Jill Engel-Cox: Welcome to our webinar on the Pathways to Decarbonization and how natural gas and renewable energy are part of the evolving power sector. I'm Jill Engel-Cox. I'm the Deputy Director of the Joint Institute for Strategic Energy Analysis. The Joint Institute conducts in-depth analysis of energy systems, specifically related to energy finance and society. And our pathways to decarbonization analyses have focused on the future of cleaner energy sector and the potential role of complimenting – complementary resources, including natural gas and renewable energy, which we'll talk about today.

Today is the first of three webinars in a series on our natural gas analyses that we have completed over the last year. These studies have been funded by the private sector companies, various companies, and we would like to thank them specifically for their input – although this does not imply their endorsement of the results. The results are completely independent – an independent study conducted by the Joint Institute.

So, today, in our first webinar we will cover broad power market trends towards decarbonization, which is the reduction of emissions from the power sector. On April 20, our next webinar will be on methane emissions and control, and on May 4, the third webinar will be on spatial and temporal considerations of energy. And you can find announcements for these on the website that is shown on your screen, as well as full reports on these studies on the website as well.

We have three speakers. Our first speaker is going to be Jeff Logan, who's going to talk about sector and regional trends in the US electric markets. Wesley Cole will discuss the role of natural gas and decarbonization. And Jacquelyn Pless will take us down some pathways to decarbonization through her work with stakeholders.

So, at the end of the talks we will have time for questions and answers. You should have a questions box on your webinar, so please go ahead and type the questions in the box. You can do that during the talks or you can wait till the end, and then we will cover all the questions at the end of the webinar.

So now, I will turn it over to Jeff.

Jeffrey Logan: Great. Thank you, Jill. And thank you, everyone who's on the webinar. We're pleased to present results today on a study that we published back in October looking at high level trends in the US electricity market. And we focused there on the regional and sectoral trends that are occurring, with a special focus on natural gas.

So, the outline for today's talk is very simple. I'm going to keep things at a very high level. First, focus on some of the national trends in the electricity sector. Then, look at regional trends by NERC region, and we'll have a map there for those of you who are not familiar with NERC regions. We'll have a map to guide you on which states we're talking about. And then, finally, we'll have a brief summary of some of the sectoral trends, looking especially at, for example, industrial use of natural gas and LNG exports.

So, without further ado, we'll begin by looking at some of the national trends. And we have here a map of electricity generation by fuel type from 1950 until the end of 2015. And I think you'll notice here that there's been unprecedented change in the US electricity markets, especially over the past seven or eight years. Coal generation is down by one-third from its peak in 2007-2008. Many of you may have heard today that Peabody Energy declared bankruptcy. That is the largest coal supply company in the United States, and that follows earlier bankruptcies this year from Arch Coal and several other major producers. So, the coal industry is in rapid decline, while natural gas is largely in ascendency in replacement of that lost gas generation. But you'll also note that non-hydro renewables have grown very rapidly, although from a small base, beginning and around the year 2005. Most of the other major generation sources in the US – nuclear and hydro, for example – are fairly stable. And petroleum generation continues to decline and currently accounts for less than 1% of US generation – although, in the states that still use petroleum it's a very important fuel to ensure that supply and demand are matched.

So, this slide I won't spend a lot of time on; it's very similar to the first one. It just shows the share of generation that each of these fuels supply. And you'll note that coal and natural gas largely came into equivalency in 2015. Coal still beat out natural gas generation by about 20 terawatt-hours, but gas generation led coal for seven of the 12 months in 2015. And the EIA, which is the main forecasting agency at the Department of Energy, anticipates that natural gas generation will exceed that from coal in the year 2016 for the first time ever.

The next slide just looks at what new capacity additions have been brought online in the United States over the past 65 years or so. And we'll start from the most current era, and we see that, number one, a lot of coal has been retired in the past four years – about 35 gigawatts have been taken offline. A lot of this is the result of very low cost natural gas generation, which makes it difficult for especially the older and dirtier coal plants to compete. And many of them need to add new environmental control equipment to comply with, for example, the mercury and air toxin rule which came into effect last year.

We also see here in the past few years very strong growth in wind generation – or, sorry, wind capacity brought online, and solar capacity as well. In 2015, wind capacity was the leader in the United States for new additions. And in 2016, many analysts believe that solar will be the largest new source of capacity additions in the US.

We also see here in this chart beginning around the year 1999 and extending through 2004 a very large addition of new combined cycle, gas-fired power plants. And when these plants came online they were initially – they initially took the system into oversupply, and the natural gas plants were not used at their full capacity. We had a lot of excess capacity for natural gas generation. That has changed over the past few years. And in fact, in 2015 the capacity factor for natural gas combined cycle generators exceeded that for coal in the United States for the first time ever. That's pretty remarkable. I believe they're up – the fleet-wide capacity factor for combined cycle plants is now up to about 56%.

And we see other things in here such as, you know, throughout history, from 1952 to the mid-1980s, coal generation, coal capacity additions were – grew very strongly. But that really began to subside in the 1980s as economies of scale for coal generators no longer achieved the historic improvements that they saw during the 50s and 60s and 70s. We also see that there have been no real significant nuclear additions in the past few decades. There are five gigawatts of new nuclear capacity under development in the Southeast, and that new generation capacity will come online in the next few years.

And so, what has been driving the significant change in the US generation sector? At last one of the drivers has been this availability of very low priced natural gas, most of it coming from shale gas formations. And we see here in this slide the sources of shale gas in the US, and especially we see very strong growth in the Marcellus Formation in the Northeast, and the Utica play, which is in Ohio and Pennsylvania and West Virginia. It's really unprecedented that we went from this period of a shortage in natural gas up through even 2007-2008 to this period now where shale gas alone is supplying about 58% of the country's total dry natural gas production.

So, with that overview of the national trends we'll now look at some of the regional changes by NERC region. And we'll start off with a map of the NERC regions themselves. And I want people to note that the NERC regions are the North American Electric Reliability Corporation regions, and these differ from the traditional ISO and RTO boundaries that some people are also familiar with. Just note, for example, the MRO region, which is the Midwest Reliability Organization in light blue at the top, with Minnesota and Wisconsin and Iowa and some other states. This region is significantly different that the MISO region, which is the RTO and the ISO for the Midwest. So, please keep that in mind as we're going through some of these slides.

We're really going to only look at three regions in some detail here. The three largest generation regions here are SERC, which is the Southeast – that's the deeper blue region in the bottom right-hand side of the map, shown here; the RFC, or Reliability First Corporation region, which is Pennsylvania and Ohio and some other regions that are shown in the green; and WECC, which is the Western Electricity region shown in yellow in the far left of the map.

And we see here in this chart the generation mix that occurs in each one of these reliability regions, and we see quite a bit of diversity here. Some areas like the Midwest and the Southeast are still dominated by coal generation. Others, like the Northeast and Florida and Texas, which see an awful lot of natural gas generation. And others, like WECC again, which is the leading region for renewable electricity generation.

So, with that, we're going to now look at three specific regions. And we're going to start with the Southeast region: SERC. And what we've seen here, what we have in this slide shows the generation in the top left corner and the capacity additions in the bottom right corner. And for the capacity additions we show both the historical additions plus what is planned in the near future. And these planned capacity additions are – should be viewed as a conservative estimate, because these are only plants – or, new products that have entered the – that have entered advanced levels of planning or construction. So, there's probably additional plants that will also be added that are not shown in the – in this chart.

And what's unique, I guess, about SERC is that coal generation has declined significantly in the past few years, and we're only showing generation changes through the year 2014 here. In the year 2015, some of these changes further accelerated. So, we show an 11% decline in coal generation over the years 2009 to 2014 for the Southeast, but there was additional degradation in coal generation in the year 2015 as well. And we've seen a rapid expansion in gas generation: It's up over 50% in the past five years. And pretty strong growth in non-hydro renewable energy, but from a very, very low base. Total demand growth in the Southeast was actually fairly strong compared to many regions. But compared to historical levels of demand growth, this is only about 1% a year, which is fairly slow compared to historical levels. The Southeast, I should note, is also the only region that has new nuclear capacity under development. And I think that will cover it for the Southeast region.

Next, we look at another eastern region – this is the Reliability First region. That's the green states in the map here. And we also see in the RFC very rapid decline in coal generation and a replacement with natural gas generation. But even more than that, more than just a replacement, there's new growth in natural gas generation. In the RFC we also see very strong growth in non-hydro renewable generation – but again, this comes from a very low base. And total demand is relatively – has been relatively flat in this region, like many others. Wind power, I think especially, is expected to grow fairly strongly in the RFC region.

And then, finally, we'll look at the western region. And what we see here is coal generation declining a little bit, but it has not been replaced by natural gas generation. That – natural gas generation has also declined in this region. Non-hydro renewables have grown very strongly and from a fairly significantly larger base than the eastern regions that we looked at earlier. Total demand growth is relatively flat there, and we see very strong expected growth in solar, and to a lesser extent wind in the western region.

So, that summarizes three regions that we looked at. There are – all the additional regions are included in this PowerPoint that will be made available at the end of the webinar.

So, we'll look at now some of the sectoral changes that are occurring in the US gas sector. And one thing we can note, that after – what we see here is all the different types of natural gas demand by different sectors in the US, and one thing that immediately jumps out is that the industrial sector has seen a resurgence in natural gas demand over the past four or five years after a period of steady decline. And I think this is where many people are aware that there have been a lot of new investments in petrochemicals and other natural gas products that are used in the industrial sector with the emergence of the shale gas revolution and abundant low cost gas supplies. The other thing to note here is that, as expected, demand for gas in the electric power sector has been very strong over the past 10 years or so, and it really surged in 2015 again because gas prices came down significantly due to oversupply.

Another sector that we'll briefly look at is the trade in natural gas. And according to the Energy Information Administration's most recent Annual Energy Outlook, the United Sates will become a significant gas exporter by the year 2020. And we can see evidence of that in the far left of this graph for the year 2005 to 2013: There's already been a significant decline in the net imports the United States sees. And by 2020 we will expect to see – at least in a reference scenario – a large amount of – a large and growing amount of LNG exports, and exports by pipeline as well. And we see three other scenarios here that showed varying levels of gas trade depending on the availability and price of natural gas.

So, with that, my final slide just looks at the natural gas storage outlook in the United States – and again, this was also developed from the EIA. And we can see fairly strong stockpiles of gas and storage in the United States, which would tend to indicate continued downward pressure on the prices for natural gas, for the near term anyway. We've just gone through one of the warmest winters on record, if not the warmest winter on record, and very little gas demand was used for heating. So, that tended to prop up very high storage levels.

So, in conclusion, these very simple findings result from the study that there's a large amount of redispatch from coal to natural gas in the eastern half of the United States – or, the eastern one-third of the United States is probably more accurate. And this is called *redispatch*, meaning that utilities that own large fleets of coal generators and natural gas generators are choosing to ramp down their coal generation and replace it with gas generation, or use their gas assets more than they had previously. And we've also seen very strong growth in wind and solar generation, mainly in the western half of the country. But at the same time, the western half of the country has not seen this redispatch from natural – from coal to natural gas, at least not through the years 2009 and 2014. That may have begun to occur more in the year 2015, given the very low price natural gas environment.

And I just wanted to note that you can access this full report at this link shown at the bottom of the slide. And with that, I am going to hand it over to my colleague, Wesley Cole, who will talk about some modelling results related to deep decarbonization and natural gas. So, thank you.

Wesley Cole: So, yeah, we're going to switch gears a little bit. So, Jeff has kind of set up how the natural – how natural gas in the electric sector has been changing over the past – recent history. So, now we're going to in this portion talk more about, forward-looking, how natural gas might play as – in a decarbonized US electricity system. I just want to acknowledge the other people involved in this work: Ross Beppler, Owen Zinaman, and Jeff Logan all contributed here.

So, what we're going to generally talk about here is: What is the role of natural gas in transitioning to a decarbonized power system, just with the focus on the US here? And how does that role change as other technology pathways that also lead to decarbonization become more attractive? So, specifically in this work we looked at energy efficiency, low cost nuclear power, low cost renewable energy – primarily wind and solar – and low cost carbon capture and storage as additional decarbonization technologies. And full details are in the paper; we'll provide a link at the end of this slide. But I'll just hit some of the high level pieces in this webinar today.

So, to do this forward-looking modelling work, we're using the ReEDS model – the Regional Energy Deployment System model. This has been developed out of NREL over the past 15 years or so. It's an optimization model of the US power sector. It represents both the transmission and generation within the United States. It has relatively decent granularity – 134 balancing areas across the US – and represents resources with even more regions. And it looks out through 2050, so it solves from essentially now through 2050, looking at how the power sector might evolve under a variety of economic, technology, and policy assumptions that we put in place. This is the tool that we're using to evaluate the model. There's more details on the tool in the paper and in other resources that we have online.

So, when we were saying we want to look at how the power sector might be decarbonized over time, the way we were doing that was imposing these CO2 emission target trajectories. So, we have two levels of CO2 emissions out of the power sector that we're considering. The low emission target trajectory reaches an 83% reduction in 2050 from 2005 levels. The mid carbon target achieves half of that reduction – so, 41.5% reduction by 2050.

A couple of notes on these. First is that we have taken out CHP-related emissions. That's why our historical numbers are sort of suggested there: We've removed CHP – combined heat and power – related emissions. And the other note that's important here is that we're only considering burner tip emissions. So, we're only considering CO2 emissions that are out of the power plant. Anything upstream in the natural gas processing or anything related to methane leakage isn't captured in this work, and depending on what kind of assumptions you use there that could impact results down the line here.

So, we talked about those four technology pathways before, and those have fallen into these scenarios. The scenarios we're going to talk about here are shown in this table, but the reference scenario that we'll compare against with this assumption is shown here. But in addition to that reference scenario, we're running sensitivities on natural gas prices – so, low and high natural gas prices. And then, we have sensitivities using our four – we'll call them decarbonization technologies here. So, one with a high amount of energy efficiency where we say there is no – there's no demand growth after 2014; all additional demand growth is essentially offset by energy efficiency. We have a low nuclear costs scenario where we reduce the capital costs of nuclear power by 30%. A lower renewable energy costs scenario where we essentially implement lower cost trajectories for wind, concentrating solar power, and photovoltaics. And then, two low carbon capture and sequestration trajectories where in the low cost one we've reached $40.00/ton of CO2 captured, and in the very low cost we've reached $10.00/ton of CO2 captured.

So, these are scenarios we're going to consider in the following slides. I guess a final note on these is: This work was done prior to the finalization of the clean power plant of the tax credit extension, so those aren't represented in this work. So, I think the general trends that we see here won't be impacted by that – by those emissions here.

So, we'll start with a summary of natural gas generation in 2030. So, you'll see this bar chart on the bottom that has the scenarios we showed in the previous table, and for each scenario it shows what the natural gas generation in 2030 was when there was no carbon target imposed – we just let the system evolve under normal conditions – when we imposed that mid-carbon target that reaches the 41% reduction by 2050, and the low carbon target that gets to 83% reduction by 2050. And what we see in all cases is that as we impose a more strict carbon target, natural gas generation increases irrespective of the scenario that we consider. So, whether we're looking at high natural gas prices or low RE cost, as we increase the stringency of our carbon target, we're getting more natural gas generation. So, this is pointing to natural gas being used as a tool to help decarbonize the grid in the 2030 time frame to reach those lower emission targets.

The other thing that you'll note here is the right four technology cost scenarios all look relatively similar. The biggest changes are in the low and high natural gas prices. So, what we've seen in the 2030 time frame is the natural gas generation, it seems to be sensitive to natural gas prices than it does to competing technology changes.

So now, if we jump ahead to 2050 and look at the same type of figure here, we see that when we go from a no carbon target to a mid carbon target across all the scenarios we're getting an increase in natural gas generation. So, in our mid carbon target scenario, in 2050 natural gas is still being utilized more than normal, we'll call it, towards decarbonizing the grid. But then, that changes as we go to this much lower carbon target, the 83% reduction. In that case, natural gas generation is lower than it is in a no carbon target scenario across all the scenarios we looked at. So, as – depending on the stringency or how much you want to decarbonize the grid, that will also dictate to some extent the role that natural gas will play in that decarbonization.

The other piece we note here is, again, the natural gas price scenarios are the ones with the largest difference in natural gas generation. So, again, the sensitivity to natural gas prices is very strong.

And so, we're going to hit that point again here on this figure. So, what we've done is we've taken those scenarios here now and have grouped them. So, the left – this left figure has the range of natural gas generation under the four technology scenarios – so, the low EE – or, the low EE cost scenario, the low renewable energy cost scenario, the low CCS cost scenario, the low nuclear cost scenario. So, the range of natural gas generation with and without the carbon target is shown on the left, and then on the right it shows the range of generation with and without a carbon target for the natural gas price scenarios. And the key takeaway here is that the range on the left is relatively small; the range on the right is huge. And so, really, the – what is dictating a lot of the role of natural gas in these scenarios is going to be the price. It's very – it's going to be very price-sensitive going forward, even if other technologies become more or less attractive. Future natural gas prices is going to dictate a major part of the role natural gas will play.

So, the other piece we looked at was this – the role of CCS. And just one of the things we found is that natural gas was – at least in our model – was more cost-effective than coal CCS was. And so, what you'll see in this figure is natural gas generation with no carbon target on the bottom in the blue, mid carbon target in the red, and then the top, the green one is with the low carbon target. And you can see that natural gas generation in the reference with the low carbon target begins to decline in the mid-2040s, unless there is low cost CCS that becomes available. So, that dotted green line that continues to go up after 2040, it's utilizing low cost carbon capture storage and it's able to increase natural gas contribution to meeting grid needs. So, CCS can really change how natural gas plays in a highly decarbonized grid, from going from needing to decline in the long term to increasing usage over the long term.

Then, we looked a little bit about how the grid is operating with more or less natural gas – there's two slides on that. So, this figure on the bottom is showing curtailment or unused renewable energy as a function of variable renewable energy penetration. And so, you can – if you look, for example, at a fraction of 0.2 – so, 20% of the load is being met by renewable energy on an annual basis, you can see that curtailments at that level of renewable energy penetration are highest when there's high natural gas prices and lowest when there's low natural gas prices. And we've seen from the other scenarios that high natural gas prices means there's not as much natural gas operating on the grid; low natural gas prices means there's lots of natural gas operating on the grid. So, for the same level of penetration, having more natural gas is lowering the curtailment that we're seeing on the grid. So, it's essentially creating a more flexible system: We're able to utilize more of the renewable energy and have a more effective grid in that sense.

So, we looked at a similar kind of thing in terms of storage. So, this figure has the same x-axis as the fraction of load that's being met by variable renewable energy; on the y-axis is storage capacity. And you can see there's this general trend over time. There's some anomaly points. The ones that require more storage for a given level of penetration are our low nuclear cost scenario.

That's not surprising because nuclear generation is not as flexible, so the model wants to add more storage to account for that and deal with flexibility challenges. And the high natural gas price scenario, when there's not as much gas in the grid – again, it wants to add more storage to help with flexibility – while in the low natural gas price scenario there's less storage that the model sees as needed in order to help integrate renewable energy into the system.

So, just as a summary here, natural gas is – across this range of scenarios is providing a large amount of the generation. It obviously depends on the level of decarbonization. We saw that in the mid case with just some decarbonization, natural gas' role was increased, versus higher levels of decarbonization, natural gas in the long term was decreased – but it still had a substantial share of – or, it still had substantial levels of generation.

We also saw that natural gas generation is strongly sensitive to natural gas prices, that there's – really, that's going to dictate a lot of the role natural gas plays going forward. We also looked at how getting to low cost carbon capture and storage could increase natural gas demand over the long term, especially in the decarbonization scenarios, that natural gas could continue to grow even as the grid reaches very low levels of carbon emissions. And finally, that natural gas provides additional flexibility to the system that reduces the need to invest in other more expensive flexibilities like storage or curtailment. So, there's a lot of good opportunities for natural gas to contribute to a system that has a lot of zero carbon resources on it like wind and solar, and there's just a lot of potential for them to interact together there.

And lastly, I'll note this again, because I think it's important, that the upstream life cycle pieces like methane emissions could change some of how we're looking at natural gas, considering natural gas in the power system, and what we've looked at here is just the power sector itself and the burner tip emissions. And with that, we'll turn it over to Jacquelyn.

Jacquelyn Pless: Great. Thank you. So, we've heard from Jeff and Wesley about the potential for natural gas to contribute to decarbonization. And so now, I'm going to transition a bit into talking about the complementarities of gas and renewables, what we learned from a series of workshops that we held with stakeholders, and then also a little bit about the economics of investing in hybrid systems.

So, although gas and renewables have traditionally competed for market share, particularly in the power sector, there is growing potential to use these technologies synergistically. So, both resources – gas and renewables – offer the benefits of abundant domestic resource cases and a low carbon footprint; however, they have these different and complementary risk profiles. So, building upon some of these observations and some previous work done by JISEA as well as some other papers in the literature, JISEA held a series of workshops in 2014 with its partners to explore natural gas and renewable energy synergies in the US power sector. So, this report and the presentation here is going to capture some of the key insights from that workshop series that we called "The Synergies of Natural Gas and Renewable Energy: 360 Degrees of Opportunity." And then, I'm also going to present a summary, a very high level summary of the analysis that we conducted to start quantifying the value proposition of investing in gas and renewables together, both at the project level and also taking a system-wide perspective.

So, we held three workshops that were kind of strategically located: one in New York, Washington, D.C., and San Antonio, Texas. So, the goal for each workshop was to define kind of unique regional or sectorial opportunities for gas and renewables to complement one another. So, in New York the workshop really targeted bringing together the finance community. In Washington, D.C., more of the policy community. And then, in Texas – the Texas workshop had more of a regional focus.

And so, participants included industry and policy thought leaders in natural gas and renewable energy markets that represented a diverse sampling of stakeholders and included representatives from all of the types of groups that you see here on the screen now. So, conducted under Chatham House Rules we discussed questions such as the importance of gas and renewable synergies, where did they occur, what are some example business cases, how can investors link together renewables and gas, what policy options can help really catalyze this linkage? So, I'm not going to get to cover everything today, but there were several recurring themes that surfaced that I will summarize.

So, the first was in regards to opportunities. And there was a very clear recognition of the large domestic resource bases that we have in the US. While both resources in isolation might face some disapproval on a variety of social, political, or even economic grounds, their pairing offers a lot of security: financial, economic, and environmental benefits as well as a long-term competitive advantage to industry. So, furthermore, as we saw in the last two presentations, investments are really undergoing substantial shifts in favor of natural gas as well as in favor of renewables, due in part by technological advances, either in hydraulic fracturing on the natural gas side, or in renewables – technology advancements on the renewable side that are really driving down the cost of some renewable technologies, policy incentives, innovative financing mechanisms, et cetera.

And so, at the same time, there are a number of potential barriers that we discussed to these, to really seeing a strong uptake to gas and renewable synergies in the market. So, there are numerous uncertainties, such as volatile natural gas prices or uncertain financial incentives and policy landscapes for both renewable and gas, public concern regarding – and the social license to operate was something that was discussed quite a bit. So, on the natural gas side, there was some discussion about some of the issues with hydraulic fracturing moving into new regions, or on the renewable side definitely some siting issues or some discussion of aesthetics. And then, future growth in electricity demand. All of these uncertainties really contribute to making it difficult to project cost and revenue streams for investment, and they introduce different sources of risk.

And so, then, in addition to that, another barrier that was discussed were infrastructure needs – so, more gas pipelines are needed, more transmission for renewables. But innovative business models can capitalize on shared infrastructure investment, so this can be overcome. And also, investing in information infrastructure – so, that can offer significant benefits, since obtaining price signals from the market really requires better information, communication, and control.

And so, lastly, one of the more prominent barriers that was discussed quite a bit was the need for gas and electric power market harmonization or coordination. We're going to talk about that a little bit more here on the next slide. And so, this increased coordination between the two markets is really needed for operations as well as to maximize investment _____ and to avoid stranded capital.

So, solutions really are going to depend on market structure and location, but some options that were discussed include things like flexible scheduling and nomination schedules, flexible contracting, things like that. And so, communication will play a critical role that will enable this coordination, whether it's communication of operational information between gas pipelines and electricity transmission operators – something like this would increase the sharing of nonpublic operational information between utilities and pipelines, for instance. Then, this is complicated a little bit by the fragmentation in some state regulatory policy regimes and their decision making processes.

So, second, here on this slide, there was a lot of discussion about the importance of flexibility and diversification. And so, we did hear a little bit in the last presentation about how increasing renewables often means an increased need for dispatchability, and natural gas generators can offer that. So, natural gas generators can respond to these rapid changes in renewable energy output, and so then, greater coordination is still needed between balancing areas to really manage that variability and to reduce curtailment.

And then, also, going beyond kind of this levelized cost of electricity measure for – thinking about cost comparisons between technologies was discussed quite a bit in terms of portfolio diversification. And so, this LCOE measure really omits factors that generate or detract value, such as the need for firming on the renewable side or gas price volatility. These – which introduces risk. So, there are numerous nonmarket benefits and costs that are associated with these two technologies that contribute to their attractiveness but which are not typically included in cost calculation that add benefits that aren't quantified by diversifying the generation portfolios and reducing risk.

So then, a key driver for natural gas and renewable synergies that was discussed is the ability to aggregate systems and operate them in a way that creates value for the customer. So, customers really place a high value on reliability and affordability, and so one mechanism might be – for enhancing reliability – might be to place more information on gas price stability and portfolio purchasing strategies or financial hedges that can help flatten the gas price peaks.

And then, further growth in customer connected devices will lead customers to be able to lead services of value back to the system. So, for instance, customer devices and decision making can allow some of these customer-driven services through energy management provided so that a utility or third party aggregator of energy services can then pay the customer for the value that they provide.

And then, lastly, the – one of the other key things that came out of this workshop series is that the policy and regulatory landscape really needs to enable this market for gas and renewable synergies.

So, the hybrid model is emerging as a mechanism for creating this customer value, but market structure must allow for investment returns as well. So, we need better pricing signals for distributed energy resources. Something like this could be market enabling for these energistic investments, and the integration of hybrid systems – such as microgrids, for instance – will require kind of new legal frameworks to accompany new ownership structures that may impact things like property transfer rights.

So, just transitioning a little bit into some of the quantification of these investments, of potential hybrid investments that we conducted – so, past work from JISEA and others has provided a lot of anecdotal evidence of the gas and renewables synergies in the power sector. However, very few studies in the literature have quantified the actual value of investing in these systems. So, we sought to kind of – to try to close this gap by applying some economic valuation techniques to hypothetical investment opportunities at the distribution edge, as well as from a system-wide perspective.

And so, innovative business models can create numerous potential revenue streams for these types of applications. So, here we show a residential sector application, or a number of different examples. For instance, the green arrows here show potential different revenue streams for a few examples of utility-managed distributed generation, demand response programs, neighborhood microgrid managed and operated by a third company – a number of different possibilities that we can think about here.

So, valuing the investment opportunities in gas and renewables really requires a detailed analysis of the complex kind of system interactions that captures factors such as electricity load profile, nonelectric gas demand, electricity rate structure, renewable output, gas prices, volatility, things of that nature. All of these things affect system operation, cost, and revenues.

So, we considered some hypothetical hybrid gas and renewable projects relative to their – basically, their gas-only or renewable-only comparatable alternative, as well as a business as usual case, which would just mean buying all of your natural gas and electricity through utilities as you would otherwise. And we characterized operations at the hourly level over 25- and 30-year lifetimes for residential and commercial application, where the commercial operation is a critical services building such as a hospital.

And so, in this study we really just focused on the use of solar PV panels and natural gas microturbines – and these are both commercially available in the market today – and assumed that these were standalone systems that would fully meet load, and analyzed everything at the hourly level so that we could capture some of the inherent uncertainties associated with variable output from renewables, and then also capturing natural gas price volatility on a daily basis.

And so, we were able to use location-specific data for solar output and natural gas projections, as well as utility rate structures, policies incentives, anything that's going to impact the cost and revenue streams – and that's the investment attractiveness. And so, we used two different methods, just kind of a cash flow analysis and a real options analysis, and make – and take a look at residential and commercial applications in two different locations, New York and Texas, which have pretty different policy and market structure landscapes. And then, we – I want to highlight that we did not do any type of system design optimization or anything like that. We made some assumptions about system design and some cost – using some cost data as well for – especially on the – to think about the initial investment outlay. But what we really focused on was the stochastic nature of natural gas prices as well as the variable output of solar on an hourly basis.

And so, I'm just going to present two examples of some of our results without getting into too much detail here. So, what you have here is the valuation results when we were looking at just a single residential home in New York. And we were looking at both – they were either facing standard or time-of-use electricity rates with net metering or no net metering available, and this is over a 25-year project lifetime. And we did a number of different sensitivities to gas price volatility, but this is just our baseline case here.

And so, basically, the way that you would interpret these numbers is that the highest value kind of relative to comparable systems – gas-only systems or renewable-only systems or business as usual – would indicate the more attractive investment option. So, the less negative the MPV, the more savings achieved relative to the business as usual. So, the red numbers in parentheses are negative, otherwise they are positive. And what we see here is that the hybrid solar and gas systems are consistently more attractive than both of the gas-only or renewable-only options, as well as obviously the business as usual case where you would just be paying for everything – the reason those numbers are so negative is because those are just cash outlays, essentially what you are paying to utilities. And so, we are consistently finding across all different measures of economic value, net present value, the real option value, and payback, that the hybrid system appears to be more attractive in this case.

And then, when we look at a commercial example, our critical services building, the results are very consistent. The story is the same: The hybrid system tends to be more attractive. And this is both when we have incentives for solar or no incentives for solar. So, we did a couple of different sensitivities across the board here. So, the story is pretty consistent. I'm not going to present the results from Texas because we're a little bit short on time, but a pretty similar story. But I will say that there are some sensitivities that we definitely see more so on the gas case – or, the Texas case as well in regard to gas demand. So, in New York there's a much higher kind of non-electricity natural gas demand which makes these systems a little bit more attractive. However – and then, some other sensitivities across the board is just gas price volatility, changes that result, the efficiency of the microturbines, the availability of incentives for renewables. And then, these investments do become more attractive with scale – so, as they become larger.

And so, again, just to wrap up, all these – the combined hybrid cases are favored over the business as usual. And then, we also talk a little bit in the paper about the importance of an enabling policy environment for these types of investment.

So, very quickly, going beyond the project level synergies, we also conducted a valuation analysis of the system level using output data from NREL's Renewable Electricity Future Study, which examined the feasibility of meeting electricity demand in 2050 with greater penetration of renewables. So, we used data from the 80% incremental technology improvement scenario, basically to analyze profitability of that scenario over time. And so, here we analyzed profitability focusing just on California using a discounted cash flow analysis. And so, we just looked at the effects of varying magnitudes of capacity payments for gas, combined cycle capacity on profits to compare energy-only markets to energy plus capacity markets, where capacity payments are awarded to dispatched electricity sources such as gas for available capacity after generation.

And so, here we see that the net present value is positive for all cases, and so these combined cycle plants are profitable even without capacity payments. However, we do see that the profitability increases quite a bit with higher capacity payments. And with that, I will wrap it up and hand it back over to Jill to moderate the questions.

Jill Engel-Cox: So, thank you to all the speakers. And we're already getting some questions in. If you have questions, please go ahead and type them in the question box on the webinar. I will go ahead and go ahead through the questions we've received so far, but please feel free to send in more questions. We have about 10 minutes.

So, our first question, I believe, is for Jeff. And the question was – or anybody, but it was provided during Jeff's section: How is it possible to drop the contribution of coal to such an extent in such a short span of time? So, where are all the coal power plants established earlier in the same period, and how is the replacement so quick? And specifically, the question is: In India they are primarily dependent on coal and they're trying to switch, but a significant drop is not being seen so far. So, just curious how it's actually happening.

Jeffrey Logan: Sure, thanks for that question. It's a good one. I think the rapid transition from coal to natural gas has occurred in the United States largely because of the fact that we had underutilized natural gas capacity in the system. So, there were many, many plants out there that were not operating as frequently as they could have been. And then, so, when low gas prices emerged beginning around 2010, the owners of generation fleets would choose to operate their natural gas plants more frequently than they had in the past and operate their coal assets less frequently than they had in the past. That was the optimal solution for them.

And we did show one chart that showed how much new natural gas capacity had been installed over the past number of decades. And really, there has not been a lot of new natural gas generation entering the system: Only about roughly five gigawatts of combined cycle capacity has been added each year over the past decade. So, we didn't need to add new generation capacity; we could just make greater use of the existing capacity. And at the same time, as noted, coal generators have been retiring, and especially in the year 2015 a lot of coal generation was taken offline because it no longer could compete in the system.

Jill Engel-Cox: Okay. Thank you very much. Our next question I would say is either for Wes or Jacquelyn. And it's: With the ongoing significant growth in natural gas and subsequent changes in the power generation sector, have you observed any changes in the business model innovation in natural gas or renewable energy sectors, especially in financing and policy assumptions? You want to take that, Jacquelyn?

Jacquelyn Pless: Yeah, I could start with that. So, I think one of the – I mean, this is definitely a hot topic and something that is discussed quite a bit is how do we actually finance these systems and what are the policy conditions that would enable these types of investments? And I think the one thing that comes to mind off the bat is that there's been quite a bit of discussion about microgrid development, particularly in some of the northeast regions that are prone to getting hit by hurricanes and things of that nature. And I think that's – especially I'm thinking of kind of New York and Connecticut where you see the states starting to take the lead and trying to think about financing or even providing some incentives for developing microgrid applications, and thinking about how to integrate those microgrids given the legacy grid.

I don't know if you have anything to add to that, Wes?

Wesley Cole: No, just that especially in – at least in our long-term scenario now, financing is always something that comes up and is a challenge, because – you know, we showed the sensitivity of natural gas prices being very large in 2040, and that's hard enough for us to deal with outside of the financing. So, I – we acknowledged the challenge but we don't really know what to do with it in our long-term sector analysis at this point.

Jill Engel-Cox: Okay. Great. Well, Wes, the next question is for you too. What are some of the major factors that would contribute to increased prices of natural gas that would be significant enough to affect its usage? So, supply, operations, environmental risk – is natural gas and renewable energy integration necessary to avoid stranded capital, such as Jacquelyn mentioned?

Wesley Cole: So, in terms of what could lead to increased prices, in a lot of cases I don't know what could lead to increased prices, only that there have been enough changes over the last 10 or 15 years that I kind of feel like anything is possible. And so, we just want to get an idea of what might happen. We definitely don't think the high natural gas price scenario is a likely scenario, but we still want to understand what happens in a scenario that limits natural gas usage. So, I mean, potentially something that could happen is "Methane leaks are a big deal and we're going to do something to regulate that" and that makes natural gas production more difficult.

Or, I mean, so you could have – there are plausible scenarios even though they may not be likely.

And then, the second piece is: Is natural gas and renewable energy integration necessary to avoid stranded capital? On a project-specific basis, I don't know. But definitely on a grid basis, the integration is often independent of the investors. You may have a – somebody investing in a natural gas plant and somebody else investing in a wind plant, and it just so happens that they – the wind plant benefits from the flexibility offered by the natural gas plant. So, some of that – some of those things are brought about in utilities' IRP processes, where they are thinking about the future and how to integrate things, and so they may see more value in different generating technologies and then – or, see that there may be risks for stranded assets and choose to invest differently.

So, I think these are mostly – especially as transition begins to – or, as transition continues to more decarbonized power systems, these are things people need to be thinking about as they're making decisions.

Jill Engel-Cox: Okay, excellent. Thank you. Not sure who this next question might be – maybe Jeff. Did they electricity forecast take into account potential or actual increase in demand from electric vehicles?

Jeffrey Logan: So, some of the forecasts that Jacquelyn showed toward the end of her presentation referenced the Renewable Electricity Futures Study that NREL published back in the year 2012. And we did do a scenario there where we looked at stronger electricity demand growth due to demand from a growing fleet of electric vehicles. And I think this is a very pertinent topic, given that many of you maybe saw that the Tesla Model 3 rollout occurred – was it last week, I guess, or a week and a half ago? – and there were 300,000 – more than 300,000 people that preordered this vehicle and put down $1,000.00 as a refundable deposit to have the opportunity to buy this vehicle, which is the first considered mass-produced – at least car from Tesla that will in theory enter the market in late 2017. So, there was very strong pent-up demand for this vehicle, and I think – so, potential for strong electricity demand due to electric vehicles that are priced at a range that the average person can probably afford.

Anyway, I hope that answered your question.

Jill Engel-Cox: Well, we've got lots of questions on batteries. We've got two more questions on batteries, both for electric vehicles and how the sensitivity of battery prices can affect vehicles, but also how it may potentially affect storage and large scale battery storage, which is an important issue related to the ability to provide some baseload power. So, does somebody want to talk a little about batteries and how battery prices might have an effect on –?

Wesley Cole: Yes, I can talk about batteries. So, we have quite a bit of work ongoing right now looking at low cost batteries because we've seen this as – this has the potential to make some major shifts in the power sector, and variable renewables coupled with low cost batteries certainly changes the ability of renewable energy to compete with other technologies and makes it more challenging for things like natural gas with carbon capture and sequestration to be cost-competitive.

So, there – it – yes, it definitely is a game-changer. There is a huge amount of uncertainly on what battery prices might be. They definitely look like they're going down, but what – where they're going to land, there's wide error bars there.

Jill Engel-Cox: Okay. So, certainly a lot of work left to do in batteries. Do we have time for one more question? Or, we – should we – okay. We can give one more to Jacquelyn. On one of the last slides there seemed to be a rapid growth in biomass: Can you talk a little bit about that?

Jacquelyn Pless: So, I think that's referring to the one image from the REF Study – the Renewable Energy Futures Study. So, I – for the study, the valuation work we were doing, we were just using the output from that study, and I actually did not author or do the analysis for the actual REF Study, but I will certainly point you to Renewable Energy Futures in 2012, a very large study that really details all of the assumptions that were made there. And so, given the time and my lack of knowledge on that study, I'll just direct you to that.

Jill Engel-Cox: Okay. That's great. Lots of these studies are available online. We talked a little bit about a transformation to different power types. Has there been any discussion of going to a highly decentralized system instead of a – the large power plants and a grid system? Has there been any work on that area?

Jeffrey Logan: Yes, there has. And that continues to be ongoing, not just here at NREL and JISEA, but many, many stakeholders are looking at what the utility of the future might look like, and whether it's more centralized or less centralized. And the – obviously, one factor that's going to play into that is whether or not new business models can be created to accommodate customers generating a lot of their electricity at their residences using solar panels.

Jill Engel-Cox: That could be a real game changer. So, one last quick question: What – that we've received – what changes would the carbon tax, if we do have a carbon tax, what changes could that result in the system?

Wesley Cole: Well, so, the carbon cap scenarios are analogous to having a carbon cap. So, at least in a – there is – essentially, a carbon cap implies an underlying carbon tax, and a carbon tax implies a carbon cap to some extent, so they're somewhat analogous to each other. So, the – depending on your level of carbon tax, you could achieve the same kind of scenario results that we looked at with a carbon cap. They're essentially different mechanisms for achieving the same end. And…

Jill Engel-Cox: Great. Well, we're basically out of time. I want to thank everyone – all the speakers, all the great questions we received. Those slides will be made available on the website, so you'll be able to see them there. And also, there's the other reports – more detailed reports these are based on are available on the website. And just a reminder: We have another webinar on April 20 – Wednesday, April 20 – related specifically to methane emissions and abatement. And so, please register for that to get the next in the series. So, thank you very much for attending and participating.

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