CLEAN ENERGY SOLUTIONS CENTER
ASSISTING COUNTRIES WITH CLEAN ENERGY POLICY

Energy Sector Resilience

—Transcript of a webinar offered by the Clean Energy Solutions Center on 24 June 2016—
For more information, see the clean energy policy trainings offered by the Solutions Center.

Webinar Panelists

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Sean Esterly Hello, everyone. I'm Sean Esterly with the National Renewable Energy Laboratory, and welcome to today's webinar, which is being hosted by the Clean Energy Solutions Center, in partnership with the Asia Pacific Economic Cooperation, also known as APEC, Energy Working Group, and the U.S. Department of Energy. Today's webinar is focused on energy sector resilience.

And, one important note of mention before we begin our presentations is that the Clean Energy Solutions Center does not endorse or recommend specific products or services. Information provided in this webinar is featured in the Solutions Center's resource library as one of many best practices resources reviewed and selected by technical experts.

And I just want to go over some of the webinar's features. You do have two options for audio. You may listen through your computer or over your telephone. If you do choose to listen through your computer, please go to the audio pane and select the mic and speakers option. It will help eliminate any feedback and echo. And if you dial in by phone, please also go to the audio panel and select that telephone option. A box on the right side will display the telephone number and the audio PIN that you can use to dial in. And if anyone's having any technical difficulties with the webinar, you can submit a question, and I can try to help you out virtually, or you can call the GoToWebinar's help desk at 888-259-3826, and they should be able to help you out there.

Throughout the webinar, we do encourage anyone from the audience to ask questions. The way to do that is to simply submit it through that question pane. We will receive it there, and we will present those to the panelists during the question and answer session following the presentation. And if anyone's having difficulty viewing the materials through the webinar portal, you can go to the URL that I just sent out a few minutes ago. It's within that cleanenergysolutions.org/training. And you can download the PDF copies of the presentations and follow along as the speakers present.

Also, we will be posting a publicly available and free audio recording of this webinar following the broadcast. That should be available within about a week of today's webinar. And just a reminder: we are also now adding the recordings to the Solutions Center YouTube channel, where you'll find other informative webinars, such as some interviews with thought leaders on clean energy policy topics.

So we have a great agenda set for you today, and it's centered around the presentations from our guest panelists, Drs. Steve Folga and Guenter Conzelmann. And these panelists have been kind enough to join us to discuss the concept of resilience as it applies to the energy sector; tools to assess energy sector vulnerabilities in resilience options; and recent case studies from different regions within the U.S.

And before our speakers begin their presentations, I'll provide a short informative overview of the Clean Energy Solutions Center Initiative. Then following the presentations, we will have the question and answer session, where panelists will address those questions submitted by you, the audience. And then some closing remarks and a brief survey at the very end.

And so this slide provides a bit of background in terms of how the Solutions Center came to be formed. And the Solutions Center is one of 13 initiatives of the Clean Energy Ministerial that was launched in April 2011, primarily led by Australia, the United States, and other CEM partners. Some outcomes of this unique initiative include support of developing countries and emerging economies to enhancement of resources and policies relating to energy access, expert policy assistance, and also peer-to-peer learning and training tools, such as the webinar that you're now attending.

And there are four primary goals for the Solutions Center. The first goal is to serve as a clearinghouse of clean energy policy resources. Second is to share policy best practices, beta and analysis tools specific to clean energy policies and programs. Fourth goal is to deliver dynamic services that enable expert assistance, learning, and peer-to-peer sharing of experiences. And then the final goal is to foster dialogue on emerging policy issues and innovation from around the globe.

The primary audience for the solutions center is typically made up of energy policy makers and analysts from governments and technical organizations in all countries, but we do also strive to engage with the private sector NGOs in civil society.

One of the more key features that the Solutions Center provides is its technical assistance, that's expert policy assistance known as Ask an Expert. The Ask an Expert program has established a broad team of about 40 to 50

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experts from around the globe who are each available to provide remote policy advice and analysis to all countries at no cost to the requester.

So, for example, in the area of renewable electricity policy, we're very pleased to have Paul Komor, from the Renewable and Sustainable Energy Institute, serving as one of our experts. So if you have a need for policy assistance and renewal energy policy design, or any other aspect of clean energy, we do encourage you to use this valuable service. Again, it's completely free to you, so if you have a question for our experts, please submit it through our simple online form at cleanenergysolutions.org/expert.

And we do also invite and encourage you to spread the word about this service to those in your networks and organizations.

Now I'd like to provide some brief introductions for today's distinguished panelists. First up today is Guenter Conzelmann, the director for the Center for Energy, Environmental and Economic Systems Analysis. Guenter is also a senior fellow of the Energy Policy Institute at University of Chicago, as well as with the Northwestern University's NAISE Institute, and an adjunct faculty with the Stuart School of Business at the Illinois Institute of Technology. His research focuses on the development and application of modeling and simulation tools to study strategic energy and power sector issues, including renewable energy integration, smart grid and microgrid implementation, advanced grid modeling, energy sector resilience, and environmental impact of energy production.

Our second speaker today is Dr. Steve Folga. He is a senior manage in the Risk and Infrastructure Science Center, also at Argonne National Laboratory. He has been involved for more than 15 years in projects related to infrastructure assurance, which has included contributing to the development of systems analysis methodologies to use natural gas and petroleum fuels; infrastructure assessment and developed methodologies for estimating the potential consequences of component disruption and the time needed to return disruptive components into service. He has also helped to determine the interdependencies between the natural gas and petroleum infrastructures with other critical energy infrastructures, such as electric, power and telecommunications.

And so, with those introductions now, I will go ahead and turn things over to Guenter and welcome to the webinar.

Guenter Conzelmann Thank you, Sean. Thank you, everyone, for joining us tonight, or tomorrow your time, and it's a pleasure to be here with you, to talk to you about this issue. And so Steve and I will basically go back and forth throughout the presentations. We'll be switching it off, going through the presentation, and we'll be more than happy to address questions that you'll have at the end.

So, on the first slide, just a quick summary of what you're going to hear. We'll start out with introducing—Sean already introduced us, the speakers, but we'll introduce you a little bit to the Argonne National Lab just very briefly. And then we'll talk about why are we concerned about resilience, how do we define resilience, how do we model resilience, and then the types of tools and data that you need to do this, study resilience issues. And then we'll show you examples of applications of these data sets and tool sets across the United States, to look at a variety of different resilience issues related to different kinds of hazards or concerns that you might have. And then lastly we'll show you a few model applications in Asia as well, and then take questions.

For those of you who do not know Argonne, who have not been to Argonne, Argonne is one of the 17 national laboratories that support the Department of Energy. The Natural Renewable Energy Laboratory obviously is the one that's hosting today's webinar. Argonne's another one of those laboratories that's supporting the Department of Energy. You might have heard of Lawrence Berkeley Labs, Brookhaven, Los Alamos National Labs—these are all labs that are supporting the Department of Energy.

You'll see the map at the bottom right, and Argonne's in the Midwest. We're right outside of Chicago, so we're one of the older laboratories. We were founded in 1943, and we're managed by the University of Chicago, an entity that is [phone noise] run by University of Chicago. We have about 3400 full-time employees. In the meantime, we have close to 6000 visitors every year coming to our campus to use some of our research facility, with annual budget of about $800 million dollars.

It's a beautiful site, outside of Chicago about 40 kilometers southwest of downtown Chicago. So if you come to Chicago, don't come in the winter; come in the summer and come visit us. We're about a half hour, 45 minutes' drive from downtown Chicago.

Why are we qualified to talk about energy sector resilience? Well, energy sector resilience is one of the core initiatives that the laboratory has had for a number of years, and we're investigating in general resilient infrastructures. Not just purely the power grid or the energy infrastructure—in general, resilient infrastructures. And obviously, energy infrastructures are one of the core topics, focus areas that we have, and that spans the capabilities. We tap into capabilities across the entire national laboratory, from the basic science kinds of aspects to very applied aspects.

And this slide sort of shows you the pipeline of different things that we bring to the table when we look at energy sector resilience. We start out with advanced algorithms, algorithms that might be advanced optimization approaches, or better, newer simulation approaches that allow us to run our model at a larger scale, or faster, higher resolution. We use those advanced algorithms to develop these newer models, models that can address critical issues. And then of course we use those models in-house to study a range of different topics that are important. And grid resilience and energy sector resilience, cascading failures of power systems, and power system restoration—this is obviously one of the core application areas.

In some cases, these models and tools that we develop in-house also then get deployed in other places outside where a lot of the tools are used worldwide,

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in a variety of different places. And so our mantra is, we want to develop something that is useful. I mean, basically addresses something of significance or importance, useable, something that you actually can use. And then, of course, the end goal is, we want our tools to be used.

So this is an example for what's involved in resilience analysis, and this is an example for the power grid. You could have a similar sort of flow chart for other infrastructures, the natural gas infrastructure, or the petroleum infrastructure, or the water infrastructure. And so typically, you start out with defining the kinds of hazard or event that you're concerned about.

And those could be weather events—think of tropical cyclones; here we call them hurricanes. In Chicago, where we live, Steve and I, we also have to face the occasional ice storms that hit the Midwest. And so ice storms can do fairly significant damage to our infrastructure and have fairly significant replication. And we also face tornadoes. So this could be different weather events, could be weather events based on historical records. Or we could look at weather events that might occur in the future under climate change scenarios. So we can look at future impacts as well. And of course, it could be earthquakes or man-made hazards or concerns you might have, too. Like for example a cyber event.

So you define your initial starting event, and that sort of like goes to defining your scenario. So we have a number of different approaches that allow us to define a scenario as any one of these hazards. We call those the multi-hazard analyses. Then we have to translate that initiating event into a physical impact.

So what part of your infrastructure is actually impacted by this? So some of the assets, are they damaged? You see a picture of a transmission tower on this chart. It could be other damages. Could be damages caused by flooding. Could be damages caused by ice buildup on transmission wires. You name it. So we have to translate that initial event into what is the physical implication on the infrastructure. What's breaking? What is down?

And then, of course, these are individual components in the system, and there could be multiples of those. Could be dozens or even hundreds, depending on the size of your event. If you think if a large hurricane or a large tropical cyclone, you might have hundreds or thousands of individual assets damaged. So then we have so say, "All right, so what is the overall system impact?"

And so we do system modeling, where we say, "Well, what's the system impact of losing a variety of different components, and what other sectors might this impact." Say, if I lose electricity, are there effects downstream on other sectors? Or if I lose natural gas supplies, is my electricity system impacted by it? So we have to look at that as well, and then basically determine if there is sufficient damage in the system. In this particular case, the power grid: will I have cascading power outages leading to either a regional blackout or a larger blackout?

And then, of course, once we have that, then we have to say, "Well, all right. So how long would it take me to restore power back to people?" And so that involves a last step, where we do the system restoration modeling, where we have data and tools to allow us to estimate: how long would it take to repair a certain piece of equipment? How long would it take if I had to repair hundreds of those? And so what's the timeline of that physical repair or restoration, given that I have limited resources, limited number of people that can repair things, limited equipment to replace damaged components?

And then once I'm done with the physical restoration or repairs, then I have to say, "All right, so how can I bring back up the power?" So in this particular grid, this is an example for power, "How do I electrically restore the system?" And so we do that both at the transmission as well as the distribution level.

So this is all like a general sort of overview of the kinds of things that we do, and the kinds of things that qualify us to basically speak to you about the topic today. And at this point, I'll hand it over to Steve now. And I'm on slide 7, and Steve will talk to you a little bit about background and the significance of resilience analysis. So, Steve.

Stephen Folga

Well, thank you very much, Guenter, and I'd like to again also thank the participants of this webinar. And so, as such, we're saying that energy resilience is becoming an increasingly important topic because weather events that were once considered like rare are now happening on a more regular basis. For example, it was very rare for hurricane to severely affect the U.S. energy sector, and that was prior to the year 2005.

But the figure on the left-hand side of this slide shows you that there have been many, many hurricanes that actually have affected the United States. But it's only until recently that the intensity of those type of hurricane activity resulted in the type of flooding that you see in the upper right-hand side. A number of refineries as well as petroleum terminals were flooded as a result of Hurricane Katrina in 2005.

Now, as time has gone on, hurricanes that you see over on the bottom right-hand side are occurring with increasing regularity, and one of the roles that our organization, Argonne National Lab, has is to be able to apply our tool to be able to anticipate what are the impacts of the transit of this type of a hurricane on the energy sector in terms of impacts to the electric, natural gas and petroleum infrastructures.

So overall we can expect that the exposure of the energy sector to weather events such as the hurricanes that we're seeing here, and tropical cyclones that occur in other parts of the world, that this type of risk will remain high in the near to immediate future. Next slide, please.

This slide actually shows data from the World Energy Council, and as you can see, it reinforces the assertion of the increased likelihood of extreme events with time. Now, on the left-hand side you can see that in 1980, there were 38 recorded extreme weather events, and this is based on data that was collected by world insurance carriers, and so it's a global overview of what

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the impacts would be throughout the entire world, not only within the United States.

As you can see, the information on the right-hand side for 2014, that this has increased by four times to 174 extreme events in year 2014. So, now, given the predictions that are being made with this point, many more events similar to these can be expected in the future which are driven by the increase in the global average temperature, and that essentially they're being driven by climate change. Next slide, please.

And this slide, I'm sorry, is a little bit busy. But what it does is, it actually has data from UNICRE economic research and consulting company, and this is the information that they have gathered from a variety of sources to actually show what are the number of events that have happened as a function of time, and the impacts of these events. Now, the figure on the upper left-hand side shows that the overall insured losses due to meteorological events—and you see that's meteorological events that are things like tropical storms, convective storms, even local storms—has increased by over 40 percent over the last years, compared with the average over the last 20 years. That's a very big increase.

The figure on the upper right-hand side shows that most of the insured losses are increasing within the last 10 years at an increasing rate. Now, the figure on the bottom shows that the scope of these losses are not just localized over to the North America, but they're worldwide. And so a large number of top-50 extreme events have occurred in Asia, and these events reflect that the overall exposure, and as I said, the severity of critical infrastructure such as the electric, natural gas and petroleum sectors, is increasing. And we can expect this to become even more dire in the immediate future. Next slide, please.

Okay. As we said at the beginning of the agenda, we want to discuss resilience. And so, there are new emerging risks that are posing even greater threats to the energy sector. And so now resilience is a term that's increasingly heard in the energy sector as a means of protecting the world's most vulnerable regions, including those involving energy systems.

Now, the upper three text boxes give you different definitions of resilience as it relates to critical infrastructure, and you can see that it pulls, from an executive order put out by the United States President, information. The second one is based on the thoughts of local utilities, and the bottom is something that we put together. But in general, a more simple definition is really shown at the bottom of this slide, which is that resilience is the ability, the capability, to bend but not to break after a disruptive event. And the corollary to this is that you have the ability to bounce back quickly, to be able to get back to the usual equilibrium state that you had prior to that, or even if possible, to a better state as the result of the resilience measures that you have taken prior to that destructive event.

Now, the next slide, slide number 11, shows the classic definition of resilience. And that, for the energy sector, accounts for resilience measures

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that could be used which would help result in quicker restoration of electric service in the case of a disruption. So, on the left-hand side of the figure it shows initially the energy sector is at equilibrium, and this is prior to the disruptive event that you see over at the top. Then, in each of these different portions of the timeline, different resilience measures could be actually used, to be able to bring back the energy sector as soon as possible back to its equilibrium position.

So in the preparedness phase, before the actual event occurs, you could do things, say, like stockpiling spare parts in anticipation of this event, as well as mitigative actions such as increasing your construction standards, strengthening your infrastructure to resist and absorb the impacts of the expected event. That event could be an ice storm, could be a hurricane, or whatever. But if you do things in anticipation from that, you'll be able to reduce the amount of loss that's shown in the figure.

Then, once the event occurs, enhanced response measures, such as operating the energy sector under a safe-fail approach, would allow you to be able to respond and adapt better and more quickly to the event. And finally, during the recovery phase, you could use things like MOUs, MOAs. They could be very useful resilience options that could accelerate the response after the event to bring you back to your previous or your new equilibrium.

And so the ultimate goal of resilience is to return the service back to the affected customers in a shorter amount of time, and also to decrease the number of customers that are initially impacted by the event. Now, when we go to the next slide, slide 12, this slide actually gives you an understanding of why we actually try to do infrastructure modeling as it relates to resilience.

Really one way that a lot of people use to identify the risk of the energy sector to extreme events is just to model the potential impacts of these events, so we understand whether or not that type of event would impact, and what is the overall expected losses.

Now, the figure on the right, which is sort of dense, I'm sorry to say, shows that energy systems are becoming increasingly integrated. Such that, as you could see, the electric power requires fuel from natural gas, but that the electric power then is used to power compressor stations and control rooms. And so there's a symbiosis between each of the individual lifeline utilities. And so, as such then, the resilience in this type of an interconnected world is no longer just about really returning a single sector or energy asset back to a full operation, after you've had a disruptive event.

Now, you've got to take into account all of the interdependent portions of it. And so when these interdependent portions of this overall system of systems is blacked out, the system really could become deadlocked. That's what was actually seen at Hurricane Sandy over in 2012 in the United States, where the restoration of the electric sector was dependent heavily upon the transportation sector, which was being limited by the amount of fuel, to be able to transport needed crews and spare parts to the adversely affected electric areas.

If we had done this prior to this, the modeling of the energy sector could really provide insights in what did work after such an event. And you could actually look at that, and actually highlight options to be able to increase energy sector resilience prior to an event. By doing this, you would be able to do much better, effective planning, and this would increase the overall resilience of the energy sector. Next slide, please.

Guenter Conzelmann I'll be taking over here again for a few slides. So if we do the modeling, what is it that we need? Well, obviously for any modeling you need data. For this type of modeling, you need data that describes the hazards, the things that you're concerned about. Weather and climate is obviously one of the major concerns. These are some of the major events that keep hitting our infrastructure, so we need data and information on that. And then obviously we need data on the infrastructure itself.

At least here in the United States, some of that data is publicly available; some of it has restriction. But we typically gather that information to merge essentially the infrastructure data with the hazards data. So overlaying the infrastructure information with weather event or with an earthquake event, or with a cyber event or whatnot—whatever event that you want to analyze. And then we need the tools, and so we will present to you in a few minutes a range of tools that allow us to evaluate the impacts, the effects of these hazards onto our infrastructure, and allow us to identify where are the vulnerabilities in our system, and allow us to develop mitigation and resilience options, and to determine the benefit of those options.

You can use tools to address a range of difference resilience considerations. You can make become more resilient by doing a better job in preparing yourself. You can become more resilient by doing a better job in mitigating for something, so to get to reduce the impact. And then once the event happens, and once you have the impact, then you can do a better job in responding and recovering. And all of those things make you more resilient.

Because it goes back again to the simple definition of bending but not breaking, and bouncing back. And then of course we have tools that allow us to identify these resilient operations, make our systems more resilient, but we also need to then determine, "Well, okay, if a system is resilient, how would we –?" Once we have a resilient design, we still want to make sure that we run that resilient infrastructure system both reliably as well as economically.

So we have different tools that allow us then to say, "All right. So how would I run, operate that resilient system?" There is a different set of tools that's available for that.

Looking at data, I said we usually need to look for data on the infrastructure and on the hazards. And again, it's the hazards that we're concerned about. One thing that often hampers us, when we look at weather and long-term climate concerns, is the fact that we have current or historical weather records, but if we want to say, "Well, how do we design a system that is resilient 30 years from now, or 50 years from now, from future weather events?" then we need to have access to high-resolution climate data.

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Typically, what is out there is data that the resolution in the chart that you see in the top left. That's sort of like the typical resolution of a global climate model, run in a scale of 100 squares of 100 kilometer x 100 kilometer, and that's a very large area. For detailed planning, looking at impact at the local scale, that is not sufficient enough.

What we have done, over the last two, two and a half years, we've used our supercomputer. It's the fourth largest supercomputer that's open to the public in the world. We use that supercomputer to essentially run for the entire North American continent—not just the U.S. but including Mexico and Canada—to run tools that basically allow us to get down-scaled data at a much higher resolution level: 12 x 12 kilometers. What you see on the right side is basically the higher resolution results from that, and you go from a very coarse picture to a much finer picture.

And that is useful if you want to look at what is the impact at a particular location, all right? Right now, it's a 12 x 12 kilometer—we're actually working on scaling down to 4 x 4 kilometer. That will be the highest resolution data that would be available anywhere. And again, that would be for the North American continent, but it can be developed and provided for other regions as well. So we're already in discussion with some folks in the Department of Energy to possibly do that.

Now, the reason why we use the supercomputers, because not only do we downscale for one scenario; we run it for many scenarios, and so we actually can give you uncertainty ranges around the main climate parameters, and we can also have a lot of information on extreme events which of course where resilience is one of the primary concerns. We give you different time scales, mid-century, end-of-century, at three-hour time steps. So it's time theory, the three-hour time steps, and can [phone noise] ___ ____. There's a lot of data, so that actually takes up 200 terabytes of data on that supercomputer.

This is available publicly here in the U.S. and is used in regional resilience assessments, different infrastructure events. Some of the studies we're going to show you in a little bit, they actually tap into that data as well. In addition to making data available, especially if you make 200 terabytes of data available, people quickly get overwhelmed, and they don't know what to do with it, so the people who pay for the work to develop this data, also pay for a user's guide for that data that actually tells an infrastructure analyst, a resilience analyst, "How do I actually use that climate data? How can I use it in my infrastructure resilience analysis?"

Provides basically recommendations how to apply that data, what data to use, in what situation. So that is the first of a kind, and was posted recently at this website that's highlighted here at the bottom left.

This is climate data. Similar, of course, you have to have data on other hazards, and of course, you need data on infrastructure. In the United States, we are fortunate; we have quite a bit of data. But as models, we can never have enough data. So we always like to have more data. Especially for resilience data, certain data is not always publicly available. So if you do this

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type of analysis, at least here, we are always limited and constrained by the fact that some data are hard to obtain. And so there are multiple government agencies working on developing and making available infrastructure data that will be available publicly, at least to government agencies.

The National Geospatial Intelligence Agency is one such agency that works on this, as well as the Department of Energy, and a recent new initiative has made several, half a dozen awards to different entities, including Argonne, to develop synthetic grid data sets for transmission and distribution. So we would have that data set, and then the other agencies working on developing, preparing and making available data sets on multiple different infrastructures.

With this, of course, then we can run models. We said earlier resilience is sort of like preparing yourself, and then mitigating against an event; the events happens, and of course then responding and recovering after the event, so that you bend, but you don't break, and you bounce back.

So tools that are typically out there can be grouped into these four different buckets or groups. Again, there's many different tools available. These happen to be the tools that we here at Argonne have developed and are making available. There are also tools available by other agencies and other entities and other national laboratories and other research institutions.

But typically you can think of structuring it this way: It's tools, again, that allow you to prepare for something, that allow you to train for something, to exercise, to get ready in case something were to happen. Tools that allow you to make sure that, if something happens, that the impact is sort of minimal—so you mitigate against that event. And then tools that allow you to quickly and most efficiently respond and recover after the fact, so that you can bounce back quickly.

And so with this, I will now turn it over again to Steve, to talk about some of the more specifics on some of these tools. We won't go into a lot of detail because we only have an hour or so, but Steve will walk you through six of the key tools. And so, Steve, turning it over to you again.

Stephen Folga Thank you again very much, Guenter. So as Guenter was saying, Argonne National Lab offers a wide range of resilience-related capabilities which can be used to study things such as interdependencies between the energy sectors, as well as to respond to things like rapidly changing situations in the energy sector—a hurricane coming through, ice storms, other types of extreme weather events. On this page shows a suite of tools which we call the Fast Suite of tools which were developed by Argonne for a quick turnaround analysis of the electric, natural gas and petroleum sectors within the United States.

These tools leverage data that Guenter was talking about, and critical infrastructure assets in the energy sector to examine the impacts of different types of events, such as, on the left hand side, the ET Fast Tool was used to be able to look at what would be the impact of the loss of a major electric substation, transmission substation, hit by a very high-intensity tornado, and it led to a cascading—if its loss would lead to a cascading impact which affect a very large regional area of the United States.

So this tool gives us the ability to look at cascading impacts, as well as whether or not islanding would occur. Such that we could now, with those stools, look at contingencies of 10 minus one and minus two. This tools was developed so that we could look at 10 minus K, where K could be up to a few hundred [phone noise] energy assets, electric assets such as transmission lines, substations, generating plans, and see what would be the impact of simultaneous loss of these energy assets on the electric infrastructure, whether or not it would actually lead to a wide-area blackout.

The tool in the middle was developed to help complement our fast turnaround efforts for hurricane analysis for the Department of Energy, and it's called NG-Fast, and it determines how shortages in the gas supply can affect the electric generation within an individual area. The figure itself shows the impact of a hypothetical hurricane, and the states that are green are t hose that are not adversely affected by the loss of gas due to impacts on offshore gas production. But it shows the states in red which would be impacted by that. And lastly, we have the tool which we call PWELL-Fast, which performs a system-wide analysis of disruptions to the petroleum sector. We use this to be able to see whether or not mitigating actions such as increased pipeline capacity, imports outside of the U.S. coming into the ports in the U.S.—can actually compensate for different types of disruptive events.

Now, the next slide shows another series of tools that have been developed by Argonne, and these other tools allow us to look at things such as, we estimate the impact of an impending tropical cyclone on the electric sector, and that's the head-out tool. In this tool, when given information from the National Hurricane Center, using their weather projections to be able to estimate what is the number of customers affected both by distribution and transmission impacts from high winds as well as storm surge. And the model can produce these results in a matter of minutes, which we could then provide quickly over to decision makers for them to be able to determine how to mitigate against the impacts.

The model in the middle is called the Restore tool, and we use that to account for interdependencies between the energy sector in terms of its restoration. We use it a lot to actually identify what's the most active path during a repair and restoration phase. Then, given that information, we can take a look at that and try to determine how we can lead to a reduced recovery time for not only individual assets but for individual systems.

Lastly, EGLIP is a newly developed tool for power system restoration, and we use that to support restoration planning and operational decision making on the electric side. We have also used it to analyze intentional islanding for extreme weather preparation. So these suite of tools on the energy side allow us to be able to look, going through the four phases of emergency management, starting from prepare and all the way over to respond and react. We can use those to be able to understand what would be the impact of individual ____ [phone noise] event on a regional as well as a national level, from disruptive events such as hurricanes and others. Next slide, please.

Now, when we do these types of analyses, one important key element is situational awareness. And situational awareness is a key way of being able to enhance energy resilience. Y'know, we have better information about what you should be trying to do at the time, instead of using old information which may be outdated and lead you down a wrong path in terms of repair and recovery.

So Argonne has developed a suite of situational awareness tools that has been used with a number of energy exercises, and these are shown over here in the figures on this slide. We've done work looking at a series of tornado strikes in Operation Powerplay, which looked at a widespread earthquake affecting the Midwest of the United States, and how one could use the information that's being gathered in near real-time—how that could actually help you to expedite recovering restoration.

These web-based tools also contain a range of integrated spatial relationship models which can really help us, and we use that to enhance the analysis of the resiliency of the energy sector. And we use that because we get insights provided by the exploitation of the real-time information coupled with the data on the critical infrastructure. And so, as such, the tools that I'm showing right now have been applied in a number of applications, and we'll be highlighting them in the next series of slides. Next slide, please.

One major implication that Argonne has been involved in over a number of years is a program called the Regional Resilience Assessment Program, or RRAP. What that is, is that's an assessment of specific critical infrastructure within a designated geographic area, and we also do a regional analysis of the surrounding infrastructure supporting that region. These studies are designed to address a range of hazards that could have regional as well as national significant consequences.

There have been a total of 56 of these studies have been completed from the years from 2009 to 2015, and they addressed multiple infrastructure, but also with a heavy emphasis on energy. These look at information associated from weather event like drought, extreme precipitation, and other things that are not weather related, like earthquakes, tsunamis and others. And we'll be highlighting those and showing how these types of programs allow us to integrate multiple infrastructure assessment.

So that we have a better understanding of the loss of telecommunications—how would that impact, say, the electric sector, and what measures could be taken to be able to strengthen both infrastructures so that they would not coincidental lose their services at the same time. Next slide, please.

One very interesting study that we've been involved with examined the resilience of the United States Pacific Northwest region to what is called the Cascadia subduction zone event. What that is, is that's an offshore earthquake of around 9.0 magnitude which has a resulting tsunami that's similar in nature to the Fukushima great Asian earthquake that was experienced by Japan. We were asked to look at the potential impacts of this type of an event, look at what would be the short term as well as the long-term impact.

The analysis results are shown on the left-hand side—are for summer conditions where a lot of energy is coming from the Canadian provinces over into the United States. This type of event would have two types of impacts. We'd have a quick area that would be affected by the shaking as well as liquefaction which would topple transmission towers, lead to outages as such. Then the loss of those individual electric assets would result in a cascading impact and a wide area blackout affecting multiple states and provinces in both the United States and Canada.

We looked at what would be the—Given the availability of spare parts, as well as the magnitude of damage, and we used our tools to be able to try to determine that the projected blackout would last from weeks to months, depending on the individual areas within the affected zone. This information is being actually used right now to determine staging areas to help expedite restoration of the electric sector, with these staging areas being located in regions that we could be assured that would have electric power until—

This type of information allows us to be able to prepare in the event that this type of an earthquake would occur, and give us an idea how to plan for it, and what would be the best way of being able to help minimize human and health impacts, as well as restore and repair critical infrastructure in the shortest amount of time. In other words, basic reasoning for resilience. Next slide, please.

Now, Guenter has talked about the data that's actually collected in terms of climate change. As such, climate change is often used to describe the changing nature of weather characteristics over time. The effect of climate change on the electric sector was investigated in a resilience study that was performed for the state of Maine. Now, the state of Maine is one of the regions of the United States which is seeing increased temperatures very rapidly within the last few years, and so they were asking us to look into how that would actually impact their overall energy demand, as well as what would be the impact on the daily temperature and storm surge.

That information is shown on the left-hand side. We took the downscaled climate data that was developed using Argonne's Mira supercomputer to identify impacts on the electric sector such as the growth of electric demand due to higher temperatures; the reduction in the transfer powers' capability of transmission line; as well as individual electric assets like generators and substations that could be at risk from storm surge. The analysis was used to be able to identify those substations and power plants at risk from enhanced storm surge, and the overall outcome was to identify possible methods to mitigate against these projected effects. Next slide, please.

Now that that was done for one state within the United States, we were asked to perform an additional climate change analysis for an entire region, which was FEMA Region I. FEMA Region I includes in the upper northern part of it

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the state of Maine, so we were able to leverage the information that we determined about the resilience characteristics of Maine; use that to collect greater information about the electric infrastructure throughout this region of the country which is called New England; and account for an effect that they're very worried about, which is major risk of future climate change due to sea level rise. This information was derived from the IPP studies to determine what areas would potentially become flood plains and what would be the potential impacts to electric substations.

The figure on the bottom right-hand side actually shows a real-life event that just occurred in the state of Maine in the Bath region, where the electric and other lifeline utility facilities were affected by flooding caused by extreme precipitation that they had not seen for many, many years. As such, resilience measures such as flood protection barriers were utilized to minimize the flooding impacts and to be able to keep electric service on for customers that otherwise would be adversely affected.

Now, the next line talks about a study looking from the other end of the spectrum, meaning drought. We do expect that climate change can lead to climatic changes in the prevalence and the widespread nature of droughts. There was a recent drought in the state of Texas in 2012, which highlighted the dependence of the electric sector on water availability. The two figures on the right show how the low water availability occurred in the year 2012, compared to 2011.

Now, the State of Texas was interested in the potential impact of future climate change on their water sector and actually how that would impact power generation. And so downscaled climate data was coupled with an estimated temperatures of the water based, on the increasing local average temperature, to determine potential reduction or even curtailment of power generators within the affected region. This information is now being coupled with long-term transmission planning to site future electric facilities near areas that we can expect would have available water resources, and not those that we know that would be at risk from drought conditions. Next slide, please.

The last slide I'll be talking about is work that we're doing for the Federal Energy Management Administration to look at power outages that extend for extended periods of time, over one month. We are looking at the resilience of the U.S. electric distribution and transmission sectors to two extreme scenarios. Now, one is a cyber event that actually affects electric generation, and the second is a one in one thousand-year winter storm affecting multiple states within the mid-part of the United States.

The figure at the bottom shows what storm that we're actually using as our anchor facility which occurred in 1949, and you can see that this one had major impacts on the electric sector at that time. But people at that point were much more resilient, I believe, than we are right now. And so what we're doing is we're using that information to be able to estimate the restoration time on the distribution end of it from this type of storm which would then be used to elicit from stakeholders what resilience measures they would have in a series of workshops within the affected states.

Okay, Guenter?

Guenter Conzelmann Yeah, so I'll be taking over for the rest. So it's just a few more slides, a few more examples, and then we'll wrap it up, and we'll be happy to take questions.

One of the last U. S. applications that we wanted to present is the work that's ongoing, that's a very operational sort of angle, and here we're working with the people who are basically managing and operating the transmission grid in a large portion of the United States. So we have multiple large organizations that are sort of in charge of managing our transmission system, and we call those independent system operators. This happens to be the mid-continent independent system operator, and you see the geographical extent of this region on the map on the right side.

In general, they have like three regions: the north region which is green, the central region is sort of purplish, and then the southern region is sort of like this orange here. From a geographical scope, they are the largest grid operator in the U.S., and second largest in terms of capacity. But in terms of geographical scope, the largest part.

So they have to deal with all kinds of events within their territory, because they're stretching all the way from the southern parts of the United States that touch on the Gulf of Mexico, with regular exposure to hurricanes, tropical storms, all the way to the northern region, where you have to deal with winter blizzards, and stretching through the central United States, where we actually have to be worried about earthquakes as well. We have a major fault line running through the central United States, so earthquake concerns are there as well. So they have to deal with a range of those.

After the large power blackout in the United States back in 2003, where 50 million people lost their power, they've instituted a drill where they conduct two drills every year. One drill in the spring, that essentially goes through things that they can do to prepare themselves. So that's sort of like up front, before the events happen. And then one drill that simulates, that prepares them in terms of saying, "What could I do after something happens?" So their response with trouble and to restoration.

We've been working with them, supporting them for the last several drills, and so the maps that you see on the top are examples of simulations and results that we've provided as inputs to their drills, where they have dozens and dozens and dozens of operators participating for a full day, in terms of getting ready for what if a hurricane hits the southern region of their footprint; what they should be doing; how they should react; what kind of information has to be exchanged; what can they do to mitigate the impact of this coming threat. We developed a timeline of this hurricane moving forward and estimating the impacts at different time steps, not just on the electricity system but on other infrastructures, including telecommunications. Because as Steve pointed out earlier, being able to talk to different people during an emergency is important.

And what we have seen over the last 10, 15 years during major disruptions is that often telecommunications get disrupted, and so this hampers the preparedness as well as the restoration process. So we've also had models that allow us to estimate what is the impact on the telecommunications infrastructure and how would that impact the service territory and the availability of phone and wireless services. So that's what you see in the central map.

In fact, tomorrow morning we have a phone call with them to get ready for the fall drill that we'll be running in October. And there they want to look at this interdependency between natural gas, electricity and telecommunications. What if some major event happened on the electricity side? How would that impact the natural gas infrastructure, the natural gas supplies—and a lot of my power plants that I rely on, when I restart the system—if they're mostly natural gas, and now all of a sudden the natural gas fuel is not available.

So those issues they want to simulate during the upcoming October fall drill. We are actually helping them to develop the scenario, and we will work with them to develop the model simulation that will then seed their drill simulator. And that is a very exciting project, because we're working typically with dozens and dozens of operators, but we've also trained them in a government-approved, certified training course that we've developed on electricity-natural gas interdependency, and we've trained [brief phone cutout] ____ operators. Those are the people that actually run the grid.

So this is really hands-on, because in the end, who is responsible for bouncing back? Remember the definition of resilience? It is those folks. Those are the people who will try to bounce back. So they are the ones with their hands on the buttons, and they need to know what to do to make sure that the power doesn't go out, or comes back very quickly. So this is sort of a very exciting project for us.

We've shown you a lot of model applications and types of resilience studies for the United States. We don't have really resilience studies and applications in Asia; however, we do have a number of our tools being used across Asia, not necessarily for resilience studies but more for the operational reliability kinds of studies. You remember earlier I sort of said you take the data, you sort of design a resilience system, but you still want to make sure, once you have that resilience system—you also still wanna make sure that that's a reliable system on a day-to-day basis on days when no major event happens. And also you want to make sure it's economically and officially ____.

So those are the kinds of tools that we have users across the Asian region. This here shows one slide to kind of give you an example of an application in the Philippines as well as in South Korea, and a whole list of countries that use some of these operational grid tools to look at feasibility studies, or market studies, or range of reliability studies. Here there's another slide with a couple of more examples, like with India and the Indian region with neighboring countries, and a list of different customers of our tools in Japan and Korea.

Typically what we do ____—we make models available, and we also provide training. Over the years, we've trained over 2000 modelers, analysts, policy analysts, electricity analysts, 90-plus countries in a range of different tools. These workshops are usually conducted here in the Chicago area on our campus, or we've done a whole bunch of training courses around the world, including Asia. So training programs can be highly customized as desired. We've traveled to many countries to help people implement the tools and use the data that they have.

So with this, we are at the end of the presentation. This is our contact information. If you want to contact us after this webinar, feel free to give us a call at these numbers, or send us an email at these email addresses, and I think they'll be available on Sean's website as well. At this point, thank you for your attention. Thank you for staying with us for an hour. I know everyone's busy, so we appreciate the opportunity to talk to you for an hour about this topic and our capabilities with some of the applications of our tools and data sets. And I'll turn it over to Sean now at this point.

Sean Esterly Great. Thank you so much, Guenter and Steve, for the presentation, and we will move right in now to the question and answer session. I just want to remind all of our attendees, if you have any questions for the panelists, you can submit those now into the question pane, and we will present those to them.

So just to start us off here, a couple questions. How would someone engage with the resilience analysts?

Guenter Conzelmann One way to do this—I mean, obviously you can get in touch directly with us at these contact information, like phone or email. You can engage to us through bilateral agreement. We have been asked to sort of engage with the APEC working group on resilient energy infrastructures. So I think that is an avenue to engage in the future. But in general, often we have done bilateral agreements, so if you have an interest in working with us, you can contact us, and we can work with you to sort of find a mechanism to make this work, to make the tools available as well as the data available.

Sean Esterly Thank you.

Steve Is that everything you needed?

Sean Esterly And you did touch a little bit on the next question, which was, "How might resilience tools be made available to someone looking to access those?"

Guenter Conzelmann Yeah, so the tools are not directly on a website for download. The data is. I mean, the climate data that I mentioned. So that is on a publicly available website. So is the data guide, of how to use the data. But the tools typically are not just a click and download kind of thing. So we would recommend you get in touch with us, and then many of these tools, you just sign a form, and we can make those available to you.

Typically what we do is, when we engage with someone since that is a new tool to the user, our preference is that when people get our tools, there is some kind of engagement involved in this, in terms of training to make sure you really fully understand how to use the model so that you get the most of the tool. So it's not a direct download, but once you contact us, you explain to us what you want, we can make many of our tools available directly.

Sean Esterly That's great. And it's also great that you build in some training with that. So if anyone wants access to those tools, you can reach out also through the emails on display right now on the slides.

So, moving on. Next question from an audience member. They're asking, "What is the rate of response that's needed in order for it to be considered resilient? Does the transition have to be prompt?" And what I think they're referring to is the response time after, let's say, some sort of natural disaster, for the system to bounce back. Is there a time frame needed for it to be considered resilient?

Guenter Conzelmann That's a very good question. Well, that actually touches on one of the core challenges that we still face in the resilience side. Y'know, how do we measure actually how resilient we are? So if you think about it in other aspects—For many years we've been worried about reliability, so that's usually when something happens to go wrong, right? I mean, so how reliable is our system? And so over a period of many years we've sort of developed ways to measure that. So that I can compare the reliability of my system with the reliability of your system, and we can sorta not just compare across utilities, but we can also sort of see if there's trend lines. So I can sorta say, "Am I becoming more reliable over time, or less reliable." And that is of course something that's of concern that we want to track.

Similarly, for other aspects, in terms of sustainability, we measure all kinds of things. We measure carbon emissions, and we can compare carbon emissions per kilowatt-hour, or per capita, or total carbon emission, to sort of compare different systems. And we can track carbon emissions over time to see are we moving in the right direction or not.

We have metrics for all these different things. And we have metrics for a range of other things that we're concerned about. Resilience is sort of like a newer concern, right? So it's only in the last, I don't know, five to ten years or so, we've sort of become aware of this issue and have started working, developing models.

But we really don't have an agreed upon way of measuring—How do we measure? How do I track resilience? How can I really make that statement? How resilient am I compared to you, and am I on the right track? Am I making my system more resilient? And what is a desirable level of resilience? What should I expect. How many hours to bounce back, or days to bounce back.

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We don't really have an agreed upon method and approach to doing that, and so, interestingly, the Department of Energy over the last year and a half started a very large initiative on grid modernization. And one of the key foundational activities that the department is funding multiple laboratories to work on is metrics. Developing metrics, so that we can track are we on the right path to modernize our system. So they've designed it to look at six metrics in six different areas, and one of those areas is resilience. So that is one of the research focus areas over the next year, or two, or three, to really come up with a consensus approach and method to measure metrics. So that we can eventually say that, right?

So what should you expect? And how does your expectation measure up to what you actually see in simulations like this. So that we can say, "All right, so how resilient should we actually design our system?" That's a very good question that really touches on one of the core challenges that we have in the resilience phase, is that we don't really have yet those metrics that everybody agrees on.

So stay tuned for that. Hopefully the research team that has people from six or seven laboratories contributing to it—hopefully they can come up with a consensus view that's being bought into by people that run the system, the operators, the industry, as well as people who oversee the operations, meaning the regulators in the government agencies. So there is much work to be done, to be actually able to give a really good answer to that question. But a very good question indeed.

Sean Esterly Great. Thank you, Guenter. Next question from the audience is, "Do you have any results or recommendations that you can share from the interdependencies analysis that you've completed?

Guenter Conzelmann Steve, so you wanna answer that one?

Stephen Folga Well, the results are showing that we're becoming highly more interdependent—such as right now everybody is using telecommunications to be able to connect to each other. And the energy infrastructure is no different than any of the other industries within the world, where telecommunications is becoming a key way of being able to monitor, control, and operate the energy infrastructures.

[Phone noise]_____ What services are they being supported by? So if you're an electric company, who is your telecommunications provider? Where do you get your water from? Do you have critical materials that you need? And what about fuel, such as natural gas? So on the interdependency side, it's better to be able to know who are your suppliers, have contact information, be able to do exercises and drills, looking at the concurrent loss of different sectors and how you would all coordinate together. And do it prior to some type of event coming that may happen in the future which would then tax your system, and you would be unable at that point to be able to know who to turn to. So that's one interdependency aspect that we're seeing.

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Another is, at least within the United States, on the energy side, is the increasing impact of natural gas as a fuel of choice in response to reduction in the amount of coal use within this country. And so we're seeing interdependency aspects of the contractual arrangements of natural gas for electric power plants which are causing them to actually lose and have curtailed supply of natural gas when they need it the most.

So these interdependency issues should be addressed by both the electric and natural gas industry to assure a continued supply of natural gas. Also, if you lose electric power, that also has adverse impacts on natural gas production, as well as cleaning of raw natural gas to produce a pipeline-quality product that is provided to ultimate consumers like you and me.

Guenter, do you have anything to add to that?

Guenter Conzelmann Yeah, if I may. I just [phone noise] ____ add a little bit to this. So in our recent engagement with that large regional grid operator, the mid-continent independent system operators—So in our training exercises last year, that was at the forefront, because we used a simulation of a gas supply disruption to see what might be the impact on the power system side, on the grid side.

Part of what came out was that they wanted to have actually their focus there at their fall drill this year on this particular subject. And so a few things that sort of came up was, "Well, okay. If I have a major blackout, all right? Once the blackout is fully out there, then how do you bring back the power system? How do you restart?" Okay?

So you usually restart the system with what's called black Start generators. Those are power plants that can start up without the grid actually up and running. There's a few of those out there. Every utility has a number of those. Could be as little as one or two. Depending on the size of the system, could be more. But those are very special units, okay? Traditionally the types of power plants that can do that are either diesel generators—but we don't use a lot of diesel generators in the U.S. anymore; hydros—but hydropower stations are not available in some parts of the region. We have some regions that are very rich in hydro, but a lot of the regions of course where we don't have hydro. And so in the Midwest, the black start generators are generally that are using natural gas.

So one concern that they wanted to specifically focus on, because it was sort of discovered last year in our training exercise and our discussion with them, is: "Well, if I have a major event that impacts my natural gas supply system, I better make sure in my restoration planning that the black start unit that I will rely on to restart the system, that they can get fuel." If they can't get fuel, then you have trouble. Because then those black start units that you need to crank up everything else, may not run. And so this is going to be one of the focus areas in this fall drill, and that's the first time that they're actually looking at that.

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Another thing that we sort of learned from some of these engagements, and the conclusion that was there, is that in that process, too, you use gas generators to do the initial startup. But then you usually send the power over what's called a cranking path, a transmission path, to particular other power plants to start them up. It's almost like when the battery in your car is dead and you have to rely on another car right next to you to connect wires to the two batteries and jumpstart your car. So this is essentially what we're doing when we're trying to restore the power from a blackout.

So now, if I want to restore a coal plant, that coal plant to start up actually may use natural gas to heat up, to initially warm up. They can't just use coal for that initial warm-up. So again, if they don't have gas, then they're down, too, and we cannot crank them up.

So these concerns are now coming to the forefront, and we're discovering them by having these in-depth simulations with the operators. And all of a sudden, somebody says, "Well, but what about this? We didn't think about that." Okay. All right, well, then let's see if we can simulate this, and see is there really a risk to that? Is this just something that we think could be a problem, or can this be a problem? Can the models tell us if there's really a quantifiable risk? If the answer is yes, then we have to prepare ourselves and mitigate against that, and institute some contingency plan for that.

These are all insights that you sort of discover once you go through these modeling exercises.

Back to you, Sean.

Sean Esterly

Great. Thank you both. We are running out of time, so we're going to go ahead and wrap up the webinar. Before we do that, we do have a quick survey for our attendees, and so I will display that first question on the screen, and I would kindly ask that our attendees respond to the poll.

Great. And the second question.

And the third.

And then we just have a couple of yes-or-no questions for you.

And the final question.

Great. Thank you so much for participating in the survey. We really do appreciate it, and we use your feedback to help improve our future webinars.

I would like to once again just thank our panelists for participating and giving those excellent presentations today. And also our audience—thank you very much. We do appreciate everyone's time and thank you for coming out and attending our webinar.

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I'd like to mention that we will be posting the audio recording of the webinar to the Solutions Center page, the Training page, within about a week of today's broadcast. The PDF version of the slides are currently up there, so you can go out to download those if you'd like. Additionally, we are now posting recordings to the Clean Energy Solutions Center YouTube page. That link is also up on the slide right now. If you go out to the Clean Energy Solutions Center page, you can get access to all of these different resources as well.

Additionally, I just want to remind everyone about the Solutions Center Ask An Expert, technical assistance, which is free to requesters. And I would encourage everyone to spread the word about these resources and services to those in your networks and organizations.

So with that, I would like to conclude the webinar, and wish everyone a great rest of your day or evening.

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