Maximizing Clean Energy Integration: The Role of Nuclear and Renewable Technologies in Integrated Energy Systems

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Shannon has held multiple leadership roles in DOE Office of Nuclear Energy Programs since joining INL in 2010, ranging from space nuclear power and propulsion systems to advance nuclear fuel development to her current work in integrated system design and demonstration. She currently serves as the National Technical Director for the DOE-NE IES program within Crosscutting Technologies Development. Integrated Energy System designs seek to coordinate the use of multiple clean energy generation sources. For example, nuclear and renewable, to meet both thermal and electrical energy needs. Shannon holds a Ph.D. and MS in Nuclear Engineering from the University of Michigan and a Master’s in medical physics from the University of Texas at Houston and a Bachelor in Nuclear Engineering from Texas A&M University.

Thank you again Shannon for volunteering to give this webinar and without any delay I am handing you the floor. Thank you Shannon.

Shannon Bragg-Sitton
Thank you so much Patricia for that introduction and for this opportunity to address the Gen IV International Forum Community. I'll say good morning and good afternoon to all of you. I know we have participants from around the world. I welcome you today.

Let's go ahead and get started. When I think about how we need to design our future energy systems or even to better utilize our current energy systems, we need to stop and take a step back first to address what goals we are trying to achieve. In general, we can agree that we'd like to have clean energy systems, non-emitting systems. We also need them to be reliable and resilient while maintaining affordability and hopefully achieving sustainability.

Next, we need to ask the question as to what our energy needs are. How are we going to use that energy that is generated? Do we simply need to supply electricity to meet grid demand or do we also have energy needs such as thermal energy to drive chemical processes or industrial facilities or even to purify water? Only then can we begin to address what role or roles each energy source might fill within a particular application. That will, of course, depend on our resources available in that location as well.

The global reality is that we have a challenge in front of us. In most developing nations, we aren't seeing dramatic increases in energy demand. In fact we see a lot of energy efficiencies that are maintaining relatively stable demand. But there are many regions around the world that don't have access to energy today, don't have access to clean water that requires energy. In fact, the projected increase in the world energy use is 28% by the year 2040 as predicted by the US Energy Information Administration.

If we don't make a change, if we continue to emit greenhouse gases at their current rates, the projected increase in atmospheric temperatures is 2.7 degrees by that same year, and that's by work done by the Intergovernmental Panel on Climate Change. This is a challenge that we need to address and we need to begin addressing it now.

If we look around the web and we look at many different articles and announcements coming out, we can find numerous examples. I have examples of attempts to address these challenges. I've only included a few here related to introduction of federal clean electricity tax credits and utilities moving toward 100% clean electricity or clean energy in different use sectors. We are even beginning to see nuclear plant owners and operators begin to look beyond the electric sector to address what else their energy can be used for.

I'd like to draw your attention to this article that was put out last December by the non-government organization Third Way. Now this article and several of my slides will focus on the US, energy markets in the US sectors. Many of these trends I believe will translate to your countries as well, so please take these as just examples. I encourage you to take a look at what's happening in each of your countries and regions as well. This article by Third Way began to look at clean energy commitments around the country to assess how we are going to achieve these incredible challenges associated with emissions and environmental impact. Prior to 2016, 90% of the commitments out there were exclusive to renewable energy. We saw renewable portfolio standards goals for 50% or even 80% or 100% renewable generation.

However, since 2016, we've seen a reversal in what those commitments have been with 65% of the state's utilities and major cities that have these types of goals and standards now embracing commitments that are technology inclusive. These clean energy standards now allow us to take advantage of all clean energy generators, including nuclear energy, carbon capture and sequestration, as well as other carbon-free options. We see a dramatic increase in the numbers of these commitments. This is exciting and this is an opportunity for us to really understand what we can do to impact this change.

Just a little bit of a deeper example. These are just some of the US utilities that have made these types of commitments to reduce emissions. If we look down that list, we see a majority of them focus on CO2 reduction or net zero CO2 or carbon free resources. We still see a few that are focused solely on renewable energy but the vast majority are looking at technology inclusive opportunities to achieve these really aggressive goals.

So, another way to do this, of course, is by increasing renewable generation. Introduction of wind, and solar and hydro, where it is available is a great idea. We really have to look at all the technologies available to us in a particular region to meet these aggressive goals. But let's pause for a moment and understand what that means. All of you know that wind and solar energy are not available 24 hours a day 7 days a week. They are variable. If we look on the left, this is an example of a region that has a lot of wind and the impact on the overall net load.

Let's walk through this a little bit. The red curve on the lower portion of this plot is the wind generation over a two-week period. So you see the variability and it's fairly random from what we can see. It doesn't match day-night cycles. So there's a great amount of uncertainty associated with generation from that wind resource. If we look at the blue curve on the top, that's the overall load or the demand in that particular region. The green curve in the middle is now the net load or the net demand that must be met by other generators on the grid or by utilization of stored energy. A few things we can take away from that is that now the difference, that ramp range between the peak and the valley is dramatically increased relative to what the overall load was. We have to have other generators that can meet that ramp range and we see that ramp rate much more significant than in the overall total load.

Other generators on the grid have a pretty big challenge in matching this remaining demand once wind has supplied some of that electricity. On the right you see a representation of what a solar dominated region might look like where the yellow curve in the center represents solar power generation where it's peaked in the middle of the day as you might expect. However, that peak generation doesn't match the peaks and demand that occur in the morning hours as everyone's getting ready for work, and in the evening hours as everyone is coming home.

Hence we need to either utilize things like energy storage to shift excess generation to evening hours, or we need to utilize thermal power plants in a load-following mode or curtail thermal power plants in the middle of the day unless we can use that energy in other applications. That's what we'll be talking about today.

Please understand that we need renewables. We need wind. We need solar but we need those in parallel with other generators in order to balance this variable generation.

We did some analyses at INL, at Idaho National Lab, which is the nation's nuclear laboratory in the US. We did some analysis to better understand the volatility within the net demand and how that changes as we increase the penetration or the production from variable generation in a particular region. What I am showing here is synthetic time history. These are statistically equivalent to wind generation in a particular region. And we use this to compute the sigma, the changes in the net demand as that generation of wind, that fraction of contribution from wind was increased. Now this only looks at one wind source so we don't see the spatial de-correlation of multiple sources in a region, but we really wanted to understand the volatility associated with introducing these resources.

So the bottom curve, the blue curve here represents the demand. As we add more and more wind you can see the dramatic increase in that sigma, in that variation in the net demand that we now need to meet. This introduces those challenges we were seeing in the previous slide on how we began to maintain a stable grid as we have more and more variable sources. A little bit of wind doesn't make a huge difference. A lot of wind does. So we have to think about this differently.

When we look at what types of energy systems we might consider, we also have to consider the resource potential in a particular region. On the left you see a representation of wind energy where we have different classes of wind, different amounts of wind in different regions. We have a lot of wind in the coastal regions around the US and in the Midwest region of the US as well, in the middle of the country. We wouldn't want to look at large amounts of wind generation in many of these regions, in the east for example because it's simply not highly available. If we look on the right, we see something similar for the solar energy potential, where it's quite significant in the southwest region that gets sun year round and has a lot of sun, but not so much in the Northeast. We want to utilize the right resource in the right location.

On the bottom you see an example of reactor siting options. Now this plot is a little bit old, but it represents a good understanding as to how we might overlay the availability of these resources. Now in this plot we see large reactor options and where we might site those large reactors in dark green. In light green we see the dramatic increase in what we might do with small reactors and where we might locate those, recognizing that they have a smaller footprint and smaller amounts of water need. So using this as an example, we can begin to understand that we will have different energy mixes and different opportunities in each region.

Each of these analyses and these considerations that we were considering different types of energy systems need to take this into account for particular regional locations.

What is the future of nuclear energy? Where are we going? How will it play a role in these future energy mixes? I'd like to draw your attention to the future of nuclear energy study that was completed in 2018 by the Massachusetts Institute of Technology and many experts that they brought in to work with them. I've just summarized a couple of the key findings from this report. Bottom line, the world faces new challenges of drastically reducing the emissions of greenhouse gases while simultaneously expanding energy access and economic opportunities to billions of people. Those regions that don't have access to energy right now and certainly don't have access to clean energy.

Second, there are a variety of low or zero carbon technologies that can be used in a variety of combinations in order to meet this growing demand. Absolutely, there are a number of solutions that we can look at. But their studies showed that without contributions included from nuclear energy, the cost associated with achieving deep decarbonization targets, dramatic reduction in CO2 emissions, the cost of those solutions increases significantly.

Overall, the least cost portfolios always include an important share for nuclear energy and the magnitude of that share grows significantly as we bring the cost of nuclear down. So we need to reduce cost of nuclear to ensure that it continues to play a very important role in these future energy systems.

Similarly, the International Energy Agency developed a nuclear power and a clean energy system report last May, in May of 2019. What they found and one of the key points that I like to pull out of this one is that despite significant renewable energy growth globally over the last 20 years, the overall contribution of clean energy supply to electric generation really didn't change. Why is that? Well, in the US and in many other parts of the world, we have extremely low-cost natural gas, historically low-cost natural gas. As that comes in, it is displacing nuclear generation so we have more renewable generators coming on, low-cost natural gas coming in, and pushing nuclear energy out of that marketplace. Natural gas turbines are scalable. They allow for rapid ramping and therefore they are great complements to wind and solar generation, but they have associated CO2 emissions unless carbon capture is also implemented.

We need to think about how we do this. We need to be cost-competitive to these other resources to ensure that nuclear generation is not pushed out of the market and that it continues to provide such important shares of clean energy generation. Globally, nuclear provides one-third of the clean electricity generation around the world. In the US, it's more than half of our non-emitting electricity. So, it's important that we don't push this out of the market inadvertently.

Often when we think about how we can achieve these emissions reductions we traditionally think about the electric sector. Now in the US, the electric sector contributes 38% of the emissions that we see in our country. But that's not all we need to be concerned about, particularly if we are looking for these aggressive goals that that reduce emissions overall. We need to then also look to the 34% of emissions from transportation as well as 18% that come from industrial processes. Those industrial processes are often very difficult to electrify and very difficult to support with something other than a carbon-based resource that provides high quality heat. So that's what we really need to address is those top three emitters: electricity, transportation, and industry as we look to alternative energy resources and alternative configurations in the future.

At this point, I'd like to take a little bit of a diversion to talk about planning tools that are used for future energy resources and talk a little bit about energy market modeling. Now, I am no expert in this area and I would have to defer many questions about these modeling tools to my colleagues that work with these quite a bit, but I've been learning a lot on how these tools model our markets and how they model the different technologies. It is extremely important in understanding how we plan for our long-term energy mix and how we utilize these systems on a day-to-day, week-to-week basis. Let's talk a little bit about those and understand how they impact the decisions that we make.

First, Capacity Expansion Models. These are models that are used to model evolution of systems of electricity generation assets. These are used over long range time periods. These models consider changes in the demand for energy. They also consider retirements of different units as well as completion of construction projects to build new generation capacity in order to determine if at some future time, we will need additional capacity to meet demand. If new capacity is needed, these tools will determine the lowest cost capacity additions necessary to meet projected demand, including a factor for reserve energy as well. They also take into consideration how long it takes to build these new technologies, these new systems. Some models include other parts of the economy to determine demand, but in general these focus on the electricity sector.

Production Cost Models work over a much shorter timeframe. They model the current year in much greater detail than we can with the CEM. They are used to predict which existing facilities in a particular year will be operated in order to meet the demand. The selection of those facilities will be based primarily on the lowest short-run operating cost and they will be constrained by what those systems can actually do. They will be constrained by physical limitations within the grid, constrained by dispatchability, are they available all the time or are they only available some of the time, as well as considerations for startup time and ramp rates and the operating history of those systems. The outputs from these models include things like electricity cost, revenues to the individual plants, reserve margins, and a few other things as well.

Let's talk a little bit about the time scales that they operate over. When we think about planning for our energy systems, we need to understand a wide range of time scales. On the left, you see that we are working down to the 10 to the minus 3 or millisecond time scale. All the way over on the right we're at the 10 to the 9 second time scale, 30 years. We need to understand how the different assets will be utilized across all of these time scales. On the right you see those capacity expansion models. That's that long-range planning. Those are informed by a number of approximations. In the middle you see production cost models that look at the near-term or near markets such as the hour-ahead dispatching and day-ahead scheduling of our different resources. Again, those are informed by a number of approximation from the lower end of the time scale where we have assets providing frequency regulation and inertial response to ensure that we have a reliable and resilient grid. Changes in our portfolio mix as we add variable renewables or batteries or we remove some of our large-scale thermal generators and various technology assumptions associated with modification of those systems such as the introduction of integrated systems or extension of plant lifetimes. These changes are outdating the current models that we utilize for PCMs and CEMs.

We need to understand what that's doing to our predictions. A little bit further on capacity expansion models. As I said, these cover large regions. For the US, that means they cover the whole US or they cover large US regions. They take into account a number of different initial conditions. What the current portfolio is, the cost projections associated with many different technologies, the cost projections for feedstock, the raw materials that need to go into those certain processes such as natural gas or coal or uranium. The predicted portfolio mix over the long term is highly sensitive to how we set those initial conditions; this sensitivity creating non-linear feedback associated with all these externalities that we just don't model.

As we said, the time horizon associated with these is 30 years or more, so these are designed for a long-term economic equilibrium. These CEMs can take into consideration different policies. How will those different policies modify cost projections such that it will modify the end portfolio that is predicted? We have investors feeding some of that as well. Utilities use these tools to develop an integrated resource plan. We need to understand all those different variables going into the system to understand their output. Their outputs overall look at projected portfolio compositions. They look at increases or predicted increases and decreases in the cost of electricity. They can predict CO2 emissions at a given time in the future.

As we were referring to, they look at 'what-if' scenarios with respect to new energy policies. If there's a consideration to introduce a new energy policy, we can put that into these CEMs as an externality to understand the potential impact of both current laws and potential new policies that can strain the portfolio composition. We can also consider impact of technology maturation.

What happens if technology costs drop dramatically? What happens if the capabilities of those technologies increase dramatically? We can also look at the impact on resources, changes in feedstock. For example, no one predicted the historic low cost of natural gas that we have today that was introduced by fracking. We can look at 'what-if' scenarios that consider well what if natural gas were half the cost that it is today, how would that change how we build out our systems or what if new reactors cost half of what we expect them to cost? How will that impact our overall mix?

It's important to understand how these results are used. These results are used by federal organizations in order to inform policymakers, decisionmakers concerning how achievable some of the goals they set might be and how costly achieving those goals might be. Goals that might be looked at include CO2 emission limits, energy independence, portfolio diversification or grid reliability. These results are used by research organizations such as the Department of Energy in the US in order to prioritize the research budgets, in order to meet certain technology development goals or deployment goals. They are also used by large companies to prioritize research and capital investments. They are used as input to energy planning to develop those integrated resource plans, for example.

They are also used by international organizations and developing nations that want to consider different scenarios as they plan for development. As you might expect, these scenario studies have a strong feedback mechanism. If we look at certain scenarios that look pretty good 30 years in the future, investments will be made in the technologies associated with those scenarios and investments may not be made in other technologies such that we in a way make our own future by trusting some of these predictions overtly.

So, we need to understand the predictions and any associated biases in these predictions to ensure that we don't write our own future in a way that is overly constrained.

Production Cost Models. Let's talk a little bit more about those. As I said, these are shorter time horizons. These look at one-year horizons. These cover large regions with different levels of fidelity. They have a higher level of fidelity and time fidelity associated with them than the capacity expansion models. They are independent from deregulated or regulated market assumptions. Again, they have a lot of initial conditions coming into them. Looking at the current portfolios, they include estimates for variable costs as well as the grid topology. These are used to understand, remember, how we might commit certain assets on the grid from one point in time to the next.

How are they used? These models are used to test various dispatch strategies. They can also help us predict potential grid congestion problems. When we are going to have too many assets in one region, trying to meet net demand, further down the grid architecture, then where that generation is. They can also be used to predict unit revenues. Revenues associated with certain plants. They can be used to estimate whether or not we have sufficient reserves being produced at a given time. Just as an example, and I'll talk about this excellent case as we get further down this presentation.

We utilize Capacity Expansion Models such as the ReEDS tool developed by our colleagues at the National Renewable Energy Lab to look at portfolio evolution from today out to say 2042. For any given year, we then use an associated production cost model such as PLEXOS to predict how those assets will be utilized. Now, here in the work that we've been doing, we have now added an additional tool, and we'll talk about what RAVEN and HERON are, to assess what the optimal design for a future energy system might be to produce the maximum net present value for that system. We're using these optimization tools that we have developed within the laboratory to now design those systems and feed those back into this process. There is room for improvement with regard to how these models approach nuclear energy technologies and the assumptions that are made. There are limitations in the nuclear technology that is represented within these models. There are limitations in the plant sizes that are considered. They are limited in how long these systems operate and sometimes do not have license extension opportunities within them.

Many of them don't allow for economic dispatch or load following of different units, instead treating nuclear as a base load supply. They also are limited in what they can do with regard to progressive capacity addition. Many of the small modular reactors being developed would be multi-modular plants where we can build capacity, add capacity to those plants as it is needed by a particular community. That's not well represented in these models, nor are power upgrades which we've been implementing in current fleet plants for some time.

There are many market limitations that can also impact nuclear differently than some of the other assets being considered. With regard to global system costs, there are some considerations with regard to waste management environmental impact, including topics around spent fuel management or environmental management such as decommissioning and CO2 emissions.

Now let me take a moment to talk about how nuclear is different here. Now, our nuclear assets, we essentially pay for the decommissioning costs. We include that into the cost of operating that plant. This is a requirement of the Nuclear Regulatory Commission. This is something we do in the United States, but not all assets do. We have to begin considering lifecycle costs of all of our assets that we might consider for future generation in order to do true cost comparison between option one or option two etcetera. For instance, when we think about building different technologies, we need to think about the resources upstream. What does it take to build those? Where are those resources coming from? Is that a sustainable process? Is that a domestic supply or is that a foreign supply? How will that supply impact the ultimate potential for that system? On the back end, what will it cost to decommission that plant? Is that being rolled into the overall cost estimation when we are choosing lowest cost technologies?

Again looking for areas of improvement, going back to this time scale plot, we need to begin thinking about tools that allow for multi-scale approximation, not just looking within one time scale or another but these multi-scale approximations are really important to include in order to equal out that competition among generators to make it a fair competition. We need to begin to capture the cost and benefit of changes in the portfolio at all of these scales. Understanding how selection of a certain asset 30 years in the future will impact the inertial response or the frequency regulation within the grid at that future time is extremely important, yet extremely difficult to capture in a single tool. These multi-scale approximations really do matter directly to nuclear energy that do provide inertia to the grid at that low timescale that operate for extremely long periods of time. Additional aspects of these systems that can be brought in when we begin to introduce flexible load following operation or hybrid integrated system opportunities where we are producing and utilizing not just electricity, but also thermal energy. So understanding how these different considerations can impact across this wide timescale range, is really important to understanding the impact on our future systems and our predictions.

There are also areas of improvement for Production Cost Models. Again, PCMs contain multiple time scale approximations, but they are not used to cover for more than one year due to computational limitations. There are many aspects that simply can't be treated within these PCMs. They can't include grid expansion opportunities or capacity portfolio changes fully. The ramp rates assumed in these are also linear, so they are missing some important memory effects in some of the systems. They also don't fully include uncertainty in demand or variable renewable production in most of these models. There's always areas for improvement in any models and we need to understand how those limitations impact our results.

Some key takeaways from these market modeling tools and our discussion here. We certainly can improve the modeling of the technical and the economic aspects of nuclear technologies. This does appear to be feasible. We have some work to do. Currently many of the capacity expansion models just model one nuclear option, which is a gigawatt scale light water reactor that operates as base load for 40 to 60 years. Those of you on the webinar mostly know that yes that is what we have today and that's great. Those are fantastic assets. But those opportunities are changing. We have a large number, dozens of companies that are developing advanced reactors that come in various types and sizes and operate at different temperatures. These systems allow for load following. We need to begin including those options in these capacity expansion models as well. We need to begin understanding how the various modeling assumptions can introduce unintended bias in the results. We need to understand the impacts of different assumptions in how the impacts of those assumptions on the decisions that are made. We can also improve market representation, offer many different opportunities or types of markets within these models.

We talked a little bit about total lifecycle costs. This is a pretty challenging issue to tackle. But again, it will provide a more balanced approach in evaluating competing technologies if we look at full lifecycle costs for all of the technologies. We also need to look to inclusion of risk metrics or uncertainties, as well as multi-scale approximations which can differ in their impact to different technology options.

I am really excited to say that we are embarking on a model inner comparison study within my program this year that will begin to look at the impacts of different assumptions and decisions across different capacity expansion models as well as production cost models. Now, INL is the Nuclear Energy Lab. We've not developed those tools and we don't utilize those tools regularly. We aren't going to be doing that model inner comparison. Instead our colleagues at the Electric Power Research Institute, the National Renewable Energy Laboratory, the Energy Information Administration, and the Environmental Protection Agency will be working with their own models to understand how assumptions impact results and how results differ across these different models such that we can begin to identify limitations in each of those models and improvements that may be necessary to ensure that we are looking at future energy options accurately or as accurately as we possibly can. So, we hope to have results for that in about 1-1/2 to 2 years in the completion of that study.

Okay with that let's talk a little bit more about innovative nuclear technologies that we can draw upon for our future energy systems but also approaches where we might modify how we utilize our current energy systems, our current nuclear technologies. Today, we have a fairly strong electricity-only focus. We have independent assets such as a nuclear plant or a wind generation facility or a fossil plant or solar farm that provide electricity to the grid independently. We have independent system operators that manage the grid and manage those assets on the grid.

Now we also have assets that independently provide thermal energy to industrial applications such as coal-fired or natural gas-fired units that provide heat to drive different processes. What we are working to shift to is a future grid or a future energy system that looks to maximize energy utilization, maximizing the invested capital that we have in these different generators on the grid while maintaining generator profitability and affordability to the end customer as well as grid reliability and resilience. So as we begin to consider these coordinated energy systems or tightly coupled energy systems that might be in an energy park type of configuration, we need to look at all of the assets that we have available to us including renewables and fossil with carbon capture and sequestration as well as nuclear technologies either at the large scale or at the very small scale down to microreactors.

We need to understand how both the heat and electricity produced by these assets can support the grid, but can also support coupled industrial facilities, factories, can support chemical processes and chemical plants that are producing end products for consumers, how those can support production of clean water or hydrogen, that's an alternative energy carrier that will meet a number of different needs. So we want to consider all of these pieces collectively, holistically, as we plan for these future energy systems.

Let's talk a little bit more about what these involve. What do integrated energy systems really mean? Now, the image on the right is admittedly extremely complex and that's because these integrated energy systems involve so many different integration points. They involve connections and exchange of energy via thermal and electrical integration as well as process intermediates such as chemical intermediates that might be produced. Hence, these systems are more complex than a co-generation facility or a combined heat and power facility that only used one generator to produce power and then to utilize heat to support some industrial process for example. We can exploit the economics associated with coordinated energy systems in this fashion. We can also begin to consider how integrated systems can now provide more grid services through demand response than independent generators would be able to do. Now when it comes to the nuclear system here, bottom line is we'd like our nuclear plant to run at its nominal power capacity either providing electricity to the grid or supporting the energy demands of these coupled facilities such as hydrogen generation or providing thermal energy to an electrochemical plant while also leveraging electricity from renewable generators when they are available.

So we'll dive into this a bit deeper as we walk through this as well. Now some of these solutions, these opportunities for integrated systems, could be implemented today and I will introduce a couple of demonstration projects that are moving forward based on electrical integration. However, to truly take advantage of the opportunities these systems provide, we need to also consider some technology development in the areas of new energy storage technologies where we want to consider opportunities for thermal storage and chemical storage in addition to electrical storage. We also want to look at different thermal and electrical chemical conversion processes and optimizing those processes to fit the energy supply that we have. Now, as these systems increase in complexity, you can envision a lot more data moving around in these systems to manage that real-time energy dispatch.

We need to introduce advanced informatics and decision systems that can handle these massive amounts of data and do so in a way that provides cybersecurity. We have so much more data moving around. There's more opportunity for cyber-attack if we don't design these systems properly from the start. We also need to consider embedded sensors for health monitoring and condition monitoring throughout the system to ensure that they operate in a stable fashion in this integrated system approach.

Truly, we are introducing a new paradigm for nuclear energy where we are looking at opportunities to utilize that energy in its various forms, whether that be electricity heat or even using radiation to drive some of these processes to meet consumer needs, to produce the products that we show on the right as just some examples. This might include processes such as electrification to achieve some of these end goals or process intensification and redesigning some of these processes again to better meet the energy supply that we have available within a nuclear system. It may include evolutionary direct conversion processes as well that we can implement in these integrated systems to achieve production of these consumer products on the right.

Let me introduce you to one of the programs that's working on this. I lead the DOE Office of Nuclear Energy Program on integrated energy systems which falls within the cross-cutting technology development program area. Cross-cutting means that we want to support multiple applications, multiple programs across the Office of Nuclear Energy overall. You've already seen our mission. Our mission is to maximize how we utilize our energy resources to achieve these end goals of reliability and resilience using our nuclear energy resources across all energy use sectors in coordination with these other generators on the grid. Our vision overall is that we will achieve a robust economically-viable fleet of both light water reactors, like those operating today, as well as advanced nuclear reactors that can support both baseload electricity needs as well as providing flexible operation to support a broad range of non-electric products and grid services.

The goals in the program look across the technology potential. We look at current fleet applications and what can we do now with current fleet that can commercialize these concepts. For small modular reactors, we have a slightly longer timeline of one to five years to understand how we move integrated system options towards commercialization with those types of facilities. For advanced non-water-cooled reactors, we'll look at a slightly longer time horizon of 5 to 15 years. Work within our program is spread across computational as well as experimental activities. In the simulation area, you'll see examples of how we are developing this modeling and analysis ecosystem that allows us to optimize integrated system design options that can consider a variety of reactor types as well as a variety of renewable technologies, energy storage options, and energy users. Coupled with this is economic analysis. Just because something works technically does not mean that it will be a viable economic option. We wrap these analyses and these optimization approaches with that economic analysis as well.

Finally, we bring that to hardware, experimental systems to allow us to demonstrate operation of these integrated systems first within a non-nuclear facility that allows us to look at coupling of these technologies and the overall interactions of technologies to validate our models, and to do initial technology demonstrations, and then moving to nuclear demonstration as well.

What I really want to leave you with – if you don't dive into all the technical analyses that I'll go through, I want you to understand that integrated systems offer a key opportunity for flexibility, an enhanced flexibility of our grid systems and our overall electricity supply. Nuclear plants in many regions have been operating flexibly for many years. France has a great operating history of flexibly operating their plants as do many plants in North America that respond to hydro generation. But we can do more in how we operate these systems flexibly. When we begin to introduce concepts such as product flexibility which is at the heart of these integrated energy systems where when we have sufficient electricity to meet grid demand by other generators, renewable generators for example, excess thermal energy from our clean nuclear plants can be used to create many diverse products such as clean water, hydrogen can provide for district heating production of synthetic fuels or ammonia and refining different metals.

We can also direct that excess energy to different storage components such that it can be accessed and utilized when it's needed at a later time. As we have more and more advanced reactors being developed, we then can begin to consider size flexibility as well or deployment flexibility. Most of our plants today are very large scale operating on the order of a gigawatt of electric power. We see more and more small modular reactors being introduced on the order of 300 megawatts electric as a maximum. We are even seeing development of very small systems on the order of one megawatt electric, in some cases even smaller, to meet needs in a variety of communities or remote applications such that nuclear energy now is an option that can be right-sized to meet those needs and in fact can be right-sized to match renewable installations that are also located in these decentralized grid infrastructures.

When we evaluate the wide range and variety of candidate integrated systems, we have to approach this in a couple of fashions – technical feasibility first. We need to make sure that we can connect these diverse systems, generators, and energy users and storage components such that the dynamic exchange of energy streams and data is stable, that it can vary as needed, it can be flexible and that we will not have a shutdown of the system if one asset is turned off for maintenance. We need to understand the technical integration approaches and the technical control approaches to operation of these systems dynamically.

Then as I mentioned previously, we have to assess the economic feasibility of this technical solution such that we can understand how it impacts the overall plant revenues as well as the affordability of the products from the system.

We take a multi-phase approach when we analyze these energy systems. We start with basic process modeling. These are using off-the-shelf tools, Aspen Plus and HYSYS. This process modeling allows us to do the initial assessment of technical and economic value of a proposed configuration. Most of this work is in steady state just to look at feasibility.

When we find feasible solutions for a particular application and location, we then move into dynamic modeling. Now here we develop complex detailed models for these systems that will address both the technical and the control feasibility of these different options.

Finally, we move into utilizing an optimization tool that we have developed to assess system-wide coordination and optimization in the design as well as use of individual assets within a configuration. We'll talk a little bit more about that optimization approach in just a moment.

When we do these assessments, we have to consider resource potential, how much of that resource is available, what is the quality of that resource. We are using coal as a carbon resource for a consumer product that contains those carbon-based molecules. We need to understand what the quality of that coal was. How will that impact the processes? How will we move that resource where it is needed? What are the infrastructure requirements? We then assess technology potential, thermodynamics and overall performance, what is the availability of that technology today or the readiness and what will it be in just a few years. We then look at economic potential and the various cash flows in these systems and the return on investment. Then we need to understand market potential. What is the competitor in the market? How will the market be influenced by potential new policies or regulations? All of these come into play when we assess these potential options.

These physical assets models that I mentioned that Modelica piece, these provide high fidelity system models over short timescales so that the system dynamics are truly understood and characterized. The program has developed a number of detailed dynamic models for reactor concepts, hydrogen production, water purification. We also include gas turbine models for additional power input for power peaking, and storage models first including batteries. We are continually enhancing the models that we have available, introducing new models for thermal storage or heat storage as well as advanced reactors. Over the next year we'll be introducing many more models into this toolbox to allow us to assess different configurations.

We also use artificial intelligence or supervised learning to address some of the computational challenges associated with these analyses. We use artificial intelligence to develop surrogate models for these complex computationally expensive physical models and that allows us to reduce the number of simulations to achieve good statistics. In the example here, using the full model versus the simulation models we were able to reduce the number of simulations to 200, using the real model, whereas we accessed the surrogate model for the other simulations necessary to achieve the good statistics. This goes into our modeling tools.

I've already talked a lot about these market assumptions or these market modeling tools and what we can do to improve them with regard to representation of nuclear assets with regard to generation options, timelines, and costs associated with those. How we can dispatch those nuclear energy systems allowing for load following. We need to understand – I am going to dial down further on this chart to look at how these models can also include integrated energy systems. Representation of these new systems that bring in multiple assets can help us to better understand how these new technologies could absorb volatility in the system that could reduce our need for ancillary services or reserves. We also need to include those additional revenue streams. Now these integrated systems aren't just producing electricity but they are also producing other products and supporting heat applications. Bringing this into these market modeling tools will be very important to ensure that we consider these new technologies in the future.

When it comes to plant modeling and simulation, we've talked about connecting those technical aspects, those technical tools with the economic analysis so that we can truly begin to assess the cost of inserting volatility or in this case absorbing volatility with these systems with regard to how it impacts the overall system. We can also begin to understand the impacts on system cost and understand how that's changing when we look at hourly resolutions versus seasonal resolutions. Finally using these detailed physical models becomes more and more relevant as we get down to those lower timescales as you might imagine.

With regard to the financial framework, we use a system cost approach. We can also use profit analysis. We ensure with the constraints in the system that overall energy system will meet the demand with high reliability. Overall we need to understand if these new systems, these new integrated approaches will decrease the cost of electricity. As we go through these analyses, we usually use the term levelized cost of energy or electricity, but really we are looking at what the cost is of covering that overall demand.

We have a financial analysis workflow that has all these lower level models, the molecular dynamics, neutronics, and CFD feeding into these high-fidelity conceptual designs represented in the process models in Aspen and HYSYS and the Modelica detailed physical models. These are used to predict process costs, the overall cost of these different processes. They also feed the RAVEN tool such that we understand the dynamics of these systems. When we do these analyses we bring into account the electricity market data. We use that data to develop synthetic time histories of what the market costs are and the generation. We also bring in market elasticity for the co-products as well as the feedstock that feed these systems. All of these go into this set of tools, this suite of tools to develop an optimal system design that will maximize revenue and minimize system cost.

This optimization scheme uses RAVEN. This is the Reactor Analysis and Virtual Control Environment that allows researchers to gain a better understanding of the probabilistic nature of complex systems and how they are represented numerically. The overall goal of this multi-fold optimization scheme is to optimize economic performance within these technical performance constraints. We first look at a level of optimization that looks at how large we need each of these different subsystems to be. How will they work together when we have a reactor, a wind generator and a hydrogen production facility? Then we wrap that with an overall analysis of how we would dispatch this in real-time to achieve the optimal economic performance. All of this, taking into account regional information on demand and renewable availability, as well as electricity costs etcetera.

We are moving these tools to open source, so you will be able to access them. You will be able to look at how they can be used within your own application space. RAVEN is already available open source and has been for a while on this GitHub site. We have now released two additional plugins to RAVEN to support these integrated system analyses. The first is TEAL, this is that cash flow analysis for energy systems. And then also HERON which is a Holistic Energy Resource Optimization Network that allows us to optimize integrated system design, including these component sizing approaches when we have multiple generators and energy users.

These analyses that we are doing truly are breaking new ground. There are certainly other efforts out there to optimize energy systems. We bring some new approaches in what we are doing within this program. Nuclear energy, of course, has different requirements than many other generators. We have to ensure nuclear quality assurance. We need to bring in aspects of safety and licensing as well as reactor operation. These tools bring in a full probabilistic approach as well as detailed system dynamics that we've talked about. In doing so, we leverage existing toolsets as well as ongoing efforts in order to enhance our abilities to analyze and optimize these system designs.

Let's talk about examples. How are we using these tools? This example shows you how we might use multiple interconnected generators to produce electricity to support grid demand. When we don't need all that electricity on the grid, we can divert both electrical energy as well as some thermal energy to support processes such as hydrogen generation.

Now, if we select a low temperature PEM electrolysis, this would just utilize electrical energy. If we use high temperature electrolysis or steam electrolysis, we also need some of that thermal energy to drive this process. Now traditionally hydrogen is produced by steam methane reforming which breaks down methane or natural gas into hydrogen and CO2. When we use electrolysis, this breaks down water to produce hydrogen and oxygen. Hydrogen is a really interesting energy carrier. It's highly versatile. It can be transported through natural gas pipelines. It can be stored on site for later use, or it can be moved to its end location of use for electricity production and fuel cells or combustion in gas turbines. It can also be taken to a number of different users for the production of chemicals, for the production of synthetic fuels that can support then the transportation sector with reduced emissions relative to our standard fuel use in these systems. It can be used to support steel manufacturing, to produce ammonia-based fertilizers. It's highly versatile. By using this type of configuration, it provides us a second source of revenue for our generators. It also provides us opportunities to support grid services, including reserves as well as grid regulation. This is a high priority area that's represented in one of the other programs then in the department of energy called H2@Scale where we look at production of clean or green hydrogen that has no emissions associated with it, to support the transportation sector shown here in the green circles as well as the industrial sector shown in the purple circles. So there are a lot of opportunities for hydrogen and we see that being embraced.

Now how do we assess this? What does this look like in real time? This example shows some of our early analyses using the tools that we developed to evaluate these types of systems. And this plot shows us the potential of how energy would be dispatched in one of these types of energy systems that includes a nuclear plant, a hydrogen production facility, a gas turbine to support peaking, that includes electric battery storage as well as a wind generation at sufficient capacity that the wind could fully meet the demand when it's available.

In this case, we can begin to see how the nuclear plant sends energy to the grid in the blue, or in the brown how it is sending energy for hydrogen production using the electrolysis facility. We can also see when the battery is being charged and discharged in the green, and when we are calling on that electric battery to also meet load. This is the net demand after we have taken into account the wind. This doesn't represent any particular region or location, but it's just an example as to how we can use these tools to dynamically assess energy flows.

This has been very successful in feeding some of our analyses that are represented here. These are publicly available reports where we looked at utilization of existing fleet reactors operating in the US to produce hydrogen in those markets. We looked at a number of different cases in these studies to understand how this compares to steam methane reforming on the left. How we might utilize low temperature electrolysis and the overall prices of hydrogen that result from that, as well as high temperature electrolysis. Now there are many assumptions and variables that go into this plot, so I don't really want to dial in on the specifics of this. But I encourage you to take a look at these reports to better understand the assumptions being made and the impact on the overall prices that are predicted here.

When we look at this configuration, the upper Midwest of the United States we might see utilization of a nuclear reactor alongside a wind or a solar generation facility supporting the grid, but then also supporting steam electrolysis where that hydrogen is going now to regional markets, petrochemical plants, fertilizer plants, and steel manufacturing facilities. It's also going to chemical facilities in that nearby region and to support the clean transportation fleet. There are many opportunities where we are simply looking at what is currently available in that regional location and how we might use these new systems to support that.

Again looking at these reports you'll see many different analyses of predicted costs of the low temperature electrolysis. This is a relatively small plant producing hydrogen. We do begin to see with a number of different assumptions on the electricity prices and the demand for that hydrogen. We do see that low temperature electrolysis can outperform steam methane reforming using this light water reactor. Similarly, if we look at steam electrolysis, there's some thermal energy coming into this process as well, we again see that we do have opportunity to outperform the traditional means of hydrogen production using light water reactors at these types of price points for the levelized cost of electricity.

We are not just looking at hydrogen. We are also looking at other applications where we can utilize carbon feedstocks. For example, here rather than burning our carbon-based resources to produce electricity or to produce heat to drive industrial processes, we are looking at those resources such as coal and biomass as feedstock to achieve these end products on the right, such as fuels, chemicals, carbon fibers, and polymers and using energy derived from non-emitting sources such as nuclear facilities and fossil facilities with carbon capture and sequestration as well as renewables that can provide energy to drive these processes.

When we look at different markets for nuclear energy, we do have to understand what the cost of producing steam is and how that impacts the cost of the end product? These are some of the initial analyses that we can conduct to understand whether or not nuclear generated steam is an option to support these industries.

We are also looking at experimental demonstrations. Before we move to these nuclear implementations, we are developing a non-nuclear electrically heated laboratory that allows us to understand the various interconnections and control approaches in these integrated systems. We take advantage of a number of facilities within our laboratory including a microgrid representation on the left. We have a human system simulation laboratory that represents a control room, what this would look like in an actual nuclear plant so we can understand how these systems would be operated when we are now having multiple product streams that need to be understood and managed. We have a coupled industrial process. This is an installed hydrogen production facility, a high temperature electrolysis system. We are currently installing these components at the bottom – our thermal energy distribution system as well as a micro-reactor emulator here at the bottom, the MAGNET facility.

What this will allow us to do is to understand how we can make all of these interconnections between a reactor facility, an intermediate loop to move that energy to a variety of users as well as energy storage, controlling that system such that we can support electrical energy users via the grid, electric vehicles or electric batteries, and bringing in our renewable resources. We represent the power systems in the grid using digital real-time simulators within this laboratory as well so that we have this overall experimental capability to understand the interaction and interplay of these different components, these different assets. This facility is currently being built. The High Temperature Electrolysis System is installed and operating. These components on the left of the rendered image are nearly complete and will be operating in December.

So looking a little more deeply at the thermal energy distribution system, this includes a thermocline to represent thermal energy storage. We include a controllable heater element to represent dynamic input, thermal energy input from a reactor, and this will be coupled to that microreactor emulator as well. It will allow connection to multiple loads including a power conversion unit that will be installed later as well as high temperature electrolysis and other loads as well.

As I mentioned, our high temperature electrolysis system is already operating. This is a 25-kilowatt electric facility and we are going to be installing a much larger facility this next year that can go up to 250 kilowatts for the hydrogen production.

As I mentioned, we used our analysis tools to understand how we might produce and the potential economic performance of producing hydrogen at existing plants. These projects were done in collaboration with industry partners at Exelon as well as Energy Harbor that also includes partners at Xcel and APS in the US.

We are working toward demonstration of these concepts. At Exelon, they will be demonstrating on-site production of hydrogen at one of their plants in the US midwest that hydrogen will be used to meet on-site demands, but it will also be used to meet demands of the regional hydrogen market, so for transportation and other nearby users. They are working through the detailed engineering designs now and they expect to commence testing in about 1-1/2 year. They will be announcing the plant that this will be implemented at very soon.

If we look at the Energy Harbor project, this is using a slightly different approach for the integration of the hydrogen production facility and using a different vendor for those hydrogen production components and operating within a different market. We can look at very similar projects with very different variables to understand the different performance. This project is among a consortium of utilities, as I mentioned, and will be implemented at the Davis Besse plant. The work that we do in these current fleet plants will allow us to establish a foundation that will help us to understand how we might move forward in designing a greenfield facility specially designed to utilize these nuclear technologies, advanced reactors, for example, to produce alternative products.

You all are from the advanced reactor community. You know the variety of options that advanced reactors bring to us ranging from molten salt reactors to liquid metal fast reactors and gas-cooled reactors operating at higher temperatures and with enhanced safety. What this means when it comes to production of alternative products is higher efficiency. The top line in this plot represents what we'll be doing at these current fleet plants, implementing PEM electrolysis, low temperature electrolysis to produce hydrogen with an overall efficiency of about 22%. When we introduce high temperature electrolysis using heat augmentation techniques with those light water reactors, we can bump that efficiency up to about 35%. When we begin to move to these higher temperature reactors, that's the real win. Now we begin to get to these very high efficiencies in how we produce those end products. There's great potential for these higher temperature reactors in achieving alternative product production.

Now we are working with a number of different programs to help move toward these advanced reactor applications. Many of you are probably aware of these programs, but briefly, the Gateway for Accelerated Innovation in Nuclear, or GAIN, was established about five years ago to provide an access point to laboratory facilities and expertise from the community into the laboratories. GAIN is working with NRIC, the newly established National Reactor Innovation Center which will provide the capability to build and demonstrate reactor concepts working with the laboratories. We are moving in a direction where we have a lot of capability to demonstrate these advanced reactors. By 2025, NRIC is charged with developing at least two different advanced reactors to move these technologies further toward commercialization on a very rapid time scale. I am excited to say that Integrated Energy Systems are a key part of these test facilities and the plan for demonstration of these advanced reactors.

We expect words to be coming out very soon and to understand what reactors will be demonstrated.

With that I do want to leave you again with this slide. Remember, Integrated Energy Systems are diverse in their options. They are diverse in the opportunities that they present that will allow nuclear technologies to work alongside chemical plants and renewable generators, providing us with a key opportunity for enhancing the flexibility of our grid systems and how we meet our overall energy demands in this country and in others.

With that, I know I was a bit long-winded. I hope that that you have learned something and that I have inspired you to go out and read some of these reports. On each of these slides you also saw our website ies.inl.gov that provides links to all of these reports, journal articles and an overview of our programs.

Thank you for listening. Thank you for your time. If you have any questions please enter them in the questions box. I am not seeing any questions right now. I don't know if that's because none have been asked or I just can't see them. But please let me know what questions you have. If you have questions later, please reach out to me as well.

Berta Oates
Thank you Shannon thank you very much for your presentation and sharing your expertise. As questions are coming in, let's just go ahead and take a quick look at the upcoming webinar presentations that we have scheduled. In October, we have a presentation on Global Potential for Small and Micro Reactor Systems to Provide Electricity Access. In November, Neutrino and Gen IV Reactor Systems. In December, a presentation on Development of Multiple-Particle Positron Emission Particle Tracking for Flow Measurement.

Give me just a second and I will queue up. I do have questions coming in. The first one is how will future IES affect the siting of energy producers and energy end users?

Let me see if I can post it.

Shannon Bragg-Sitton
That's an excellent question. I'll just repeat it again. I'm not seeing it so let me just repeat what I understand. The question is about siting. Will

introduction of these integrated systems impact siting opportunities both for end users and for generators? That's a great question.

When we look at the regulations and the siting approaches necessary for nuclear plants and we compare that to chemical plants, there's some differences. How we approach that is very important to ensure that we don't have inadvertent impacts of the generator on the user and that we aren't limiting operation of those facilities. We are going to learn a tremendous amount with these initial demonstrations with the current fleet plants that will be putting hydrogen production facilities on their sites. They are working through a safety analysis. They are working with the regulator to ensure the safe operation of those facilities under all conditions. Now in some cases if we're using thermal energy, they will need to be co-located and on the same site like that. We will need to understand impacts on safety, on performance, and we'll need to do that working with our industry partners and then working with the regulators as well.

In other cases, some of those users may not need to be located directly on site. We may have coupled hydrogen users where we are producing hydrogen on site and then shipping, transporting that hydrogen to the end user a few miles down the road that might be using it in a fertilizer plant or in steel manufacturing. So while I hate to answer a question ‘it depends’ it certainly does depend. It depends on how that energy will be used? Are there intermediate products that are transportable and therefore allowing some of the facilities to be somewhat separated? We may be able to take advantage of existing sites that have a lot of these different components on-site already. Retired coal plants, for example. They provide some great facilities that have all the permitting for these large-scale industrial-type processes. We'll have to evaluate siting on a case-by-case basis to ensure that it can be accomplished appropriately and within safety and regulatory standards. That's where partnership with industry gets so important and not just working within the laboratory window.

Berta Oates
Thank you. What is the biggest hurdle to reducing carbon emissions in the US?

Shannon Bragg-Sitton
Well, not having a federal energy standard and a federal standard for reducing emissions becomes a challenge and we have different policy impacts. But I am encouraged. Policy drives a lot of decisions with regard to how we build out our portfolios. We see many utilities. We see industry. We saw Google just recently announce that are looking at not renewable standards or renewable goals but clean energy goals. When we have that grassroots level of the private sector as well as

municipalities and states announcing that they are going to move toward these clean energy goals and reducing emissions, then that will drive a lot of other decisions. Costs are always a big challenge, I mentioned that at the very beginning. Nuclear energy needs to get costs down. These advanced reactors need to be affordable. They need to be cost competitive to these other generators. We need to look not just at that electricity sector. We have got to consider how these generation technologies can support industry and can support transportation.

Transportation is a huge component of our emissions, so we need to look at how we can introduce hydrogen fuel cell vehicles, rapid charging for electric vehicles. Until we have an infrastructure that can allow us to drive hydrogen vehicles or electric vehicles in the same way that we drive our traditional gas vehicles, they would not be broadly adopted. In the US that change is going to be really difficult. We have wide spaces. We have independence. We need to make sure that we have charging stations. We have refueling stations for hydrogen just like we do have gas stations if we're going to impact the transportation sector. We need to be impacting heavy transport as well. We see the introduction of fuel cell heavy transport trucks – the large semis moving forward, which is really exciting, because that can begin reducing emissions in that sector as well. There's no single solution. There's a combination of policy and technology and adoption of these new technologies that will get us to our end goals. And culture as well, we need people to culturally understand what these changes mean.

Berta Oates
Thank you. In a distributed energy market, each energy source must be profitable or subsidized, otherwise it will drop out. How is that model led?

Shannon Bragg-Sitton
I think the question was with a distributed energy market everything needs to be profitable. Exactly. Independent generators need to be profitable. I think the question was how that was model led? Is that correct?

Berta Oates
Correct, how will that model be led?

Shannon Bragg-Sitton
When we look at modeling those systems, that's exactly what we evaluate is how will they independently profit? What does that cost of operation and production need to be such that they compete within those different markets? We have to look at these analyses within the context of those independent markets. We can do analyses for a large-scale centralized configuration or we can look at those independent operators within more distributed generation. We have to understand how those play. I talked

a lot about capacity expansion models and production cost models. We need to ensure that those types of configurations are accurately represented in those so that we can do that predictive modeling to understand what those price points need to be to compete and then dial into the detailed dynamic modeling on the system level to understand how we can bring the cost to be at that competitive level.

I am not sure I am fully addressing the question. If I didn't, please feel free to send me an email and I'll do my best to answer that or connect you up with my modeling team.

Berta Oates
Thank you. Does the suggestion by the MIT report and potentially the CEM modeling that nuclear only becomes potentially cost competitive when deep carbonization occurs? If so, is there a range of thresholds for decarbonization when this occurs. For example, if a utility commits to clean energy goal of 50% by some date, does that cross the threshold to make new nuclear competitive at the currently estimated cost per kilowatt?

Shannon Bragg-Sitton
That's a long question. I encourage you to take a look at that report because they look at a number of different scenarios. No, I don't think that that the conclusion is that it only becomes cost competitive when we have carbon constraints or carbon taxes. There are a number of different factors. If we can bring down the cost of constructing new facilities, that will also help to make these plants cost competitive. There are so many factors going into that, I hesitate to answer that question. We've looked at utilization of our current fleet plants. How do we make sure that they are cost competitive within markets where they are being economically driven out? Those markets, when we look at introduction of these additional revenue streams such as diverting excess electricity to hydrogen production, we do find scenarios in which those can be cost competitive with these other generators within that region even in the absence of a carbon tax. So, I wouldn't draw the conclusion that was implied in the question but assess what that looks like in different markets.

Now if we operate purely as an electric generator, that may be the case in some markets. It may be that using those nuclear plants in a load-following mode, avoiding very low-cost electricity or even negatively priced electricity in some regions when we have high renewable production by curtailing or reducing power output so that changes revenues. If instead of curtailing and reducing the revenues we have an alternate revenue stream, that changes that equation and it changes the profitability of those systems. Like I said, we have found that under a number of different assumptions for the electricity markets, markets for the alternative product, scale of production, we do find points at which it is cost competitive even without carbon tax. So, I wouldn't make a blanket assumption or statement. We really have to understand that within the context of capital cost associated with new plants, markets that they are operating in, and markets for the end products.

Berta Oates
Thank you. Currently, how does the grid deal with what happens to excess electricity production?

Shannon Bragg-Sitton
Well in some markets when there is an overabundance of electricity production, electricity prices go negative. In some cases, plants reduce power output, some plants do that by control maneuvers to reduce output, some plants do that by dumping steam so that they are not producing that electricity. There is a grid management. I am not the one to speak to all the details of grid management. That's not my area. I can certainly direct you to some folks who do that more readily. But there are a number of different approaches that drive some of these resources to modify their production to the grid or they are basically paying the grid to take their power in some cases.

Many regions must take on renewable generation, so that means that that impact is being taken by the other generators, the thermal generators on the grid. Of course in some regions we are seeing more electric storage where that energy is pushed to electric storage. So, it looks like we are at the end of our time and unfortunately I have another commitment to talk to a group that's starting here very shortly.

Berta, I don't know if you can send me the questions that we didn't get to. I'd be happy to try to address those if you contact me or redirect to those who can address them better within my team. But I do thank you for this opportunity. I thank you for hanging in there with this this long webinar and I look forward to meeting you all in person at some point.

Berta Oates
Thank you Shannon. Thank you very much. And yes I will definitely forward you the questions that we did not get to today. What we could do is post them on the website but it would mean that I would have to request you to answer them in writing in order to do that. But I will definitely forward them to you and you can act on them either in that manner or contacting the people directly as you see as beneficial for your time and energies. But thank you very much for all that you put forth into sharing your expertise and developing this presentation to share with us today.

Patricia Paviet

Thank you Shannon. Thank you so much.

Shannon Bragg-Sitton
Thank you everyone. Have a wonderful day or evening.

Patricia Paviet
Thank you.

Berta Oates
Bye-bye.

Patricia Paviet
Bye-bye, Berta. Bye everyone.

END