Questions from Chairman Lisa Murkowski

Question 1: Nuclear reactors provide clean, emissions-free power. As we look across the nation at the nuclear reactors slated for retirement before the end of their operating licenses, I am concerned about the long-term consequences.

- *I understand that the costs of maintaining a nuclear reactor on standby are unmanageable, so when these reactors close, they will not reopen. Do you agree with that assessment?*

Response from Dr. Tierney:

I agree with Chairman Murkowski that it not realistic to assume that an owner of an existing nuclear reactor would decide to mothball the unit and continue to maintain it so as to enable it to re-open at some later date. If the going-forward costs of an existing nuclear plant are not expected to be supported by revenues from operating the unit and the owner decides that it is no longer economic to keep it open, then mothballing would be a costly and burdensome enterprise. The latter would involve maintaining security, regulatory licenses, taxes, transmission rights, some staffing levels, and other activities to retain the potential to reopen the plant at some future date. An owner of a nuclear unit—and in particular, an owner of an unregulated "merchant" unit—would have a hard time justifying such expenditures for many years without a revenue stream, and without the expectation of highly attractive financial returns in the future.

- *Are you concerned about the long-term consequences if our current nuclear fleet shrinks considerably? If so, what are the ramifications?*

Response from Dr. Tierney:

Yes. As I have written elsewhere, there are negative cost and air-pollution consequences when a safely operating existing nuclear plant closes.

- Susan Tierney, "Don't Let Nukes Go Too Fast," *The Hill*, July 15, 2015, https://thehill.com.opinion/op-ed/247858-dont-let-nuke-plants-go-too-fast
- Susan Tierney, "Is Nuclear Power Vital to Hitting CO2 Emissions Targets? Yes: Renewables Can't Fill the Gap Yet," *Wall Street Journal*, November 11, 2016. https://www.wsj.com/articles/is-nuclear-power-vital-to-hitting-co2-emissions-targets-1479092761;
- Susan Tierney and Karen Palmer, "Grid Resilience, Generation Portfolios, and National Security," Resources for the Future, May 8, 2018, https://www.resourcesmag.org/common-resources/grid-resilience-generation-portfolios-and-national-security

I have three concerns regarding the near-term closure of nuclear plants, which today produce power almost around the clock (e.g., 93 percent of hours in 2018), produce one-fifth of total electricity supply to American consumers, and nearly two-thirds of carbon-free power.

- First, from a climate change point of view, whenever a nuclear plant closes in the near term, its output is replaced with electricity generated at plants that run on natural gas, coal, and/or oil, all of which produce carbon emissions. This happens because the solar and wind facilities that exist on the system at the time the nuclear plant retires are already producing as much as electricity as they can (in other words, whenever the wind is blowing and the sun is shining). When a 1200-MW nuclear plant retires, for example, the replacement power from fossil-fueled generating units would lead to carbon emissions equivalent to adding from 0.5-1.0 million cars on the road, depending upon where that plant is located. Replacing both the energy production and capacity of a 1,200-MW nuclear unit with wind and solar alone would require a massive investment, along the lines of 2,000 MW of offshore wind *plus* 1,350 MW of utility-scale solar *plus* storage. (One MW of nuclear capacity produces power over 92 percent of the time, compared to offshore wind (31-51 percent), on-shore wind (11-48 percent), utility-scale solar (15-27 percent), and rooftop solar (12-21 percent). (National Renewable Energy Laboratory, "Annual Technology Baseline," 2018, https://atb.nrel.gov/electricity/2018/summary.html)) The prospects of replacing that much energy and capacity so quickly is daunting, especially since at present, and even after the massive build-up of wind and solar capacity over in the past decade, together they provide 8 percent of the nation's electricity.
- Second, when a nuclear plant retires, power production costs also tend to rise, because more expensive plants will have to be operated to replace the nuclear unit's output. And the investment in zero-carbon generating assets to fully replace the nuclear unit's capacity and energy tend to be more expensive than the going-forward costs of keeping a nuclear unit in operation.
- Finally, there are national security considerations associated with closure of the nation's nuclear fleet: The U.S. has maintained an important seat at the table in international discussions of nuclear technology development, deployment, safety, and security, due to the expertise and capability of American researchers, designers and operators of U.S. nuclear plants. Although not reflected in market prices for power, this capability remains important for the U.S.'s strategic interests. Without a set of plants in operations and research/development underway, this capability will be substantially undermined. (Please see the report of the Energy Futures Initiative, "The U.S. Nuclear Energy Enterprise: A Key National Security Enabler," August 2017, https://static1.squarespace.com/static/58ec123cb3db2bd94e057628/t/59947949f43b55af66b0684b/1502902604749/EFI+nuclear+paper+17+Aug+2017.pdf).

Question 2: While concerned about premature closures in today's U.S. nuclear fleet, I am bullish on the future of advanced reactors. Last week, Dr. Birol of the International Energy Agency and I discussed the importance of re-establishing U.S. global leadership in nuclear to ensure that advanced reactors are designed and deployed here. During the hearing, the important government support that brought wind and solar technologies to market and brought down the cost curve was discussed. I have been working on policies that will do the same for advanced nuclear technologies like small modular reactors. These advanced reactors may provide different value streams like high-temperature heat for manufacturing or off-grid power to remote communities like those in Alaska. They will also provide power to the grid. As you look forward to these next-generation technologies, what kind of value will advanced reactors provide and do you anticipate advanced reactors playing an important role in a lower-emissions economy?

Response from Dr. Tierney:

Idevelopment of next-generation energy technologies, through a combination of RD&D support, tax policy, environmental regulations, technology standards, and policies that underwrite technological development risk. In this context, I think it is important for the U.S. federal government to continue to help support such things as R&D on materials and advanced reactor designs, on manufacturing models for advanced nuclear-reactor components and systems, regulatory reforms to align federal safety reviews with the characteristics of advanced reactor designs, and methods to mitigate risks associated with early stage demonstration projects, among other things.

Question 3: In your written testimony you expressed the importance of the federal government avoiding the adoption of narrow technological solutions to address climate change.

- *What technology options do you think can make the biggest difference?*

Response from Dr. Tierney:

In addition to continuing to fund research, development and deployment of advanced materials, systems integration, and performance of more efficient wind, solar, biofuels, and to support policy instruments that move them (and more energy-efficient devices, equipment and vehicles) into private markets, I think there are at least five areas where the federal government should be involved in supporting RD&D:

- Advanced nuclear technologies and business/manufacturing business models
- Carbon capture and utilization technologies, approaches, and systems
- Storage systems with lengthy energy-storage periods

- Carbon removal technologies, approaches and systems
- Grid modernization investments

- *With limited federal funding, where do you see the biggest potential impact being made*

Response from Dr. Tierney:

I encourage the Committee to probe this question with a variety of experts, including those from the Department of Energy, academic institutions, innovative start-up companies, NGOs, the National Academies of Sciences, and others who are working on the technical and non-technical barriers that need to be addressed to help move these advanced technologies forward through research, development, initial deployment, and commercial operations (where warranted).

Question 4: In order to see increased adoption of carbon capture, we know we need to make some important breakthroughs in technology and cost.

- *What role will carbon capture play in our clean energy future? What are the things that Congress can do to accelerate the development of carbon capture technology?*

Response from Dr. Tierney:

In light of the importance of reducing carbon emissions from domestic and international energy systems, combined with abundance of carbon-intensive fossil fuels in the U.S. and in many parts of the world, it is critically important for the U.S. to continue to explore the technical and non-technical issues associated with carbon capture, utilization and sequestration ("CCUS") technologies, approaches, and approaches. The U.S. government should continue to support, if not expand, the RD&D agenda for a variety of approaches (e.g., technological carbon-capture systems for large and small-scale applications; biological processes for capturing carbon; regulatory regimes to support utilization and sequestration approaches).

Question 5: In 2014, two Department of Energy labs worked on a report that mapped out a plan for "deep decarbonization" of the nation by reducing greenhouse gases 80 percent by 2050. This plan was part of the "Deep Decarbonization Pathways Project" (DDPP).

- *Do you think that we can reduce carbon by 80 percent by 2050?*

Response from Dr. Tierney:

This good question goes to the heart of the challenge our nation faces and which is why I appreciative the work that the SENR Committee is undertaking, with Chairman Murkowski's and Senator Manchin's leadership, to explore the electric industry in a changing climate.

I am by nature an optimist and, by professional experience and expertise, a principled pragmatist. So, in response to your question, I say that we must significantly and urgently reduce GHG emissions from our economy, and in order to do so through a combination of political will, policy action, and markets, we must find practical and effective ways to do so.

Based on my own review of the literature on what it might take to achieve deep reductions in carbon and other GHG emissions from the U.S. economy—including the Deep Decarbonization Pathways Project, among dozens of other studies—I understand that it will be much easier to accomplish 'modest' GHG emissions reductions than it will be to reach the levels of emissions reductions (e.g., at least 80 percent reductions by 2050) that are consistent with limiting the worst impacts of climate change.

A number of themes come through this "deep decarbonization" literature that are relevant to this question, including among other things:

- Deeper GHG emission reductions will require a combination of: technological innovations and performance improvements that are likely to be non-linear; continued cost reductions across advanced technologies, materials, and biofuels; significant investment and turnover of capital stock, as well as working through stranded costs in the multiple sectors and systems where fuel-switching and replacement equipment will need to take place; diverse behavioral changes; new business and investment models; new market designs; and many other changes. Addressing such issues will be needed in any of the alternative technological decarbonization pathways explored in the literature.
- Increasing energy productivity through energy efficiency investments and practices is assumed to be an essential part of virtually all deep-decarbonization strategies. The studies assume efficiency improvement rates that are typically twice to three times historic averages.
- The strong consensus in the literature is that a more diverse portfolio of electric technologies—rather than an energy mix assumed to rely exclusively or nearly entirely on renewable energy technologies with intermittent supply—will likely be more technically feasible and will lead to a lower-cost and low-carbon economy in the United States. Recognizing that not all of the studies

explicitly model economic considerations, those that do and that compare the costs of alternative technological pathways conclude that mixed portfolios of energy technologies achieve that outcome at lower cost. This conclusion is driven by a number of factors, including: the need to add much more total capacity in an all-renewables system due to the intermittency of output and low capacity factors, and the need for substantial collateral investment in storage capacity; the very large size of the geographic requirements for siting the large amount of renewable capacity that would be required; the need for storage technologies that are ubiquitous, at scale and capable of discharging across multiple days and/or seasons when wind and solar are less abundant; and the new investment that would be required in substantial additional transmission and distribution capacity, combined with the difficulties of siting the former.

- Finally, the deep-decarbonization literature tends to focus on what outcomes are possible and/or needed (technically and/or technologically), with less attention to *how* those outcomes may be able to unfold. There are many technical, social, economic, institutional, financial, political, and other aspects of the transition that merit substantial continued analysis and attention by researchers and analysts, as well as by public policy makers and electric-system stakeholders.

Together, the studies suggest that an electric system comprised of diverse zero- and low-carbon supplies coupled with an economy that is more reliant on electricity increases the possibility of accomplishing deep decarbonization at lower costs than other approaches. A diverse portfolio would include those technologies that can provide supply on demand as well as those dependent on weather-related and intermittent sources of energy. An important implication of the literature is the combination of both technically available *and* economically accessible clean energy resources is key to the social and political acceptance necessary for the nation to proceed on a transformative low-carbon pathway.

The future U.S. electric system anticipated in any of the deep-decarbonization scenarios will be even more complex than it is today. It will have a different and much larger set of components, including dispatchable and non-dispatchable and decentralized and central-station technologies, and many more devices and controls that affect power flows on the high and low voltage systems. It will have customer-usage profiles that differ considerably from those that have existed even in the recent past.

Given the scope of the challenges and the inherent uncertainties about any individual pathway, the literature suggests that it will be important in the near term to keep as many clean-energy pathways on the table as possible. Betting on a single technology, or a narrow suite of technologies, would lock in a constrained pathway with fewer contingency options in the event that the world changes in ways that are hard to foresee. Diversity is a common feature of decentralized and resilient ecosystems. The same is true of the nation's future energy system.

- *What are your thoughts on achieving this goal not by 2050, but by 2030, the date targeted in the Green New Deal?*

Response from Dr. Tierney:

As I said in my prior response, I think that it will be much easier to accomplish 'modest' GHG emissions reductions than it will be to reach the levels of emissions reductions (e.g., at least 80 percent reductions by 2050) that are consistent with limiting the worst impacts of climate change. So, I think that an accelerated timeframe for such reductions will be even harder—even as I agree with the aspiration to reduce emissions as quickly and as deeply as possible.

In my view, the original Green New Deal resolution—that is, the non-binding one introduced by Senator Markey, rather than the binding resolution introduced by Senator McConnell and voted upon in late March 2019—sets an aspirational goal for decarbonizing the American economy, among other things. In terms of its goals for GHG emission reductions, I view it as more a statement about the imperative of action than a specific legislative agenda. I like its narrative that pulls together ideas for actions in different sectors of the economy, for investment in clean infrastructure, for a just transition that should accompany changes in energy systems and the ways Americans use energy. But it does not include any specifics about policy instruments, and therefore does not lay out either a legislative or as-yet-actionable strategy for accomplishing its objectives. (I don't think its intention was to do so at this point.) As a consequence, I do not see it as revealing a clear pathway for making the very challenging transition to a zero-carbon electric system by 2030.

- *While we have seen information on 80 percent by 2050, do you have any thoughts on why we have not seen any substantial reports mapping out exactly how the nation could reach 100 percent by 2030?*

Response from Dr. Tierney:

Although many individual companies and sub-national governmental entities and other institutions in the U.S. have committed to near-term zero-carbon electricity supplies for their own use, I am not aware of any organization that has offered a strategy for full decarbonization of the American economy (or even of its electric system) by 2030. Perhaps this reflects awareness of the significant political, cost, financial, scientific/technical, technological, legal, regulatory, behavioral, systems, and other impediments that stand the way of accomplishing such dramatic transformation of the economy so fast.

Looking at the power sector alone, the amount of long-lived capital stock (e.g., fossil power plants, transmission equipment, and consumers' energy-using equipment that does not now use electricity) that would need to turn over and be replaced by a combination of zero-carbon technologies in a single decade is enormous. And the challenges of accomplishing a 100 percent decarbonization goal by 2030 in a reliable and affordable way are daunting, especially in a federal/state system where collective action toward that goal depends upon bipartisan legislative consensus in Washington and/or the states, outcomes of myriad legal contests, and disbursed decisions in regulatory proceedings that focus on discrete issues rather than omnibus solutions.

Question 6: Your written testimony includes a pair of charts that show, as you wrote, "nearly every state experienced a reduction in CO2 emissions from in-state power plants from 2005 through 2016." One of the states that stands out in the minority of those charts is Washington State, which appears to have both increased power sector emissions over that period, and to have increased the percentage in its power sector CO2 emissions as well. Please expound on what might be happening in Washington State, specifically, to cause its power sector to be increasing its CO2 emissions over a time period when "nearly every state" is going the other direction.

Response from Dr. Tierney:

In the data presented to the SENR Committee to indicate the progress that has been made across the nation to reduce carbon emissions, there are at least two states—Washington and Oregon—that warrant further explanation, so I appreciate this question. The electricity sector in each of these two states has had relatively low levels of carbon emissions for many years, in light of the abundant hydroelectric resources available to the electric utilities in these states. Due to the combination of a baseline of low power-sector carbon emissions and variability in the availability of hydropower from year to year, small absolute increases in carbon emissions (from, say, the operations of gas-fired generating facilities to make up for low-hydro years) can lead (mathematically) to higher percentage changes. Unlike in many other states on the chart I presented in my testimony and where there have been significant structural changes in the electricity supply portfolios, Washington (and Oregon) experienced small absolute (and somewhat anomalous) increases in 2016 relative to 2005, but the power sector in those states is still relatively clean.

Question 7: Clearly the power sector is not the only industry contending with emissions. What other sectors of the economy should Congress focus on to reduce overall emissions?

Response from Dr. Tierney:

As power-sector emissions have gone down in recent years, the relative importance of reducing emissions from the transportation sector, from buildings, and from industry has increased. The extensive literature on decarbonizing the American economy points to the importance role of electrifying certain activities and processes in these other sectors (e.g., through adoption of electric vehicles, through adoption of electrical technologies to heat and cool buildings, through changing industrial processes that now use fossil fuels), while continuing to reduce carbon emissions from the power sector as electrical demand grows. The literature suggests that by 2050, electricity generation could double relative to today's output. Without much deeper electrification and a lower-carbon electricity system, it will be much harder, technically, and much more expensive for the nation to deeply reduce its GHG emissions.

I hope that Congress looks for ways that existing or new federal policies could support development and application of cost-effective and innovative emissions reductions in buildings, industrial processes, and vehicles, fuels and transportation systems.

Questions from Ranking Member Joe Manchin III

Question 1: You pointed out in testimony that, although there was an increase in carbon emissions from 2017 to 2018, overall, power sector emissions declined substantially over the past decade, with electricity generation and use remaining relatively flat. Carbon dioxide declined by about 28 percent from 2005 through 2017.

- *What technologies have you seen in practice that have shown the most success in emission reductions so far?*

Response from Dr. Tierney:

In the power sector, the emissions reductions that have occurred over the past decade have resulted from a combination of technologies:

- Private companies' application of hydraulic fracturing and directional drilling to tap domestic natural gas resources at relatively high speed and low cost, leading to availability of abundant supplies of natural gas at relatively attractive prices;
- The existence of a large number of new gas-fired combined cycle power plants around the country that have been installed in the post-2000 period and which were underutilized until that low-priced gas became more widely available in the market. With low-cost fuel supply, these gas-fired combined cycle plants (as well as new combustion turbine generating units) could produce power more efficiently than many other, older fossil steam units (such as those that burned coal).
- Wind and solar technologies that experienced significant cost reductions and performance improvements over the past decade, so that (for example) wind turbines and projects could access areas (e.g., altitudes) with higher-quality wind, and solar projects could be installed relatively affordably on residential and commercial rooftops and in utility-scale solar systems.
- Energy efficient appliances (such as LED lighting) that enabled consumers to experience high-quality energy services with less need for electricity.

- Communications and control technologies that enable customers to better manage their electricity usage (and tune it up or down in ways that have afforded grid operators with flexible resources they need to operate the electric system reliably and efficiently).
- Battery-storage technology improvements, which have led to storage applications (along with gas-fired resources and demand-response technologies) that have begun to support the integration of many non-dispatchable wind and solar facilities on local distribution system and on the higher-voltage electric grid.
- Systems-integration, power-control and communications technologies that allow grid operators to better visualize and reliably control power flows on the system.
- The continued operation of existing nuclear plants, which currently provide three-fifths of all carbon-free electricity in the nation.
- High-voltage, direct-current transmission facilities that, under certain configurations and conditions, allow for larger quantities of power to move across regions and at lower cost than in conventional alternating-current technologies.

The successful deployment, retention and operations of these low-carbon technologies has been supported over the years through a wide variety of federal and state policies (including tax credits, appliance efficiency standards, regulatory policies and rules in wholesale power markets, R&D, among many others).

- *What technologies have you seen at DOE and the labs that have a great deal of promise for providing a reliable energy with a lower emissions profile?*

Response from Dr. Tierney:

The technologies I describe above have benefitted from federal support for RD&D, with that work carried out by the national labs as well as in academic institutions. These efforts are supported by DOE energy-program offices, including ARPA-A.

- *What can Congress do to foster commercialization of these innovative power sources?*

Response from Dr. Tierney:

Congress can continue to support various activities and approaches, including:

- Funding RD&D that addresses technical, cost and performance issues, including work on materials, systems-integration, system modeling, and advanced manufacturing that affect the understanding of and eventual development/availability of technologies that affect their commercial deployment.
- Authorizing agencies' (e.g., the Defense Department) interest in testing and deploying early stage technologies.

- Ensuring access to public lands (including offshore wind areas) for renewable development.
- Providing tax provisions (such as the new 45Q) that support private investment in advanced and/or clean-energy technologies.

Question 2: Between 1990 and 2014, total greenhouse gas emissions increased by 30 percent, but three quarters of those emissions came from three sectors – electricity, manufacturing, and transportation. As a large scale energy source, nuclear power has a significant potential to contribute to emissions reductions goals. In the U.S., due to phase-out policies and financial challenges, 30 gigawatts will be lost by 2025. This represents an 8.7 percent increase in carbon emissions for the U.S. power sector and according to an MIT study will cost the country $7 billion a year.

- *What potential do you see nuclear power having to aid in the reduction of carbon emissions in the future? What about utility scale nuclear versus small modular reactors (SMRs)?*

Response from Dr. Tierney:

I agree with the premise of the question, which points to the important role that nuclear energy plays in helping the nation meet its electricity requirements without producing GHG emissions. (In my response to a prior post-hearing question from Chairman Murkowski's post-hearing Question #1, I describe the economic, carbon-reduction and national-security value of retaining safely operating existing nuclear plants in the U.S.) The federal government has been a critical actor in supporting the development of commercial nuclear technology, and will—I hope—continue to do so regarding next-generation nuclear technologies, through a combination of R&D support, tax policy, environmental regulations, various technology and safety standards, and policies that underwrite technological development risk.

In this context, I think it is important for the U.S. federal government to continue to help support such things as R&D on materials and advanced reactor designs, advanced manufacturing systems, regulatory reforms to align federal safety reviews with the characteristics of advanced reactor designs, methods to mitigate the risks associated with early-stage demonstration projects, and so forth. Given the extremely challenging economic and investment conditions associated with the deployment of conventional reactors, I encourage continued federally supported work on small modular reactors which aim to use advanced materials, reactor designs, manufacturing models, and investment approaches on nuclear technologies with very different cost, operational, waste-management, and security profiles from the existing commercial reactor fleet.

Question 3: We have seen the European electricity sector transformed in the past decade. For example, last year the United Kingdom went coal-free for a record three days, relying on gas, renewables, and nuclear instead to keep the lights on. In fact, both UK Prime Minister May and German Chancellor Merkel announced plans to phase out coal in the next decade. European Union countries have committed to achieve 32 percent renewables by 2030, and an organization of 3,500 European electric utilities has committed to 100 percent carbon neutral power generation "well before" 2050. Aggressive climate policies are driving these decisions and European customers also seem willing to pay more for their electricity. Depending on the country, these shifts have occurred because of an emissions trading system or subsidies for wind and solar, and, in others, because of the ability to draw from significant hydropower or nuclear resources.

- *What are the differences between these European countries and the United States that make shutting down coal a feasible decision for them and more challenging for us? Can you speak to the implications, both positive and negative, of their plans to phase out coal?*

Response from Dr. Tierney:

There are several reasons why many European countries have been moving faster than the U.S. to reduce if not eliminate their reliance on coal. For example:

- There has been a deeper level of consensus among policy makers, corporations, and civil society in many large European countries (as compared to the U.S., until recently) that climate change is occurring and that carbon emissions from human activity are contributing to it. This has supported a greater degree of political will in many of those European countries to take action to reduce such emissions.
- The economic content in Europe is one in which energy (e.g., electricity, gasoline) prices have historically been higher than in the U.S., with significantly less energy used per capita than in the U.S. These differences in the energy intensity of national economies in Europe versus the U.S. has contributed to the varied political and economic reactions to changes in domestic energy systems.
- There is an energy system in the U.S. where states play a strong role in shaping trends in electric-sector policies, plans, and resource portfolios—and where significant regional variation exists across the American states with regard to political, regulatory and popular support for maintaining coal-fired generation (until the past decade or so).
- Notably in the U.S., the most significant driver of reduction in coal-fired generation is less national political will than the reality of market forces, combined with targeted state policies and federal support for technological innovation. For example, key factors affecting this outcome are:
  - The low price of natural gas, given development of the U.S.'s abundant supplies of unconventional natural gas which are now economically accessible through the application of hydraulic fracturing and directional drilling in the past decade.

- Federal and state policies (such as federal appliance efficiency standards and federal energy management programs, and states' policies that advance the installation of efficiency measures by utilities and other service providers) that have helped to flatten electricity demand;
- Federal policies that support R&D on renewable energy technologies and states' policies to promote the development and adoption of renewable energy; and
- States' policies to reduce carbon emissions (e.g., through the Regional Greenhouse Gas Initiative) or maintain zero-carbon electricity sources (e.g., Illinois' and New York's zero-carbon emissions programs aimed at maintaining existing nuclear plants that are financially at risk of retirement).

Questions from Senator Mazie K. Hirono

Questions: In your testimony, you stated that "greenhouse gas emission reductions are not happening fast or deeply enough." The Department of Energy's Energy Information Administration ((EIA) projects the U.S. power sector will only cut emissions 34 percent by 2050 compared to 2005 levels, meaning only an extra 6 percentage point cut below the 28 percent reduction achieved by 2018. That is not fast enough to make the economy-wide reductions needed to avoid the worst impacts of climate change. For many years, I have called for a national renewable power standard to set a clear target for power companies to meet while helping create American jobs in technology development, manufacturing, and installation. From your testimony, I understand you would prefer to include other low-carbon sources of power in any national policy. Do you think a national power standard would help drive down the costs of zero-carbon power sources and accelerate cuts to greenhouse gas emissions from the power sector (compared to the current policy projections offered by EIA)? If you think a national power standard to reduce GHG emissions is important, do you have any recommendation for design of such a standard?

Response from Dr. Tierney:

I agree with Senator Hirono that a national renewable power standard would help to drive down the costs of zero-carbon renewable power sources and accelerate cuts to GHG emissions. Moreover, a national clean-energy standard, with eligible resources including not only renewable power sources but also other zero-carbon-emitting resources, would have amplify those positive effects and, according to numerous studies (e.g., https://www.thirdway.org/report/clean-energy-standards-how-more-states-can-become-climate-leaders), would do so in a way that provides for reliable clean power at lower costs.

Regarding design elements of a clean-energy standard, I encourage the Senate to look at various studies and policy discussions that address an efficient and effective design for a clean energy standard. Over the past decade, many parties have examined how to structure CES policies, including, for example:

- Resources for the Future (https://www.rff.org/events/all-events/a-federal-clean-energy-standard-understanding-important-policy-elements/;
- World Resources Institute (https://www.wri.org/blog/2011/04/how-design-clean-energy-standard);
- Center for Climate and Energy Solutions (https://www.c2es.org/document/an-illustrative-framework-for-a-clean-energy-standard-for-the-power-sector/);
- Breakthrough Institute (https://thebreakthrough.org/articles/clean-energy-standards); and
- Brookings Institute (https://www.brookings.edu/wp-content/uploads/2016/07/05_clean_energy_aldy_paper.pdf).