Center for Strategic and International Studies

TRANSCRIPT

Event

"Powering America: Transmission Modernization and Flexibility"

DATE

Monday, September 28, 2026 at 10:00 a.m. ET

FEATURING

Yuro Dvorkin

Associate Professor in the Departments of Civil and Systems Engineering and Electrical and Computer Engineering, Johns Hopkins University

CSIS EXPERTS

Joseph Majkut

Director, Energy Security and Climate Change Program, CSIS

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Joseph Majkut: Today in America, everybody wants more power faster. They don't necessarily want to wait 10 years for a new transmission line, five years for a new gas turbine. And one of the concepts that's arisen at this moment of urgent demand and load growth in the electricity system is using our existing system much more efficiently.

Today, I'm joined by my guest Yury Dvorkin; Yury is an associate professor at Johns Hopkins University and a power systems engineer. Recent research that he and his colleagues have published might chart a path to using so-called grid-enhancing technologies more fulsomely, more commonly, and more cost-effectively. Yury, welcome to CSIS.

Yuro Dvorkin: And, Joe, thank you for the invitation. Great to be here.

Dr. Majkut: Do I have the problem statement correct? We have a large, complicated machine in the United States grid. We know, even though there's desperate new demand, it takes time to build bigger/better. So how do we use today's system better?

Dr. Dvorkin: Absolutely, that's very accurate framing. And just to add additional meat to the bones that you sketch, the U.S. power grid is perhaps the largest cyber-physical system that the country operates on a continuous basis – 24/7, 365 days a year. And one of the most important indicator is that we don't use this system to its full capacity.

Just a very quick example. The PJM part of the grid, which is the largest market-based interconnection in the country, serves 60 million of Americans. It has around 180 gigawatts of installed power generation capacity. But on average, it only uses half of it. So what that means is that during an average time half of the power grid capacity is being idle and it's not being used. However – however – on the other hand, when there are stress grid conditions, we use about 160 gigawatts of it. So we have literally about two, three tens of gigawatts of a margin that we can rely on. And this margin is not as big as we think it is because some generators are on maintenance, and so on and so forth, so we always tap into this margin.

So the problem we are facing is that we have a really large infrastructure system that has been underused during regular times, but it barely copes with extreme conditions. And part of the reasons is that we are used to producing energy in places where we don't consume it.

Think about a big power plant. Do you really want to have it in your backyard? Probably not. And it does not depend on technology. There is opposition to offshore wind if it gets into the ocean view. There is opposition to coal or gas power plants. It's just natural that we want to place large-scale power generation somewhere else. But if we do that, we also need to have resources to move power from the places where it's being produced to the places where it's being consumed. And that includes, for example, manufacturing sites, large cities and metropolitan areas, and datacenters.

So, one of the biggest bottlenecks on the grid is that we cannot move this power more efficiently. And there are various technical, economic, and social issues which prevent us from doing that. One of the most important issues in that space is that we cannot build transmission lines as effectively as we used to build it 50, 60, 70 years ago, when the country was undergoing electrification. And that's a real problem, because the growth rates on electricity consumption that we have in this country due to AI, due to transportation electrification, due to building electrification, due to manufacturing electrification, in many counties is in double-digits per year. So we have not grown electricity consumption that much since '50s and '60s and '70s. So it's a real challenge.

So we need to look into this transmission problem and think how those resources that we place in the grid could be used more efficiently, and at the same time, what we can possibly do to stretch these resources even further without waiting 10 years for approval. Because if I want to build a new line right now, it's going to take me roughly 10 years. That's the Department of Energy's own estimates. And what is interesting is, out of these 10 years, only three years on average will be used for construction and seven will be used for permitting, procurement, and so on and so forth. So that's where the target is.

But at the same time, we also have a new generation of transmission technologies that do not require as much construction time and are easier to deploy. And colloquially, in this space, these kind of technologies are called "grid-enhancing technologies," meaning that they take an existing grid and, with an easy fix, you can stretch more power from place A to place B. And these technologies are also easier to permit.

Dr. Majkut: So –

Dr. Dvorkin: The reason why – oh, go ahead.

Dr. Majkut: Let me ask you, like, what are the canonical examples? Like, many people in Washington have now heard of a grid-enhancing technology, but I'm not sure they could point to a specific technology or a project. What should the listener have in mind when we're talking about these kinds of technologies?

Dr. Dvorkin: So all grid-enhancing technologies can be roughly split in three categories. The first category would be the category I would call advanced conductors. Basically, due to years of progress on how we design new materials, what we can do, we can replace existing wires with new wires that can carry more power and will not sag as much. So the way how you can think about advanced conductors, essentially in terms of the road infrastructure what you do when you replace old conductors with the new conductors, you repave the road with new pavement, right? And you've got new additional lanes, and instead of a two-lane highway you get a four-lane highway.

Dr. Majkut: It's smooth instead of bumpy. (Laughs.)

Dr. Dvorkin: Exactly. And, from this viewpoint, it's more operational capacity to move power from the places where it's being produced to the places where it's being consumed. But on the other hand, what you have to do and what your limitation is that you're constrained by the current right-of-ways, right? And it's a curse, but it's also a benefit. The benefit is that now, if you are not expanding your right-of-ways, you can dramatically reduce the permitting times. And deploying advanced conductors can take from several months up to several years.

The only problem with the deployment here is really to think about the fact that for a long period of time, maybe weeks or months, you will have to take this line out of operation. The reason why you need to de-energize the line is because you need to take all the old conductors, replace them with the new ones. And that takes time. So for that period of time, you need to schedule an outage on that line so that, you know, people can actually work on it.

The second type of technologies is referred to as dynamic line ratings. And, just to go back to my road infrastructure parallel, imagine that instead of fixed speed limits on any interstate road, you have speed limits which vary across time of the day. So in the morning, when there are many cars, the speed limit is a little bit lower. During the time when there is nobody using the road, the speed limit is a little bit higher. That's exactly what the dynamic line ratings do, because based on ambient condition – which is science-speak for weather –

Dr. Majkut: (Laughs.)

Dr. Dvorkin: – they recalculate how much power can be put through a given line. Traditionally – in traditional contexts, power-flow limits on the power that can be sent through a line are fixed. And they are set up very conservatively, primarily because we want to maintain power-system reliability and we don't want to overload transmission lines. So we select these values below what it might actually be. So what a lot of companies do, they deploy sensors which measure the actual temperature of a conductor, ambient conditions, and based on this they can recalculate the limit on five-minute, 10-minute, 15-minute intervals as it is needed.

Dr. Majkut: So one of the things I think is most interesting about this is it's actually quite a physical problem.

Dr. Dvorkin: Yes, it is.

Dr. Majkut: I mean, a big transmission line really is, when you think about it, a long wire, and that wire is sensitive to environmental conditions – gets hot, the line may stretch and sag; it's colder, you get less stretch and sag. And actually, the stretching and sagging increases the length of the line, which then affects its conductivity. Is that kind of what's happening physically?

Dr. Dvorkin: Absolutely. And it's even more complex than that, because at one period of time look at our weather. At one interval, you have one weather; like, 20 minutes after, you have a completely different weather. So the ability to carry power in an ambient environment which is changing depends not only on what happened in the past and how you used your line in the past, how hot the conductor was, but also on what's going to happen in the future. And this is one of the complications with the dynamic line rating, that we need to have a computational technology and sensor technology in place that help us get these estimates reliably.

The other thing is the physics of the conductor by itself moving power from point A to point B is very nonlinear, and a small change in ambient condition or a small change in the power flow across the line can change to a dramatic difference in the power-flow rating.

The third problem, which goes on top, is uncertainty. Like, as you know, there are, like, lies, deep lies, and weather forecasts, right?

Dr. Majkut: (Laughs.)

Dr. Dvorkin: So if we make weather forecasts part of the scheduling and power-system operation problem, right, we need to take into account that there is no such thing as perfect foresight. And we need to be able to accommodate fairly significant margins of error on the forecast, especially if we are looking into multiple hours ahead. So the –

Dr. Majkut: So, if you think about this, like, you've got a grid operator, right, and that person has – their job is to match generation and demand, and they can dispatch generation and use transmission lines to help meet demand. And in the sort of old management practice, you – those transmission lines had a fixed line rating; we're able to move so much current through that line. And what we are – what new technology might enable us to do is vary the amount of current that moves through that line based on the ambient conditions and still maintain a safety margin which is acceptable for meeting reliability goals, correct?

Dr. Dvorkin: And it can go either way, because one of the problems that exists right now is the system operators run their power systems with fixed ratings but they actually don't know how these ratings are accurate because, for example, of an extreme hot day, when actually instead of stretching some flexibility out of the conductor they need to be a little bit more conservative and even reduce their already conservative fixed ratings to make sure that they maintain reliability. So having this advanced sensing and computational capability is very helpful, not only for reducing the cost but also to make sure that the system is being operated during extreme heat, as an example.

There are many interesting factors how these sensory capabilities and this AI capability to predict dynamic line ratings is correlated with other variables on the system. For example, I use the heat example because heat not only affects the transmission line ratings; it also affects the demand. We tend to use more electricity on a warm day, just one naïve example, when we all turn on our AC units. But also there could be a positive correlation when, for example, there is strong wind conditions, and the wind blows and additionally cools the wire. It also increases the power output of collocated wind farms. So we need to look into – holistically into this situation, to better understand what we can potentially do.

Dr. Majkut: So I also – yeah. Now you've studied this. So, you know, how much do you – in your research, how much does the dynamic line rating – you know, how much how much of a system improvement can we get out of utilizing these new techniques?

Dr. Dvorkin So that really depends. I think if you look at the high-level system estimates, the best reference case that comes to mind is the study by RMI, the Rocky Mountain Institute, a very well-established not-for-profit in this space. And they estimate that in EGM alone switching to GETs technologies will really help to avoid building 6.6 gigawatts of new generation. So just to give you what these numbers mean in perspective, the very recent capacity auction at PJM cleared about seven gigawatts short. So essentially deploying GETs technologies on the scale of PJM will help us to clear the market gap that we now need to think how to procure.

That is an example of what you're going to do if that is deployable at the scale of the entire interconnection. But it's a very hard problem to do because the PJM grid, for example, it spans more than a dozen states and the District of Columbia. So we need to make sure that permitting and regulation across state lines is met, and so on and so forth. There are a lot of problems related to the business models because utilities are not exactly excited about deploying grid-enhancing technologies because these are very often a lower capital cost solution. And the utilities, at least many of them, they effectively make money on capital cost recovery, which is a guaranteed return. So they don't necessarily have financial interest in prioritizing the cheapest available option.

If they have an option to put up a GETs solution which has a low capital cost versus putting wires into the ground, which has a very high capital cost, the financial incentive is misaligned. And that's why what is really important is to focus on regulatory actions. And several states, both in PJM and outside PJM, they have already taken action on mandating or requiring or suggesting that – depending on the state – that utilities should consider GETs technologies as part of their portfolio. And they need to evaluate and do specific assessment, ensuring that these things are delivering value at a lower cost. That's not a universal principle, but it's a very important principle because, effectively, what this regulation does, they move from the old paradigm of how utility make investment to the new one, when their base – when their evaluation is based on the benefit delivered to the system, not based on the capital cost.

Finally, in our own work, we ran analysis of very little DLR deployment, because we wanted to see what is going to be an incremental benefit of one, two, three, four projects deployed at the same time. Because we don't expect that, despite the dramatically low permitting times, we will be able to deploy many technologies at many projects quickly. And even in case, and we run the simulations based on the New York power system, we deploy one project. We can reduce one percent of system costs. So one percent doesn't look much, but when you convert it on an annual basis that goes into millions and tens of millions of dollars of savings. Additional benefits also include emission cuts. Additional benefits also include the fact that if you strategically choose areas for deploying these resources, they will have to interconnect new loads. And that is a big problem as we face the crunch to connect as much AI facilities as possible.

But one of the most important things is that we have a positive international experience, because in Europe they did manage to deploy these technologies at scale. That is often related to the offshore wind integration. And that is also related to the integration of onshore renewable resources. So there is a positive experience where such technologies can be deployed at scale. If we want to look into a domestic situation, I think we have the state of Virginia, which is part of PJM, as a perfect example where grid-enhancing technologies, whether these are dynamic line ratings or advanced conductors, they essentially count for the majority of transmission network improvements. And that shows a positive experience when you have a demand, which in case of Virginia was largely driven by the interconnection of large loads such as datacenters, they have a natural response of the system and a natural urge to innovate.

What could be helpful in this context is to study this positive experience abroad and domestically and figure out whether we can come up with a national plan that respects state boundaries and state jurisdictions, but at the same time help us to advance this technology where right now it's very hard to deploy. That is, interregional transmission, which is either between different system operators or between different states. That is the real bottleneck.

Dr. Majkut: Oh, that's very interesting. So within a state you might say, all right, we can set a regulation, or the utility commission can say we want this studied or implemented. But we don't yet have a mechanism to say, how do you use this to more efficiently manage the transmission system within a region or in between regions on the power grid?

Dr. Dvorkin: Exactly. That's why if you look into the systems which are most active about this technology, you will see typically single state ISOs. Like, an example would be New York state. When you go into multi-state ISOs, such as PJM, or the ISO New England, or Midwest ISO, you will see that these solutions require additional finesse to make sure that individual states that are part of these interconnections can solve this problem.

The other issue related to it, even for the same state deployment, is the fact that essentially deploying grid-enhancing technologies work as a nonmarket mechanism to pick winners and losers. And here, I mean generation resources. If there is a congestion, it means that our plant that is behind that congestion gets to collect congestion revenue, which is an important stream of revenue. Now, by deploying GETs, you potentially avoid this congestion. So there is a lot of institutional resistance from market players to deploy those solutions because it might cut into their profits.

So, from this viewpoint, what we need to think really is about a business model underlying the deployment of those technologies. Because utilities will be affected. They can no – they would no longer be able to charge as much due to capital expenses. Generations will be – generation will be affected. Consumers will be affected. So we need to really find a new solution what this business model for sustainable deployment of grid-enhancing technologies would look like.

And going back to the role of the regulator is that they are being very – at the state level, they're very largely encouraging of the technologies, but they still put a lot of a work on utilities and system operators and grid planners because they don't prescribe to adopt. They essentially say, show the business case for it. And that's where we need to provide thought leadership on how it should be done in order to make sure that we have a sustainable rebalancing in this industry.

Dr. Majkut: Yeah, who do you think would be the prime mover here? I mean, FERC has had rulemakings on DLR, but nothing final yet. You know, state utility commissions, should they be looking more closely at the potential of these technologies? How do you take, as you said, the few examples we have – whether it's your study of New York, or the experience in Virginia – and start to learn from them in other contexts?

Dr. Dvorkin: That's a great question. And I think we can provide for – it takes a village to move the costs. I think one of the key issues that FERC Order 841 and FERC Order 1920 address is that they open an avenue for these technologies to be considered. And actually they provide an opportunity for these technologies to be integrated on a par with the existing technologies. But I think the fundamental reason here is that we need to find a market-based solution to adopt those technologies, because what we have right now is a two-pronged push. One side of this push is from datacenter industry, which is prepared to pay a premium for electricity just to make sure that it's available. And effectively the compact at the White House led was to make sure that this massive investment that the AI industry makes into the electric power sector, A, does not affect ratepayers, so-called the ratepayers pledge; and the second one is that they're going to use this new infrastructure to help reduce the cost of electricity supply to others. These are very important principles that need to be fleshed out.

The second important factor in this conversation is to keep the flexibility, because nobody knows their grids better than the state authorities and to have one recipe hit all probably will not work. The reason why the state of Virginia was so effective in deploying those solutions is because they had their utility, their state regulators, and the private sector working hand-in-glove to address those issues. And that's a perfect example of where we actually need to concentrate our efforts while every ounce of federal effort must also be appreciated and supported, like the REWIRE Act by Senator McCormick and Senator Welch. It's a bipartisan effort. One is a Democrat, one is a Republican. Pushing this forward would really help because we need a legal framework and then we need a business model. And when you have the federal framework, and when you have different business interests – the state, the utility, the large loads aligned to solving the problem – that will happen in a way that is suitable for each in particular jurisdiction.

Dr. Majkut: And if you think about the political economy of these technologies, I do think there's something interesting here in that, you know, a lot of how datacenters are – or, the datacenter developers are being called to the table is, you know, can you give us money to solve this problem or that problem. But my understanding is it is – it is AI and machine learning and other sort of digital practices that help the whole power system get better. It's not just money; it's capability that these firms can bring to bear, so long as the grid operators and utilities can trust the systems that are developed and then implement them under the right business model.

Dr. Dvorkin: Absolutely. And it's part of a very important conversation about AI, because very often we have a very pessimistic look on this technology because we clearly, clearly emphasize the risks of this technology, and there is a lot of information in the public space about it. But what I think makes this conversation lopsided is the fact that there is no real conversation about potential benefits of this technology, and we take that for granted. And the energy sector is one of those spaces where AI technology can really work out miracles.

The unit commitment, which is a mathematical model that is being used for scheduling power generation, is based on mixed integer linear programming, which is a mathematical framework which was pioneered at a theoretical level in '70s. We adopted it in practice about – in about 2007. Actually, PJM was the leader in that. So it took roughly 20, 30 years to move from theory to practice. It is being used right now, 20 years after 2007. So what we are asking from mixed integer linear programming is to run the 21st -century grid using the mid-20th-century science.

And AI and different ways how machine learning and computational technology help us to move this computational framework forward to replace or assist mixed integer linear programming with neural network or with deep learning or with other verifiable and transverse machine learning techniques would help, because we already do pieces of that equation using machine learning. For example, weather forecast, right? You want to predict dynamic line ratings, you need to have an accurate forecast, you will use machine learning. But machine learning is still not being used inside of power-system scheduling to effectively be part of the day ahead and real-time operating routines.

So there are plenty of opportunities, and that's a positive case about AI use in the energy sector that every stakeholder is interested in building. Utilities will and system operators will have easier time to do their job better because AI will help them to reduce the costs and to improve reliability. The datacenter industry will have a really good showcase for how AI can deliver the public good, because right now the AI industry is being blamed for the problem they created – they are blamed to have created, like, by building the datacenters.

So it's a win-win solution. And the more constructs like that we can build where everyone benefits from technologies such as AI or from deployment of physical or cyber-physical technology such as dynamic line ratings or any other kind of grid-enhancing technology, the better it will be for us. We need to build public momentum for transmission in this country to stop being a bottleneck.

Dr. Majkut: What's the timescale of feedback here? And by that I mean, you know, as you said earlier, it takes 10 years to build a new transmission line. I don't think dynamic line rating gets us out of needing to build a lot more transmission over the decades. But if you think about, you know, instrumenting a line so that it can be managed dynamically, or you think about the New York case, you know, are we in a situation where ratepayers, who are also voters, will see the benefits of these technologies in the space of years in reduced rates or better service? You know, and can that create, you know, sort of positive feedbacks for these kinds of technologies faster than we'll be able to realize a whole new transmission buildout?

Dr. Dvorkin: First of all, absolutely. And the increasing availability of grid-enhancing technologies does not – does not mean that we have to give up on traditional transmission expansion. We have to push on both fronts. We have to accelerate permitting to enable more traditional transmission construction where it's possible, and we have several positive examples. Just a few weeks ago, we saw some very good news from the Midwest in ISO when they deployed a new interconnect. That's fantastic. We also need to push with dynamic line ratings to make them more accessible and more deployable.

I think at this point most of transmission expansion that we observed in terms of the number of projects is part of – it's one or another grid-enhancing technology. So this technology is not some miracle which is going to be available in a few years; it is available right now. Advanced conductors takes from between several months to several years to be deployed, dynamic line ratings can be deployed from weeks to months, and they provide different benefits. They provide different – they have different requirements. Not all lines are suitable for dynamic line ratings. Not all lines are suitable for advanced conductors. But we need to find the cases where each technology works better.

That will generate a tremendous benefit to the public. And in fact, it has already been generated, benefit to the public, because there are tens if not hundreds of the projects around the country that are being considered right now and that have already been implemented.

One advantage of those technologies is that these technologies are often produced domestically, and if we sometime may have a shortage of domestic production and produced in allied nations. And at the same time, these technologies can be easily friend-shored or domesticated here in America.

So, to answer your question when American taxpayers will finally see the benefit of these technologies, they're seeing it right now. The problem why it does not show up on their rates as expected is because the industry, the electric power industry, is in a growth mode. Electricity is a commodity, so the price of electricity is determined by the – by the intersection of the supply and demand curve, just in the same way it is done for any other market commodity. And we have so much demand for electricity that it pushes electricity prices up, and that is reflected in the rates.

An additional factor that is included in the rates, it's not only the cost of electricity or the cost of electricity delivery from generators all the way to consumers; there are also fees, taxes. And very often states use electricity rates as a very easy vehicle to deliver some – on some programs, like energy efficiency programs. And that all adds up, and that creates a lot of additional costs that are being – that consumers are being burdened with.

So what we can do here, we can use grid-enhancing technologies to offset the growth. But fundamentally, the price of electricity is – are driven by market dynamics. And unless we find a better way to produce a lot more electricity in this country and deliver it to consumers a lot more efficiently, it will be nearly impossible to stop this price growth.

Dr. Majkut: But if you have – if one of the cases for grid-enhancing technologies is it gives us a way to deal with the capacity utilization problem that we began our conversation with, does that allow for more – allow the system to meet more demand, at least at a decreased cost, right? So the benefit might be counterfactual, but it's still quite real.

Dr. Dvorkin: Yeah, absolutely. And then what it's going to do, it's going to unlock a lot of capacity that consumers need. And it will help to deliver it to them more efficiently. And probably from even cheaper generators. But the important thing is that the power grid is like a church, right? You build a church for an Easter Sunday to accommodate everyone. The power system is also built for the peak, right?

Dr. Majkut: (Laughs.) Right.

Dr. Dvorkin: Same thing here, right? We need to meet the peak demand. And that's where every generator is on. That's where every transmission asset is deployed. And that's when the consumption is at its highest level. So we will unavoidably have to build more transmission. We'll unavoidably have to build a lot more generation. But the effects that you mentioned, when it will reduce the cost is during the times when we don't have full capacity utilization. And by deploying grid-enhancing technologies, we can run the system more efficiently during these times.

Dr. Majkut: You know, we have referred – here at CSIS, we've referred to this period as the sort of speed to power era. There's incredible demand from datacenters.

We know that there is a lot of load growth coming in the 2030s from mixture of datacenters and electrification of other parts of the economy. And part of what we need to manage, from a government standpoint, is, you know, cost expansion over the next five years while we resolve the policy environment that allows for sustainable and long-term growth. And to me, the GETs, and dynamic line rating as a leading example, are something that help us deal with the speed to power era. And then they become institutionalized and a factor in the growth era. Is that the right kind of – I don't know, what do you think about that, the breaking up of the time in that way?

Dr. Dvorkin: I think it's a really good analogy. And I totally support it. Another way to put it is that the states should ask for forgiveness, not for permission, to deploy GETs. That's exactly what the state of Virginia did. And we should all learn from their experience. Just deploy the solutions, benefit your state residents, and then wait until regulatory issues are resolved.

Dr. Majkut: And you mentioned this, and I think it deserves a little bit of thought or discussion. These technologies are also very useful at moments of material constraint. So we talk a lot about the generation constraint and the need to build up a bigger power system. But we also have supply chains that can get short on the distribution side of the power grid. Or we have a new executive order which may prohibit companies from building with foreign-procured power electronics, and could limit the system – at least temporarily. You know, are GETs a usable technology while we are also dealing with other securitization issues for the power grid?

Dr. Dvorkin: Absolutely. And they provide us with an important relief while we're restructuring our supply chains. Also, would like to say that the – at the source of our supply chain problem, and at the source of community opposition to building our transmission grid, you probably have the same source. There is an increasing amount of evidence, including articles in The New York Times by Steve Myers and Dustin Volz about Chinese involvement with fueling local opposition to datacenters and to power grid projects, how this – not only China but also Russia and some other nations – they fuel concerns of so-called NIMBY movements, which has been a real problem for the transmission construction. So it's a very complex nexus. And there is a lot of benefits from having these technologies produced in the country, or, I would say, on allied or friendly territories.

So we also looked, in my group, into supply chains for transformers because you can have generation, you can have datacenters, you can have transmission lines. But unless you have the transformers that connect them together into a system, there is very little you can do. The datacenters will be idle. The generators will not be producing. So we also need to resolve this issue. And actually, one of the reasons why eventually we may run out of projects to install grid-enhancing technologies is because we will expand the capacity of our transmission network, but we might not be able to support this transmission capacity with enough of the transformers. So we need to look into this problem holistically and to address the concerns and vulnerabilities of the supply chains, at the same time cost scheduling these issues with availability of other technologies. Because we don't want to end up in a situation when we only solve part of the equation. We want to address the system-level issues.

Dr. Majkut: Right. Well, we await the day when we are overutilizing dynamic line rating and other grid-enhancing technologies. (Laughs.)

Dr. Dvorkin: This day is not that far.

Dr. Majkut: Yury Dvorkin is an associate professor at Johns Hopkins University and a leading scholar on how market reforms and business models can bring new efficiencies to our grid here in the United States, and inspire growth, lower rates, and the power system that will help meet national needs. Yury, thank you for joining us today. The links to your recent work will be included on the website. We thank you for your – for all the work that you do, and for joining us here at CSIS.

Dr. Dvorkin: Thank you for the invitation. It was fun. I really appreciate you and your time and your team. Thank you.

Dr. Majkut: Thank you. Colleagues who've joined us, thank you so much. This is part of a series of work we're doing here at CSIS talking to leading academics to bring new ideas into the policy conversation around the American power grid, and transmission in particular, here in the United States. We thank you for joining us. This is Joseph Majkut, signing off.

(END.)