CLEAN ENERGY SOLUTIONS CENTER
ASSISTING COUNTRIES WITH CLEAN ENERGY POLICY

Integrating Variable Renewable Energy into the Grid: Key Issues and Emerging Solutions

—Transcript of a webinar offered by the Clean Energy Solutions Center on 29 July 2015—
For more information, see the clean energy policy trainings offered by the Solutions Center.

Webinar Panelists

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This Transcript

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Tim Reber

I'd like to welcome you to today's webinar, which is hosted by the Clean Energy Solution Center in partnership with USAID and the National Renewable Energy Laboratory. Today's webinar will be focused on integrating variable renewable energy into the grid with a focus on key issues and emerging solutions. One important note of mention before we begin our presentations is that the Clean Energy Solution Center does not endorse or recommend specific products or services. Information provided in this webinar is featured in the Solution Center's resource library as one of many best practices resources reviewed and selected by technical experts.

Before we begin, I'll quickly go over some of the webinar features. For audio, you have two options. You may either listen through your computer or over your telephone. If you choose to listen through your computer, please select the mic and speakers options in the audio pane on the right side of your screen. Doing so will eliminate the possibility of feedback and echo. If you choose to dial in by phone please select the telephone option and a box on the right side will display the telephone number and audio pin you should use to dial in. If anyone is having technical difficulties with the webinar, you may contact the go to webinars help desk at 888-259-3826 for assistance.

If you would like to ask a question, and we ask that you please do, you can use the questions pane on the right side of your screen where you may type it in directly. If you are having difficulty viewing the materials through the webinar portal you will find PDF copies of the presentation at cleanenergysolutions.org/training. You may follow along as our speakers present. Also, an audio recording and the presentation will be posted to the Solution Center training page within a few weeks and will be added to the Solution Center YouTube channel as well. You'll also find other informative webinars, video interviews with thought leaders and other clean energy policy topics.

Today's webinar agenda is centered around the presentations from our guest panelists, Dr. Michael Milligan and Jessica Katz. Jennifer Leisch has also joined us today to help moderate the question and answer portion of the webinar. Our panelists will be reviewing challenging to integrating significant quantities of variable renewable energy into the grid and discussing emerging solutions that policy makers, regulators and grid operators have taken to integrate wind and solar to meet renewable energy targets. Before our speakers begin their presentations, I will provide a short informative overview of the Clean Energy Solution Center initiative. Then following the presentations we'll have a question and answer session closing remarks and a brief survey.

This slide provides a bit of background in terms of how the Solution Center came to be. The solution Center is one of 13 initiatives of the Clean Energy Ministerial that was launched in April of 2011 and is primarily led by Australia, the United States and other Clean Energy Ministerial partners. Outcomes of this unique initiative include support for developing countries and emerging economies through enhancement of resources on policies relating to energy access, not cost expert assistance and peer-to-peer learning and training tools such as the webinar you are attending today.

The Solution Center has four primary goals. It serves as a clearinghouse of clean energy policy resources. It serves to share policy best practices, data and analysis tools specific to clean energy policies and programs. It delivers dynamic services that enable expert assistance, learning, and peer-to-peer sharing of its experiences. And finally, the center fosters dialogue on emerging policy issues and innovation around the globe. Our primary audience is energy policy makers and analysts from governments and technical organizations in all countries though we also strive to engage with the private sector, NGOs and civil society.

One of the marquee features of the solution center is the no-cost expert policy assistance known as Ask an Expert. The Ask an Expert program has established a broad of over 30 experts from around the globe who are available to provide remote policy advice and analysis to all countries at no cost. For example in the areas of renewable electricity policy, we are very pleased to have Paul _____, energy education director at the Renewable and Sustainable Energy Institute serving as one of our experts. If you have a need for policy assistance and renewable electricity policy or any other clean energy sector we encourage you to use this valuable service.

Again the assistance is provided free of charge. If you have a question for our experts please submit it through our simple online form at cleanenergysolutions.org/expert or to find out how the Ask an Expert service can benefit your work please contact Shawn Esterly directly at shawn.esterly@nrel.gov or call him at 303-384-7436. We also invite you to spread the word about this service to those in your networks and organizations.

Now I'd like to go ahead and provide brief introductions for today's panelists. First up today is Dr. Michael Milligan, a principal analyst with the transmission and grid integration group at NREL. His research focuses on large-scale integration of wind and solar energy on the bulk power system on which he has authored and coauthored more than 200 journal articles, conference papers, technical reports, and book chapters. Michael has provided expert testimony in numerous public utility commission proceedings and workshops and he advises power system planners and operators on wind and solar integration issues.

Our second speaker today will be Jessica Katz. Jessica is an analyst at NREL and focuses on coordinating and implementing technical assistance in support of the U.S. government's enhanced capacity for low emission development strategies or ECLEDs program. She has developed tools and trainings related to clean energy development topics such as renewable energy resource assessment and integration of large-scale renewable energy systems to the grid to accelerate sustainable economic growth and minimize greenhouse gas emissions.

And finally, moderating our question and answer session today we will have Jennifer Leisch. Jennifer is a climate change mitigation specialist in the USAID office of global climate change. She supports the U.S. enhancing capacity for low emission development strategies programs and manages the USAID Greening the Grid partnership. She also directs agency work to account for greenhouse gas emissions reductions as a result of USAID clean energy programs. And, with those introductions, I'd like to go ahead and welcome Dr. Milligan to the webinar and hand it over to him to get us rolling.

Michael Milligan

Great. Thank you very much for the introduction and thank you all for joining us on this webinar. What we'd like to do is to talk about some of the key issues surrounding how to integrate large amounts of renewable energy primarily wind and solar onto the power system. And so, in our agenda here we will start with those key issues, taking a look at some of the key challenges. We'll then move on and talk about flexible power systems. It turns out that the more flexibility that we have in the power system the easier it is to manage the increase in variability and uncertainty from wind and solar resources.

Part three we'll take a look at some, a few common myths and some frequently asked questions. And actually, there are many, many of those questions. We'll just touch one some of the key ones. And then, we'll discuss the tool kit that we have for Greening the Grid and then we'll wrap up with a bit of Q&A. So, as we move through the material if you do have a question please use the webinar facility to ask it and we will try to get to all the questions at the end, as many as we can.

So moving on the key grid integration issues section of this – the reason that grid integration is important is that we see trends in many countries where we've got a combination of an increase in demand. In many cases, we have an increase in urbanization, which is obviously connected to increasing demand for energy. And, of course, we're focusing on electricity here but one of the key concerns that many countries have is how to help mitigate climate change. And so, one of the motivating factors in moving towards more wind and solar, perhaps the key motivating factor is to try to reduce emissions and mitigate climate change issues. At the same time in many areas, there's a need for grid modernization. And it turns out that some of the things that we would need to do to the grid to modernize it, to increase its efficiency are also things that we can do to help integrate more wind and solar. So, that's kind of a nice synergy between these two things.

So what we focus on a lot here at NREL and others around the world also take a look at these issues. How can we design and how can we operate the power system in such a way that we could more efficiently integrate renewable energy. And when I say efficiently we want to do it at least cost and we want to do it according to some reliability target which can be set by different countries based on policy decisions. So as we move on what is it that's unique about renewable energy? It's variable and it's uncertain and it's geographically diverse. And that dispersion that we get of wind and solar actually helps when we take a look at the variability. And we'll take a look at that in just a moment.

But what this does is it suggests that the increase in variability and uncertainty means that we need more flexibility on the power system. And I do want to note that even in power systems with no wind and no solar there's still a significant amount of variability and uncertainty. You don't know when a transmission line is going to trip out, when a generating unit is going to fail. Demand varies throughout the day as a function of weather and a host of other variables. But when we add wind and solar we certainly do increase the level of variability and the level of uncertainty that has to be managed by the power system operator.

When we add a lot of wind and solar to the system it also means that existing thermal assets are used less frequency, less frequently which if you think about it is part of the point. We want to reduce the fuel that we're burning so that we can reduce emissions. But that can present some challenges with respect to some units that still need to be paid for. How are they going to cover their costs? We do need more reserves and that does not mean that we need to build more generation when we have very renewables but it does mean that we may need to have some additional operating reserve to help us manage times when the wind dies down or the solar is reduced because of the clouds or things like that.

We generally will need more transmission and better planning. That's a tough one but it's – fact of life is when you're putting in particularly wind turbines, windy regions are typically not close to population centers and so you need to deliver that wind energy via wire to the demand center. And of course, that's where the requirement for transmission comes in. And solar inverters and wind turbines can now provide a large number of what we call ancillary services, services that the grid needs in addition to just supplying energy. And some examples are listed here, voltage control. It's important to maintain voltage within certain limits so that the devices work properly, the grid continues to operate. And there's something called inertia response and frequency response that wind turbines and inverter panels can provide. That provision typically comes with an increase in cost but what that actually does is it allows the renewable energy sources to actually provide some of the flexibility that is needed to run the power system.

So let's talk about flexibility. This next graph is an example. Every system is a little bit different but we think that this graph does a nice job of showing what it means when we add variable renewable energy into the power system with respect to variability. So what you see in the graph is this is actually one week of data and on the y-axis of the graph we're measuring megawatts and so megawatts of demand. And on the x-axis, we're measuring time – and I apologize. The axis isn't terribly informative. But you do see midnight and you see 12:00 noon for one week on this axis. Now as we start dissecting this graph a little bit, the yellow curve that you see sort of in the back represents demand. And so in a power system with no wind and with no solar the all the generating fleet, coal, gas, whatever you have, hydro, would be dispatched in such a way that that yellow trace of energy would be supplied every hour of the day for this entire week.

Well in this particular example, we add a lot of wind energy and you see the wind energy at the bottom of the graph in green. It's measured on the same scale so if you take a look right before February 20th at zero hours you'll see the wind peaks at nearly 5,000 megawatts or 5 gigawatts. And you can see that the wind is pretty variable in this week. And there are times that there's a lot of wind energy. And if you take a look along February 23rd on the axis you'll see that there isn't very much wind. And so clearly, there's a lot of variability that's introduced by this wind.

But what does that mean for the way that I'll operate the power system? Well if I am able to make full use of all of that wind energy for this entire week you can imagine that we could take the demand and subtract out whatever the wind is supplying and whatever is left is what I need to supply with my existing thermal units, my hydro units and so forth. And we call that net load or something net demand and you'll see that depicted in this picture with the orange trace. So essentially, we start with the yellow demand. We subtract off the green wind. And what's left is the net demand, which is the orange curve. And so that allows us to now compare what is it that my hydrothermal fleet has to be able to do in order to accommodate all of this energy, all of this wind energy.

And what it has to be able to do is shown on the orange graph and we can take a look at some of the things going on. So for example, you'll see a notation for shorter peaks. On February 19th the net peak, the demand minus wind is quite a lot less than the peak demand by itself. The peak demand is somewhere around 12,000 megawatts. The net peak demand is something around 8,000, a little bit more than 8,000 megawatts. A ramp is a chance in demand or it can be a change in a generator output and you can see the next annotation talks about steeper ramps. The ramp is simply the steepness and the length of the curve and so the arrows pointing to the fact that we have a steeper ramp right around February 20th, starting sometime in the middle of the night. That ramp is steeper and it's deeper than the yellow ramp. And so that can be a challenge for system operations.

And then the final feature that you can see is that we need to be able to turn down our hydrothermal fleet to a lower minimum generation level. So if you can sort of visually look for the minimum of the yellow curve throughout the entire week its somewhere around ten, ten gigawatts. If you look at the minimum of the orange curve, you find that it's roughly half of that. Actually, a little bit to the right of where the arrow is you see where the green and the orange almost intersect. We have about 5,000 megawatts of net demand. So that means that if I have a lot of coal units or gas units in order to take advantage of all of this wind energy I need to be able to reduce the generation for my coal and gas to 5,000 megawatts now whereas in the past with no wind all I had to do is to reduce the generation to about 10,000 megawatts.

So these are some of the key challenges with respect to the variability that the power system operator is faced with. And of course the question is can we manage this increase in flexibility. And the answer is well yes. There's a lot of tools. Now I'm not going to attempt to go through this somewhat complicated but really thorough graph. What I would like to do is sort of draw your attention along the bottom of the graph where you see the box labeled system operation and then mark it load, flexible generation, networks and storage. So these are sort of the categories of things that we can look at to help increase the flexibility on the system. So for example with markets there are market designs that can be put together. We have many of those in the U.S. and some in Europe that can be designed in such a way to elicit as much flexibility from the power system as possible. And there are a number of specific steps involved with that.

The next sort of category is load or demand and with demand there's the opportunity to have either residential customers or more often commercial customers actually behave in a sense like a generator where they can reduce or curtail their demand and they – they're doing that to provide a service to the power system operator there's typically a payment involved. So if I'm a company I can easily turn off or turn down my productive process for a while. I get a payment for that in return. That might be nice for everybody. Flexible generation is also clearly important. So there's some generation is more flexible than others, other types of generation. So that can be a source of flexibility. And then obviously, transmission networks help deliver the energy to where it needs to go and then storage.

And so what you see here in this grey box that just appeared on the screen, this is sort of a summary of I think the key points that you can take from this particular slide. There are many options for increasing flexibility. Every power system starts from a different starting place. So some systems may have implemented some of these things already. Others may not have implemented very many of these. But there are many, many options. And one of the really key points is that even though I may have a lot of flexible generation I may not have the appropriate institutional framework in place to allow me to access that flexibility. I can give you a quick example.

Here in the western United States we have balancing regions which are not part of larger organized markets. Within the balancing region there is generation owned by a third party and the dispatch in the process of moving the generation to match demand is done once every hour. And so if I happen to build a flexible generator in a region like that the power system operator would have no mechanism to ask me to turn the unit up or to turn the unit down unless they waited until the top of the next hour. And we'll talk about that in a moment. And then the third point here is that the cost of flexibility options will vary but we think that institutional changed can be among the most cost effective. Once you make the change, it may involve expensive new communications devices, computer software and hardware. But once those changes have been implemented, they can deliver the benefit forever essentially.

So as we move on I said I wanted to talk a little bit about this idea of faster economic dispatch. This particular graph shows two different ways of meeting the demand. And in both cases, demand is shown by the green line. Now in both graphs the green line is exactly the same. So we're not changing the demand. What this diagram or these diagrams are doing are they're showing the change in the way that we could operate the system. So let's start on the left. On the left hand side on the y-axis, we have megawatts of demand, millions of watts of demand. We have a sort of a general time scale. It's not clearly labeled here but this is a couple of hours of time and the time, the amount of time is the same on both axes, on both graphs.

So if you take a look on the left you see that on the left just above the red it says hourly schedule. And then you'll see an up ramp and so that unit is now being directed to increase its output. And then you see a pretty long flat red line. And so that long flat red line represents the hour or so, where this particular generator is running at a constant output. But then if you take a look and compare that flat red line with the green line which is moving all over the place you'll see that there's still a lot of variability and the economic dispatch is not able to respond within the hour because of the institutional practice of saying we only dispatch once an hour.

So how do you meet that demand? You meet that demand by taking a subset of your generating unit, a small group of generators that can respond to what we call automatic generation control signals. And that subset of your generation fleet has to respond to all that variability and we call that regulation. And you can see that there's a lot of regulation and again I want to emphasize that that regulation that you see is provided by a small number of generating units because most of the generating units are always run on economic dispatch.

So then, compare that to what happens on the right hand side where we have a sub hourly dispatch and in this case, it's a five-minute dispatch. So what that means is that there's computer software that has all of the information for all the generating units. It's monitoring the demand. It knows exactly what the demand is. It can calculate a fast demand forecast for the next five or ten minutes. And so what you see now is instead of having a flat dispatch now we see a new line, which is a blue line, and you can see that it operates in some kind of small stair step sort of function. And what that means is that the economic dispatch is responding every five minutes and can therefore come pretty close to matching the demand.

And the key thing to compare between these two figures is the amount of regulation that's needed. On the left, we talked about it. There's a lot of regulation that's required and again that's required to be provided by a small number of generating units on my system. On the right hand side, I still have a small number of units providing the regulation but there's clearly a lot less regulation that needs to be provided. And so in the economic dispatch I'm allowing more units to respond. They're responding more quickly and so I can incorporate all the response to variability or most of the response into a five-minute economic dispatch, which really helps and it brings out some flexibility that you have in the power system.

The other thing that you can do is expand the balancing footprint. Larger systems are generally easier to balance and that comes about for two reasons. One reason is that the demand tends to smooth out over longer, sorry, over wider areas. So one region might be experiencing an increase in demand at the same time a neighboring region is experiencing a decrease in demand. So if they can sort of net out their demand changes everybody can dispatch their units less which results in cost savings. The other thing that happens which is what this graph shows is that the variability of variable renewable energy is reduced over large areas.

The data that you see here comes from a wind plant in Minnesota here in the United States. That wind plant has many, many wind turbines and you can see in the graph that the red line is showing the variability for 15 turbines and the blue line I believe it is showing the variability from 200 turbines. And the thing to note here is the red line from the small number of turbines, 15 turbines, is moving around a lot. It's highly variable. But if you take a look at the 200-turbine output, it does vary also but it's not varying nearly to the extent that the red line is. And this is simply illustrating that when I have 200 wind turbines they're going to be spread out over a larger geographic area. And the wind doesn't do the same thing at every wind turbine location. And so you tend to get the smoothing. This example is only for 15 turbines and 200 turbines. It's one-second data for 12 hours. But the same principle would apply if you were looking at many hundreds or even thousands of turbines and especially if those turbines are split among multiple different locations, different wind farms or different wind plants. And the same principle applies to solar where clouds will come by and cover up some of the solar panels in one region but will not cover the solar panels in another region.

So there are a number of things that we can do to increase coordination between balancing areas. And this is kind of a conceptual diagram that shows several different steps that could be taken. And if we start in the bottom left and we say – sorry – the y-axis is showing how much this will help with integration of renewables and the x-axis is showing sort of the time scale of coordination. So down at the bottom left we have a box called contingency reserves. And this is essentially the process for determining what level of both spinning and non-spinning reserve needs to be online or ready to come online to cover a contingency. If the generating unit trips off line or a transmission line trips open. We can have two or more areas sharing their contingency reserve obligation. It's a very common thing. I know in the United States we've been doing this for decades and it does help a little bit with renewable integration but not so much because most wind and solar is never going to be large enough and the output will never change fast enough to constitute what we call a contingency which is a sudden drop in output that happens in seconds.

But as you move up the scale and look at the various building blocks here, the next category if you will is regulating reserves. So we could have two or more neighboring systems that share regulating reserves. This is something else that's been done in parts of the United States, sharing only regulating reserves. And what that does is that it results in everybody needing a little bit less regulation which is a cost saving. The next box is flexibility reserve which is essentially the reserve that you need to cover variability and uncertainty with wind and solar. So you've got two or more regions that share flexibility reserves. But up to this point the two or more regions have not in my description here they've not decided to go into some sort of coordinated economic dispatch and that's sort of the next step.

We could – we could coordinate economic dispatch. A good example of that in the United States right now is an energy and balance market which is now operating in California and in part of the Pacific Northwest. And in this type of a setup, the two regions still separately do their unit commitment, which is starting up their units, usually a day in advance or more. So that process is not coordinated yet but what they do is they combine the economic dispatch across the two or more footprints which results in savings because one region might be having an increase in demand at the same time another region is having a decrease. And this economic dispatch coordination allows us to net that out so that we're not chasing demand up in one area at the same time we're chasing demand down in the next area.

And then the final coordinating step would be unit commitment. And this really involves a full operational coordination where two or more regions would get together. They'd have a process, probably a big computer with fast calculation capability and they would commit or start up the generation a day or more in advance by taking a look at the entire merged region, two or more regions together, coordinate unit commitment which would generally result in the need for less units being online tomorrow or the next day. And so this whole idea of consolidated operation can happen at a lot of different levels. And again going back to the beginning we started with contingency and regulating reserve. There's some benefit to doing that but if you move up these steps you find that the benefit goes up, as does the cost because these are more costly options. But again, these can be really good solutions long term because once they're put in place they're put in place forever.

So moving on the other source of flexibility is increasing thermal cycling. These graphs came from a large study at NREL and I don't want to go through all the gory details because there's a lot here but I'd like to draw your attention to the black trace in the curve. Each graph is showing a week of generation. On the y-axis, we show how much generation in gigawatts is running and we can see time on the x-axis. So I want to draw your attention to the black part which represents the coal generation. And in the upper panel we don't have any wind and solar and coal generation is running at nearly a constant level of output for the whole week. In the bottom graph, we have a substantial amount of both wind and solar energy. Thirty-three percent annually of all energy is coming from wind and solar.

And if I can again draw your attention to the black trace, the coal units are now moving around a lot more. You can see at the beginning of the week they're generating somewhere around maybe 30 gigawatts minus the nuclear which is in red. And then you can see around Marc 29th – March 30th they're not generating very much at all. Some people thought that coal generators couldn't do this. We can't ramp our coal units. We can't adjust them. But it turns out different coal units can be adjusted at different rates and some of them are easier to adjust than others. And coal units that have difficulty in moving around like this can be potentially retrofitted so that they can move around. So you can extract more flexibility from existing thermal resources even if those resources are coal.

And one of the most interesting things that's happened over the last couple of years is that we can actually get flexible generation from wind itself and also from solar. But this graph is talking primarily about what; it's talking only about wind. This is an example from near where we are here at NREL, the public service company in Colorado. What the graph shows is a period of time starting at about 2:00 in the morning and ending at about 6:00 in the morning. And so you'll see that on the x-axis. On the y-axis, we have megawatts and the graph is showing a couple of different things I'll walk you through. It shows the potential of this particular wind farm or wind park. And this is particularly windy night and so with all of the turbines generating or nearly all of them you could get just over 500 megawatts of generation out of the wind turbines.

Now what happened is the operator came in on the night shift and took a look at the we call the area control error, which is, abbreviated ACE. And you can see the yellow trace on the graph. You want to have low ACE because the area control error is measuring the imbalance that you have on your system. And for public service of Colorado and ACE that's within about 50 megawatts plus or minus it's fine. But the operator came to work and found that ACE was more than 200 megawatts and the operator said I've got to do something about that. There's low demand. There's high wind. So the operator at 2:45 initiates what we call a block curtailment of wind. He said, "I'm just going to turn all of the wind down to 300 megawatts. And that will fix ACE. Well you can see that on the graph that happened at 2:45 and 2:55 ACE drops but it turns out that ACE went too negative, negative 100 megawatts and the operator said, "Well I've overcompensated."

And so the next step was to put the wind on what we call automatic generation control. This is the same feature that we use to regulate the power system with other units. Excuse me. So at 4:00 the wind is put on AGC and you can see that after 4:00 the wind moves around a little bit. So some of the wind is being curtailed. But if you take a look at ACE, ACE remains within 50 megawatts plus or minus for the rest of the time period. So this demonstrates that you can actually get a lot of flexibility out of wind. In this case, the wind generation was turned down a little bit. We were not fully utilizing all of the possible wind energy. But at the same time, we were able to use the flexibility in the wind turbine controls and the wind plant controls to help manage balance on the power system.

We can also look into flexible demand. And there are many ways that this could be implemented and in different countries, you're going to find different potential and different ways of going about this but this could be direct load control or real time pricing. We have an example in Texas here in the United States where a number of industrial units are paid to provide contingency reserve. And so if the unit, the generating unit trips offline or a large transmission line trips open these industrial processes can quickly reduce their demand, which from the point of view of the power system that's kind of like increasing output from the generator. So we think that from the policy point of view it's important to make sure that the rules for either participating in market or for otherwise being able to provide a demand response, the rules have to be set up in such a way that they're really aimed at capability.

So as a system operator to some extent I don't really care if I'm employing a demand response in industrial user by pushing the button to say I'm going to reduce its load and pay them the price or if I'm going to push a button to increase generation from a unit. If the capabilities are the same, I give them both five minutes' notice. They could ramp it at 100 megawatts in 20 minutes. And those kinds of capabilities I really should be indifferent between the two and I could push the button for the one that delivers what I need at minimum cost. So we think the rules are really important to get right with demand response.

Moving on to some myths and frequently asked questions people ask, "Well can my grid support a high level of variable renewable?" And I won't go through this whole graph but you can see Denmark hit 39 percent penetration from wind in 2014. Denmark is a small country. They have a lot of wind relative to demand. They have large interconnections with the Nordic power pull and much of Europe, which really helps them out a lot. Down at the bottom of this graph you see Ireland, which is literally an island. It's an island geographically and electrically and in 2013 the interconnection with Great Britain was not working, the pump storage was not working, and so this 18 percent annual penetration in Ireland was achieved with no interconnection, market, external market or anything. Now having said that the Irish generation fleet has been designed to be fairly flexible because they know they cannot depend on other units. But this gives you sort of a range. Denmark on the one hand, small, large interconnections. Ireland 18 percent – Ireland has some pretty high renewable energy objectives. They're not stopping at 18 percent and they're actually going through a marker redesign right now to try to make sure that their market allows them full access to physical capabilities.

People often ask "Gee. I have a 100-megawatt wind plant. Don't I need to have a backup for that wind plant?" And the answer is you could but it would be needlessly expensive because we don't back up individual units in the power system. Reserve policies and methods that we have for calculating reserves take into account the entire system. And we never back up individual plants unless there's some sort of a market imperfection that might otherwise require me to do that. But in every case, if you're building an individual backup you're needlessly increasing cost. We do know that wind and solar can increase the need for operating reserve. But there are a couple of interesting things.

If I have an increase in wind generation over a couple of hours, I'm going to be needing to turn down some other generation. Maybe it's a gas unit. Maybe it's a coal unit. So if that unit that I've turned down was generating at 300 megawatts and now it's at 200 megawatts that unit now has a capability of providing 100 megawatts of reserve. And so I don't need to have another backup per se of wind. And the other thing to note is that – let's say two extreme examples. I have a wind plant and it's generating zero right now because there's no wind. Well I don't need any reserve to guard against wind dropping off because it's already zero. It can't go below zero. And the other extreme, suppose that my wind is generating at 100 percent. Well if it's at 100 percent, it might drop off and so I might want to have some sort of reserve, not necessarily one to one reserve but a reserve to help me in case the wind does drop off. But I know that if the wind is at maximum output it can't increase and so I don't need to worry about down reserves from other units. So there are a number of methods for calculating this but essentially this is a dynamic reserve that depends on what the wind and solar is doing.

So we need storage? Well I don't know. We love storage. But you do not need storage to integrate large amounts of renewable energy. As I pointed out Ireland successfully managed 18 percent over the year with no storage whatsoever. We've done a number of integration studies, the Western Wind and Solar study, California PJM, that have looked at up to 30 percent annual penetration without needing storage. Now if you have storage already the storage will be used in a way that will be beneficial. Storage is almost always helpful but it isn't necessary. We recently completed a study in Minnesota looking at up to 50 percent annual penetration from wind and solar and there was no need for storage that was found in that either.

Moving on historically people have been, have asked questions about integration costs of wind or of solar. And over the last several years, I think that conversation has changed because every type of generation imposes some sort of a cost on the system. The three graphs that you see here have several days, maybe a week and a half, two weeks' worth of data. This is a simplified system to illustrate a couple of things. So if you look at the upper right hand panel this is a simple system that has one coal generator that's shown in black, constant output. The dark blue shows natural gas combined cycle and they move around. They go up and down every day. And then the light blue or turquoise show combustion turbines. And that's all very nice. It shows that the three plants can meet demand for the time period. Then we add wind in the middle panel and the wind is shown in green.

And let me draw your attention, as I seem to do a lot to the coal plants, the black. Now the coal is cycling. And you say well, ok, integrating all that wind has caused the coal plant to cycle. The coal plant is going to be operating a little bit less efficiently and so shouldn't that be an integration cost of wind. Well let's take yet a third example so if you jump down to the very bottom we don't have any wind but now we have nuclear which almost always in the U.S. at least runs at a constant base load output. And now take a look at what happens to the coal plant. The coal plants are cycling. And so this is just a simple example that shows that many different types of generators might have some sort of integration cost but what's really important is the total cost of the system. How much does it cost to operate this system? How much does it cost to build the pieces that we need, biflux generation, build transmission and so forth? So we think the conversation has changed a lot to look at total cost.

So let me wrap up here. I know I've covered a lot of material here but wind and solar certainly do increase variability and uncertainty. We know that there are a lot of ways that we can manage that both through physical assets as well as institutional operating practice. We have experience now around the world that shows that at least 39 percent can be achieved. Denmark, Ireland, many other countries are aiming for much more renewable energy than what they have today and I think they'll get there. A lot of things that we can do to help with operational changes, make improvements to efficiency are institutional kinds of things. And they deliver a lot of benefit for a relatively low cost in many cases.

And we don't need specific backup nor do we need specific storage for variable renewables. Storage is always good. We do need to think about how we're going to operate the system with flexibility reserves. And specific questions can be answers with detailed analysis and modeling so that we can better get a better grasp of how to integrate a lot of wind and solar. So at this point let me turn this over to Jessica who is going to talk a little bit about the Greening the Grid toolkit. So Jessica.

Jessica Katz Thanks so much Michael and hello to everyone on the line. I have the privilege today of introducing you to a new initiative called Greening the Grid which is that initiative sponsored by the U.S. agency for international development. As Michael's excellent presentation showed us grid integration is a really rich area of study. I mean there's constantly new research and case studies that are emerging as more and more power systems gain experience in integrating variable wind and solar to the grid. Greening the Grid aims to put the latest and greatest information about grid integration into the hands of power system decision makers and their support organizations. Greening the Grid is a technical assistance project. Its objective is to inform energy system planners, regulators and grid operators in overcoming the challenges associated with integrating variable renewable energy to the grid.

Greening the Grid offers two types of support. The first is a toolkit of information and guidance materials that are intended to inform power systems in developing and implementing grid integration road maps. And the second is direct technical assistance to power system operators and planners in developing countries. And that technical assistance is tailored to unique needs of each partner. USAID is partnering with NREL to deliver assistance to Greening the Grid under a program called enhancing capacity for low emission development strategies, which supports countries around the world in making their economic growth and development goals while minimizing greenhouse gas emissions. Grid integration is emerging as a critical issue for many countries that are working toward low emission development. So our program is intended to provide support specifically on this topic with the ultimate goal of helping countries meet their clean energy and climate change goals.

This summer we launched the Greening the Grid toolkit. It comes in the form of a website and it is live. You can access it at greeningthegrid.org. Our vision is to establish this website as a platform for the best available information, guidance and case studies on grid integration. The website also serves as a gateway to access training materials like this webinar and also technical assistance. And it serves as a repository for several different types of resources. And all of the resources and materials on this site are in the public domain so there is no cost of anything on here. One example of a resource that you'll find on the Greening the Grid website are short fact sheets on grid integration topics.

NREL develops these fact sheets with a developing country audience in mind. Those are only two pages so they're really intended to provide a high-level introduction to key grid integration issues and those range from everything from target settings to balancing area coordination to data requirements to grid integration studies and many of the other topics that Michael covered in his presentation. Several of these fact sheets are now available on the website and more are coming in the coming months. The titles are all listed on the slides so once complete this collection will consist of about a dozen of these documents.

Beyond the fact sheets which provide sort of a concise overview of grid integration issues. the Greening the Grid toolkit also provides a set of in depth resource pages organized by topic ranging from ancillary services to balancing area coordination and the others that you see here. These in depth resource pages are really the heart of the toolkit and we developed these with the philosophy that there is already a significant body of knowledge about grid integration so the intent here is really to collect and conceptualize the best of what is out there. Again, the system is in developing countries in mind. Each topic page includes an introduction to that topic, a list of examples of actions that a power system can take and a _____ and annotated list of resources. And those resources include tools, reports, case studies. And I think maybe one of the most valuable pieces are example policies and regulations from other systems related to that topic.

Greeningthegrid.org also provides a gateway to targeted technical assistance. That assistance comes in two different formats. The first and the one we suggest that most users access initially is the Ask an Expert service. This is something that we've partnered with the Clean Energy Solution Center and the Clean Energy Grid Integration Network to provide. To use this service we make a form available on the website and anyone can submit a question or request about grid integration. We then review that request and partner the requester with an expert from NREL or the Solution Center network and that expert provides no-cost technical assistance to the requester. This service is intended to provide higher level guidance and it can be used for example to request technical review of documents like grid codes or policies or strategies to ask specific questions about your power system and grid integration in that context or to request examples from other systems.

We really welcome requests through this platform and would also love to get the word out about it so we encourage you to let your organizations and partners know about this service. Along with the Ask an Expert service, we're also working with a select number of ECLED partner countries to conduct more in depth demonstration projects. And these are ongoing projects that are centered on activities like developing grid integration studies, integrating forecasting into system operations and addressing the challenges related to integrating distributive solar to the grid.

The rollout of the greeningthegrid.org website represents the first phase of this effort and in the next few months, we're going to be continuing to build it out and add more content such as additional fact sheets and integration topics as I mentioned. Today also marks the kickoff of the Greening the Grid webinar series which we're operating, which we're offering in coordination with the Solution Center. The next webinar will be on best practices in grid integration studies. It will be in the September timeframe so please stay tuned for the exact date on that. And we plan to offer these webinars about once every six weeks on different topics. We will also be posting the webinars as web based trainings on the website.

Again we'll be rolling out the demonstration projects with our partner countries and we plan to post the outputs of those projects be they templates or reports or other products to the website so that they could be useful to other systems. And finally, we're hoping to incorporate more case studies and examples from developing countries into our resources since many of what's available in the public domain are from the U.S. and Europe. So we really welcome any feedback on resources that you know of that you'd like to see highlighted. And we also invite you to submit ideas for fact sheets or integration topics or issues that aren't already covered in our materials. And of course, we'd love to get your feedback on the toolkit in general. Our contact information is at the end of this presentation and of course, you can always reach us through greeningthegrid.org. So with that I think we're going to move to questions and panel and I'll turn it back over to Tim and Jen. Tim and Jen I don't think we can hear you yet.

[Break in audio from 54:43 to 57:27]

Tim Reber Hi everybody. Thank you for your patience. We're just resolving and audio issue really quick and we'll get back to you in a second.

Michael Milligan Hi everybody. Sorry. Technical issues. We're back now and so we'll continue with the question and answer session. Ok. I'll repeat the question because I'm not sure if anybody heard me. The question was explain more about why we do not need any storage when we have 30 percent energy from wind and solar. The answer to that question is because we typically have generation on the system that can be controlled or even turned off. And so during periods of high wind or high solar we can turn down a gas unit or we can turn down a coal unit as you saw in some of the graphs. And that sort of makes room if you will for the wind or the solar energy.

When the wind and solar energy dies off because the sun goes down or because the wind stops blowing we then have these generators that we've turned down or turned off that we can then increase the output. So in a sense during periods of time when it is windy or sunny and we're getting wind or solar energy in a sense what we are doing is storing the fuel that otherwise would have been burned at a gas plant or a coal plant or we might be saving the hydro, saving the water behind the dam which is a form of storage. But we use essentially fuel storage already and that's why we don't need separate storage like batteries or pump storage necessarily to help integrate large amounts of wind or solar.

Jennifer Leisch Great. Thank you Michael. So we've been getting a lot of questions coming in so please continue to submit those and while you do that, we just had a great question come in about forecasting. So we have a lot of folks interested in understanding a little bit more about how forecasting or the role of wind and solar forecasting can enable the integration of variable renewable energy into the grid.

Michael Milligan Yeah. Thank you. That's a great question. Because many power plants need some notice before they're available to be used for energy a forecast is helpful. And the forecast, the way that you did the forecast will depend to some extent on how the system is operated. But a fairly typical case would be day ahead, the day ahead before the time in question the system operator has a demand forecast and then gets all of the generators ready to go, turn them on and make sure that there's fuel in all of that so that they can be operated the next day. And part of that process when you have wind and solar is to develop a day ahead forecast. Now the day ahead forecast by its nature is not going to be as accurate as a forecast would be let's say one hour in advance.

But the day ahead forecast can typically provide enough information so that I can decide whether or not I want to start a particular thermal plant or not start it. If I start a plant today that I don't need tomorrow that's a needless cost that I've incurred and I'd like to avoid that. And conversely if I don't start a plant that it turns out I do need tomorrow then I might have a reliability issue. I may not have enough generation on the system to meet demand. So the day ahead forecast plays a really important role in deciding which units, which generating units start up and have available.

And once I get within the day, the forecast can help me decide how to do the economic dispatch. If for example I expect a big windstorm to be coming through in the next hour I then can prepare by turning down or getting units ready to turn down in advance of that windstorm. And if it's a really severe windstorm it may be that the wind, it's so windy that some of the turbines turn off. If I have a forecast that tells me that that type of thing is possible or likely that can help me and get my system ready to go so that I'm not caught unprepared. So generally forecasts are always helpful.

The last comment I would like to make about forecasts is that frequently updating the forecast can be a valuable thing because as you get closer to real time the forecast accuracy can improve. But at the same time there needs to be some sort of an operator action associated with a new forecast. So for example if somebody says I can give you a pretty accurate two hour ahead forecast the question becomes what is a system operator going to be doing two hours ahead of real time. And if there's no system operator action that happens two hours before real time that forecast may not be terribly useful.

Jennifer Leisch Great. Thank you, Michael. So we've had a lot of questions coming in with regard to developing country context. So many times developing countries have very different situations. For example they have capacity challenges or they have a lack of markets. So what do you think some of the ways that flexibility can be improved in these systems, so these non-market context or systems where there are capacity challenges? How much renewable energy can they handle and what are some ways to improve that flexibility?

Michael Milligan Well that's a good question. I suspect that there's not a one size fits all answer but I think markets themselves aren't necessary to achieve the things that we know will help with renewable integration. There are two factors that I talked about in the presentation that help a lot. And one of those if you recall is enlarging the size of the balancing area. And the second one is to go to a faster economic dispatch going to five minute or subhourly dispatch. Both of those can be done with a market but it's not necessarily that you have a market. It could be that you have a utility. It may or may not be state owned. It's more less a monopoly type of system and what can happen is that the system operator whether you're in a market or not can talk to neighboring systems about various levels of coordination can also incorporate a faster time step for economic dispatch.

Now those don't come for free. So if you're moving from a slower dispatch, maybe hourly, maybe even a couple of hours to a subhourly dispatch there will be a need for increased tools to enhance system visibility so that you can see what's happening on the system. There may be a need for new computer hardware and software that can help do the faster economic dispatch. But those things are achievable. They may not always be easy but I don't think you necessarily have to have a market structure in order to have a large balancing region and in order to do a fast economic dispatch.

Jennifer Leisch And Michael, what about the case of capacity limited countries?

Michael Milligan Capacity limitations, those can pose a challenge and I think that renewable energy can help with that challenge to some degree. It may not be able to solve all of the problems but in cases where there's a capacity limit and I assume that the question is referring to limited generating capacity so I may not have the ability of supplying demand at all times. I think that that might present an interesting, possibly challenging opportunity to maybe develop some more I would say operating rules or framework around moving from curtailment that may be undertaken by the system operator based on sort of last minute judgment as opposed to a demand response type of program where instead of curtailing demand that may not be economic to curtail in other ways I could maybe put together demand response programs somewhat more easily. Because if some consumers are used to being curtailed already then I think it might make sense to sort of explore that as an option to say, ok, well how can we make that curtailment more economic and bringing it into a demand response framework of some type that could actually help with integrating variable renewables on the system.

Jennifer Leisch Great. We are getting a lot of questions about islands and how islands can be very unique systems. So what is the difference or what is the cutoff for maybe a small versus a larger island system? And in the island case what are some of the options that really need to be considered? Is storage more important in that situation? What are some of the things that can be done on these smaller situations?

Michael Milligan That's a good question. It's kind of a hard question because a lot of the benefits that we look at in power systems to integrate renewables comes from large size. And that may not be possible in many cases. So with an island system I think the issues are a bit more acute because you can't depend on neighboring systems. Do you need storage? I won't say that you do but storage may become a more attractive option. When you take a look at the types of flexibility that may be available it ranges. There are many technologies for example reciprocating engines which are relatively small generators that can be – you get a ten megawatt engine that ramps from zero to full output in a matter of five or maybe ten minutes. You could also buy a whole series of these engines and the ramping capability would scale linearly. And those types of units or aero derivative turbines can be turned up and turned down fairly, pretty quickly.

So those may be options. Other more controlled generation whether it's from hydro if there's some controllable hydro on the island would be useful. But it may come down to a requirement for some sort of storage if other options are not available. And if that does happen it will likely increase the cost compared to what you might be able to do in a larger system. I know that I'm not real close to this work but I know there's a lot of work going on in Hawaii really pushing the envelope on what you have to do for the system. And I know they have a bunch of old oil burners for generators that historically they have not operated in a very flexible manner.

And so the question is technically can I change the way I operate those units? So I cycle them more often turning them up and down. I turn them off more often. Or is there an inherent limitation to the device? If there is an inherent limitation sometimes that can be solved by retrofitting it with either enhanced controls or other features that can help make existing generators more flexible. So it's a hard question because there's no one size fits all. But I think that there are a number of flexibility options that you would want to look at if you're an island system. And I do think that the challenges are going to be maybe a little bit higher on an island system.

Jennifer Leisch And something to point out is that we do have a lot of resources for islands and to answer some of these questions on greeningthegrid.org. So we're excited to keep hearing from you on the forum. In the meantime we've had a lot of questions coming in about distributed generation, specifically distributed PV. Michael, do you think you can speak to some of the challenges that are particular to integrated distributed PV versus utility scale or large scale PV?

Michael Milligan Yeah. That's a good question. I know here in the U.S. there's a lot of attention that's being focused on that issue. Primarily, and I don't know if this is true in all parts of the world but I know it's true here and in many parts of the world. The distributed PV is not visible to the power system operator. So I'm running the transmission system. I know what the large generator are. I know what the transmission line loading is. I know what demand is. Actually I may not even know what demand is because now if I have a lot of solar PV on the distribution network I can't really tell if a cloud has come by and reduced solar output or if somebody just turned on a big massive load of some kind. And so I think one of the biggest challenges is to figure out a way for the distributed solar to be visible to the power system operator so that decisions on how to best operate the rest of the system can be made efficiently.

The other issue can be sort of the – you may be getting some back flow from the distribution system to the transmission system which isn't necessarily a problem. But again you need the ability of being able to see what's happening and probably some means of controlling the PV. As I mentioned earlier wind turbines can respond to all kinds of signals. PV panels can also.

But the question is if I have 1,000 rooftop panels and I need as a system operator I need to reduce their output what sort of equipment do I need to do that? There's got to be communication. There's got to be control. And how do I best do that as a system operator. So I think that's a – it's a great question. I don't have an answer much better than this but I do think that the challenges really come down to visibility and potentially control so that I understand from the operational point of view exactly what's going on.

Jennifer Leisch So, we have been getting a lot of questions about flexibility and thermal systems. And so someone was curious about really what does turning up or cycling, turning up and down or cycling thermal plants really mean and how do you actually increase the technical limits of those coal plants?

Michael Milligan That's a good question and I'm not an expert on the coal plant design but I know that not all coal plants are created equal. Some plants are designed to be flexible. Other plants are designed to be run at base load. So if the plant is designed to be run at base load there may be some things that you can do to it. I know that the boil tubes for example are _____ with basically everything but the boiler tubes in particular are sensitive to thermal gradients, extreme changes in temperature over short amounts of time. And so those tubes can kind of basically break. But in a case where a coal plant is designed to be run at base load nobody probably cared that much about designing tubes that are strong enough to withstand the thermal stresses of a lot of these thermal changes.

So again every coal plant is different. There are companies that can come in and assess the plant and say here's what you can do to increase the efficient or sorry, to increase the flexibility out of that unit. And I don't know that you could necessarily get the same level of flexibility if you retrofit two different units. But I think that's something that's worth looking at. We tend to think of flexibility options as a whole suite of things. And so for any given particular system I would want to take a look at what are the five or ten or however many options are there for increasing flexibility.

And I want to go after the ones that are cheapest first. And if that gives me enough flexibility that's great. I'm done. I haven't spent that much money. If that doesn't give me enough flexibility then I need to go to the more expensive one. But I think that there's a lot of potential for many plants to be retrofit so that they can become more flexible. But that's sort of up to the individual owner and the engineering firm to come in and assess the plan.

Jennifer Leisch And Michael is there an impact of that cycling of those thermal plants on the greenhouse gas emissions associated with the system?

Michael Milligan That's a great question. Yes but it's a very minimal impact. We did a really large study here at NREL that we published a year and a half or so ago. It's called the Western Wild and Solar Integration Study Phase 2. And we actually did a couple of things in that study that were I think one of a kind and very, very detailed. One of them was that we got pretty detailed information about the impact of cycling on thermal plants, both coal and gas plants. And we built those costs into the economic dispatch. And we did find that dispatch changed a little bit. The cost changed a little bit. But the other thing we did was we got actual emission curves from every generating unit in the western interconnection for every thermal generator. We got that based on empirical data and that empirical data shows what happens when the plant is started, when the plant stopped, when it's turned down to a less efficient point, when it ramps up, when it ramps down. All of those things were captured in our modeling.

And what we found was that there was a small penalty if you will on the emissions when the plants were cycled. And I don't recall the exact numbers but we reduced emissions by somewhere around 30 percent overall and when you take the cycling into account instead of 30 percent we found the benefit was maybe around 29 percent. So yes, there is an impact but not much of one. And if you think about what's really happening when I've got that amount of wind and solar on the system I may have a couple of thermal plants that are going to be operating at a less efficient point. They may be burning more fuel per megawatt hour. But on the other hand I've turned off a whole bunch of plants and that impact of turning off many plants is going to really drive the emission reduction and will by far overcome any small penalty I might have by taking a small number of plants down to an inefficient loading point.

Jennifer Leisch I think we have time for just one last question and this question has to do with really the state of the art right now. And so I'm going to try to merge several different incoming requests in this. So from your perspective what are really the most relevant and state of the art things right now in terms of planning and the type of tools that you need for planning for capacity additions, etcetera. What's the state of the art that we should be watching in terms of technologies and what's the state of the art in more of the soft side of the system?

Michael Milligan Oh that's an easy question. Ok. Let me see if I can address at least parts of that. So from the planning point of view I think one of the things that we've been able to see over the last several years is that the development of high quality renewable energy data sets is really critical not only to doing integration studies but to do an assessment of flexibility. For example, well, take India as one example. So in India you've got some pretty aggressive renewable energy targets and so then the logical question would be, well, ok. If we aim for 50 megawatts of – sorry – 50,000 megawatts of wind and then 30,000 megawatts of solar or whatever the numbers are what sort of flexibility do we need in the rest of the power system? We can actually help – we can look at that by taking the annual hourly demand and then say let's imagine that wind and solar is built these capacitates at these locations and we can look at the same kind of curve that I showed you early on in the presentation that shows the demand by itself and then we subtract off the wind and solar and we can see what sort of flexibility is needed in the remaining part of the fleet.

So from that you can calculate what sort of minimum run level might I need, what sort of ramp rates might I be needing, and of course you want to do maybe a couple of scenarios to try to get an idea of what sort of flexibility do I need? I think the transmission planning tools – I don't think there's a need to fundamentally change what we do there. But of course when we're building out renewable energy we're somewhat constrained with respect to where we put the wind and solar. But I think there are a lot of interesting questions maybe in particular with wind. Suppose I have two locations in which I'm considering putting a large wind plant. One location is closer to demand which wouldn't require very much transmission but the wind is not as energetic. The other location is further transmission but the wind for a given level of capacity I would get a lot more energy out of it. So I think that's an interesting tradeoff that can be looked at and I think the existing tools allow us to do that with planning models, transmission models and so forth.

Moving to operations, the things that help us integrate wind and solar also help us more efficiently operate the power system without wind and solar. And those are some of the things I mentioned earlier, the large balancing regions, the fast economic dispatch. What you need for that is visibility. You need to be able to see what's happening on your system and we see in the U.S. there's a need for more visibility. We have every so often we've got reliability issues that somebody couldn't see what was happening and so a part of the grid goes dark. And so you need that for efficient integration. With respect to technical sources of flexibility, storage is always great. I think the only downside to storage is particularly batteries is the cost is high. But there's also some complications with respect to how do I know when I should charge my storage and how do I know when I should discharge my storage. So you need good forecasts to use it. Forecasting technology is getting better.

And I think the other interesting source of flexibility is coming out of two different sources, air derivative turbines that are basically jet engines, which are turned into generators. They can ramp very quickly. They can start very quickly. They have minimal heat rate degradation at start up and over the ramping cycle. They're pretty efficient and so that's one source of flexibility. Another one as I mentioned earlier, reciprocating engines. It's a little bit different technology. Both of these can cycle very, very quickly from start to full load maybe five to ten minutes. The _____ can be scaled linearly by getting a whole bunch of small units. We're starting to see a few of those in place. We have one here in Colorado not too far away and it's being used in the public service system that I showed you earlier. And then I think the last operational thing is take advantage of the fact that you can squeeze a lot of flexibility out of wind plants and solar, particularly central solar.

I mentioned some of the possible difficulties with distributed solar. We don't want to do a lot of curtailing of wind and solar obviously because that's going to limit the objective, which is to reduce emissions. But on the other hand there's a lot of flexibility that can be obtained from these – from the renewable sources themselves. And I think that's a fairly new and pretty innovative thing. The slide I showed you earlier from public service of Colorado is – I don't know that it's one of a kind of public service of Colorado is a real leader in terms of coming up with interesting and creative solutions for how to integrate a lot of wind. I don't remember. They have 2,800 megawatts of wind on about a 6,000-megawatt system so – and it's not very well connected to the rest of the world. So I think there are a lot of innovative things that are emerging. Hopefully that gives you an idea of at least some of it.

Jennifer Leisch Great, Michael. Thank you, Michael and Jessica. This has been really informative and I'd like to encourage everyone if you have further questions you can contact everyone on the panel on the email addresses that you see there. And I'd like everyone to try and head over to www.greeningthegrid.org where we will have other training materials and these slides available and of course lots more information for you. I'd like to turn it back over to our colleagues from the Clean Energy Solution Center.

Tim All right. Thank you all three of you, Jessica, Jennifer and Michael for that great webinar. Before we wrap up here we just have a quick survey for those in attendance, three questions that will appear on your screen shortly and we ask that you just go ahead and answer those. Your feedback is important to us as we strive to always insure that we provide quality webinars. So with that if you would please answer those questions. And the next question coming up. And finally the third question. All right. Thank you very much. On behalf of the Clean Energy Solution Center I'd like to extend one last thank you to all of our expert panelists as well as to all of our attendees for participating in today's webinar. We will invite you to check the solution center website where you can see the slides and listen to a recording of today's presentation, which should be posted within the week.

You'll also find previously held webinars on the Solution Center website as well. The recording will also be posted at the Clean Energy Solution's YouTube channel and we invite you to inform your colleagues and those in your networks about Solution Center resources and services including our no-cost policy support at Ask an Expert that now includes support through Greening the Grid as well. We ask that you all enjoy the rest of your days or your evenings as the case may be and we hope to see you again at future Clean Energy Solution Center events. Thank you again and this concludes the webinar.