s, and there was advocacy for ramping that up to 80 roughly. What that was based on is the way we do all of these comparison of CO2 equivalents of greenhouse gases is very imperfect. What you would like is an economic damage function and a discount rate back to the present. We don't know how to do it. So the IPCC in 1990 adopted an approach based upon ray deforcing. And what you do is you integrate it out to a certain time period and that gives you the factor. The IPCC has settled on, and the EPA and everybody else, including us, has settled on a 100-year integration period. That then covers a substantial part, although not all, of the CO2 ray deforcing you would have over time because CO2 is in the atmosphere for many centuries.

Methane is very short-lived. So in the Howarth paper he advocated moving the integration time back to 20 years, which captures the full impact of methane and a very small part of the impact of CO2, thereby increasing the factor. We just, I mean, okay, if it's transparent it's fine but we think 100 years, which is the standard approach, makes a lot more sense.

MR. GOLDWYN: Thank you, Ernie. Thanks. Let me do four thank yous. First, thank you to the audience for being patient. I know we've run over but we could probably spend another hour and a half on these issues. Thank you to Ernie, to you, and to Melanie and to MIT for adding so much to the literacy of the public on these issues which are so important. Thank you to our panelists for participating today.

One plug for Brookings. Brookings' Charlie Ebinger is leading a task force on natural gas. We're looking at supply, demand, exports, and the geopolitical implications of access to gas for China, India, Eastern Europe, and other places where it's so important to their security. So there will be more to follow.

It's been a very, very rich morning and we'll commend the study to you on our website. Thanks for coming.

SPEAKER: And thanks to Brookings and to David. (Applause)

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I, Carleton J. Anderson, III do hereby certify that the forgoing electronic file when originally transmitted was reduced to text at my direction; that said transcript is a true record of the proceedings therein referenced; that I am neither counsel for, related to, nor employed by any of the parties to the action in which these proceedings were taken; and, furthermore, that I am neither a relative or employee of any attorney or counsel employed by the parties hereto, nor financially or otherwise interested in the outcome of this action.

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