HARVARD ELECTRICITY POLICY GROUP

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Rapporteur's Summary*

Clean Energy Policy: Tools and Trajectories

The goal of clean or at least net emission free energy systems by a certain date dominates discussion of the policy agenda. The question of feasibility of such an objective, at least for the electricity sector, can be answered easily as a purely technological matter. It is possible. The challenges will include both costs and systemic inertia. The interesting questions have to do with the relative merits of different tools and trajectories. How fast would the transformation occur? What would be deployment of existing technologies versus reliance on research to identify and develop new technologies? What deployment policies would be needed and what strategy for deployment would be internally consistent? What choices must be made, as between markets and mandates? How can we pursue our objectives while minimizing the creation of new stranded assets? Do any of these questions matter? Are there tradeoffs? And how should the answers affect electricity market design and regulation? What have we learned from the green energy analyses addressing these matters?

Moderator.

Thank you and I'm happy to be here today. We have an excellent panel to talk about these issues, which was motivated by many discussions amongst the group, about the changing attitudes and commitments for net zero energy by sometime relatively soon, and what does that actually imply. How does one go about it now?

The basic idea of net zero emissions for energy is not a particularly controversial idea if you don't specify when it's going to happen. But if you get serious about doing both of those things at this specific date or via specific data, it has dramatic implications and there's been all of the cumulative activity around the world on the recent changes in the rhetoric and policy in the United States that you're all familiar with and which I'm not going to review here.

But the studies are coming out about this subject. I noticed in the press that yesterday the National Academy released its own study on decarbonizing the United States economy. And there were two things which I thought were important about it. One was it placed a carbon price in a prominent role, which we'll hear. And, secondly, to the carbon price, that said that it was based in part or largely using a lot of results from the Princeton work that we're going to hear about.

The purpose of today is to talk about what this net zero energy target: 2050 or whatever date of interest, the connection to 2° and 1.5°. We have the many studies from the IPCC about this that you're familiar with, and then these more recent efforts that we're going to hear about today. We're going to start with Speaker 1, who's been thinking about these things for a long time, wrote a very interesting paper almost two decades ago about time inconsistency with climate policy, which I remember. He has a new book that was just out last year on net zero and I'm going to turn it over to him.

Speaker 1.

*** HEPG sessions are off the record. The Rapporteur's Summary captures the ideas of the session without identifying the discussants. Participant comments have been edited for clarity and readability.**

First of all, let me say thank you very much for inviting me along, especially in view of being surrounded by so many eminent people. I think Bill Hogan and I, we go back a very long way, but I suspect I'm unfamiliar to most of the people on this Zoom.

Let me confine my remarks to three or four key points and I want to illustrate them. The first thing I want to cover is, when we talk about net zero what exactly is the objective, what's the question to which net zero is actually supposed to be an answer? It turns out that's not quite as straightforward as most of the people who just adopt net zero think it is.

The second thing is to ask whether net zero should be unilateral and defined in production rather than consumption terms. That turns out to be very important with regard to the instruments that we might use.

The third thing is to make some comments about the costs, which I think are considerably underestimated.

Then the fourth thing is to say a few things about policy context and hopefully segue to just seeing the very much more impressive work that Princeton and others have done.

So let me start at the beginning, the reason I wrote my book on net zero, and I'm revising it for paperback at the moment, is because it struck me that we've been trying to address climate change for 30 years and achieved roughly nothing.

Why do I say that? Well, climate change is about the concentration of the stock of carbon in the atmosphere and the other greenhouse gases. Emissions are a flow and so is sequestration. But what matters, what causes the greenhouse effect, is that stock. And every single year since 1990 we've added about two parts per million to that stock, including in 2020. There isn't a single blip in the increase in the stock of carbon in the atmosphere since 1990, including both the financial crisis and the coronavirus lockdowns.

That's a staggering fact, and really quite frightening when you think how much political and economic capital has been expanded already to try to address the problem. The conclusion I draw from that is more of the same and one more heave is highly unlikely to achieve the 1.5°, let alone the 2°, ceiling to the increase in temperatures.

So the objective of a net zero policy ought to be, how is it going to stop the increase of the stock of carbon? And how is it going to then reduce that stock of carbon? Not simply what's it going to do to emissions.

And that's the second point. Climate change is not caused just by emissions. The stock of carbon in the atmosphere is the consequence of the balance of sequestration by nature and emissions. We've spent virtually no time in climate change policy thinking about not only the damage we're doing to the natural environment, but the degree to which we're reducing the ability of the natural environment to take out the carbon which will always be emitted, but hopefully not at the level that's currently being emitted.

Soil has roughly four times the carbon of the atmosphere and the rate at which we've been stripping out the carbon from the soil—not just the destruction of the rain forest, but modern agriculture is a serious contributory factor to the balance. So when we look at climate change, we're looking at, of course, the electricity sector and the energy sector, but we're looking at transport, we're looking at heating and we're looking at agriculture and land use as well.

And, by the way, the energy sector applies to all of those because electrification, robotics, digitalization technology applies to all those sectors. But in the UK, for example, the power sector comes behind the transport sector, behind the domestic heating sector and, relative to size, massively behind the agricultural sector. Our agricultural sector contributes 0.6% of GDP and produces between 11 and 15% of total measured emissions, and the soil emissions are not measured properly.

So any policy like net zero has to be devoted to this overall objective and it has to apply to sequestration and to emissions in order to be meaningful.

Now the second thing to say is that most of the net zero policies that have been adopted are unilateral carbon production targets territorially defined. The extreme is the UK. We are an 80% service-based economy and we're an open economy, much more open than the United States, for example. We have been de-industrializing at an incredibly fast speed over the last 30 years. We basically closed our aluminum industry, most of our steel industry. Brexit will probably kill off most of the car industry. We have very little petrochemicals left, etc. We even import cement. Where's that stuff come from? Overwhelmingly from China and, actually, other global sources. So, essentially what we're doing is reducing emissions in the UK and importing those emissions instead, not totally, but at the margin. And it’s the margin for an economist, that counts. The higher we drive up the cost of electricity in particular in the UK, the greater the subsidy to imports for products which are more carbon intensive than those produced at home and have all the shipping and transport costs associated with them.

If you're going to genuinely address the problem, then you have to have a carbon-consumption at target, independent of the location where production took place for the goods that you consume. And that means that it isn't a nice add-on to consider border adjustments. It's in the essence of any sane carbon policy. And the British public have been told, many publics around the world, that when they get to net zero, they'll no longer be causing climate change. That's complete nonsense, unless everybody else gets to that point at the same time. I suspect there's no chance of China, India and Africa in aggregate anywhere near net zero by 2050. That's the second point I want to make.

The third point, a quick point, is on cost. In the UK, people run around saying that isn't going to cost us anything, in fact, it might be net-positive in cost. If you're an economist you say, “Look, here's an externality. We're not paying for it, OK?” So in a strict sense our cost structure—the relative prices in the economy, etc.—don't take into account a big important particular cost. And then we want to say, “What if we did take it into account? It wouldn't cost us anything more than it does if we don't.”

It's intuitively implausible to say that if you're living beyond your environmental and climate means that getting rid of that constraint is costless. And if it is costless, then I would like to see everyone demonstrating in the UK with placards saying, “Remove renewable subsidies, cut out support mechanisms, because we don't need them, because the net present value of all this stuff is positive.”

I simply don't believe that, and I believe there's a huge amount of capture of the economic estimates of those costs. The second argument is, “Yeah, but it’s economic investment. Aggregate income equals consumption plus investment plus exports minus imports. So an increase in investment leads to an increase in aggregate demand, there's spare capacity in the economy. So on a good Keynesian argument, it's free. The multiplier will take care of the outcome."

Well, there are two things to say about that. First of all, I have a great degree of skepticism about the macroeconomics that makes up that story. But the second thing is in all the estimates that come from the IPCC, from our own Climate Change Committee, government failure is assumed to be zero. In other words, all the government policies work.

Well, in my country you only have to look at the green deal that we launched, which produced virtually no outcomes; the smart meter program, which has cost 11 billion and is still way off completion, etc. Large government-induced projects supported by subsidies attract lobbying capture, and government failure has to be taken into account alongside market failure. I'm not saying the projects that are being pursued aren't projects we ought to pursue, but any cost estimate cannot be based just on market failure. It has to have government failure in there.

Our treasury has just produced a report on the costs of net zero. It has two chapters on market failure and an annex on market failure, and the words "government failure" do not appear anywhere in the analysis. I could go on further about that, but time is short, so let me just push on to the instruments and the policies that follow.

If you think that it's sequestration, as well as emissions; if you think that it's about agriculture, transport, heating as well as the power sector themselves; and if you think it's about consumption, not just territorial production, then the obvious instrument, a necessary condition, is a carbon price and you want it uniform across all sectors of the economy. And you want it applied to imports, as well as domestically.

There are arguments about whether you should start with a low price and allow it to rise through time, about how the carbon price should be targeted to the achievement of the overarching target, who should adjust the carbon tax, etc. But I find very few economists who think that you can do this great transition from carbon-intensive to low-carbon economies in just 30 years without a sensible carbon mechanism.

It's necessary but not sufficient. Of course, you need the infrastructures through which this operates, you need the system operations and the system planning that's required. And you need the sequestration policies on top. But the central role of the carbon tax has to be crucial. But my reasoning is not just because the carbon tax is the right instrument to use for the power sector. It's the right instrument to find the lowest marginal costs across the economy. And it's, at the border, the only way of making sure that doing the right thing domestically is not simply subsidizing carbon-intensive production and therefore imports from China, India and Africa. By the way, it's those areas of the world where climate change will be determined, not in Europe, not in the UK and probably not in the US, either. But I'll stop at that point, with those brief remarks and hope that's helpful.

Moderator: Thank you. That's an excellent beginning. Let me add that we're open for questions for the participants.

Let me ask the first one. I mentioned this paper you wrote back in 2003 about the time consistency and related to climate policies. If you put that idea together with what you just said about the costs, obviously if the cost turned out to be extremely low, and you do see lobbyists in England actively trying to get rid of the subsidies, then the time consistency problem isn't so severe.

But if you don't have that and it turns out to be expensive, how is your prior analysis affected? The ability to actually sustain the policies that you're talking about, which is what, obviously, is a big worry. Because if you delay and delay or backtrack along the way, then this cumulative concentration in the atmosphere problem gets just progressively worse at an accelerated rate.

Speaker 1: OK, so the first point is if it turns out to be as cheap to decarbonize as, for example, our Climate Change Committee states, our Prime Minister states, etc., you haven't really got a problem**.** It's a kind of no-brainer, it's going to happen. If it's actually a positive net present value, there might be some temporary subsidies, but it's not really going to matter. The only time it's going to matter is if this costs. My view is the costs are grossly understated.

In the UK, the government promises all these initiatives, ahead of the COP26, and then it says customer bills aren't going up. So, the last thing that is going to happen is electricity bills are going to rise for political reasons. And, of course, taxes are not going to pay for this, because we need every penny of tax to pay for social care, the health service, the unemployment. So basically the argument is, you know what, just borrow it. What we'll do is we'll make future customers and future taxpayers pay.

Not only do I think that's ethically highly questionable, given that it's our generation of the mucking up environment and expecting them to pay. But if I was an investor, I'd ask, "So are they actually going to pay and is government going to force either future tax papers or future customers to pay?" My guess is the answer is no. So what I thought about with, actually, Cameron Hepburn on timing consistency is the following: I advocate using a carbon tax, the problem is, who sets the carbon tax? And how do we know that they're not going to do time inconsistency? The parallel I drew in a couple of articles I wrote at the time was with the independence of central banks, where nobody trusted governments not to interfere with the interest rates, with regard to short-term electoral success. You know, "Oh, Lord, make me pure, but let me carry on sinning in the short term."

The answer, that is that you have to think about the setting of the carbon tax by an independent body in the same way we think about the independent setting of interest rates by independent central banks. The less you're prepared to create the institutional structure to sustain the policy, then it will fall into exactly the problem that you highlight.

Moderator: Thank you. I see a question.

Question: Impressive talk, I have to say, you have not lost any sharpness at all. I completely agree, of course, on the central role of a carbon price for all the reasons you have outlined. Partially you have answered my question already, but maybe you can dive a little deeper into it.

There's a long history of non-cooperation between governments when it comes to joint taxation and joint fiscal policies at large. There's a long history of markets being able to link up to each other, much faster and easier, in particular financial markets. And there is this whole wide issue of government failure which, when you have a carbon tax, and of course you have to pick a tax rate which you think would be sufficient on environmental grounds. Whereas, if you would pick a volume target then you could rely on scientific advice. Maybe you can elaborate a little bit why a carbon tax, not a carbon price determined by carbon cap and trade.

Speaker 1: Well, thanks, you ask a whole set of questions. Let me try to answer two bits of them. First of all, on the intergovernmental issues. So Cameron Hepburn and I have another paper on the political economy of carbon border adjustments. I've always been concerned that the top down kind of Copenhagen/Durban/Paris aren't making any impact on climate change. Back to my opening remark, but there's been not a blip since 1990. So I've always been trying to think of other bottom-up ways of doing this.

Then the question comes, can you unilaterally act, even though the others haven't acted? Which is what these net zero targets are about. Then it's the carbon consumption issue and the carbon border. What Cameron Hepburn and I do is look at the incentives that are created if you introduce border carbon taxes. So, supposing there's a Chinese steel company sending steel to America or to the UK, and America or the UK has their own carbon price. The stuff arrives at the port and they're charged the equivalent carbon price that they would have been charged if there were a UK or American steel producer.

So, if you're the Chinese company, you say, "But is there any way we wouldn't have to pay this?" And the answer is obvious: "Yes, you can have an exemption certificate if you've got a parallel carbon price at home." So the choice is, do you want to pay it to your own government, or do you want to pay it to a foreign government? And we produced a game theory model to go with this to show that this is probably the best way of pluralizing a carbon tax to those countries that don't have it to avoid paying it to the governments to which they are exporting the product.

Just imagine what the dynamics of this will be between the United States and China. I mean, America is a big player in this game. We're a bit part player, 1% of emissions, and a trivial bit on the end of Europe, now we've done silly things like Brexit. So I think the political economy bottom-up, of a carbon border adjustment, with the exemption certificates works.

Now, on the EU ETS versus the carbon tax, I've written a lot of criticisms of the EU ETS, and we have to accept that it's achieved virtually nothing so far. It's produced a low and volatile short-term price, which only recently has been increased up to €30. Why? Because the European Commission has effectively started interfering to manipulate the number of permits to produce the price they would have liked to have had, had they had a carbon tax. The EU was absolutely right in 1991 to say a carbon tax was better than permits, but the lobbying, the vested interest, the industrial interest in grandfathering the permits pushed for a permit scheme.

And it's worse than a carbon tax, because the commission is effectively continually interfering in the permits to produce the answer that would have much more easily been achieved by virtue of setting the tax. I can't tell you how complicated and expensive the banking, the *ex poste* interventions are, and the vested interest of the carbon traders in having carbon trading system, rather than the tax.

So I think it's been pretty disastrous and, if you look at the price behavior, it's not the trajectory you'd want if you wanted to have the most cost-efficient way of getting from here to net zero in 2050.

Question: Thanks. The question that I have is/ how do we measure the emissions from agricultural use or silviculture, in particular? So I'm thinking deforestation and reforestation. And how do we get to net zero when we think about the power system, given those questions, when we know we're going to need something that's controllable along the lines of, let's say, still natural gas units to help meet ramps with variable intermittent generation? How is that all going to work in with a net zero world in your opinion?

Speaker 1: OK, so while I've been thinking about climate change, I've been chair of our Natural Capital Committee for the last eight years in the UK, and I've been thinking very hard about the sequestration side of this issue. I've written a book on that topic. There are a whole host of companies rushing over the parapet to declare they're going to be net zero, but a particular time. ESG has come to bear on that, black rocks, around pressurizing particularly energy companies to do this stuff.

So they turn around and say, "We've got to do sequestration, what the hell do we do?" And, of course, fairly simplistically they say, "Oh, we just bought trees." Never think about the biodiversity that goes with that. And, of course, if you want to sequestrate carbon as fast as possible, cover the world in eucalyptus trees, they grow faster than anything else on the planet. You'll wipe out the biodiversity in the process, but, hey, you'll get the carbon reductions.

So this is a complicated problem. It's got dimensions to it. Now, that said, the big transformation is that we can now digitally map any square 20 meters on the planet. So, in a separate activity, I work with a whole science team in Oxford, we digitally map land and we establish natural capital baselines.

And then, separately, you work with energy companies to work with big landowners and you work about voluntary carbon offset contracts and you keep rerunning that baseline. The satellites go around all the time. There are drones, all sorts of stuff. You keep reading. You can do it virtually every day, if you want, but annually or whatever, to demonstrate what's actually happened to, in this case, the vegetation in the form of trees and their carbon uptake.

So, you accredit that, that creates a market in carbon offset permits, and, eventually, because you create the platforms, you get a tradable platform in carbon offsets which sets along the tradable platforms in energy generation, etc, If the carbon price is common between the two, then the tradeoff between whether you reduce a fossil fuel plant or build a wind farm or you put the carbon back in the soil or you plant trees, etc., are measurable, tradable. Providing it's an automated platform, it's like a normal agricultural market, but you simply upload to the cloud the number of trees you want to plant. You put the polygon as the map that you require, and then you do the estimates from that. I think we pioneered that, doing it with a massive estate in the UK. Not on an American scale—a big estate is trivial for you guys—but brokering those deals in energy companies and landowners.

And the soil side, because we've got out of the common agricultural policy, all agricultural policies are usually dreadful for the environment. Yours is dreadful, ours has been dreadful, Europe's worse. But now we're just going to pay public money for public goods and one of those things is going to be the preservation enhancement of soils and peat bogs, and that's about getting this carbon back in the soil. Again, you can use satellite technology. By the way, just on the side, most biodiversity is below your feet.

So, in addition to soil having four times the carbon of the atmosphere, it has nearly all the biodiversity in the world, and it turns out the carbon in the soil is closely correlated to the biodiversity in the soil. So this is a massive win for biodiversity and for the climate, and there are lots of opportunities there which may turn out to be cheaper at a given carbon price than the emissions reductions. But it's a really important area and the science is advancing in terms of digital mapping phenomenally fast.

This is a fabulous opportunity. It's not just you can now see which bits of the Brazilian Amazon have been burnt by that ghastly government over there, and precisely what they're doing. You can see down to 20 square meters anywhere on the planet and that enables us to bring land into the game of climate change and it's cost effective to do a lot of this stuff.

Questioner: Thank you, that's really helpful.

Moderator: I will turn to Speaker 2, who will ask the last question.

Question: I just wanted to echo, to start, all of Speaker 1's comments about the importance of focusing on the land carbon sink. It's a major focus of our Net Zero America study, as well, which I won't have time to talk about in my remarks. So just to thumbs up on that.

I did want to ask a couple questions. I'm a little concerned about the idea of using land carbon sinks and protection of biological sinks as an alternative to decarbonization of energy and industry. Do you see differences in the shallow carbon cycle and maintaining the shallow carbon cycle in the biosphere relative to avoiding fossil emissions or permanent sequestration of carbon in geologic sequestration, which is a much longer-term cycle? Are they really equivalent? Should we be paying the same for the two?

And you mentioned briefly in your comments that need to sustain the political conditions necessary for a carbon price across the economy. I've yet to see very few political economies anywhere in the world even begin an economy-wide carbon price, let alone sustain them. So I'm curious if you could speak more to how you see that happening, and, if there are certain sectors that act as blockers for that, shouldn't we proceed as rapidly as possible in those sectors that can make progress today.

Speaker 1: Thanks for your questions, and it's a real privilege to be able to listen to what you're going to have to say in a minute. I don't think I can answer all your questions briefly, but I'll try. So, on the issue about sequestration versus emissions, of course you've got to do both. All my comments were really directed at saying you can't get away with it by just doing emissions. And the extent there is a political constraint on the willingness of people to pay, we should do the cheapest ones first, and the reason why some of the sinks in the land are particularly attractive is because, quite a few of them—but obviously not planting eucalyptus trees—produce a lot of other natural capital benefits, and we have to recognize that climate change is not our only environmental problem. The destruction of biodiversity is incredibly important, and I'm amazed that biodiversity is not treated at least as seriously as climate change, even though in some circumstances, they are correlated.

So, wildlife, biodiversity, mental and physical health, water management, air quality—all of these have payoffs which come from things that you would be doing for climate change reasons, as well. I made the point about the soil and the carbon dioxide. I see the two problems as joint problems challenging almost the existence of our species on this planet in 100- or 200-years' time, or at least a lot of the planet. And that's why I've gone that far. But no way do I want to not reduce emissions, I simply don't want people to believe they got there.

Our Climate Change Committee came out with a recommendation for net zero and I read it. I was so angry, that's what motivated me to write my net zero book. They said when we get to zero, we will no longer be causing climate change at zero emissions. I mean, what could possibly be more wrong than that statement.

So that's why I'm on that side. On the politics of this, you're absolutely right. We've just been through a consultation and debate in Britain. We've come out of the EU and we're no longer a member of the ETS, so the treasury produced a really good consultation paper which said, should we have a carbon tax, should we have a UK ETS or should shadow the European EU ETS?

They chose the worst option. A UK ETS. Why? Because industry lobbied to be able to use our industry department to do sectoral deals for each sector of the economy, which meant special pleading jobs, etc. And because our prime minister vetoed a carbon tax, because he didn't want customers to see any tax rise in their bills.

Now, my response to that is straightforward. It is that if you choose not to use the most efficient instrument, any other set of instruments you use will have higher cost than the one you've chosen. And you can pretend that the costs don't exist, but you can't abolish the costs by choosing the wrong instrument. So I really seriously ask the question, if we're not prepared to pay the price of incorporating our pollution in our consumption decisions, and politicians reflect the public's unwillingness to pay anything towards climate change, then the reality is we aren't going to address climate change. We're going to waste quite a lot of money. We'll have quite a lot of indirect costs, but we're not actually going to correct this problem.

And, to come back to my opening remark, that's what we've been doing for 30 years, pretending we're doing something about it, doing incredibly costly and inefficient things and making no difference to the concentration of carbon in the atmosphere. I play the role of an economist, in the sense of saying, "OK, if you really want to do this, I think it's a lot more expensive than you think it is. I think there'll be a lot more government failure. But if you want to do it in the most cost-effective way, this is the way to do it. If you want to tell yourself you're making progress, but just import the pollution instead, by not having the border adjustment. If you want to use subsidies and pay out to the lobbyists and pay more for doing that, fine, go ahead and do that. But don't believe you're going to meet 1.5° or 2°, because you're not." And that's essentially my argument.

Moderator: Thank you. That was terrific start for our conversation. I recommend everybody read *Net Zero*. You can get it on Kindle. You don't have to wait for the paperback revision, and it's, of course, very consistent with the summary that you just heard. Now, we're going to turn to Speaker 2 and *Net Zero America*. I warn you, I've got a question about page 204.

Speaker 2.
I'll cue up the slide deck for the full thing. Thanks, it's a pleasure to be here at the Electricity Policy Group.

I'm an assistant professor at Princeton in the departments of Mechanical and Aerospace Engineering and the Andlinger Center for Energy and Environment. Since joining the Faculty here in 2019, I've been fortunate enough to work alongside about 18 colleagues on this major *Net Zero America* study that came out as an interim report in December. We'll be producing a final report this spring.

As the Moderator's comment indicates, it's released basically as a 350-or-so-slide deck rather than a lot of prose. The idea is to help make it easy for folks to dive into the data and the results and not have to wade through the prose and comments. That's how we will be structuring the final report, as well.

This study kicked off a couple years ago with a recognition that we would be nearing perhaps a political turning point in the United States, with a change in government and seeing an increase in these net zero commitments that both states and major corporations are starting to make. And yet we'd seen very little detailed analysis of what it would actually take to get to net zero emissions in the United States across all greenhouse gases, not just carbon dioxide, but also, accounting for land carbon sinks and non-CO_2 greenhouse gases.

We wanted to look at a more granular scale, not just at a high-level set of modeling results. We've seen integrated assessment models and other studies that a national or aggregate scale look at this question. But really try to understand what it would look like across the country, on the ground, in terms of the amount of infrastructure that would have to be deployed when and where across the country and what would be the associated impacts, both costs and benefits, associated with that transition. So that's what the report focuses on.

What we did was create five different pathways to get the US economy to net zero by 2050. These are not the only set of pathways. There's, of course, many other possible ones that we'll go down. It's probably unlikely we'll go down any one of these specific pathways in the end, but what we wanted to do is map out several different plausible pathways that could achieve the goal of net zero greenhouse gas emissions and rely on technologies that we fundamentally understand how to do today. So, technologies that have been proven out, the engineering has been demonstrated at pilot or commercial scale or in widespread use today. So we're not relying on commercial fusion reactors or fourth-generation nuclear power or other things that we should be investing in today for future benefit, in recognizing the world doesn't end in 2050.

But also recognizing that if we're going to hit this goal on this time frame, we need to rely on technologies that can start scaling rapidly now, and that means there's little time to bring new technologies out of the lab and into the market at a material scale.

So we created a reference scenario, which is a benchmark that is used, similar to the Annual Energy Outlook from the EIA, with no new policy changes. You can see that in the current policy trajectory we get a little bit of growth in wind and solar, a little decline in coal and little else in terms of our eventual change in our primary energy supply through 2050. All of the other scenarios meet the same demand for final energy services as the reference case.

So we're not talking about wholesale changes in lifestyle or restructuring our urban economies to require less vehicle transit. It's a very business-as-usual type evolution of services, including no additional offshoring. So, the same domestic content share for our economy over time.

The five scenarios we created span three different key axes or dimensions that might drive us in different directions along the path to net zero—the first being the degree of end use electrification vehicles and buildings, space heating and cooling and buildings and industrial activities.

The second is the degree to which we rely on bioenergy or biomass in the economy. And the third is the degree that we rely on wind and solar power. We take a look at the five scenarios, the first two relate to that degree of electrification so the E+ and E- scenarios, respectively, involve basically full saturation of markets for electrification in the E+ scenario and about 50% saturation of those markets in the E- scenario. We have varying degrees of electrification there. Then, the E- scenario, with less electrification, there's greater demand for liquid fuels and gaseous fuels.

The other axis that we explore is a variant of that E- case that allows greater supply of biomass. So in four of the five scenarios, with the exception of this B+ case in the middle, we constrain the supply of biomass for the energy sector to avoid any conversion of new lands that are currently devoted to agriculture/forestry into energy production. That means we can use the current lands that are devoted to growing corn for ethanol production, which is about 40% of our current corn crop, as well as sustainably harvested waste biomass from agricultural and forestry lands and municipal solid waste.

So, in all four of those scenarios that have a constrained bioenergy supply, you can see that bioenergy grows relative to today. But all those scenarios basically max out that utilization of available biomass. In the E- scenario, since we have this greater demand for liquid and gaseous fuels, one way to meet that demand would be to rely more heavily on bioenergy. The E- B+ case is a variant that relaxes that constraint and allows conversion of lands from agricultural forestry into energy production and essentially allows the full billion tons study estimate of supply for the United States—that report that was produced by USDA and DOE on the estimated bioenergy potential in the US.

The last two cases are variations of our E+ high electrification scenario, RE- and RE+, which respectively push and pull on the role of wind and solar energy, as the third axis. The RE- case caps the rate at which we can deploy new wind and solar to the historical maximum that we've achieved so far, which is about 35 gigawatts per year.

That scenario is meant to reflect a future where we cannot scale up the supply chains. We can't deploy wind and solar faster due to siting constraints, or maybe due to the inability to expand our transmission at the pace required to support that growth. So it may be an extreme case where we can't go any faster than we have today.

But it's designed to act as a scenario that constrains wind's and solar's role and sees what else is needed. As you can see here, the orange bar, which is uranium or nuclear energy, expands substantially if we can't grow wind and solar at the same pace. As does the role for natural gas, primarily in stationary sources for methane reforming and power plants with carbon capture and sequestration.

And then, finally, RE+ case, it's 100% renewable primary energy supply. So wind and solar has expanded much more dramatically in this case, alongside the bioenergy to supply virtually 100% of our energy, along with a little bit from hydro, geothermal and other renewables. That scenario is fully primary energy from renewable resources. We achieve that by, in the model, prohibiting the use of fossil energy or geologic sequestration of CO_2 and require the phase down and retirement of the nuclear fleet by 2050.

So these scenarios look very different in terms of their primary energy supply composition, in terms of the degree of end-use electrification and the role of carbon sequestration or use. All the scenarios capture at least 700 million metric tons of CO_2 from point sources, which is a huge amount relative to today and as much as 1.7 gigatons or 1700 million metric tons in one scenario. Most of that is sequestered, if permitted, whereas the RE+ case, the 100% renewable case where we prohibit that, uses all the CO_2 captured from biomass indirect air capture for synthetic fuel production to produce a synthetic methane or fischer tropsch fuels for liquids to offset the use of fossil fuels.

What we found is that, while all of these pathways require wholesale transformations of the entire energy system, so by no means a trivial undertaking, they are relatively affordable, not net present value positive, but a modest cost, especially when you compare it to our historical expenditures on GDP and think about how much we can afford to spend to spend as a country while maintaining a prosperous economy.

This chart shows the historical share of energy expenditures in the US economy, which you can see during prosperous times is basically extended from about 5-8% of economic activity devoted towards energy purchases. During periods of great recession or oil price shocks, you can see that that that share spikes up, either due to economic contraction or higher oil prices on either side of the ratio here, to much higher levels above 8%, as much as 14% during the oil price shocks in the 1980s.

Now, if you look forward at the modeled costs of these scenarios, we see that they're in all in the range of 4-6% of GDP spent on the transition to a net zero emissions energy system. Some of them are more affordable than others by 2050, but through the first two decades of the transition there's very little difference in the overall cost.

And, of course, the further out we go, the more uncertainty there is about what the actual modeled results would be in reality. Note that this is more expensive than the reference scenario, in which we enact no further policy changes to transition towards net zero emissions. It's about a 3% increase in annual expenditures through 2030 and about 1-2% of GDP in 2050. So it's not an insignificant amount. But also note that we're not running a global CGE model with a good representation of global oil price responses to these changes in demand for oil and gas.

So we note that it's plausible that this reference case would be quite a bit higher cost if we think that, in a world in which we don't reduce our oil and gas consumption, that prices all else equal should be higher for oil and gas in that scenario than in the net zero scenario. So we fix them to be equal in all scenarios for comparability because we lack that CGE-type model.

But you would expect from basic economic theory that, if we're going to be reducing oil and gas demand substantially in a net zero transition, oil and gas prices would be lower than the reference case. Of course, these also look like nice smooth lines, and in reality, is an economy that still remains reliant on global oil price shock on oil would be exposed to global oil price shocks that might make the reference case much more volatile than these net zero pathways as well.

Final point on this is that, of course, these are private costs, direct expenditures on energy that don't reflect the public benefits of a net zero transition, including the avoided impacts of climate change, but more relevantly for the near term the substantial public health benefits that we estimate in the report as well, are on the order of several trillion dollars of avoided public health costs from reduced air pollution. So there's significant salient benefits to these pathways as well.

Of course, the fact that it's potentially affordable does not mean this transition is easy. I want to focus the rest of my talk on three different challenges that I think are important to focus in on. None of these challenges are about finding the most cost-effective route to net zero, so I'm going to take a bit of a heterodox approach here.

I understand the economic case for carbon pricing, I understand the economic case for the lowest single-cost pathway to get there. But I don't think that's how our economy works, and I don't think that's how politics works.

What I'm more interested in is the lowest-cost feasible route to get there, which is unlikely to be what we would ideally see out of an economic model. So there's several challenges that might impede our progress beyond just getting the price signals right. The first is the need to mobilize significant amounts of capital and labor towards the transition to net zero. So, whereas the incremental costs for household expenditures or business expenditures over the next decade may only be about $300 billion or less, according to our modeling, the amount of upfront capital that needs to be mobilized and invested over that decade is on the order of $2.5 trillion.

We can see here the areas in which that incremental investment is leveraged, relative to a policy-as-usual case. This is sort of the policy to-do list. We have to start mobilizing this investment now and we need to be thinking in a dynamic context, not just a static equilibrium context where we're trying to cause substitution between readily available substitutes. We have to think about the pace at which infrastructure and durable assets are switched over over time. If you miss the point of infrastructure turnover, the point where you purchase a new vehicle, the point where a new power plant goes online or an industrial process is retrofit or invested in, that infrastructure is going to be locked in for the next 20, 30, 40 years.

Some of those investments that we have to make now to avoid that lock-in will look like a very high marginal cost investment from a static equilibrium perspective but are actually the lowest-cost investment to be made in a dynamic context. Additionally, of course, technology and cost of solutions is not static either, and so, whereas Speaker 1 is arguing we've done very little to address climate change to date, putting aside the counterfactual question, I'd argue we actually have done quite a lot in the sense that we have transformed the economics of decarbonization in the electricity sector, where the cost of wind and solar have plummeted by about 70% for wind and 90% for solar over the last decade. And now for electric vehicles and light-duty electrification, where we've now seen the incremental cost for electric vehicles fall substantially. The battery pack costs themselves, which is the primary incremental cost, have fallen by about 85% over the last decade and are projected to continue.

That fundamentally changes the cost of transition and the balance of solutions available. So this is another dynamic reason to invest up front in things that may seem more expensive but are actually part of driving down the marginal cost over time and unlocking the lowest-cost transition pathway, as well as fundamentally altering the politics.

The reason we're seeing the majority of major US utilities committing to net zero transitions in the power sector is because of that fundamental change in the economic costs and the reason we just saw GM commit last week to fully transitioning their light-duty vehicle products over to electric, is again because of these dynamic technical changes. So we have to think about what policies can mobilize this kind of change up front and that may require—while a carbon price can help on the back end—a number of more proactive policies that may seem to increase the near-term cost but substantially reduce the long-term cost and change the political calculus of the transition over time.

The second challenge is that even if the cost is relatively affordable, there are a number of very real implementation challenges and tradeoffs across these different pathways. This chart ranks in order, from zero being easiest and 100 being hardest, several different potential implementation challenges and the ordinal ranking for each of our five zero emissions pathways.

And you can see from the spider diagram there's no single pathway here that dominates all of the others, that's easier on every dimension. In fact, what we have is instead is a whole series of tradeoffs. It's difficult for me to think *a priori* which of these challenges is likely to prove most challenging. In fact, many of these are likely to be threshold type challenges where the first amount of wind and solar deployed in a certain area is perfectly easy to do. But as the cumulative impact mounts there's a threshold at which public acceptance is thrown to the wind and there's no additional way to deploy further capacity. Same thing on any of these axes.

What that argues for is that we should be trying to make all of these pathways as real as possible viable options going forward, as well as opening up as many others as we can think of. Because if we move in one direction and run into impermeable barriers along any of these routes, we need other directions to pivot and tack to. And because of the urgency of climate change, we can't afford to fail in this transition, we need to make it as quickly as possible to reduce cumulative greenhouse gas emissions and to drive down the technological costs that the rest of the world needs to make that transition, as well. So we need to be moving along these axes as quickly as we can, without running into any barriers that halt progress entirely. Or, if we do run into those barriers, we need alternative directions to head to.

Much of our report was focused on moving beyond the headlines or the high-level modeling results like this to think about what those tradeoffs and impacts look like across the US landscape and to try to visualize those in a more granular and visceral manner. I'll start here with the high-level graphs and then I'll show you an example of that for the power sector. We have similar analysis for all of the major sectors of the energy economy, as well in the full report.

This chart shows the change in electricity supply across those five model pathways. We can see that, at least over the first decade, all five of these paths, or at least four of the five—the ones that don't constrain exogenously the pace of wind and solar growth—follow the same transition path, the least-cost transition. And that's to basically expand wind and solar capacity by between 550-600 gigawatts over the next decade, which would be sufficient to bring aggregate wind and solar generation from about 10% of our electricity in the US today to about 50% by 2030.

The second thing you can see here is the dramatic increase in overall electricity production needed to support electrification of end-use activities, whether we're in the E+ or E- case, as well as production of hydrogen or direct air capture, which also rely on electricity.

So we've got 150% growth in the first four scenarios and actually 300% growth in the RE+ case, because, in order to fully displace fossil fuels, we need an enormous amount of clean electricity to produce hydrogen and synthetic fuels from direct air capture and biomass of CCS.

You can see, also, that if we constrain the role of wind and solar, there's a much greater role for nuclear and gas with CCS. But mostly, again, after 2030. So we have some time to prepare and improve those technologies as they go forward.

This would require accelerating every year the rate of deployment for wind and solar from about 35 gigawatts peak now to an average of 60 gigawatts over the next decade, which probably means doubling that by the end of the decade to about 75 gigawatts per year.

So, to give an idea of what that looks like across the US, this is one of our spatially downscaled results, where we have here the current wind and solar capacity and their spatial extent across the US today. You can see the blue areas are wind farms across the country. If you look very closely, you can see some brown dots of solar farms that are hard to see at this national scale so far. Then, you see the transmission routes and major metropolitan areas in grey. This is about 150 megawatts of wind and 70 gigawatts of solar today.

This is what that might look like by 2050. You can see the enormous spatial extent of the wind buildout across much of the country, the northeast as offshore wind, using pretty much every site we can identify as viable. Now you can start to see the solar as populated across much of the country, as well, particularly in the southeast, mid-Atlantic and southwest.

In order to support this large-scale expansion of renewable resources, as well as the overall increase in total electricity generation, we may need to as much as triple the transfer capacity of the existing transmission system.

It took us 150 years or so to build the current grid; we may need to build twice that much over the next 30 years, which is of course a daunting implementation challenge. The model says that's cost effective but clearly an implementation challenge that is not in keeping with current pace of expansion in the transmission system.

As an alternative to deploying so much wind and solar, we could of course rely more heavily on firm low-carbon resources, like nuclear and natural gas to CCS or enhanced geothermal, that are more geographically compact and produce at a higher capacity factor. In the RE- case we need about 50%

less wind, solar and transmission built by 2050.

But, as you can see, there's no way out of the tradeoff space here. We need an unprecedented rate of growth of nuclear and gas with CCS, in order to achieve this change, with the average annual additions of new nuclear reaching 15 gigawatts per year by the beginning half of the 2040s and 25 gigawatts per year by the end of that decade, which compares to a record pace in the US of single-year expansion of 10 gigawatts historically. There is no way around unprecedented rates of change to get to net zero, and this is where the challenges really lie.

Finally, I just want to emphasize that while economists would counsel us as an important recommendation to find the lowest-cost strategies to get there from an equity and environmental efficiency perspective, we have to remember that all politics is local. I've yet to hear a politician stand up and say, "My policy delivers the lowest aggregate cost for the United States as a whole" or, "My policy is maximizing social welfare." I say it a little bit tongue in cheek but it's the reality. I've been giving briefings on energy policy questions for 15 years and I've never heard a decisionmaker ask me what the single lowest cost strategy is. They want to know if it's affordable, that's a threshold effect that's necessary for political progress. What they want to know is how this affects my backyard, my constituents, my industries, my families, my air that I breathe. Localized impacts.

What that means, I think, for us in the academic and modeling community, is that we need to focus our decision support tools and our analysis on offering more granular guidance and politically salient results beyond just the aggregate cost for the country as a whole. We have to keep exploring that finding as well, but we need to, as we talk about in the report, downscale those results to a finer scale.

As an example of that, in the report we focus on employment at a state level and granularity by sector and by type of job across the economy. If you look through our report, there's much more detail on the employment implications. This chart here shows the transition, the either increases or decreases are more or less flat in yellow. Employment trends at a state level, based on the E+ scenario. Because we have spatially detailed findings for where things are deployed, we can also estimate the jobs associated with that at a fine scale and give state level findings on the employment implications.

You can see that, as a whole, the country sees a net increase in energy-sector employment, about half a million to a million net jobs by 2030 and two to three million net jobs by 2050. But that aggregate change hides major shifts in local economies. That's where the politics is going to be most salient. So you can see, West Virginia, for example with declining coal production and power generation, is one of those areas with substantial change in the next decade. There are other heavily fossil-dependent sectors that are relying on oil and gas extraction or refining today, like Louisiana, that would see major transitions ongoing in the 2030s or 2040s. So this is where the politics is likely to hinge.

Then, finally, we also estimate the air pollution benefits at a county scale from reductions in emissions from coal power, motor vehicles and other sectors. Here, I just showed the two largest ones, coal and motor vehicles. You can see our current emissions and premature mortality is per county from both coal at the top and motor vehicles at the bottom today. In the E+ case, where we phase out coal entirely and with high degrees electrification, this is what that looks like by 2050—clean air, full elimination of tailpipe emissions, effectively, full elimination of coal-fired power plant emissions. And somewhere on the order of 200-300,000 premature mortality is avoided, which we estimated about $2-3 trillion in avoided damages. And that's without even counting the morbidities and hospitalizations that would also be avoided in this. This is only premature deaths we're estimating a broader set of impacts, as well.

It's these kinds of salient local impacts and immediate impacts, rather than the long-term avoided damages of climate change, that I think are going to drive the political conversation, as well, and that will ultimately determine what the feasible set of policies we can pursue looks like.

I'll stop there. Again, there's a 345-slide report. I encourage you to dive into it.

Moderator: Thank you. I'm going to go to the questions.

Question: Thank you very much. It's certainly a tour de force. Not only the 345 pages of results, but just trying to get a handle on the massive number of technical appendices that accompany this. In looking through one of the technical appendices, I'm struggling with the fundamental notion that we can spend an incremental trillions of dollars over the next 30 years and, somehow, it's not going to really cost anything relative to business as usual upfront investment in the grand scheme of things.

One of the things that struck me, I think was maybe page 19 of the technical assumptions document or the technical appendix document, is that there's a cost of capital that's used for apparently almost all of the technologies, including transmission, which is said to be 4% real. It's said to be based on utilities' weighted average cost of capital. In my experience in the industry, including now, is that the utilities' weighted cost of capital is considerably more than 4%, perhaps double or more than that. Also, when you look at people like Lazard**,** who are costing merchant generation, etc., they're using a number that's way north of 4%. Just wondering if you might just comment a little bit about that, because it seems that that might drive a lot of the ultimate numbers.

Speaker 1: So we do apply different weighted average cost of capital for different sectors. The fuel sector, for example, is higher risk, has higher costs to capital than the regulated industries. I don't believe it's the same cost across the entire power sector, but I'll have to go back into the appendix. You might be looking at the cost of debt, rather than the cost the weighted average cost of capital, because the cost of equity is going to be considerably higher than 4%.

Questioner: I may have misread it, it seemed to say 4%.

Speaker 1: I'll look and try to get back to you on that, but I think that the weighted average costs are higher than that. I think the long-term debt assumption is about 4% and it goes up from today's levels back to more historic averages, since we're at very low levels now. I think that my recollection is that the WACs are in the order of 6-9% across different sectors, but I'll have to confirm that. Thanks for diving into the appendix. That makes you maybe one of six that have done that. And there are more appendices coming, by the way, as we finish up the edits on those.

Question: That was really extremely interesting, obviously fantastically substantive work. Can I come back to the costs issue? It really is a segue from the last question, too. Two particular points. I made this remark earlier, that if the costs really are as low as people are suggesting, this is going to happen anyway, and we can relax and concentrate on some other things.

But I don't quite buy that. So, on the claim that lots of environmentalists make that the cost of solar and wind has collapsed, and this is a transforming situation, when I did the cost of energy review for the UK government I suggested that the cost comparisons were not on a like-for-like basis, and proposed that everyone should be at equivalent firm power.

And when you do that, for example, the idea that wind is fantastically cheaper than nuclear turns out to be not a tool as obvious as it looks. I assume in 20-30 years' time we'll crack all the storage issues, all the intermittency issues, the batteries or storage, that stuff. But in the short run, first question is, do these numbers stack up in your scenarios to produce the same cost result if you use equivalent firm power?

And my second point is that almost everyone concentrates on the dramatic falls in the cost of solar and wind. But they seem not to notice the speed of technical change and cost reduction in the fossil fuel industry. Nor is the comment about relative prices not absolute. I'm reminded that in 2014, November, when the oil price collapsed, many people in the shale industry were saying $100 oil is necessary to make this stuff fly, and then they were working and beginning to rebuild capacity at $35, with a dramatic fall in cost. These digital technologies, the seismology etc., would increase those bits.

If I had a third little rider, and you're very different from us, in the sense of you are one of the three world's greatest producers of oil in the world and you're in 10 million barrels a day, even after the shocks of the last year. What are the costs to America of closing the shale industry? I know what the benefits are. What are the costs of closing all that down? Have they been taken into account in your costing? So, equivalent firm power, relative cost of the oil and closure of the fossil fuel industry costs.

Speaker 1: Great questions. On the first point, my typical roadshow is all about the need for clean, firm resources, so I'm very much on the same page. I don't think that the method of assessment should be to require all resources to bid equivalent firm power. We don't need every resource to be a firm resource. What we need is a system as a whole that delivers reliability 24/7 for all weather conditions. What we need is firm resources to compliment shorter-duration balancing resources like batteries and demand flexibility and weather-dependent variable renewables like wind and solar. Those are three different buckets, and we can combine them in different ways to achieve an overall system cost that is reliable.

Now, in my modeling that I do in my lab with a very detailed electricity system planning model, we can capture all the hourly interactions with unit commitment constraints and ensure that we have that need met. This model that we use here, the **real** model, is about 40 representative days at hourly resolution, so it's better than NEMS, which runs 16 hourly time strips that are not at all connected, or even the ReEDS model from NREL, that does similar.

But it's not as good as a detailed power sector model, but I think what we can say with confidence is that we have enough firm capacity in the system to meet those needs throughout the year, and that requires between 500 and 1000 gigawatts of firm generating capacity across all model scenarios and all model years, which compares to about 900 gigawatts on the system today.

So, roughly the same order of magnitude is still needed. In the near term, that could be natural gas power plants as we phase down coal. But in the longer term, beyond 2030, we need substitutes for natural gas, as well. The ones that come out in the modeling, perhaps as most cost effective, is hydrogen fired in existing gas combustion turbines or combined cycle power plants that are retrofit to burn higher and higher shares of hydrogen. It's a very low capital expenditure cost, relatively expensive fuel, but for a firm resource that doesn't run very often, that's ideal. Then for resources that run more moderate capacity factors, gas and biomass to CCS fit the bill. For those that run more often, which tends to be less capacity, but more energy needed, nuclear or advanced geothermal would fit that bill. So we need a portfolio of those resources, as well.

Comparing levelized cost to levelized cost—in my other talks, I liken it to comparing the cost of a banana to the cost of a burger. It’s good to know the banana is cheaper than a burger, but that's clearly not all the information you need when you're trying to decide what you eat. It's only a piece of the puzzle.

On the incremental costs, I agree entirely there has been dramatic innovation in the oil and gas industry on par with the pace of innovation in the renewables industry. I liken that to another example of how we can change the cost of mitigation, the innovation. That was a dirty or moderately clean sector that's innovating. But it shows how rapid innovation can be when you do target investment into that sector, whether that's from natural market forces or from policy-induced market investment.

So I think you're right in terms of relative cost. We capture that with a very low oil and gas price trajectory in our modeling. So these are assuming about $50-a-barrel oil in 2050 and $3-4 gas, very low-cost scenarios in our modeling here, assuming that those trends continue. And we still find that the incremental cost of transition is relatively low. In fact, if you make oil and gas prices higher, the incremental cost gets smaller, because we're avoiding substantial amounts of oil and gas consumption at a higher savings.

Finally, on the impact on the domestic economy of reducing oil production, I’ll just note that, because we are still importing, we're exporting as well, but we're still importing oil. We can reduce the total imports, first, as we reduce our consumption, and that delays in are modeling the decline in domestic production till the late 2030s.

So, through 2035 US domestic oil production is about the same and through 2030 domestic natural gas production is about the same as today's levels. So we don't need to close the shale industry tomorrow. But there will be long-term transition costs, as we see the oil production decline by between 40 and 100%, depending on the scenario. We do not yet have estimates of the macroeconomic impacts of these changes, which are broader than what we're looking at here.

But if the direct impacts are on the order of a couple percent, the macroeconomic effects are not going to be 10%. They're going to be on a similar magnitude. They're also ambiguous. We have trade benefits, potentially, as well as reductions in domestic production from oil and gas. We also have significant public health benefits that should be costed into savings and reinvested in more productive things.

So the macro effects are difficult to estimate, but not going to change the order of magnitude, I would guess, in terms of the total cost. Just to finally close up I'd say, we're not saying that the market alone will do this. I don't believe the argument that wind and solar are cheap enough, we don't need subsidy or policy. There will be growth in those sectors, but nowhere near on the pace that's required to get to net zero, unless we have focused policy that is driving us there. So you don't let up on the policy. We want to be accelerating the policy levers at this point. That's our recommendation.

Moderator: Next question.

Question: You and I've talked about this report before. It's very impressive. Thanks, as well, for your response to the effective firm power thing, which, of course, has always been, for somebody who's spent 40 years in the power industry, is a red herring. It's always been about a system of portfolio of varied kinds of resources with varying degrees of firmness and I've always had the luxury of being able to ignore the relatively low-cost ability to make certain significant amounts of demand flexible without impacting the quality of energy services delivered to end-use customers. So I appreciated your response to that.

Your scenarios all show, quite rightly, natural gas as part of the fuel mix going to effectively zero by 2050. And, of course, under net zero, that makes sense, except in a scenario where you assume, let's take a significant amount of carbon capture and sequestration.

One of the conundrums that we all struggle with is about how to handle the retirement or stranding of natural gas transportation infrastructure. That's implicit in that eventuality. How did you guys think through that? How much of it were you able to reuse and repurpose? How much of it had to be retired or stranded? How did you deal with the stress costs?

Speaker 1: So, that's a great question. It's one we started to tackle but ran out of time to treat with the level of detail that it deserves. It's an area for ongoing study. While the power sector sees declines in natural gas consumption, the overall economic reliance on natural gas, basically, it falls by about two-thirds. So it's about half in the RE- case, where we rely more heavily on gas. It's about a two-thirds decline in the other cases. And then 100%, of course, in the 100% renewable scenario. So that decline is gradual, and I would expect that the main pipeline system, the interstate transmission, would still retain value. Not necessarily every line, but a significant amount of it, because most of the remaining consumption is at an industrial or power generation scale.

The distribution networks are where I think there's going to be real challenges. We do have an initial estimate in the report of what the decline in annual revenue would look like if we continue to charge volumetrically for natural gas, based on the volumetric changes, and a slide that shows the decline in the number of households with electric heating, which we think is a reasonable proxy for the number of houses that may disconnect from the gas system entirely.

I think that raises an enormous set of challenges around, when do we stop investing in natural gas distribution infrastructure versus avoiding leaks, which is an important methane reduction option today? And how do we phase down reliance on gas networks, while not sticking everybody who remains on the network with enormous bills? I don't think there are any easy answers to that question, and we certainly didn't provide them in the report.

But we are trying to shine a spotlight on that challenge for more for further analysis, because it is a key transition challenge. So we assume sunk cost basically for all of the assets, so that they're amortized over a fixed period of time. We don't assume that there's any cost of new investment in the natural gas distribution system, given its declines. That was our assumption.

Moderator: One last question.

Question: Thank you. That was a fascinating presentation. I'm on the board of the ISO New England and we recently heard a presentation from E3 for just our region that makes many of the same points. This is such a Herculean task of what's required. We go from a region of 30,000 megawatts to 150,000 megawatts, counting intermittency, vast developments of offshore wind, putting solar panels over a space equal to about a third of the state of Rhode Island. Literally, it's a small state, but in New England that sounds like a lot of space.

So the challenges are huge. What I'm really looking for from your group is a little more of the connecting of the dots to the policies. What is necessary if we were to have a carbon price to get this going, in your view? Given you have such a handle on costs, or you've made assumptions about costs and the pace of this. I would also add to that the combination of just how hard it is to, on the ground, make things change. Vineyard Wind has yet to get its permits. The linkage that's going to allow us to bring down another thousand megawatts of hydro power from Hydro-Quebec. The transmission link is now probably going to require a statewide referendum in the state of Maine because of strident opposition. I'm just trying to get a sense from you, having come out with your optimum results, have you backed it out up to what actually are the policies and what levels that would be required to push this through?

Speaker 2: In speaking with my report author hat on, my *Net Zero America* hat on, we were actually very deliberate in the report to not get into policy recommendations. Because there's several different ways to skin the cat for any of these sectors in any of these transition challenges, and we want to focus this report on laying out the goalposts or the to-do list for policy, without tying our analysis to any specific policy recommendations. Because we can disagree about the role of carbon prices, can disagree about the role of fuel economy regulations, etc. There's lots of different ways to push this change.

However you do it, this is the pathway that we have to be moving on. So that was the main focus of this report, to set out the to-do list for policymaking and to allow us to referee that debate, to some degree, going forward.

We're shifting our analysis over the next year, to analyzing specific policy proposals with the same toolkit, to try to understand how closely they get us to this pathway or not, and the relative costs and benefits. That'll be our focus going forward.

Putting a slightly different hat on, I was part of this National Academies of Science, Engineering and Medicine committee that just released a report yesterday on accelerating decarbonization in the United States—which is very complementary, it surveys a number of studies, including this one—to lay out what needs to transform on the technology and infrastructure side of things, but it also has a series of about 35 policy recommendations, an in-detail chapter on policy, as well. I obviously don't have time left of my clock to go through all of those.

But I dropped the link earlier in the chat to the study and I'll do that again when I'm off here. There's a nice summary table, as well as an interactive summary table, where you can filter by different sectors and different types of goals and see what policy recommendations were made there. That was a consensus committee of about 18 academics and other experts thinking about what policies we would need. Just to preface on the carbon pricing side, we did say that a carbon price would be an important piece of the overall puzzle. We recommended an initial price of around $40 per ton, rising over time, but also recognizing that that alone would not address the dynamic changes required, as I was alluding to in the beginning of my talk. Nor would it necessarily address the equitable transition challenges that are necessary to sustain political support for this transition over time.

So a lot of our recommendations also focus on how do we pull forward incentives for investment in durable infrastructure and innovation and address the localization of benefits and costs which are what's going to drive the politics. So there's a number of institutions that may be needed to guide investments and mitigate transition challenges in specific communities and industries, as well.

And those are pragmatically necessary, but also, ethically, you could argue they're necessary also. But even without that, they're pragmatically necessarily for you to sustain political support for a transition at this scale and pace. So I'll defer to the rest of the report for more details on that.

Moderator: That was terrific, and I'm going to defer my question about page 204. We're going to turn to Speaker 3, who's been working on these issues in various ways, in particular doing a lot of work on storage, although he has many things to say about the related issues.

Speaker 3.

Let me just make a quick comment. I couldn't help thinking in response to the notion that the transition is only going to cost a few percent of GDP. I remember, years ago, when I was very young, explaining to a politician, that a particular policy was only going to cost 2% of GDP and he looked at me said, "Son, do you realize they're only 100 of those?"

I'm going to focus on the electricity sector, but obviously the prize is economy wide. The plan, in the Princeton impressive study and many others, is you decarbonize electricity, you electrify what you can, and you greatly expand electricity to meet that demand. So, politically, if decarbonizing and expanding electricity is too expensive, it isn't going to happen. Though worrying about cost is important, cost is not the only thing. Average retail price of electricity will rise compared to the counterfactual, there's no doubt about that.

I'm going to argue in some detail if prices aren't efficient, widespread electrification may turn out to be too hard to be feasible. The reason for worrying about this, we focus on 2050, which seems a little bit silly. But if we put in place policy designed to drive decarbonization now, that basic policy design, that architecture, will be with us for decades. Look at the American Clean Air Act amendments of 1970. Attainment, non-attainment distinction is still with us for all its warts, and there are plenty of other examples. So I think it's important to think about what the pathway will look like.

I'm going to talk about some work from this ongoing, it's perpetually ongoing, study on the future of storage. We're looking at efficient systems, circa 2050, making up costs numbers, of course, as one does. It differs from the Princeton study in a number of ways, obviously it's focused on electricity. We don't assume a great deal of biomass, so we don't have a lot of zero carbon dispatchable resources on hand. And we're not looking at sequestration, explicitly, although I'm going to come back to it. Speaker 2 talked about using 40 days of data. We use seven years of hourly data to really find out exactly how perverse and difficult wind is.

I'm going to make three main points and they're all simple points. Let me run through them now and then try to support them. We will need to do more transmission, obviously, to increase the scale of the electricity system. We're building transmission now. The hard part is inter-regional transmission boundary-crossing lines, crossing state lines, crossing regional lines. They matter a lot. The best renewable resources are not next door to load. You can put gas plants next door to load; you can't put really efficient wind next door to load.

There are 40 megawatts of rooftop solar in the state of Maine, the last time I looked, and no matter how you look at it, that's wrong. You really want to move solar power from the southwest, you want to move wind power from the midwest. That means the kind of power lines that are hard to build or the ones that are essential. The policy problem there has to do with state and federal interaction. It's complicated, and it's going to take a long time to sort out and we ought to get on with it.

The next point is substantial. In our modeling, under a variety of assumptions, I'll give you some examples, you can cut the carbon emissions pretty dramatically at pretty low cost using wind, solar and storage, and maybe a little bit of hydro. Gas turns out to be absolutely critical. If you go to zero and take out gas, the marginal cost, the carbon price, the shadow price on a carbon constraint, becomes very high—which leads you to think we should be thinking hard about direct air capture, if this is where we want to go.

We should think about not taking zero in the electric power system too seriously because that's not the object of the exercise, anyway. We should start focusing now on other sectors. The notion that we'll decarbonize electricity and then start to think about home heating is not going to get to the end.

This, I must say, was a bit of a surprise until we looked hard at it and thought about it. If you look at an efficient decarbonized system, wind, solar storage and a few other things around the edges, wholesale prices, marginal cost much more variable than today. Much more variable. There are large fractions of the year, when the price is effectively zero.

Well, if you can mirror that in retail prices, you can encourage electrification, you can encourage load shifting, you can encourage innovation. If you price dollars per kilowatt hour, then, gosh, that price goes up and electrification becomes harder and more expensive and it's not a good plan.

Now, changing the way we set retail prices, like figuring out how to build boundary-crossing, high-voltage transmission lines, is not a simple policy problem, but I think it's a very important one.

So this is a report on some stuff that was done under the umbrella of the project that has since been published in *Joule*. You can you can see the details there, but Pat Brown and his co-author looked at the cost of decarbonization under a number of assumptions about interconnectedness. You go to 48 isolated states, 12 isolated interstate zones, and then one interconnected system and you optimize a power line construction. The limitations of the study are at the bottom.

The main point here—and it comes off the intuition that good wind and solar are not where load is, there's some distance—the cost of getting to the top, 100% decarbonization, which they do, is much, much higher if you don't have a fully interconnected national system. Because there's load averaging, but there is, I think, more importantly, spaces where load is cheap. You would like to get the power from the southwest in the early afternoon to the east coast, where it's the late afternoon, and the solar there is ramping down. So, figuring out how to do this as a policy matter is both important and hard, and will take some time.

The rest of what I'm going to talk about is based on our regional modeling, which is much more detailed. I'm not going to go into detail here, but we pick three regions, for a number of reasons. It's basically a constant returns model with perfect four sides, seven years of weather data, and a bunch of available technologies. In the base case, lithium ion is the only storage technology available and in further runs we had other technologies. I'll show you a couple of them.

As I say, we differ from the Princeton study in that we do not have biomass at scale. We're going to explore the implications of biomass in the southeast, where we think it is probably going to be more attractive than, say, in Texas. But we haven't done that yet. So, different CO_2 constraints, different assumptions about technology and costs, adding demand flexibility, blah blah blah. These are not trying to pick winners. What's the best storage technology? Not going to answer that question because, who knows. We're having big debates among the engineers about the costs of technologies that haven't yet been built. So you can't take the specifics of what turns out to work best very seriously. But there are a bunch of patterns that, as we ring these changes, seem to be robust. That's what I'm going to focus on.

Here's the northeast model and the Texas model. We are constraining carbon emissions in terms of grams per kilowatt hour. I'll tell you what that means in terms of percentage reductions in a little while. But if you look up at the top, and then in the no admission limits case, Texas goes from 481 grams CO_2 per kilowatt hour down to 83 with no constraint. That's wind and solar getting a lot cheaper and storage being pretty cheap. But it doesn't get you home. That just says, with no extra cost, you will get a substantial reduction.

You start to tighten the carbon constraint. If you look at those graphs on the left, those bars on the left down at the bottom, the bright red is combined cycle gas, you use a lot of it. It gets you through periods of low wind, it is terrific for that. You don't necessarily run it that much, but it's there. It is, in effect, long-term storage.

So, as you tighten the constraint, of course, you reduce the emissions. You go from combined cycle gas to gas with CCS. When you get to zero, you will see that bar jumps, because you've eliminated all the gas. CCS is 90% effective, not 100%.

If you really mean zero, you can't use gas, period, full stop. If you see on the right, down at the bottom, what happens with storage requirements. When you go to zero, you got to put in a lot of storage to get through bad periods, and this is storage in lithium ion, and that's expensive.

Let me now look at what is the average cost of electricity, and then the marginal cost. This is just Texas, because it was handy, but these are the system average costs for delivered megawatt hours, again, in various carbon constraints. If the constraint is 10 grams per kilowatt hour, for instance, that's 88% reduction from the no-limit case.

And the cost rises from $40 a megawatt hour to $45 a megawatt hour for an 88% reduction. Not a big deal, you go down to one gram, which is a 99% reduction, the cost rises to $50, more or less. You see that there's the fuel price, with the variable OM + Fuel, that orange at the top, shrinks. By the time you get to zero, it's all capital costs because it's all wind, solar and storage. There's no gas. But the bars have jumped up. So it says you can do substantial decarbonization at modest cost under our kind of pessimistic technology assumptions. But going all the way is very expensive.

So, here's the marginal cost. We put an optimized subject to a carbon constraint, and this is the shadow price on the carbon constraints. It's the carbon price you'd have to impose to get this result in a perfectly competitive market. You'll notice the log-scale on the left. You go to 40% decarbonization in Texas from the no-limit scenario, you're under $100 to go to 88% or somewhat over $100. To go to 100%, you're a million dollars per ton.

The northeast is a little better because there's some Canadian hydro that helps. But you're over $10,000. That's not going to happen. Nobody's going to impose those kinds of carbon prices. If people are serious about driving decarbonization with a carbon price, as you get toward the end somebody's going to say, "Well, I can do direct air capture for that." Well, yes, you probably can, but let's build a few and see. Or maybe we should back off on electricity and focus on other sectors. Or maybe we should stop obsessing with zero. Let's get the zero in home heating. Let's think about a lot of other things. But the notion that the carbon price to get you to zero would be astronomical, I think, will be news to, say, Rhode Island at that small US state, which I think wants to get to zero by 2035. Good luck with that.

Let me go to my last of my three points, and that has to do with price variability. This is the first of two slides that Paul Joskow did for us that looks at prices in ERCOT in 2019. What do they look like? System Lambda, basically. The average hourly day-ahead price, there are very few below $5 a megawatt hour. There are very few above 50.

Next slide is the same story. Very few below 5, very few above 50. The next side is Texas under various assumptions about the carbon constraint. You see the carbon constraint at the bottom. The one on the left is a set of outputs with a set of price distributions with only lithium ion as a storage technology. The one at the right adds hydrogen.

There are a number of technologies that might change it a bit. Those pictures are hard to read. The bars at the bottom are easier. The green is the fraction of the time when the price is below $5 a megawatt hour, and it's a lot. When you get the tight constraints, it can be 60% of the time. But everybody breaks even here, these are linear models. Everybody breaks even, which means they make all their money in a few hours. The generators make all their money in a few hours, the storage suppliers make all their money in a few hours. The blue is between 50 and 200, and on the zero, you can't see it, it looks like it's always below five. Well, no, it's not always below five. It's below five most of the time and then occasionally it's above 1000.

This is New England, in addition. It's a similar picture. A little less dramatic but a similar picture. The price is very low for a reasonable fraction of time and then very high for a little while. And the question we asked ourselves, what would a power system like that looks like from a regulatory and market design and institutional design framework? I mean, these are the efficient outcomes, these are the competitive and equivalent outcomes. So you could decarbonize with huge renewables, a tight renewable portfolio standard or a clean energy standard.

What do you get? Well, you get distorted wholesale prices. We all know that, because you can get negative wholesale prices because it pays to generate to support to get your clean energy certificates or your RECs. Carbon tax doesn't do that.

I keep reflecting that my son in Hawaii loves his electric vehicle. It costs him 30¢ a kilowatt hour to charge it anytime of day or night. So, at noon, when the Hawaiians are busy curtailing solar, because they have a super abundance of it, it's 30¢ a kilowatt hour. Late in the day, when they're scrambling to run their coal plant flat out to meet demand, it's still 30¢ a kilowatt hour.

Now run that large to 2050, and you have a very inefficient system that's going to resist electrification. Because there's going to be no way to avoid those high prices, prices will be up and there's going to be no way to avoid them. So what do you do? Well, the economist in me says, “Hey, here's what we do. We have an energy-only market with dynamic retail rates and we just pass those efficient wholesale prices through.”

I love this and it'd be great. But I think there are two problems. First, you will have enormous investor pushback: “You’re telling me to build a huge wind farm, but I will make all of my money in five hours during the year and you can't tell me when they'll occur because everything is very variable?” But that'll be a great thing now. In terms of all the net present value calculations in the world, that can be a perfectly fine opportunity. But I think it'll be resisted.

The second problem with this is, look at the behavior of ISOs and regulators now. Look at all the interventions in the market. California storage mandates, out-of-market actions to reduce prices. That's now, with relatively low natural variability. Imagine a regime in which there is enormous natural variability. How will regulators and ISOs behave? I don't think they can keep their hands off, I think these are humans.

This is just about as hard a policy challenge as building long-distance transmission. There will be market interventions. You would like a regime in which they're disciplined. I hate to say integrated resource planning, but that smells better than the kind of mandates that keep flying out of California. The costs of generation are basically fixed, so you want to subsidize capacity, which means you want to move, I think, to a retail regime that uses two-part tariffs, where it's fixed, like mobile phone pricing. There's a fixed component and a variable component, and the variable component ought to be low when the wholesale price is low. And the fixed component is going to have to pass an equity test. It can't be the same for everybody.

How do you do that? There's nothing technically hard here. The models all say the same story. I think that's a hard policy question. How can you get to a regime like that? If we can't, we'll be paying 30¢ a kilowatt hour to charge your electric vehicle while solar is being curtailed. We'll be complaining that not enough people are buying electric vehicles and we've got to up the subsidy again. Eventually somebody's going to say, "Wait, why do we have to up that subsidy again?"

That's what I've got. Scott Berger's work is good. I think there's more to be done there. We can talk about that. I will stop here. Thank you all for your attention.

Moderator: Thank you. I thought you were going to explain to me how batteries can sometimes charge and discharge at the same time, but maybe we can talk about that later. On to the questions.

Speaker 3: Actually, let me give you let me give you a quick answer. OK, sometimes you want to increase load to avoid shutting down a fossil generator, for which you will later incur startup costs there. I saw on an island in Hawaii, a dispatchable, complete waste load that generates waste heat. And they ramp it up to keep shutting down their gas generator, because it'll trip off if the load is too low. Batteries can do that too. It's a weird quirk of the model. OK, sorry. I love that story.

Moderator: Thank you.

Question: So great presentation. As a former regulator, I want to press you a little bit on this idea that we can't get to efficient retail pricing. Because we've actually done some work built on some of the work that Scott and others at MIT did prior to us, but really begins to look at this question of how you combine a dynamic component of retail price with a component, that is, that recovers the residual costs in some equitable way, doesn't have to be uniform. It can, for example, be some sort of subscription rate based upon expected demand levels that tends to be more income progressive than just looking at usage.

But there are lots of variations of ways that you could get to differentiated access charges to recover fixed costs. I think the other components that you seem to not have addressed—and I'm curious as to how you would—is, on the one hand, I think there will be, and we see this today in the Texas market, for example, a desire to hedge against those very high prices. Those hedges in turn produce long-term contracts that enable capacity investment, number one.

Number two, I think there is a rule, when you have retail suppliers, for having some financial stress testing to ensure that they can, in fact, serve loads at the prices that they guaranteed to their customers, even if you have very high prices—which also, then, will encourage that kind of stress testing.

And, number three, I think, there is also some need to think about and, together with my colleagues, we've actually been doing some thinking of this in a PERFORM ARPA-E project—to think about how you look at that risk of shortage of supply on an hourly and nodal basis and begin to be able to push that into the energy market, where customers can actually say, "This is much how much I am willing to pay to avoid the risk of being short supply."

All of which suggests that there may be mechanisms for beginning to price that risk of variability in ways that we don't do it now. Clearly, as a very different dynamic from what retail regulators have done historically, but I think that one of the challenges and one of the opportunities that we face is to really present to retail regulators precisely the kind of analysis that you and others in this program have laid out and suggest we need to think about how we change regulation in order to meet the challenges of getting to a low-carbon economy, rather than start with the premise that says, "Well, we're stuck with the regulation that we have." Because I think, if properly presented, there are ways to begin to change that dynamic. Appreciate your thoughts.

Speaker 3: I hope you're right. I didn't mean to say you can't conceptually get there. I didn't mean to say you can never persuade anybody. I think smart meters and retail competition may push beyond regulation to get the kind of retail prices that will be conducive to electrification. I have to say, once I saw those modeling results with those long periods of low prices, I said, "Ah, that's how we get to the rest of the economy." There's a lot of load that can be shifted, not out, not all of it, not all of it, but a lot of it. Of course, when you shift the load, you affect the price distribution and that's all fine. The most common examples of load shifting are hours. You can do that. You can shift when my son charges his electric vehicle, shifting when you do the wash by a month, because it's low wind. Well, maybe not. But there's a lot that can be done.

I take inspiration from the European scheme, which doesn't seem to sell well here, where basically you pay for a maximum kilowatt consumption. This is not on peak consumption, this is not the commercial and industrial demand charge, this is the max you're going to take and that's a flat fee. You pay for it, and then you pay a marginal charge. Well, that strikes me as likely to be pretty highly correlated with income and to strike people as fair. There's no marching band behind this proposal. But I think it moves in exactly the kind of direction you're talking about. So, I'm hopeful, but the regulatory system doesn't move in leaps and bounds. If it's going to change, it needs to start changing.

Questioner: I would I would very much like to create that marching band, because I think it's important and some of our work, in fact, references the Spanish default price, which is that kind of demand-based access charge, plus a wholesale spot price.

Moderator: Next.

Question: I very much appreciate the work that you've done on this, and the work that you've done over the years on emissions trading. I want to come back to the point, kind of bring something together that Speaker 1 said in his presentation and what you've mentioned here, which is regarding the marginal cost of abatement. The CO_2 price to get to zero or even to get to five grams per kilowatt hour would be political suicide, if you will. This is where I think an economy-wide carbon price bails the power sector out here. Because there are other means by which emissions could be reduced, or you could have offsets of the type, whether it's with planting trees or soil conservation or anything else like that.

Are there any plans for you all to do work like that, kind of looking at if you had an economy-wide carbon price, and what that might look like, in terms of deal with the opportunities would be for the power sector on this, especially for the gases that are going to be needed to maintain system balance and reserves, etc.?

Speaker 3: There's an opportunity to go there. I don't think we're going to go there. I think my fear is that when people start to see the prospect of needing a very high carbon price, they'll say, "Oh, I've got it. Instead of taxing the dirty thing, we'll subsidize the clean thing." And we will bury the subsidy costs in the per-kilowatt-hour volumetric charge. That works like a champ.

It discourages electrification, it leads to all kinds of inefficiencies, it screws up wholesale markets. But it's much less visible than a high carbon price. That's my worry. I think it's important that that not happen. It's important that we begin to think about other ways to say when we want to decarbonize the economy, let's think about all the other sectors right now. Let's push on those to go down before we push on electricity to get to zero, and maybe we don't go—there's this implicit notion in the policy discussion that we'll get to zero and electricity, then we'll do the other stuff.

Well, that's not going to do it. I think it's clear from that Princeton work that you have to start everywhere, at the same time. And maybe when you get close to zero somebody will say, "Oh, you know, we should be doing direct air capture this way and it's actually going to be cheaper" or something. But we're not going to see those carbon prices.

Questioner: If I could follow up just very quickly here. With some of the stuff with electrification and the right design—by the way, I want to get on the same band, I'll be the tuba player. That issue, about what do we do with some of the money from a carbon price. Let's say we get to 10 grams of CO_2 per kilowatt hour in your simulations. Is there something that we could do to move that money around to other places, to encourage or to offset some of the other harm in the economy? To Speaker 2's point, he's worried about the politics of all of this, looking at the old revenue recycling literature.

Speaker 3: Well, I think that the temptation is going to be—go back to Waxman-Markey—the temptation is going to be to spend it on all kinds of good environmental things, which will probably not be the best use of it, I would say, either politically or certainly economically. What economists say is, "Look, we've got distortions in the economy. We've got all these other taxes on labor and capital and whatnot. We should reduce those taxes." Well, that's completely unpopular unless, of course, it's taxes on real estate development and the Trump administration—oh, nevermind.

I think that's too cynical, but you know that's the economic prescription, that the gains are from reducing distortions, not subsidizing your favorite environmental project. What will happen, maybe it goes to low-income housing, maybe it goes to weatherization. I think it becomes a political calculus with economists sitting on the sidelines saying, "But what about the other distortions?" And probably nobody listening. But we did take a professional oath to say that sort of thing when it's true.

It's right, as Speaker 1 or Speaker 2 said, nobody lined up to say, "Obviously, do the least cost thing." No politician does that. The calculus is more complicated. But I think economists perform have a valuable if unloved function, by pointing out what the least cost approaches.

Moderator: OK, thank you. I'm going to just power on through here. We're going to turn to Speaker 4 and his work, particularly on a theme that's already been discussed and mentioned as being critical to all of this, having to do with transmission. I hope he's going to tell us about his extensive work in this matter of late.

Speaker 4.

Thank you. It's an honor to be here, I don't know how I'm qualified but it's always a pleasure to join these HEPG sessions. Michael Goggin is also in the audience; we've worked together on this stuff. We work for clean energy interests, more energy buyers these days, than sell side. We've been banging our heads on this issue for a very long time, I guess that's our main qualification.

I don't need to add much on the consensus you've already heard about a very high renewable energy portfolio in the power sector driving electrification of transportation and heating. I will not disagree with Speaker 3 that the last 10% is very hard and expensive. We talk a lot about getting to 90%, and the rest needs to be figured out by engineers and R&D and innovation in all of that. But I do think there's a relatively clear path towards 90%. In the Princeton study, the only one that didn't have nearly as much wind and solar was the one that specifically constrained wind and solar. So we'll get to the issue later. Transmission becomes, I think, the real limiting factor, but hopefully we can unlimit some of those constraints.

Our rate of all these studies—NREL studies, different national labs, E3, MIT, Princeton—all these studies end up with a relatively consistent portfolio and there's a natural reason in the power system to wind up with a relatively consistent portfolio. The portfolio tends to be around two-thirds wind and solar, and then a fair amount of new transmission. The Princeton study was about a tripling of transmission capacity, then, certainly, storage and then flexible and firm resources. This is where the existing gas fleet plays a major role for a very long time in, again, getting us to 90%.

Beyond that, some clean, firm source is needed, and we just don't know what that is yet. But the portfolio effect is also understandable if you look at effective load-carrying capability, or the declining capacity value that these resources have. When you get to a certain level, they can only contribute towards peak load or really peak net load.

Not very much declines, over time, which means you wouldn't do a solar-only scenario, you wouldn't do a wind-only portfolio. All these studies end up with high penetration where these sources aren't even really competing with each other. They're producing at different times and places, so you end up with this balanced portfolio.

I find these charts very useful. You've heard the same thing from Speakers 3 and 2, but if you look at the hourly output, and I think we're going to see a lot more of these types of models—I'm partial to the vibrant clean energy—but others are doing them. The list of researchers is there at the bottom doing these types of our early studies, where you get very granular wind and solar data.

This is a scenario in the winter, so there's not a lot of the red blotches, which is solar during the day. You have a lot of wind, most of the time. Of course, if you go a few hundred miles away wind output from one wind farm to the next is almost not correlated at all. So there's always wind blowing somewhere. Except, every once in a while, you get these three-day periods with a large high-pressure situation or just certain periods where you have a few days, so you do need that.

Usually the models find the existing gasoline fills that that gap that's the gray. Existing gas for the beige imports. Transmission and some flexible, firm resource needs to be around. We'll get into the market design implications of that later. These, in fact, I think there are two major issues before FERC, and we'll talk about them, one is large-scale transmission and the other is how do you do this energy adequacy and compensation for those resources that are low capacity factor. You got to pay for them somehow.

So turning to the policy agenda here. I'm in the Washington, DC area, I've done federal policy pretty much my whole career, including on the Hill. I think all of our ticket to admission is to say, bow to the economic gods and say, "Yes, carbon price is the hands-down best way to go, it's more efficient." This is just for my own bona fides. I came to Washington in the early '90s. Don't read all this, this is just what I said. Yes, I'm on board with carbon price, and maybe we can all make a pact to say to policymakers, "Do carbon price first. That's the priority. Try to get that done."

That's nice. But it's Manchin's world and we're just living in it. Senator Manchin has said this in many different ways: "I have repeatedly stressed the need for innovation, not elimination." Here's the famous campaign commercial taking a shot at the cap-and-trade bill. Trump beat Biden 69 to 30 in his state.

Similar issue in Arizona. It's a back and forth state. Senator Sinema, you need all Democratic votes to do anything with taxes or spending, including a carbon tax, and you need 60 votes. You need 10 Republicans, in addition, to do any type of energy policy. So that's just where we are. Personally, I support Biden's goals. But they're just goals. They're not policies. You look closely, there's nothing yet that says under what authority any of that's going to get done or how any of this is going to get passed through Congress. The Supreme Court and the Senate aren't going anywhere. So what the hell are we going to do?

I think there are some real policy options on the table, and Bill Hogan is fond of saying, "If you don't advocate for carbon price, you're not serious." I would also add to that if you don't recognize the political constraints, you're not serious.

These are the things that are on the table as far as I can tell. Maybe others have a different view. EPA can try to regulate the power sector, as well as other sectors. The Supreme Court is probably going to reject it. But might as well try. Federal clean energy electricity standard, I hear it's less efficient but potentially could pass. How are you going to get all Democrats and 10 Republicans is not at all clear. Vehicle emission standards, that's probably the most-likely-to-succeed policy. There they can do that. Energy efficiency standards, as well.

FERC transmission rule? renewables are cheap, it's delivery that's the problem. FERC can help get a lot of transmission built or we can treat the macro-grid more like the highway system and just pay for part of the things. Then you can you can make a lot of progress, just based on the economics. Tax credits? I don't know how many HEPG sessions we've debated PTC and other tax credits. Again, not as efficient, but here we are. They can pass. Go back to Manchin's quote on that earlier slide.

You could, with any of these, make them a little more efficient. Tax credits could be technology neutral. They don't have to be wind specific or solar specific or carve-outs for this or that. Same with a clean energy standard. They can include a lot more technologies and be less targeted and that's more efficient. Then, of course, state policy is very important. At the federal level, that means allowing the states to do what they want to do.

We can talk about a minimum offer price rule." But it's other sectors, as well, allowing other states to have higher vehicle emission standards and things like that.

Now, this is a question we've also debated here a lot. Are these 10^{th}-best types of policies or first best? I'll make my point once again, because they're not perfect. But they're not 10^{th} or 15^{th}, either. They've actually works quite well. Renewable electricity standards and tax credits have been the reason those costs have come down 90%, 70%. Because we deployed, manufacturers learned how to do it more and more cheaply every year.

And, again, renewable standards are now giving way to clean energy standards, so you can include more resources in them so you could be more efficient. And, of course, these policies are more popular. So, if there's a given amount of emissions reductions needed, you can get close to them. I don't know if we can get near where we need to be with any of these, but you can get a lot closer with this than you can with pricing or taxing.

And then, of course, carbon prices are not always perfect. Their efficiency depends in part on what you do with it. What you should do is, of course, use it to reduce more distortionary taxes, like working and investing. But that may not be what actually happens. Carbon price is also kind of held up as the objective, scientific way to go. But don't forget just how subjective that is. There are factors in a carbon price that completely swamp the evaluation, tripling the value of it, depending on 4% versus 2% discount rate. Ultimately, discount rate really is a value judgment. There's no economic truth of science, really, when you're talking about intergenerational equity, in my opinion.

In terms of impact, this is just for wind, but if you look at that geographic overlap, at least in this country, of wind production and coal output, there's a quite a lot of geographic alignment. You are displacing mostly coal, most of the time, with the wind production tax credit. It's not necessarily inefficient to do that.

Turning to transmission. All of those studies of large-scale decarbonization find a need for a massive amount of transmission, on the order of doubling or tripling the delivery capacity of the grid. This is for a few reasons. They happen to be, I think, true in most countries, that the best resources are far from load. Also, to get an overall more firm supply, more balanced supply to meet load, you're sending power back and forth bidirectional or multidirectional in order to meet load. You need to be delivering across balancing areas RTOs interconnections, all of it.

And, yet, our current approach to transmission was really designed for a different fleet. It was designed for the gas fleet. I mean, let's be honest, I was there at FERC, in 2003 we authorized participant funding, putting all 100% of the cost of new shared network upgrades on generators, and there was a price signal there. There was some economic value. But look what's happening now, the interconnection queues are a complete mess. Nobody thinks the 734 gigawatts are all going to go forward. But they're all stuck there in well-known pockets. These resource areas are well known to everybody.

What happens is the generator goes there once they get to the point where the transmission capacity has been exceeded. Suddenly, the costs skyrocket. The network upgrade costs assigned to the next generator go up fivefold. Then, what happens, they drop out of the queue. Now, everybody else has to be restudied. The poor RTO staff have to go study everybody else. Now, you're talking a four-year process and it's unstable. It's a system that is unstable. It just doesn't work.

This is a slide of the costs going up. Jo-Ann sent around the paper that has more detail on what's happening, the basic point being we've reached the transmission capacity limits. The costs are going up. So, we have a dysfunctional generator in our connection process. What we really need to do, all these models show, I think the easiest way to think about it is we need to be moving tens of gigawatts across and between regions, and that requires very large-scale transmission.

Transmission has massive economies of scale. To do this efficiently, bigger is better, almost the maximum-sized line you can you can get. Obviously, using existing rights of way would be better, but we really need to figure out how to do this. Especially, I would say, the cost allocation process. Because, as I know, some folks in the audience will say the current economics of transmission don't look so good if you're a merchant developer. Who's your customer for 10-20 years capacity commitments? And, on the basis differentials, it doesn't look very good at all in the near term.

There's a defeatist attitude around transmission, so I try to show this. We've done big transmission before, the MISO MVP, SPP priority projects and the California ISO and then ERCOT CREZ. There was a standard formula. You proactively plan to the known resource areas, you do it as high voltage as you can. In all of these cases, by the way, I think they look back and wish they had done the higher voltage version of it, because we've pretty much used up and fully subscribed on that transmission.

But we did build big transmission. Each one of these added access to another 10 or 15 gigawatts of renewables and improved reliability. Then the cost allocation was relatively broad. Obviously, ERCOT is full socialization. The others are in the FERC world of roughly commensurate with beneficiary pays, and we can do that again.

So, I'm advocating another round of major for transmission planning order, following and building upon the agency's similar orders in 888, 2000, 890 and 1000. I think 10 years after Order 1000, it's time to fix what doesn't work and adopt what does work. Here are a lot of the principles, the bottom right is more and better use of benefit-cost analysis I commend Bill Hogan's work on that. It's the right way to evaluate how much is needed and where.

Then, doing the cost allocation as closely as you can to that is also economically efficient. But keep in mind that we are very much in the planning process. This is a regulated industry. There are regulatory decisions about how much need to be planned. We're not doing this based on voluntary investments and FTR allocations, as some would work. We're taking into account economies of scale and all the network externalities and every market failure that exists in the transmission system. That is, hopefully, a part of an overall efficient market structure where generation is fully competitive—again, T & D or monopoly and regulated like monopolies.

The RTO, in my opinion, is limited to the two functions of balancing the real-time market doing all the standard market design. Yeah, I'll use the phrase. Along with scarcity pricing that's a key component that's becoming a best practice. Also, planning transmission. Environmental and energy policy is done exogenously. There are increasingly a lot of folks who say that should be done within the RTO and FERC world. I'm not sure that's really needed. I don't quite see the benefit. Policymakers, I think, should set, whether it's the carbon price or the clean energy standard or whatever it is. But I don't see why it has to be integrated.

We started getting into this with Speaker 3, who is saying how the hell is anybody going to invest when prices are zero most of the time and all the money's made in a few hours. I agree that's an issue. Again, we do need the scarcity pricing to make sure that prices do get to the right value lost-load level at certain times.

That absolutely does make a challenge. I still think the Texas model works. I think voluntary contracting can work if we have the right incentives and structure at the retail level. Texas does have that. The other 13 states that have retail competition, I think, have a polar distortion and they have a lack of creditworthy buyers. The retailers aren't actually creditworthy enough to procure the power they need to procure to serve their load. That needs to be fixed.

Now, if a state refuses to fix the retail market for whatever reason, as the recent Joskow and, I think, Schmalensee work shows, there are better and worse ways to do contracting. It could be done inefficiently, they could be done more efficiently. I don't want to give up hope on the voluntary contracting and the ERCOT model. But there are ways to ways to do mandating contracting that aren't terrible.

So, in terms of distortions, if we are in a world with clean energy standard and tax credits, how bad is that for power markets? I know, everybody here will be arguing about that at FERC and elsewhere. I think it's true you had tax credits and clean energy standards, you will have negative marginal cost of the carbon-free generation and they will bid that way in markets on an hourly basis. But, historically, these zero emission resources almost never actually set the market clearing price. Negative prices have happened but it's a tiny, tiny amount of time. Usually, it's the case where the transmission is almost there, didn't get there in time. There's a timing mismatch.

It's also a reflection of demand response done poorly. We can do DR and transmission better and avoid negative prices. Not that negative prices aren't necessarily always bad. And, yes, we will see energy prices very low when renewable output is high, at those times and places. Hopefully, as Speaker 3 says, that will flow through into retail rates. I'll join the band here on that and, hopefully, we'll get states to do more and better pass through of the actual hourly prices.

Then, it's not that average wholesale prices that were low necessarily go down a lot. There will be very high scarcity-based prices at certain times, when there's high ramps and high net load. I think we need to get used to that 7pm power. Whoever can be there at 7pm, you're going to make a lot of money.

If you had built storage in Texas a few years ago, you would have been making tons of money. So, demand response, storage, other flexible sources should be seeing those price signals if we do it right. I'll stop there. Back to you.

Moderator: Thank you very much. I see we have a hand up.

Question: I want to talk about your transmission planning proposal. I guess what I would say to you is you're being insufficiently bold. Where you're going is two-to-three-year FERC rulemaking, two to three years for the regional entities to implement and come forward, two to three years for the first actual planning process that implements that. So, we're now at six to 10 years before we get any project, with litigation every step of the way.

Now we've gotten to the hardest part, which is siting. As you know, we have a 50-year guerrilla war on building energy projects, and transmission is about the hardest to build. With due respect, your heart is in the right place but I don't think you've solved the problem. I don't know whether this is doable without legislation. But it seems to me that something bolder, pushing the edges, along the lines of a FERC process which actually identifies an interregional grid that needs to be built for renewables and a process then to implement that—rather than going through planning processes, along the lines that you've suggested, together with seeing how far we can stretch the current federal citing law to get around some of the siting problems and get these things built.

I guess what I would say to you is, “Go back to the drawing board on transmission. What you're proposing isn't enough.” And, looking at the Princeton work, the timescale has to be a lot faster. We just need to have a complete rewrite about how we build transmission and other energy infrastructure, or else none of this is going to happen. We need people like you really pushing the envelope, rather than small incremental changes that I don't think are going to get us there.

Speaker 4: Well, thank you. I would recommend to all of you, if you go on the cleanenergygrid.org we had a wonderful session the other day with all nine former FERC chairs, going back to 1993, both parties, basically advocating for a more ambitious FERC planning rule than the agency has ever put together. With Joe Kelleher and Norman Bay saying, legally, no question FERC has authority to do this. All of them saying absolutely the agency should That is part of the puzzle, as you say—but just part of it. It's not clear if we even really have the institutions to do what's needed going across interconnections, for example.

Let's wait and see what the Biden administration says about this. I know they've thought about it, or at least the individuals in certain roles in the White House in DOE are thinking about this and are aware of the need. The House Select Committee on the Climate Crisis used the term supergrid. So let's see where this goes in DC.

Moderator: One of the things we've talked about briefly, a little bit, is—I'm feeling depressed about it right now, but I'll ask you, anyway—which is designing this transmission expansion planning and cost benefit and cost allocation story so that it's consistent with and compatible with the rest of the market design, where you're trying to get people to change how your demand response works and everything else going on. Order 1000, which I characterize as where the courts made us say that you had to charge the cost commensurate with the benefits. So we're going to go and wave our hands and then say, “Everybody benefits.” Then we're going to socialize the cost.

When that came out, I was fully expecting that it would collapse of its own weight. It certainly hasn't worked very well, but it hasn't completely collapsed. Is this hopeless trying to make these things compatible with each other, the FERC planning where the regulators decide on the lines that are going to be built, and then they tell everybody to do? It doesn't strike me as the way to go for that process.

Speaker 4: Again, you're right. The law of the land in FERC World is roughly commensurate with beneficiary pays. I know you would probably emphasize the beneficiary pays aspect of that sentence. Others, like me, are a little bit more emphasizing the roughly part. I think we're going to have another polar vortex coming across the country next week, which means 7000 megawatts are going to wash out of MISO into PJM or back, depending on where the actual weather pattern is, in a matter of hours. Which set of ratepayers should pay for that in a regional transmission that is doing that? If you look at the NREL Seam study, it's up to 40 gigawatts needs to go back and forth on an almost daily basis between the eastern and western interconnection. Which is the ratepayer that pays for that? Which utility pays for that in a capacity market, if we actually built what's in the interconnection Seam study?

Or let's take it even bigger. We've talked about long-duration storage and firm resources. There's a vast amount of long-duration storage in Canadian hydro, in reservoirs in the west, central and eastern part of Canada that could come in in different regions if we had a macro-grid there to connect it all. Which ratepayers pay for that macrogrid?

I don't see much of an argument against just building the damn thing and throwing it into a gas tax or to have taxpayers build it. I don't have a big problem with basically allocating the extra high-voltage stuff across very wide areas. I don't see an economic argument really against that.

Moderator: Well, let me respond briefly. This came up a lot of these MVP discussions, as well, and in FERC discussions. The cost-benefit analysis is *ex ante* and it would look forward. I would say it's going to be flowing east to west half the time and west to east half the time. Then it turns out, if you use beneficiary pays, you allocate the cost 50% one way, 50% the other way, you end up with the same answer as socialization. I agree with that, so that's just fine.

But it's not necessarily true, the underlying factual basis. Now, the question is, should you assume that it’s going to be socialized and then allocate everything, so we don't have to do the hard analysis, or should you actually do the calculations and do the demonstration? And if you demonstrate that it is that way, then that's just fine.

But otherwise you get into these conundrums about, if you're going to socialize the cost of transmission why don’t you socialize my generator? Or why don’t you socialize the cost of my load? Because things are complements or substitutes. It seems to me that that requires having some internally consistent methods between the two of them. But, as I say, I’m frustrated about this.

Comment: Can I weigh in with one thought on this?

Moderator: As long as you agree with me.

Commenter: I do not. And we've had this debate it at HEPG before. But now it's different. The premise here is that we're building all of this in order to decarbonize our energy system. And we're not doing that for any particular region or area. We're not doing it remove congestion. We're doing this to decarbonize the entire system, and everybody benefits from that. So I have a lot of trouble with the notion of trying to identify locational beneficiaries associated with a national effort to decarbonize. The beneficiary is everybody.

Moderator: Now that's not true. If you had a carbon price, the thing would fall out the same way as any other costs and benefits associated with transmission. If you don't price carbon, I agree with you. Now we have an inefficient effect, because we aren't representing what the cost of carbon is.

Moderator: So we'll go to the next question.

Question: I feel there's 15 questions I have for Speaker 4. I'll condense it down to two themes, if that's possible.

One is, I was thinking about FERC and how you get the most bang for your buck. There's all sorts of rulemakings they could potentially pursue, but what can we just also do without rulemakings. A lot of that does go into the transmission space. Like what part of the Order 1000 framework is salvageable. What other things, maybe local transmission projects outside of the 1000 framework, how do we better implement the existing four orders that you highlighted that are already out there and get in relatively quick order?

Then, my second question is, what is the proper institutional arrangement? When we were testifying to FERC on good enhancing technologies, everyone said, "Oh, wow, there's no economic oversight of the transmission system in terms of asset management, thus FERC needs to come out with things like ambient dynamic line rulemakings to instill best practices." So there's a question of, should market monitors be doing this, or what have you?

As well as, is an RTO that is voluntary membership with TOs the best organization to be doing planning and then picking winners from different competitive solicitations processes? I'd be curious to get your idea on low-hanging fruit FERC can do without rulemakings, the second part about proper institutional arrangements.

Speaker 4: Well, there's a lot there. Let me just answer very simply, and generally, which is that I think the answer is that FERC needs to become a traditional public utility regulator of the transmission system, and no longer just a dispute resolver between parties—which is how the agency grew up and how the culture and all of the precedent was based. A traditional public utility regulator will compel regulated entities to build the right amount of the thing and then allocate the costs fairly. That's not what FERC does. And it should.

Hopefully, FERC and all state regulators will recognize that the generation sector is fully competitive, and there should be no more rate-based generation and do everything you can on competitive generation. But on transmission, let's plan the right amount, and that includes grid-enhancing technologies. Let's operate the existing system more efficiently first. That should fall out clearly in the benefit-cost analysis. I support more traditional regulatory function of FERC over the transmission system. That includes oversight of some of the investments, because there are areas where the utilities just get to build with almost no one looking over it.

Moderator: I think that's a very important suggestion, and I would say it's orthogonal to what we're just talking about, cost-benefit analysis and all the other kinds of things. The fact that we don't have a decision-making process is a critical part of the problem.

Commenter: Well, just a couple of quick comments on things that have been said recently. I think the market model works well. I wonder how robust it is when prices become much more variable. I realize people can hedge and all of that. But I also realize it's very hard for regulators, even in Texas, to keep their hands off. I'd love to believe they can, but I worry.

Second comment is, these conversations always involve areas with markets. We do have the southeast and we do have other parts of the country where there is interest in decarbonizing. There's national interest in decarbonizing, the regional interest may be less. I guess the question is federal legislation to sort of trump that regional view possible. You mentioned Manchin, yes indeed. And, final comment, I think saying that we would build a big new grid of an overlay of high voltage boundary-crossing lines in the interest of decarbonizing is fine, but it still doesn't answer the question of who benefits. Because if you don't build that, and we still decarbonize, different regions, different areas have different costs. So when you put the lines in, some people are better off, and some people are not. If you take decarbonization as given, then there are various beneficiaries. So I'm with the notion of let's just build the damn thing. But I don't think you solve the politics. If you can get consensus to do that, sure. I'm not sure that's possible.

Speaker 4: I'll just comment. Through legislation, if there were some infrastructure bill in which 50, 100 billion dollars went in for transmission, you could just build the thing. But if you're in the FERC World. You're in the roughly-commensurate-with-beneficiary-pays. Then you have to look at who benefits by how much. I the Moderator would agree that one pretty good way to do that is, let's plan assuming a carbon price, even if there isn't one. Let's just put a carbon price into the planning model. Then see how much is needed. Do a benefit cost. How much and which lines. Then you can allocate the cost according to who benefits according to that. That would be a pretty efficient way to go.

Commenter: We use the social cost of carbon when that comes back from the dead.

Speaker 4: Yes, that's right.

Moderator: Next question.

Question: Great to be with you, as always. I'm not going to defend ERCOT, though I think it's a great model. Works just fine.

You said in response to another question that FERC needs to act like a traditional utility regulator and demand that you just build the right amount of the thing as retransmission. But that really ends up presupposing what the right resource mix is. In other words, it relies on assumptions of what people should be buying. It also has the practical effect, I think, of superseding state policies that may direct certain resource procurements as they see fit. As a practical matter, if you blow the whistle and do what you're saying we should do on transmission, it ends up really muting the effect of the competitive market structure for buyers that you're talking about.

Because, ultimately, it makes it a foregone conclusion that people should be buying a certain type of thing in a certain place. Why would they buy something that is not connected to transmission? I'm just trying to square the two sides because I'm, as you know, very much on your side on the who's the buyer talk and the need to get to put load-serving entities in the position of consummating power purchase agreements and making them bear the risk of them. But I think what you're saying on transmission seems to run completely contrary to that.

Speaker 4: Well, it's a great issue, tough one, no easy answer. But let's take an example to make it real. Let's say PJM has option A to do what I said a minute ago, which is just throw a carbon price in the planning model and then build the right transmission; or, option B, it could say Abe Silverman here with New Jersey and a whole bunch of other states have 30 gigawatts of offshore wind that is in state law, and is going to happen, one way or another.

In option B, they actually plug that in and say, "Well, I make my best guess at a load forecast. It's uncertain but I'm taking my best shot at forecast load. Now I'm going to take my best shot at forecast—type and location of new generation additions and location of retirements. It's uncertain, but just like load forecasts, I've got to take my best bet." If it were me, I'd bet on 30 gigawatts of offshore wind that's in state policy, and I'd plug that in.

But that's the type of thing that FERC, overseeing the RTOs, ultimately has to decide what is the assumption there. I recognize you're absolutely right. Look at any region, you could wind up with a portfolio—A, B, or C—based on what transmission you build. So it's tough and it's important, and I think states really need to be actively at the table, helping make these decisions for each region.

Moderator: Next up.

Question: I really liked your presentation. I've worked extensively in interconnectors and long-distance transmission in Europe and Australia. Just a few observations, wearing some of the scars of trying to get investment projects over the line there. I want to emphasize the politics of these things. I'm pretty sure it's often between countries rather than between states, but I don't suppose it's that different. It's really difficult. For example, Norway has a 98% hydro system, a fantastic to connect to wind system like GB. You try telling that to a Norwegian aluminum smelter or paper producer, that it's going to see higher power prices. It's a really difficult problem to navigate and I think the real crux of the issue is to get around that problem. Australia has same thing with Tasmania. Those sorts of things.

And I think just saying, "Oh, you can probably get tax your way through it and let the taxpayer pay," I'm not sure that even that really solves the problem in a way. It's just a difficult set of stakeholders, one has to manage to really get these projects over the line. But I share your ambition, it's a very good solution to a difficult problem.

Speaker 4: I'll just agree, it is hard. I think we've hit on the two major issues before FERC. A lot of us pay a lot of attention to FERC, and there's two major fundamental issues. I think Chairman Glick and at least one other commissioner have echoed this, which is, how do you set up the planning and cost allocation for these very large-scale regional/interregional transmission? I'm hopeful that there will be a planning rule and a proceeding on that very soon, which we suggested.

I just put out a 100-page paper with a whole lot of recommendations on their basis for doing that and some straw man suggestions on how to do it. That's on cleanenergygrid.org. But there will be, hopefully, a robust debate about that one.

Then the other one is what Speaker 3 was talking about and others about energy resource adequacy. How do you compensate the right resources to be there? And capacity market reform and all of that, recognizing that those firm sources are needed. But capacity markets are just very, very difficult.

So these are two major issues before the before the commission, and I know all of us will be actively involved in those, trying to help the commission sort it all out.

Question: This is a great discussion, as always. We here in New Jersey are looking at exactly this problem. It's been so interesting as we look to the offshore wind buildout. Current law is 7500 megawatts, expected to be bigger before it's all said and done. I think anybody would say we should be designing the PJM transmission system for an offshore wind backbone that probably goes from Virginia or North Carolina up through New England. Yet the PJM process isn't really set up for it. It's been quite interesting.

We've been acting under the state agreement approach, the Order 1000 approach, here in New Jersey, where we actually went to PJM and said, “Hey, we're willing to sign up New Jersey ratepayers for transmission solutions, to make sure that this offshore wind is actually feasible.”

We were willing to do that. But nobody really feels like that's the optimal approach, or that we could do that for the entire scale of what needs to be done. Then you go to the Artep process and it's sort of interesting. The idea that we should be planning the PJM transmission system to meet the renewable demand that we all see coming is kind of a foreign thing to the engineering nerds, who I love dearly in the Artep meetings.

The idea that PJM doesn't have that process for identifying there's going to be, what, 50 gigawatts of wind, solar and offshore wind coming into PJM in the next decade. Yet we're going to study it all serially? That just doesn't work. I remember MISO and RGOS. That was, I think a 60-gigawatt number picked out of the ether. They did transmission studies and said, “This is what we would need.” Yet, that's not national policy and it has not yet come to PJM. I certainly hope it will, and we're certainly pushing for that. I’m very interested, is that the piece of it that needs to be done at FERC?

I’m very much with you on the FERC jurisdiction piece. They could mandate it. It's their toy. They can break it if they want, they can fix it if they want it. It is really that simple, just to tell the ISOs to start coming up with one of these least no-regrets kind of transmission plans?

Speaker 4: Well, I just think everybody needs to start thinking of this whole thing differently. Meetings like this are very helpful. If you start with all these types of studies. Let's look at what is a reliable power system. How much transmission does it involve? How are we going to build it? Who's going to pay for it?

You're right, the state agreement approach falls into the standards like the public good, the pitfall. National defense and all the other standard public goods. If this group on this call today raised their hand to voluntarily pay for our military, it would be underfunded. That's just not how we fund public goods. It doesn't work in theory or practice.

That's what you're facing as New Jersey, you should be in the textbook. New Jersey raised its hand, wants to pay for its share of the transmission system. Now, the question that there's not yet an answer for is, if we pay for it, how do we make sure that we use it and New Jersey ratepayers benefit, and not Delaware and Maryland? It's just classic public good, and we need to get out of this loop and acknowledge these physical realities.

Moderator: Another question.

Question: I appreciated all of your comments that you mentioned today, and I'll just respond to a couple of things. Certainly, rulemaking is one option for pursuing some of these changes. But I also shared some of the other concerns from others that perhaps that is too long of a lead time. And there are definitely tools that FERC has under their show cause orders and others that can advance the ball right now, rather than waiting years for a rulemaking per se to go into effect.

One respectful comment I have on the report that was issued, is that, actually, we would say that all the tools that FERC has should be used at their disposal, Then, the sequencing of how this rolls out. That show cause orders and things like that can very much be part of the solution and done here and now, versus years later, in a national rulemaking.

The other thing, in terms of PJM, it was mentioned in terms of the issues and the challenges with what's going on the state agreement approach. PJM actually has an operating agreement right now that they need to be doing sensitivity analysis relating to public policy planning. But it's just not happening in the Artep planning process. That's an example where we don't need a new rulemaking on that, just follow the OA and it just needs to be done. Clearly, there are things that can be enhanced and expanded, but there's tools FERC has in the here and now.

Then, the last point I would make is that, on the conversation that that you and Bill Hogan were having about roughly commensurate versus commensurate cost allocation, and what that looks like. I would just point folks to the attention that in the briefing stage at the DC circuit, there's no fewer than five cases that are pending before the DC circuit on this very issue. I think it's important as we think about this issue in 2021, that I understand that the DC circuit is going to be weighing in as well. Thank you.

Speaker 4: Thanks, appreciate that.

Question: Thanks so much for the invite. Really great to listen from Europe to this new inspiration coming from the west.

Just a few comments. It reminded me a lot about the debate we had in Germany and Europe after Fukushima, where we moved from transmission approval towards transmission planning. I think the main focus was on about permitting. So, at the end, we've got a process now where we get the federal parliament to sign up to the transmission plan to get more clarity for the permitting, which was the biggest issue. The costs of transmission tend to be small compared to everything else. You get that even lower if you have a long-term, 30-year time frame or secure payback.

I think the final part we just get into over the last two years, is for the decarbonization. We need so much more electricity in industry, in transport, in heating, that it's pretty difficult to get lines wrong. At the moment, at least, if you do some planning around. So it's more the question how quickly they will be fully utilized. But I'm very interested to listen.

Speaker 4: I fully agree. The economics and physics are really the same in so many countries. I was amazed in East Africa, even with the bottom of the energy poverty index, they had all the same resources available and everybody wanted them. It was worth 10 cents a kilowatt hour for them. They had this remote solar, they had hydro around the region, they could connect with transmission, that could get a full clean energy portfolio. But who pays for the transmission? It was the same thing everywhere.

Just a word on siting. There are these federal backstop siting authorities, we have in the US. DOE and FERC have chosen not to use them. I'm hoping the new administration says we're open for business on using those. There's only a few states where that one circuit decision is in effect, so there is a lot more that could be done. I would urge them to just focus on particular choke points, if a given transmission project runs into trouble and then that developer applies, and they file a congestion study there, rather than necessarily a grand national, predefine all the quarters. Because, really, how you would do that? It certainly blew up in their face when they tried to in 2007 or so. There are these authorities that could be very useful on backstop federal siting.

Moderator: OK, let's move on.

Question: Thanks for the presentation. It's very thought-provoking, as always. Good to see you, my old friend.

The question I have for you. I keep hearing about the transmission build-out, and I was putting this in the chat a little bit. I just want to give a cautionary tale about the Alberta system. Alberta has an energy-only market like Texas, but unlike Texas the transmission is socialized. The problem is that the cost of transmission as percentage of total wholesale cost is given depending on the year. It's about 50% of total wholesale costs. It's about $45 Canadian per megawatt hour, just the cost of transmission.

My question to you is, have you considered the feedback loop that comes with that? That if we do get the design right or, as we see in PJM with industrial customers in certain load-serving entities, that they will engage in peak shaving to get out of paying for those transmission costs.

And, then, what do we do with that? This goes back to the Moderator's point, which I'm in violent agreement with. You have to go to the beneficiary pays. There are beneficiaries here that we can identify through various means, so that we can get something consistent with cost causation. Otherwise, you're going to end up in this situation that we see in Alberta. The system is about ready to collapse upon itself. So how do you get around that?

Speaker 4: Two points. First of all, I have heard the same thing about Alberta. I don't know all of the factors that go into it but cutting the cord does seem to be an option for some there.

Questioner: For many. I'm doing some work there right now. That's why I'm saying that.

Speaker 4: I don't know why it's there, versus other areas. First of all, I think everybody should get used to transmission being a higher component. Generation is getting very cheap. Wind and solar energy is very cheap. But transmission is how you access it. When I hear people complain that the transmission component of their bill went up, I say, "Well, what's the overall delivered cost that you're getting?"

We have to model the future to make sure that the overall delivered cost is better and competitive. But I think what we should expect to see from these is that higher percentage on transmission and lower on generation and getting a good overall delivery cost. I'll just acknowledge there's a lot of inefficiency that can result from cost allocation, both wholesale cost allocation and retail. When you get all the expenditures to shift your load away from the peak, because of charging on peak, that's not an efficient overall system. Hopefully, wholesale and retail regulators are paying attention to avoid distortions like that.

Moderator: It happens in Texas, too. Last question.

Question: I've certainly, as always, enjoyed this immensely. I did want to mention, with regard to lower-cost scenarios, that the California SP 100 analysis from last year for carbon-free grid by 2045 had the cost of generation component basically doubling to accomplish that. The doubling was probably too low for various reasons, including that California actually runs out of electricity during the winter months.

But I wanted to just note that, if we are in fact underestimating the cost of a zero-carbon future, we will be taking away resources from the load side. Things like LED lighting and other energy-efficiency measures that could be extremely inexpensive to deploy. I just want to make sure that in the grand scheme of things we don't lose sight of some of these things that are relatively easy lifts. Thanks.

Speaker 4: I agree. It's a "compared to what?" situation. If we're meeting some decarbonization target, let's choose the most efficient portfolio that achieves it. If costs go up from the status quo, that's without hitting a decarbonization target, that's not a very interesting analysis.

Moderator: OK, with that, let me say thank you. That was terrific and very much complementary to the other presentations here and just what I was hoping for. We're going to continue on a related theme in our next session, which has now been scheduled for March 9th.

The way I would characterize the discussion today was mostly net zero emissions by a certain date is the target and we're going to get there and then what's the cost-effective way to get there.

And if you go to page 204 on the Princeton slides, you will see what the marginal costs of doing that are. When you get out there in 2050, the numbers are, like in the other presentations, are pretty high.

If that means that the cost-benefit comparison would lead you in a different direction, what does that mean for policy regulation and market design? Those are the kinds of questions we're going to be trying to address, and how does it connect to all the scientific evidence and so on.