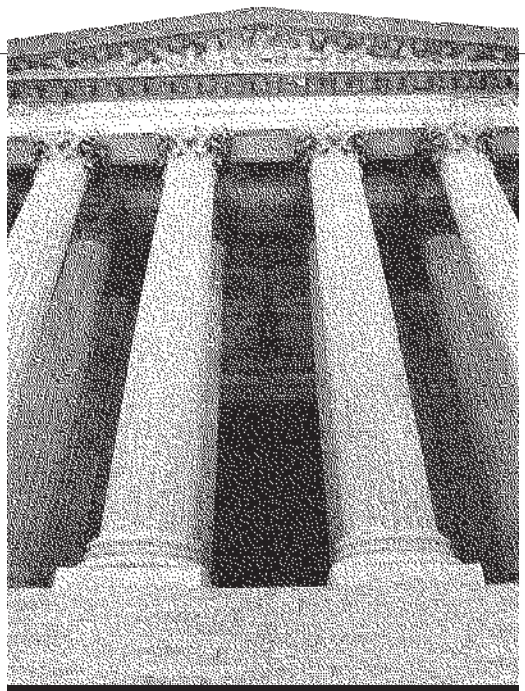

THE DEBATE
IN PRINT

Reassessing Nuclear Power in a Climate-Constrained World

Historic accidents such as Fukushima, Three Mile Island, and Chernobyl have led to nuclear energy's reputation as a significant environmental worry, mainly due to fears of potential contamination from a nuclear incident or improper disposal of radioactive waste. However, today the European Union depends on nuclear power for more than 25 percent of its electricity, and the United States is not far behind.

As climate concerns increase, many countries and businesses are reassessing the role of nuclear power in a climate-sensitive future. Questions are emerging around scheduling retirement of nuclear plants, even as barriers remain to siting new plants, including compliance with state and federal law, mitigating public concerns surrounding risks, and steep financial burdens such as building and operational costs. Some favor financial incentives for new nuclear capacity or keeping existing plants operating beyond their lifecycle, while others note the risks, including infrastructure integrity of reactors, storage and disposal capacity, and potential environmental and health contamination.

What does the future of nuclear energy look like in this evolving landscape? How do the environmental challenges of nuclear energy stack up against the possible advantages from the vantage point of climate change, whether those tasks be decommissioning reactors, disposing of nuclear waste, storage issues or others? Should nuclear energy be seen as a bridge fuel while other renewables scale up to meet energy demands, or even as a fixed piece in a U.S. lower-carbon energy mix?

Panelists in the ELI-Miriam Hamilton Keare Policy Forum, held the day of the annual ELI Award Dinner, discussed these questions and tackled the complex history, the multifaceted regulations, and the future of nuclear energy.

The 2019 forum was the first not attended by the late Douglas Keare, whose generous gifts over the years have made ELI's principal policy event of the year a tradition.

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Commonwealth Professor of Environmental Law and Sustainability
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"A major pillar of decarbonization includes clean generation to support the electrification needed to decarbonize other sectors of the economy."

Mason Emnett
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Sandra Levine
Senior Attorney
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"The only resolution is to prove that nuclear power can be safe and affordable by building power plants and operating them safely and economically."

Granta Nakayama
Partner
King & Spalding LLP

Scott Fulton, *President, Environmental Law Institute*: This program emerges out of several ELI engagements. ELI Press published a book written by John Dernbach of Widener and Michael Gerrard of Columbia, as the principal authors, and scores of other authors as well, entitled *Legal Pathways to Deep Decarbonization in the United States.*

Based on the current projected reach of renewable energy sources, like wind and solar, total power they produce is less than what is ultimately needed to meet projected demand. Does nuclear power have a contribution to make in this lower-carbon future?

Like many, I spent a fair amount of my life deeply disquieted by nuclear power. My first environmental cause was as a student at the University of Massachusetts in Amherst in 1975 opposing the Seabrook nuclear power plant in New Hampshire. The Three Mile Island nuclear accident that occurred just four years later did not increase my comfort level, nor did the failure after several decades of work to construct a repository for nuclear waste at the Yucca Mountain facility in Nevada.

The chilling story of Chernobyl in what is now Ukraine, the horrifying tsunami calamity at Fukushima in Japan, these are not children's bedtime stories. And yet if climate change is indeed an existential threat, is there a role for nuclear power in responding to it? What is the greater risk? Does technology yet hold promise in mitigating those risks? What does the development of micro nuclear reactors have to say about the risk equation? Is technology solving the riddle about the reuse of spent fuel?

So I find myself rethinking how I feel about nuclear power and am pleased to present some of the key thinkers about the role of nuclear power in a world facing dangerous climate change.

John Dernbach, *Commonwealth Professor of Environmental Law and Sustainability, Widener University Commonwealth Law School*: My job is to open the panel by asking the big question: How do we achieve at least an 80 percent reduction in U.S. greenhouse gas emissions by 2050? That was the question that Michael Gerrard and I tried to answer in *Legal Pathways.*

Our book is based on the work of the Deep Decarbonization Pathways Project, or DDPP, which looked at 16 different countries that together produce about three quarters of the world's greenhouse gas emissions. The DDPP assessed the technical and economic feasibility of deep decarbonization in each of these countries in order to limit warming to 2 degrees Celsius.

The pillars of deep decarbonization are energy efficiency; decarbonizing electricity; and moving other energy users, including those using liquid fuels like gasoline, to electricity. A fourth pillar of deep decarbonization, the need for which is becoming clearer, is negative emissions — capturing carbon from the air and sequestering it.

The long-term orientation of deep decarbonization can help avoid dead ends like overreliance on natural gas. Gas may have half the carbon emissions of coal when burned for electricity, but you have to account for fugitive emissions of what is a potent greenhouse gas. Even if there are no fugitive emissions, gas only provides a 50 percent carbon reduction.

The DDPP project is not based on energy technology breakthroughs. It also assumes projected population growth and economic growth between now and 2050. The project concludes that the United States could reduce its greenhouse gas emissions by at least 80 percent by 2050 for only 1 percent of GDP. That doesn't assume any of the co-benefits that go with reducing greenhouse gas emissions, including avoided costs of adaptation and reduced mortality.

To achieve that reduction, DDPP says, we need to improve energy efficiency in the United States by at least a factor of two by 2050. We need to have about 300 million electric vehicles on the road by the same year. Finally, to support all the energy that those vehicles are going to require, we need to double electricity supply.

The DDPP does not assume that there is a particular way to get this done. Indeed, it developed four different scenarios: First is a high renewable scenario, second a high carbon capture and sequestration scenario, third a high nuclear scenario, and finally a mix or combination of the above scenarios. The DDPP's modeling shows that you can get a very big reduction in any of those four.

The *Legal Pathways* book builds on this work. Michael Gerrard and I found that the legal tools are available to achieve deep decarbonization in the United States. They are either laws that already exist or laws that could be put on the books. We can do this. In 35 chapters, the 59 authors, who are mostly practicing or academic lawyers with considerable expertise, identified 1,500 different legal tools that can be employed to do the job. The book provides a playbook or menu of choices; we do not take a position on which options to select.

The book identifies a dozen types of tools. A lot of us concentrate on regulatory advances and market mechanisms — perhaps the two most common types of tools. So it is easy to overlook other types. But editing the chapters, I saw over and over again that for financing, for nuclear energy, for hydropower, for distributed renewables, for utility-scale renewables, for CCS, the law actually gets in the way. Removal of legal barriers is another type of tool.

We're working with more than 20 major law firms to turn the recommendations in the book into model legislation that will be published on a website. Rick Horsch, a retired partner at White & Case, is leading that project.

As to nuclear power, there are something like 100 commercial nuclear reactors in the United States right now, with a capacity of about 100,000 megawatts. The high nuclear scenario from the DDPP involves quadrupling existing U.S. nuclear capacity. And even in the mixed scenario, we need a doubling.

The nuclear power chapter was written by David Repka and Tyson Smith, who have long experience with nuclear energy law. Their recommendations fall across a couple of categories. One, not surprisingly, is pricing carbon. Another is fully valuing the benefits of nuclear, including consideration of zero-level emissions credit programs, which already exist in places like Illinois and New York and have been upheld by federal courts of appeals.

A number of the recommendations involve financial support for the nuclear industry. The chapter promotes subsidies for nuclear generation that are comparable to the direct subsidies for renewables. There are other recommendations, including research and development, particularly in new reactor technologies. There are recommendations to improve and facilitate nuclear power licensing. Those who are familiar with nuclear licensing understand that there is a more complicated procedure for review of the environmental impact statement for nuclear power than for other projects.

Finally, there are recommendations involving nuclear waste. These include reactivating and licensing the Yucca Mountain project and authorizing private waste storage. In that regard, the chapter recommends creating a Nuclear Waste Administration.

Granta Nakayama, *Partner, King & Spalding LLP***:** It is important to understand the history of where the industry has been, including its origins. I am not going to address this from a legal standpoint but more as a nuclear engineer.

Edward Teller, one of the architects of the hydrogen bomb, said there is nothing new about nuclear power. Nuclear power has been used to desalinate water. It's been used to transport that water to irrigate crops. It is called rain. But even though the sun is 93 million miles away, it still causes cancer. While nuclear power has a lot of promise, there are obviously issues.

But nuclear power is the one large-scale industrial energy source that does not involve combustion. There is no other large-scale, carbon-free energy source that you can use for central station power that is available 24/7. It also has a very small footprint with respect to actually mining the uranium.

With climate change, we are at an inflection point. The need for carbon-free energy offers a unique opportunity for the nuclear industry to make its case.

At the same time, automakers are moving to electric cars. We consume 170 billion gallons of gasoline and diesel fuel a year. If we move all that to electric vehicles, the present grid can't take it. In California, for instance, we would have to increase the grid capacity about 50 percent.

If we are going to meet that challenge, we are going to have to look at alternatives like nuclear power. Americans are not going to give up their cars, as a big for instance. Thus like a phoenix rising, nuclear power can come back and contribute to our energy mix.

While it is important to look at this technology, there are obviously problems with nuclear power. One is cost. The price to build a nuclear plant has historically been very unpredictable — the lead times, the regulations, the unforeseen occurrences. A number of utilities have been bankrupted.

A second hurdle is the public's aversion to nuclear power. I don't discount that. There have been a number of accidents. People are concerned about radiation from either an accident or the long-term release of radiation.

As to cost, nuclear power is going to have to compete with other sources of energy. Renewables are lower in cost. All those factors that contribute to the competitiveness of renewables make nuclear power a stretch right now. It has been decades since a new plant has been completed.

But is it possible to build the needed grid capacity using nuclear in a way that's cost efficient and safe? There is an example today and that's simply the Naval Nuclear Propulsion Program. They have built hundreds of reactors for submarines and surface ships.

They have operated those reactors for thousands of reactor-years and they operate them safety. You never hear about them, which is what any nuclear operator wants. And they operate in places where you would never be able to license a commercial nuclear power plant, such as in Pearl Harbor.

The other hurdle, the aversion to nuclear power based on the accidents, I totally get. I received my degree in nuclear engineering the same spring as Three Mile Island. My internship at the Nuclear Regulatory Commission following graduation was thus different than what I expected.

Later, I ran EPA's enforcement program for a number of years. I saw a lot of reputable companies get in trouble because they violated an environmental regulation. At the time they were meeting hundreds of regulations, but they had one particular incident. And we can't have that happen with a nuclear power plant. It's a different situation.

It's a skeptical public today. The only resolution is to prove that nuclear power can be safe and affordable by building power plants and operating them safely and economically.

We owe it to the environment to explore this source of energy.

Let me now close with a short story. I did work for Admiral Rickover, the father of the nuclear navy. He

would assign us engineers to a project and check back several months later. And if we answered that everything was on budget and on schedule with no technical problems, he'd explode in anger.

He would say we are either fools, ignorant, or just wasting our time. "Do you really believe, lieutenant, that every piece of metal is exactly made to the right chemical composition? It was heat treated exactly right? It was machined exactly correctly? That every computer program used to design that compound was designed with every physical phenomenon considered? And that every fastener was torqued exactly correctly, and every dockworker understood the assembly instructions exactly and all one hundred of these were built exactly right?

He drilled into us that the problems were out there and we just didn't know about them.

That's what it's going to take to make nuclear power successful in the United States. If we are going to have an organization to operate a large fleet of reactors and we are going to depend on them to maintain that engineering excellence and the transparency in their organization, it's going to take that kind of leadership. It's a steep challenge. It's a unique technology, but I think it can be done.

Mason Emnett, *Vice President, Competitive Market Policy, Exelon Corporation*: I am going to focus on the existing nuclear fleet and less about advanced technologies or investments in the next generation of power plants.

A lot of our current attention is focused on maintaining the existing fleet in order to meet our GHG reduction goals. Exelon is a large utility holding company. We have operations in the Chicago-land area and on the Eastern Seaboard from Washington, D.C., up to Atlantic City, serving about 11 million customers. We think about climate change impacts from the perspective of our customers, as delivering the electricity that's needed to power communities while considering the impact that the sources of that electricity have on their health and wellbeing.

We are also the largest owner of commercial nuclear plants in the country. So obviously we think about GHG reductions from that perspective as well as the other environmental benefits that our nuclear units provide.

There is widespread agreement that a major pillar of decarbonization includes clean generation to support the electrification needed to decarbonize other sectors of the economy, like transportation and buildings. Although the devil is in the details of the tradeoffs among all the various decarbonization activities either within the electric sector or within other sectors, there is widespread agreement that we need to prioritize decarbonization of the generation sector.

That means an exponential investment in wind and solar technologies, with storage to support them. But from the Exelon perspective, as we look at the studies, there are very few scenarios where it makes sense to retire existing nuclear generation. That is just making problems worse, taking steps backward before you can actually take steps forward in cleaning up our generation stack. And yet economic conditions are leading to the premature retirement of nuclear plants.

The Exelon nuclear fleet is a merchant fleet, meaning that it's not owned by a vertically integrated utility that has customer service guarantees through regulation at the state level. We operate in interstate, regional power markets. We compete with every other provider of electricity, including coal, natural gas, and renewables. We also compete with demand response and efficiency technologies that can operate within the regional markets.

But it's not a level playing field because carbon is not internalized within the marketplace. We are at a disadvantage to coal, natural gas, and other resources that are allowed to pollute for free. So as the shale gas revolution has driven down the cost of natural gas production and generation, we've seen the market price for electricity drop about 25 percent over the last five years, which makes it difficult for us to support our nuclear units.

As gas has driven coal out and the price of electricity down, we have seen emissions reductions with coal units switching to gas. And that's great. We've seen cost savings, which are great for customers. But the downside of the scenario is it's becoming increasingly difficult for nuclear generation to earn sufficient revenues to operate. So nuclear owners are shutting down our units prematurely or having conversations with the states as to whether that's the appropriate action to take.

We are encouraged by the zero emission credit programs that have been implemented to preserve nuclear units. Illinois, New Jersey, and New York have decided that the environmental impact of shutting down nuclear can't be tolerated within their state. ZEC programs function like renewable energy credit programs, compensating for the environmental attributes of the power that we are producing. Connecticut also has a program that has more of a procurement mechanism instead of a production-based payment. But again that's the state taking action to support nuclear within the particular region.

So this has led to some interesting conversations with the environmental community. The Union of Concerned Scientists called this "The Nuclear Power Dilemma," the title of an October 2018 report. UCS, an organization founded in part to advocate for nuclear weapons nonproliferation, actually came out in support of maintaining the existing nuclear fleet if operated safely and securely.

The science is clear: our GHG reduction targets are so significant because we have lived way beyond our carbon budget for too long. Retiring nuclear units is not an option. To put things in terms of just raw numbers, 20 percent of the nation's power comes from nuclear, 7 percent from wind, 2 percent from solar. Rounding up, the output of wind and solar together is about half of America's nuclear output. Let's assume the nuclear fleet retires — we would need to double the existing amount of wind and solar just to get back to the starting point, let alone the additional carbon-free generation needed to replace fossil fuels.

All generation technologies have their pluses and minuses. Wind and solar resources are extremely flexible, extremely responsible. But output is highly variable, not only hour by hour but seasonally, producing surpluses and gaps. Although nuclear power is not as flexible, it is stable 24/7 and year round.

The Center for Climate and Energy Solutions dug into this issue for Maryland's climate change commission. C2ES found that a 100 percent renewable Maryland could be achieved using batteries. But the state would need 50 times the peak load in energy storage to manage the fluctuations in renewable output across seasons. Their rough estimate of how much that level of batteries would cost was $473 billion. And C2ES found that other studies have had similar conclusions. So it's not that you can't do it — it's that it becomes really difficult and very expensive.

In terms of the existing nuclear fleet, it is significantly more economic to continue operating than investing in new replacement zero emission generation. Not every state has agreed. For example, our unit at Three Mile Island was retired a couple of months ago. We had long conversations with policymakers in Pennsylvania, which declined to take action to support that unit. There is an ongoing conversation about the state participating in the Regional Greenhouse Gas Initiative with Governor Wolf's commitment, which we are greatly supportive of. Yet TMI's closure means that its emissions-free generation must be replaced, which a state commission report found would take 13 years of renewable development at the state's current rate of investment. So, we are supportive of RGGI. We are supportive of market-based programs. But there is an impact associated with the loss of the unit that we just had to shut down.

We do need to address safety. As Mr. Nakayama said, we've got to be diligent. We completely agree. The responsibility is on us to prove safety, and we believe that we have demonstrated safety with our operations. We have redundant systems and security checks. We participate in 4,000 hours of inspections annually. Our operators are trained for two years before they start, and then are subject to a week of training for every five to six weeks on the job. So it is a continual, very conscious program for maintaining safety.

Yes, incidents have happened. The Chernobyl design had no containment. There were inadequate response procedures in place. In Fukushima, there was a 45-foot tsunami and weeks of lost power at the plant. Yet the cooling pools at the reactor were not harmed. They continued to operate safely. What happened was there was a loss of power to cooling equipment. At our facilities, we have invested in redundant equipment to prevent this from occurring. We also participate in regional programs that are in place that have additional redundant equipment that can be at our sites without 24 hours.

So it is on us to learn and to hopefully never make that mistake. But the business that we operate in can be dangerous. We just have to acknowledge that and be responsible for it whether that's our nuclear operations, our transmission operations, our investments in renewables or anything else.

Also you should know that it's important to keep in mind the additional public health impacts that come with closing nuclear plants. We're having an ongoing conversation in Illinois about our nuclear fleet there with proposals pending in the legislature to prevent the early retirement of our units. We're experiencing financial distress with our remaining Illinois fleet, so it's a very active conversation.

The Clean Air Task Force evaluated what would happen if we were forced to retire the predominant portion of our Illinois fleet. It found that the additional SOx and NOx and particulate matter from fossil generation replacing the lost nuclear plants would cause more than 1,200 premature deaths, 3,000 additional asthma attacks, and nearly 14,000 lost days of work over the next decade, accumulating to as much as $2.4 billion in economic damages.

So apart from the GHG conversation, which is extremely important, the other emissions coming from fossil fuel power plants are equally important. Like CATF, UCS found that, when nuclear plants close, they are replaced by coal and natural gas. That's why UCS took the position that it is important to support the continued operation of existing nuclear facilities.

From Exelon's perspective, this is not just about recognizing the value of our zero-emission nuclear fleet. Over 90 percent of our utility footprint is in non-attainment zones. Air quality is critical to the communities we serve and, therefore, our company.

As we think of going forward with the problems that need to be solved, we need to get alignment on environmental policy. What are society's goals going to be? What are our GHG reduction strategies? Then we need to get alignment between the wholesale markets that we operate in and the regulatory policy. We are struggling with that right now.

The states that have taken action

to support nuclear units are facing a backlash at the federal level. Regulators are proposing penalties that are going to increase the cost of environmental programs, whether it's for nuclear or renewables.

As we build out renewables or support the continued operation of the nuclear fleet, we all need to be headed in the same direction. Alignment among federal regulations and state-level environmental policy and also market policy, that's the challenge. I think we can do it.

Sandra Levine, *Senior Attorney, Conservation Law Foundation*: My perspective on nuclear power is based mostly on economics. I've been involved in nuclear power for about 30 years, first as a regulator representing consumers, and then more recently as an environmental advocate with the Conservation Law Foundation. I've always worked in New England. That's my geographic perspective.

As long as I've been involved in this relationship, nuclear power has held a lot of promise. There's a lot of potential energy for the public there, just as individual atoms have lots of potential energy that we can exploit.

But that promise has also been somewhat double-edged. You've heard about some of those examples here. Back in the 1950s, nuclear power was going to be too cheap to meter. That didn't happen. By the 1980s, when I came into the picture as a regulator, there was fallout from those decisions — some utilities had gone all in on nuclear power and overinvested. Some were driven to bankruptcy. Those that weren't often had to dig their way out of cost overruns by placing tremendous burdens on customers, on municipalities, and on taxpayers.

Thus there has been a yoyo effect. At times, nuclear power is springing forward as the next great promise and then it is springing back due to the latest accident — like Chernobyl or Fukushima.

The yoyo aspect of this is particularly problematic because these plants take a long time to build. They take a while to finance. They take a while to permit. If the regulations or the economics change in the interim, that's a big problem and that's going to stop or stall building new plants.

On the economic issues, there are two distinct paths that need to be considered. One involves existing plants. The other is new plants. For new nuclear plants, recent history has shown that those continue to be too expensive compared to other alternatives that are available. Even when the nuclear industry has been given encouragement, like during the Obama administration, there were a few starts but some of those then fell flat. Some fit the same old pattern of cost overruns. Others became too expensive compared to alternatives.

Today there is again promise in new technology. But none of it is commercially available now. Some may not be commercially available for 40 years. And we better do something to take care of climate change before then. Thus, new nuclear plants are either too expensive or they will involve technology that hasn't been proven.

So what about existing nuclear power? I was involved with some of the regulatory proceedings around Vermont Yankee, and then also with Pilgrim Nuclear Power Plant in New England. These are smaller and older units with some of the same designs that led to problems in Fukushima and would take significant investments to correct.

At the same time that there was an option of spending a lot of money to fix a rather small nuclear plant, there are other less expensive options available. The decision was to close those plants. So even though some of those plants had proposals for their licenses to be extended for another 20 or 40 years, the decision was made to close them. We have to accept that some plants might just be too old, too worn down, too technologically out of date.

But in my New England perspective, I think of Millstone in Connecticut and Seabrook in New Hampshire. Both are larger and more modern facilities. They may continue to be economic and operational for a number of years.

The challenge is to separate the wheat from the chaff to make sure that we are not propping up tired technology that we probably should put to rest but are sensibly supporting existing nuclear that can continue to operate safely.

According to recent reports, some of these plants, like Seabrook and Millstone, can be very viable without additional subsidies. Nonetheless, Connecticut decided to pay some additional subsidies for Millstone in a long-term contract. It's a fair question to ask if we are paying too much for this power. Might we be better off tying additional subsidies to expecting better performance or additional benefits?

Going forward, why aren't we creating and supporting a level playing field for all resources? If we want low-carbon power, pay for it. We can do that. We don't have to support a nuclear power plant to the exclusion of other low-carbon power plants. You can put them on the same level playing field, pay for that benefit, and let them compete. If we're failing to do that, it's fair to say we may just be throwing money at some plants and most likely overpaying rather than compensating for the actual benefits that we're getting.

The economics will continue to be challenging for a while. Some plants will continue to close. I don't think that should be too much of a concern. We should compensate plants for the benefits that they provide and do that on a level playing field. With a system like that in place, nuclear power will play a role over the next 10 or 20 years. Beyond that, I expect some other technologies may be more cost-effective than nuclear. We shouldn't be crowding those out by creating subsidies to

prolong the life of nuclear power plants.

The viability of nuclear power in the future depends on making sure that when we do close the plants we clean them up safely.

A few of the recent closings moved forward on a fixed-price cleanup model. It's similar to a model that's been used in cleaning up old industrial sites. Indeed, declaring these as Superfund sites may make sense. Certainly some nuclear sites have pollution problems that need to be managed carefully. Similarly, some of the entities who have operated these plants for years are not necessarily experts in nuclear cleanup. It makes sense to turn the task over to the folks who have experience.

The model that I've seen provides for transferring the entire site to a new entity and provides them all the money in the decommissioning funds — transferring all responsibility for a clean site when done. It looks good on paper. It's untested for commercial reactors but there are some experiments.

From what I perceive, there has been fairly limited oversight, effectively no real public participation in those transactions and how they move forward. There's not much of an ability for public understanding or even regulators to really understand what's going on after the site has been turned over to the new entity. More problematic is the fact that incentives are in place to do the job quickly and do the job cheaply. When it comes to nuclear power, I'm not sure that you want the cleanup to be done on the cheap.

Then there is liability. These sites may remain polluted for a long time. Some of the nuclear waste will be stored at the site for a long time. Until we open a repository to take all the waste from plants across the country, there will be liability. The ultimate insurers there are the taxpayers.

The other issue that's tied to regulatory oversight involves environmental justice and waste disposal. Where is this waste going? What are we doing with it? Certainly some of it is going to be staying at the sites until we will have a repository. Some of the lower-level waste is being shipped to other sites. Unfortunately, some of those sites are in communities that have had very little say in how the sites are managed. I think that's a shame. It undermines public confidence in what we're doing. It really leaves the problems for future generations.

In that regard, it's not dissimilar to what we're doing with climate change. We're putting the problems of climate change on to the backs of our children and grandchildren. Are we doing the same with the nuclear waste problems?

These problems are surmountable. In terms of the waste, we can have more effective public participation. If it's just the regulators and the industry at the table, that undermines public confidence in the outcome. Nuclear power cannot really be part of an effective solution to climate change if all we're doing is trading one environmental disaster for another.

The need to address climate change presents a new opportunity to make sure that we correct some of the past problems and address the current nuclear legacy. We should level the playing field and make sure we pay nuclear power for the benefits it provides, but don't overpay them so that we let them compete fairly with other available energy resources.

Audience question: I'm Donald Stever. I represented the state of New Hampshire in the licensing of the Vermont Nuclear Power Plant. I represented the state in Montague Plains, which was never built. And I've represented the people of New Hampshire in the Seabrook matter. I wrote a book about that episode that was critical of the nuclear regulatory process and the way that the plants were being built.

I have two questions. Is it better to build very large plants feeding power into the grid, which can be lost over long distances, or to build smaller, decentralized units and disperse them in various places? Secondly, whatever happened to the reprocessing of nuclear fuel to avoid the problem of disposal?

Granta Nakayama: The size question has been asked by nuclear engineers for many years. If you get a smaller-sized plant, you have the possibility of mass production of standardized designs. The problem is the cost and effort required to site a plant no matter what its size. It can make it unattractive if you don't generate a lot of power. You could possibly use modular plants, two or three of them in the same spot.

With respect to your second question, President Carter decided to stop reprocessing because of weapons proliferation reasons. The rest of the world did not follow. When you reprocess fuel, the result can be burning up plutonium and other bad things while creating new fuel for electricity generation.

In the United States, we are stuck with the worst of both worlds. We don't reprocess but we don't store it either. Instead there is a waste pool at each plant. This is something that folks like Mason will need to deal with in the long term.

Mason Emnett: We are obviously in support of a geologic repository to manage the long-term responsibility that we have as owners and operators in the interim. A central repository would make more sense.

On the question of unit size, there is a lack of expertise needed to build a very large nuclear station. We haven't done it in decades. And it ends up costing more than budgeted. So when a power company is making that bet in terms of investment, a smaller scale is just much more manageable.

Audience question: I'm Robert McKinstry with ELI. I peer-reviewed John's nuclear chapter and wrote quite a few briefs for Mason's em-

ployer while I was still at Ballard Spahr. I have two questions. To achieve deep decarbonization — and we really need 100 percent by 2050, not 80 percent — we're going to need to increase capacity. There are only two feasible ways to do it. One is with nuclear uprates. The other is to move to smaller nuclear units, more like what the Navy uses, or even thorium reactors. Unfortunately, we do indeed treat smaller units as if they were a major power station.

One of my questions is what would be a sufficient price for some of the companies to readopt the nuclear uprates that were abandoned as a result of the artificially low price of natural gas? Also, what would be the regulatory reforms?

Mason Emnett: We are not currently looking to uprate or expand given market conditions. Carbon pricing is the way to go. Establishing a social cost of carbon will allow us to drive efficiencies and compete.

We do have carbon pricing programs in place through RGGI in the Northeast and California through its program. The prices in those markets are not significant enough to drive deep decarbonization. RGGI is at a price where you get some coal to gas switching, but it's a revenue generation program so that those funds can be reinvested at the state level in energy efficiencies and renewable programs. Those are really great things, but it's not about driving deep decarbonization.

I don't know the exact numbers of what carbon price would be needed to trigger investment in an advanced nuclear facility. My hunch is that it's something north of the social cost of carbon. That's not going to be quite enough. For example, offshore wind is not going to be supported by a carbon price at the social cost of carbon. When you're getting to emerging technologies, the type of capital investment, the R&D that's needed is significant. We can use R&D dollars to help bring some of that cost down, including pilot projects so that we can get the commercial experience and we can get the designs through the NRC process.

Audience question: I'm Jeanne Cohn-Connor with Kirkland and Ellis. In the 1980s, I was general counsel to the siting commission for low-level rad waste up in Maine. It was very difficult to locate a disposal site for the waste.

With environmental justice becoming a much bigger issue, what's the current thinking of where this waste is going to go, given the public outcry?

Mason Emnett: The current thinking is it's staying where it is until we get some resolution. If you put all of the spent fuel from all U.S. commercial reactor operations since the 1950s together, it fits inside of a football field 10 yards high. It's not a huge amount in terms of physical volume but it's important to maintain the safety and integrity of storing and protecting that waste. But until we get some resolution, essentially a political breakthrough, the used fuel is going to be where it is.

Sandra Levine: I'll just add that the answer going forward should not be to just ship it off to a poor community that doesn't have any say.

Audience Question: I'm Jim Werner with the Congressional Research Service. I wanted to ask Mason from Exelon about something that your former chair, John Rowe, once said. It's one of my favorite quotes. He said every plant is one unexpected capital expenditure away from a shutdown. What's the next capital expenditure that's going to change all these numbers?

Mason Emnett: When we turn on a nuclear unit, it is going to run for 18 to 24 months. We are at about a 96 percent capacity factor for our fleet, which means 96 percent of the hours during that 18-to-24-month cycle we are at full output, which is extremely high in the electric sector.

During a refueling cycle, when the unit is down, you have to make a decision about the money going into that unit for the next two years. So we put about $3 billion of investment into our nuclear plants every year because we need to ensure that, when they are operating, they are not only safe but they are generating as much as possible because our margins are so thin.

I think that's where that quote was coming from. In this highly competitive market where we have to make decisions about the billions of dollars that we're investing on an annual basis, you can't undo those decisions for two years. And once you don't undertake a refueling and you shut down a unit, they're not coming back.

Audience question: My name is Meghan Hammond. I work for Pillsbury Winthrop, the law firm. I don't have 30 years of experience in the nuclear industry, but I wanted to get the panel's response on what the export of U.S. nuclear technology to other countries means.

Mason Emnett: The folks at Exelon worry less about the export of particular technology but instead the growing dearth of experience and knowledge in the United States. As other countries are moving forward, they are gaining the competitive edge. If we want to be in the position of investing in new nuclear technologies, we need to be expanding our knowledge and expertise and not shrinking it. That worries us.

But again in the intense market and merchant environment that we are in, we are investing some in advanced nuclear and are active in its design and development. But the notion that we are going to develop an advanced nuclear project in the current economic environment is something that frankly our investors would not tolerate.

So we are hopeful that others are able to make progress, but we worry that it's going to be other countries that are moving ahead. We will not only lose that edge, but then there are all sorts of national security concerns that come with that. **TEF**