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Serious discussions about climate change must focus intently on the global electricity sector. There are three reasons for that.

Electricity is the world's most important and fastest-growing form of energy.[1]

Electricity production accounts for the biggest single share of global carbon-dioxide emissions: about 25 percent.[2]

Third, regardless of what happens in the future –whether the global climate gets hotter, cooler, or more extreme – we are going to need vastly more electricity than what is currently being consumed around the globe. In 2018, global electricity use jumped by 4 percent.[3] At that rate of growth, global electricity use will double in just 18 years.

Given those facts, innovation in all facets of the electricity sector – from generation and transmission to storage and end-use efficiency – can help in efforts to decarbonize the global economy. I will address two questions: which low-carbon electricity-generation technologies can be deployed at significant scale and in doing so, foster decarbonization in the electricity sector? Second, what should the government be doing to foster innovation in those technologies?

I will address those questions by making two points. First, we can't rely on renewables alone. Second, I will explain why natural gas to nuclear energy (what I call N2N) offers the best no-regrets strategy.[4] Natural gas and nuclear are low-

carbon, scalable, and affordable. Those attributes make them essential to any large-scale decarbonization strategy.

Renewables Aren't Enough

Before going further, let me be clear: I am not opposed to renewables. I have 8.5 kilowatts solar panels on the roof of my house in Austin, Texas.

Further, it's obvious that renewable energy is growing rapidly. In fact, I have seen firsthand how renewables are competing with traditional forms of generation. In 2017, while I was in Lebanon shooting video for my upcoming documentary, *Juice: How Electricity Explains the World*, I visited Bkerzay, a resort in the Chouf Mountains that is relying solely on solar energy. That facility is using lead-acid batteries (with a total capacity of 300 kilowatt-hours) to store electricity produced by 100 kilowatts of solar panels. That system provided all of the electricity used by the resort, including the restaurant, ceramics studio, and guest rooms.

The growth of renewables – and solar energy in particular – is impressive.[5] That growth is being touted by numerous environmental groups and politicians who are pushing for policies that would require our energy and power systems to rely solely on renewable energy. For instance, in early 2019, some 600 environmental groups submitted a letter to the US House of Representatives which said that the US must shift to "100 percent renewable power generation by 2035 or earlier." The same letter said that any "definition of renewable energy must…exclude all combustion-based power generation, nuclear, biomass energy, large-scale hydro, and waste-to-energy technologies." It continued, saying that the new electric grid must have the "ability to incorporate battery storage and distributed energy systems that are democratically governed." Signers of the letter included groups like Food & Water Watch, Friends of the Earth, and the Environmental Working Group.[6]

The notion of all-renewable energy and power systems may be political popular, but the simple truth is that 100-percent renewable scenarios are neither doable nor desirable.

Over the past few years, all-renewable scenarios have been put forward by various groups and academics. Perhaps the most famous of those scenarios was published by Stanford professor Mark Jacobson. In 2015, Jacobson published a paper, co-written with Mark Delucchi, a research engineer at the University of California-Berkeley, in the *Proceedings of the National Academy of Sciences*. The paper, which claimed to offer "a low-cost solution to the grid reliability problem" with

100-percent renewables, went on to win the Cozzarelli Prize, an annual award handed out by the National Academy of Sciences. A Stanford web site said that Jacobson's paper was one of six chosen by "the editorial board of the *Proceedings of the National Academy of Sciences* from the more than 3,000 research articles published in the journal in 2015."[7]

But a 2017 paper published in the *Proceedings of the National Academy of Science* by a group of prominent American scientists led by Chris Clack – a mathematician who has held positions at the National Oceanic and Atmospheric Administration and the University of Colorado – thoroughly debunked Jacobson's claims than an all-renewable energy economy was feasible or affordable. Clack and his co-authors, who included Dan Kammen of the University of California-Berkeley, former EPA Science Advisory Board Chair Granger Morgan, and Jane Long of Lawrence Livermore National Laboratory, concluded that Jacobson's work contained "numerous shortcomings and errors." The paper also used "invalid modeling tools, contained modeling errors, and made implausible and inadequately supported assumptions." Those errors, "render it unreliable as a guide about the likely cost, technical reliability, or feasibility of a 100-percent wind, solar, and hydroelectric power system."

Clack and his colleagues also found that to accommodate all of the wind turbines needed to achieve Jacobson's all-renewable vision would require "nearly 500,000 square kilometers, which is roughly 6 percent of the continental United States and more than 1,500 square meters of land for wind turbines for each American."[8]

Clack's paper underscored the fundamental problem with large-scale renewable deployment: it simply requires too much land.

All-renewable scenarios rely on the vacant-land myth – the faulty notion that there's endless amounts of unused, uncared-for land out there in flyover county that's ready and waiting to be covered with forests of renewable-energy stuff. The truth is quite different. Rural communities – even entire states – are resisting or rejecting wind, solar, and high-voltage transmission projects and that opposition is already slowing deployment of new renewable capacity in the US, Canada, and Europe.

Energy policy and land-use policy are inextricable. Proof of that can be seen by looking at the protests over the Keystone XL and Dakota Access pipelines. Climate-change activists are increasingly targeting pipeline projects as a way to rally public sentiment toward their cause. Those high-profile battles have received

widespread media coverage. By contrast, national media coverage of the growing backlash against deployment of large-scale renewable-energy projects has been scant. That lack of media coverage is particularly true when it comes to controversies about wind-energy deployment.

Since 2015, I have been tracking rural opposition to wind energy projects. By my count, some 225 government entities from New York to California have moved to restrict or reject wind projects.

In New York, Gov. Andrew Cuomo has mandated that the state be obtaining 50 percent of its electricity from renewables by 2030.[9] Despite the mandate, by my count, about four dozen local governments in New York have passed measures restricting or prohibiting wind energy projects.

You won't read about it in the *New York Times*, but the towns of Yates and Somerset as well as three upstate New York counties – Erie, Orleans, and Niagara – have spent the past three years fighting the proposed 200-megawatt Lighthouse Wind project, which aims to put dozens of wind turbines near the shores of Lake Ontario.

Now, let's look at California, which has a 60-percent renewable electricity mandate by 2030.[10]

In 2015, the Los Angeles County Board of Supervisors voted unanimously in favor of an ordinance banning large wind turbines in the county's unincorporated areas.[11] During a hearing on the measure, then-Supervisor Michael D. Antonovich said "Wind turbines create visual blight." In addition, he said the skyscraper-sized turbines would "contradict the county's rural dark skies ordinance which aims to protect dark skies in areas like Antelope Valley and the Santa Monica Mountains."[12]

In February of this year, San Bernadino County, banned large-scale renewable projects throughout much of the county. San Bernadino County covers more than 20,000 square miles and is the largest county, by land area, in the country.[13] It's already home to two big thermal-solar projects, including Ivanpah and Abengoa Mojave.[14] The county's new regulations prohibit construction of new large-scale projects if more than half of the energy produced from them is to be exported out of the county.[15]

Building new wind projects in California is so difficult that the wind industry has nearly given up trying to site any new turbines in the state.[16] According to the California Wind Energy Association, the state now has about 5,535 megawatts of installed wind capacity.[17] That's *about 250 megawatts less* than what the state had back in 2013.[18]

In Oklahoma, the town of Hinton, (population: 3,200) spent about two years fighting the world's biggest wind-energy producer, NextEra Energy. In January 2017, the town passed an ordinance that prohibited the construction of wind turbines within two miles of its borders. The following month, the Florida-based company sued the town of Hinton in both federal and state courts. In a 2018 phone interview, Mayor Shelly Newton told me that Hinton officials passed the measure in 2017 because "We were trying to give ourselves some elbow room."

Earlier this week, I spoke to Mayor Newton again. She explained that the town beat NextEra in court and that the company reimbursed the town for its legal expenses. When I asked why the town fought the company and its proposed wind project, she replied, "These aren't wind farms. They are industrial wind complexes that would change our agricultural land into an industrial area. We don't want to live in an industrial wind complex. And we didn't want it forced on us." She continued, "These are not wind farms. It has nothing to do with agriculture."[19]

In Henry County, Indiana, seven communities have passed resolutions establishing a four-mile buffer zone around their towns. In a November 1, 2018 article titled "County Towns Putting Up Walls Against Wind," Darrel Radford, a reporter for the *New Castle Courier-Times* wrote that "there's still lots of anti-turbine activity" in the county and that "as many as half" of the incorporated communities in Henry County had passed anti-wind measures.[20]

Looking north of the US border, Ontario has been a hotbed of anti-wind activism. In that Canadian province, 90 towns have declared themselves "unwilling hosts" to wind projects.[21]

The anti-wind backlash is also obvious across the Atlantic. In 2010, the European Platform Against Windfarms had about 400 members in 20 countries. By 2018, it had nearly quadrupled in size and counted some 1,400 member organizations in 32 countries.[22]

The backlash is particularly apparent in the German state of Bavaria as well as in Poland. Both places have effectively banned wind turbines by implementing the

so-called 10-H rule, which requires turbines be located no closer than 10 times their height from the nearest homes or other sensitive areas.[23]

In 2016, a wind project near Scotland's famous Loch Ness was rejected by local authorities because of its potential impact on tourism.[24] Scotland Against Spin, a coalition of environmental groups that is fighting wind energy projects in that country says on its website that it is "against the spin of the turbines, the spin of the developers and their lobbyists, and the spin of the Government."[25]

It's not just wind projects.

Residents of Spotsylvania County, Virginia are fighting a proposed 500-megawatt solar project that, if built, would cover nearly 10 square miles. According to the Fredericksburg *Free Lance-Star*, local residents are opposed because they believe the solar project "is too big to be near homes and that it poses potential health and environmental risks. They also are concerned about impacts to property values."[26]

In Charles County, Maryland, environmental groups are fighting a solar-energy project backed by Georgetown University. The project would require clear-cutting 240 acres of forest that, according to the *Baltimore Sun*, is among fewer "than three dozen areas in Maryland that the Audubon Society has deemed an 'important bird area,'" meaning it is a rare remnant of large contiguous forest land. A member of the Southern Maryland chapter of the Sierra Club called the solar project "thoughtless of the future."[27]

High-voltage transmission projects are also facing opposition.

In 2017, Iowa enacted a law which prohibits the use of eminent domain for high-voltage transmission lines. The move doomed the Rock Island Clean Line, a 500-mile, $2 billion, high-voltage direct-current transmission line that was going to carry electricity from Iowa to Illinois.[28]

In early 2018, Houston-based Clean Line Energy Partners suspended its years-long effort to build a 720-mile, $2.5 billion transmission line across the state of Arkansas. The Plains & Eastern Line aimed to carry wind energy from Oklahoma to customers in the southern and southeastern US. But the project faced fierce opposition in Arkansas where the state's entire Congressional delegation opposed the deal.[29]

Also in 2018, New Hampshire regulators rejected a high-voltage electricity

transmission project called Northern Pass Transmission that was to carry power from Quebec hydroelectric facilities to consumers in Massachusetts. But the 192-mile, $1.6 billion project – which was to go through New Hampshire's White Mountains – was vetoed in a unanimous vote by the New Hampshire Site Evaluation Committee.[30]

Renewable energy's land-use problem is directly related to the issue of scale. If we are to dramatically increase the use of wind energy, it will require dramatic increases in the amount of land dedicated to that purpose. That was made clear by author Vaclav Smil in his 2010 book, *Energy Myths and Realities: Bringing Science to the Energy Policy Debate.* Smil wrote that relying on wind turbines to supply all US electricity would "require installing about 1.8 terawatts of new generating capacity," which he explained, "would require 900,000 square kilometers of land."[31] For perspective, that's a land area twice the size of the state of California.[32]

In addition to the land-use problem, renewable sources are not scaling fast enough. In fact, renewables cannot even keep pace with the growth in global energy demand. That can be seen by looking at the March 26 report from the International Energy Agency which found that in 2018, "Demand for all fuels rose, with fossil fuels meeting nearly 70 percent of the growth for the second year running. Renewables grew at double-digit pace, but still not fast enough to meet the increase in demand for electricity around the world."[33]

The IEA also reported that global natural gas use in 2018 increased by 4.6 percent.[34] To put that in context, the growth in global gas use last year was about 2.9 million barrels of oil equivalent. Therefore, *merely the increase* in global gas use in 2018 *was greater than the output of all global solar projects*. (In 2017, all global solar production totaled about 2 million barrels of oil equivalent.[35])

Natural gas can help decarbonization

Natural gas is the cleanest of the hydrocarbons and therefore it can help reduce the growth of global carbon dioxide emissions. The reasons for this: gas is scalable, relatively low-carbon, and it can be used to replace coal in the electricity sector and oil in the transportation sector.

Substituting gas for those fuels helps reduce greenhouse gas emissions. During combustion, gas produces about half as much carbon dioxide as coal and about 30 percent less than diesel fuel or fuel oil.[36]

Much of the growth in global natural gas production is due to a string of innovations that have occurred here in the United States. Thanks to the shale revolution, which combines innovations in horizontal drilling, hydraulic fracturing, and related technologies, the US has become the world's biggest and most important gas producer. Indeed, the growth in domestic gas production has been nothing short of astonishing. In 2005, US gas production was about 47 billion cubic feet per day. This year, US gas production will average about 90 billion cubic feet per day.[37] That's an increase of 91 percent, or 43 billion cubic feet per day, in just 14 years.

To put that in perspective, consider this: since 2005, *just the increase* in US natural gas production is equal to two times Iran's entire natural gas production.[38] It's also equal to four times Saudi Arabia's natural gas production.[39]

The surge in shale-gas production has transformed both the domestic and international gas businesses. Domestically, coal-fired power plants are being rapidly replaced by gas-fired ones. Between 2000 and 2017, the amount of US electricity generated by gas-fired power plants more than doubled while the amount of juice produced from coal fell by nearly 40 percent. The substitution of gas for coal in the electricity sector helps explain why US carbon-dioxide emissions in 2017 were the lowest they have been since 1992.[40]

The shale revolution has made the US a pivotal player in the global liquefied natural gas business. At the end of 2018, the US was exporting about 4 billion cubic feet of LNG per day. Only Australia and Qatar currently have more LNG export capacity than the US, and if all of the planned LNG facilities are approved, the US will soon be the world's biggest LNG exporter.[41] By mid-2020, the Energy Information Administration expects US LNG export capacity will reach 10.6 billion cubic feet per day.[42] Thus, within a year or so, US LNG exports could be nearly equivalent to the entire gas output of Norway, Europe's biggest gas producer.[43]

In 2018, the US exported LNG to 30 different countries, including Kuwait and the United Arab Emirates, both of which are major oil producers.[44] Furthermore, it's an open secret in Houston that Saudi Arabia, the world's biggest oil producer, is now trying to secure a long-term LNG contract with US suppliers. Doing so would allow the Saudis to reduce the amount of oil they are using to generate electricity and replace it with lower-cost LNG from the US.

What does the natural gas sector need in the way of federal policy? In my view, the industry doesn't need much at all. It has accomplished meteoric growth over the past decade without much government intervention. Thus, a federal policy of benign neglect would be the best.

That is not the case for nuclear energy.

Nuclear energy is essential to decarbonization

There is no credible pathway toward decarbonization that doesn't include nuclear energy. That is the consensus among the world's top climate scientists and energy analysts.

In 2013, James Hansen and three other climate scientists wrote an open letter to environmental groups encouraging them to support nuclear. They wrote that "continued opposition to nuclear power threatens humanity's ability to avoid dangerous climate change…Renewables like wind and solar and biomass will certainly play roles in a future energy economy, but those energy sources cannot scale up fast enough to deliver cheap and reliable power at the scale the global economy requires."[45]

In 2015, the International Energy Agency declared that "Nuclear power is a critical element in limiting greenhouse gas emissions."[46] It went on, saying that global nuclear generation capacity, which in 2018 totaled about 375 gigawatts, must more than double by 2050 if the countries of the world are to have any hope of limiting temperature increases to the 2-degree scenario that is widely agreed as the acceptable limit.[47]

In 2018, a study published by the MIT Energy Initiative concluded that attempting to decarbonize electricity production with renewables alone would cost 2 to 4 times as much as one that included nuclear energy.[48]

Given nuclear's essential role in decarbonization, what should the federal government be doing when it comes to fostering innovation in the nuclear energy sector? Put short, Congress should develop a strategy on nuclear energy that includes preserving existing plants and nurturing the development and deployment of new, safer, cheaper, reactors that can be used in the electricity grids of the future.

Nuclear energy should be getting federal support due to its advantages over other forms of electricity production. Among those advantages: Nuclear reactors are emissions-free. They emit no carbon dioxide, no air pollutants such as sulfur dioxide, oxides of nitrogen, and no particulates, all of which are linked to adverse health and environmental impacts.[49]

Second, nuclear energy provides an alternative to coal-fired power plants. Over the past three decades, coal's share of the global electricity sector has stayed at about 40 percent.[50] Coal continues to be popular because it is scalable, reliable, affordable, and it provides baseload power. But that popularity has resulted in increased carbon-dioxide emissions from the electric sector. Nuclear reactors provide an alternative to coal-fired power plants, particularly in developing countries.

Third, nuclear energy has very high power density, meaning it doesn't need much land. For example, the Indian Power Energy Center in Buchanan, New York, sits on about one square kilometer of land and can generate 2,069 megawatts of electricity. Thus, the power density of the nuclear plant is nearly 2,100 watts per square meter (W/m^2).[51] For comparison, the power density of wind energy is between 0.5 and 1.5 W/m^2.[52]

Fourth, nuclear plants help diversify the country's electric grid. Just as it is risky to invest all your money in a single stock, it's equally dangerous to rely too heavily on one source of energy. Over the past few years, the US has dramatically increased the production of gas-fired electricity and decreased its reliance on coal-fired generation. That transition toward natural gas has helped reduce emissions, but it has also made the electric grid more reliant on a single fuel. During extreme weather events, the gas grid can be overtaxed and unable to supply sufficient quantities of fuel to consumers.

Fifth, fuel diversity helps assure resilience. Nuclear plants require refueling every 18 to 24 months. That makes them less vulnerable to supply disruptions like those that can effect electricity producers who rely on natural gas, and therefore must get just-in-time delivery of their fuel by pipeline. During the extreme-cold events in 2014 and 2019, US nuclear plants maintained near-maximum uptime, a fact that displayed their importance to the resilience of the electric grid.

Finally, nuclear energy provides baseload energy. Unlike renewable sources, which must be backed up with other fuels, and in particular, natural gas-fired generators, nuclear units provide stable, always-on power. That always-on power

helps provide grid stability and assures that electricity is always available in large cities and industrial facilities.

The US has been a leader in nuclear technology since World War II. If the US is to continue being a leader in nuclear-energy innovation, commercialization, and deployment, the nuclear sector will need strong, bipartisan, sustained support from Congress and the White House. By sustained support, I mean decades-long support. That political support will be needed to keep existing reactors in operation and to support the development, deployment, and diffusion of the next generation of nuclear technology both here in the US and around the world. The recently introduced Nuclear Energy Leadership Act is a good step in that direction.[53]

But let me be clear: the nuclear sector faces myriad challenges.The biggest and most influential environmental groups in the US continue to oppose nuclear energy.[54] The existing fleet of reactors continue to be undercut by low-cost natural gas in the power sector. New nuclear reactors still cost way too much. Furthermore, Congress continues to dawdle when it comes to the issue of Yucca Mountain and long-term nuclear waste storage and disposal.

I don't expect a quick or easy resolution of this issue. But I must reiterate my point: there is no reasonable or affordable pathway to decarbonization of the global electricity business that does not include large-scale deployment of nuclear energy.

If the US wants to foster the innovation needed to sustain growth in nuclear-energy technology, Republicans and Democrats will have to forge significant, long-term commitments toward that goal.

Thank you.

END

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[4] In 2014, in my last testimony before this committee, I also discussed the need for N2N. I stated, "If we are going to agree that carbon dioxide is a problem, and that we must reduce carbon dioxide emissions in order to protect wildlife, then we must embrace the technologies that are most effective at reducing our production of that gas. And that means N2N, natural gas to nuclear."
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[18] California Energy Commission data, http://www.energy.ca.gov/almanac/electricity_data/electric_generation_capacity.html
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