SECTOR-BY-SECTOR APPROACHES

Restoring the Future of Nuclear Energy

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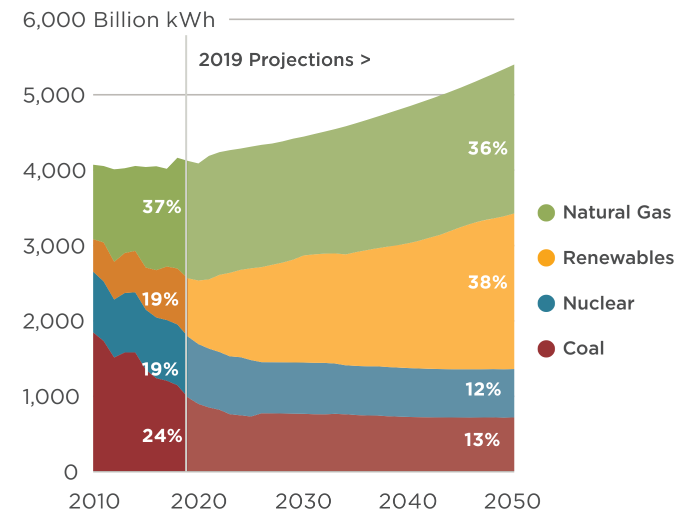
The emission of greenhouse gases—primarily carbon dioxide (CO_2)—resulting from electricity generation, ground transport, and industrial use (including process heat) needs to be eliminated as soon as technically, economically and politically feasible to avoid the most serious consequences of climate change. Technology already exists to produce and distribute low- or zero-carbon electricity, so decarbonizing the ground transport and industrial sectors can be achieved through electrification. Successful elimination of greenhouse gas emissions will, therefore, in large part come down to decarbonizing the electric power sector.

FIGURE 1 - CHAPTER IN A CHART

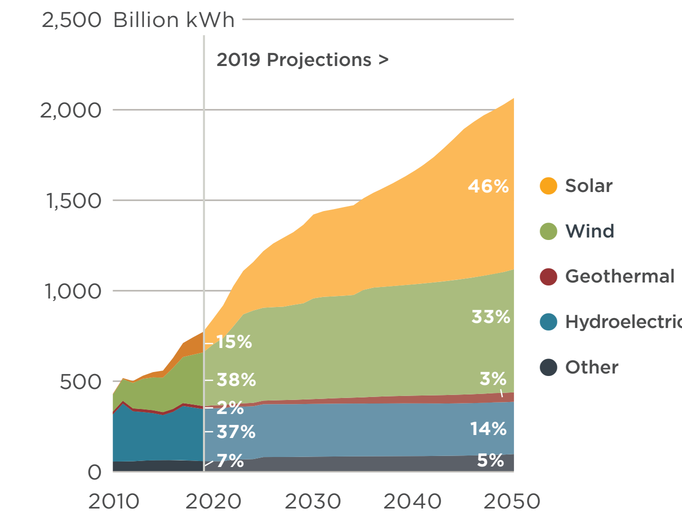
Electricity Generation from Selected Fuels



Source: U.S. Energy Information Administration, *Annual Energy Outlook 2020,* reference case.

FIGURE 2

Renewable Electricity Generation, Including End-Use



Source: U.S. Energy Information Administration, *Annual Energy Outlook 2020,* reference case.

In the absence of technological breakthroughs in grid-scale electric storage, renewable power by itself cannot reliably meet U.S. electricity needs, even before ground transportation and other high-demand sectors have been fully electrified. Supplementary power will be needed to provide the necessary stability to a decarbonized energy system, and by definition it cannot come from fossil fuels.[1] If the United States is committed to decarbonizing, it will need to accept a substantial continued role for nuclear power in the energy system mix—comparable to the current contribution of approximately 20 percent—through 2050. However, current optimistic projections show that nuclear's share will drop to approximately 12 percent by 2050. Thus, it appears that a modest return to building new nuclear power plants within the next few decades is necessary in order to construct a reliable and fully decarbonized electric grid within the United States.

Heart of the Problem

Nuclear power in the United States suffers from three serious challenges that currently limit its contribution to decarbonizing the electric power sector:

1. The high initial cost of building new nuclear power plants in the United States, a key reason for the non-competitive levelized cost of electricity (LCOE)[2] for both existing and new nuclear power plants;
2. The continued political stalemate regarding the disposal of used nuclear fuel; and
3. The poor public perception of nuclear power, fed by a lack of confidence in the safety of nuclear power plants and of the proposed permanent storage of nuclear waste.

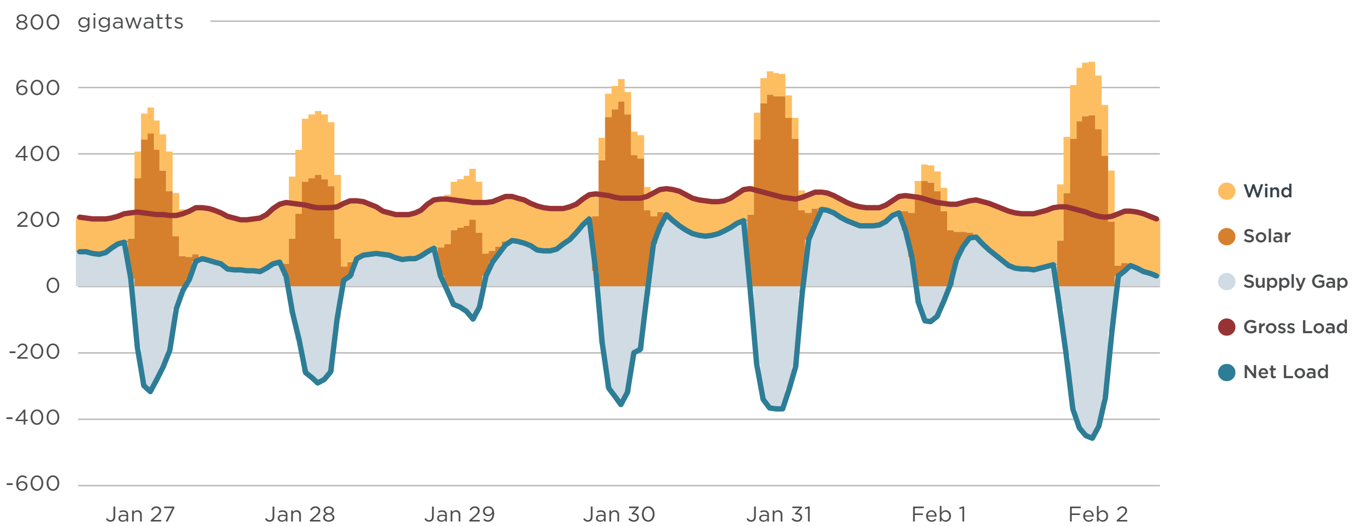
Without confronting these three issues, nuclear power in the United States will continue to decline as operating plants reach the end of their operating licenses. By 2050, most of the existing nuclear power plants in the United

1 Fossil fuel-powered electricity generation coupled to effective—meaning safe and secure—carbon capture and storage is not likely to be economically competitive with low- or zero-carbon renewable generation in the near term.

2 The EIA recently decided to use the "levelized avoided cost of electricity" (LACE) rather than the "levelized cost of electricity" (LCOE). As its latest data shows, nuclear power is at a significant disadvantage when comparing the LCOEs of various competing energy production technologies, but not when comparing their LACEs (U.S. EIA, "Levelized Cost and Levelized Avoided Cost of New Generation Resources"). But as the recent huge cost overruns of the four Westinghouse design plant projects in Georgia and South Carolina make plain, U.S. industry is at present incapable of constructing gigawatt-scale plants on budget and on time. In comparison, South Korea built four gigawatt-scale reactors in Abu Dhabi, with the time from initial construction to fuel loading ranging from six to eight years and at a cost estimated to be $25 billion (Habboush, "Arab World's First Nuclear Power Reactor); this is 25 percent higher than estimates of the initially contracted cost of $20 billion.

FIGURE 3

How an All-Renewable Energy Power Grid Could Handle a Polar Vortex



Notes: Net Load = Gross Load minus wind and solar. Positive supply gap = potential battery discharge cycle or dispatchable generation needed to balance the market. Negative supply gap = potential battery charging cycle.

Source: Wood Mackenzie, Gearino, "100% Renewable Energy Needs Lots of Storage."

States will be shut down, assuming that the Nuclear Regulatory Commission does not grant any further operating license extensions.[3] If these plants are replaced with natural gas-fired facilities, as many are slated to be, it will all but ensure that the country cannot achieve the carbon emissions reductions necessary to avoid the worst effects of climate change.

Solving Nuclear is Central to Decarbonizing the Economy

Increasing the share of U.S. electricity stemming from renewable resources will mean that grid operators and utilities will be more exposed to the risk of reductions or interruptions in supply from variable sources like wind and solar power. Today, operators largely manage that risk through contracts with fossil fuel plants known as "peakers" that can ramp production up or down based on demand. If the United States is to pursue a decarbonized future, that option will not be available long-term.

Technological solutions like carbon capture and storage (CCS) for fossil fuel plants or grid-scale battery storage for renewable generation could help address this challenge, but neither is technically ready or economically competitive enough for deployment at the scale necessary to support a decarbonized electricity system. Importing power from our neighbors—such as Canada—is a third potential avenue for meeting demand during lulls in renewable supply, but there is no guarantee it will always be available. Nuclear power is the only technology currently available in all geographic locations that both does not generate greenhouse gases while generating power and—depending on design—can ramp up or down in response to changes in demand.[4] If the United States continues down its current path toward exiting nuclear energy altogether, the national grid will continue to rely on peaking power generated by fossil fuels.

Figure 3 illustrates the challenge faced by a national grid reliant solely on renewable power. Extreme weather conditions—in this example, a shift in the polar vortex—

3 The Nuclear Regulatory Commission (NRC) licenses nuclear power plants for forty years of operations initially. Subsequently, the NRC may grant twenty-year extensions—and indeed has granted one twenty-year extension to many operating reactors— and may grant one additional twenty-year extension, for up to a total operating license period of eighty years, but only a few second extensions have been granted to date. See U.S. NRC, "Status of Subsequent License Renewal Applications."

4 Currently operating commercial nuclear power plants in the United States can ramp to a limited extent, but are not designed to do so effectively. The major limitations are contamination by Xe-135 ("xenon poisoning") and uneven burnup within the core. However, naval nuclear reactors are designed to ramp significantly, and commercial reactor designs such as molten salt reactors (MSRs) can be designed to avoid xenon poisoning.

can lead to very large discrepancies between demand and available energy supply. In the case illustrated in Figure 3, the discrepancy is entirely due to large power generation shortfalls, affecting a continental-scale distribution grid. To compensate for this gap, grid storage would need to provide approximately 100 gigawatts (GW) of electricity continuously over periods of around twelve hours.

While this illustrates the scale of a potential intermittent supply problem, the experience of electricity consumers in California during 2020[5] tells us that utilities already face such difficulties even in less extreme conditions. California has closed not only its two nuclear plant sites but also a number of natural gas-fired generation plants, replacing the resulting shortfall in generation capacity with renewable generation sources. The heat wave of late August 2020 in California has shown that even much more modest supply deficits than hypothesized in Figure 3 (e.g., on the order of 10 GW) can lead to substantial brownouts and blackouts in the absence of grid storage or the ability to import power from neighboring states.

Storage capability at the scale required to deal with weather events such as the one shown in Figure 3 is not currently within the reach of available technologies, for two distinct reasons. First, the scale of the requisite energy storage capacity—over 1 terawatt hour (TWh)—is well beyond what is currently available. In fact, in 2018 there were only 869 megawatts (MW) of installed battery capacity in the United States.[6] Though installed capacity has been expanding over the past decade, it will clearly be some time before there are facilities of the scale needed to address that kind of gap.

Second, the economics argue against this storage solution to large power supply insufficiencies. An optimistic capital cost projection for battery storage is $100/kilowatt hour (kWh) by 2040,[7] which suggests that the capital costs alone for utility-scale lithium battery storage sufficient to deal with a 100 GW supply deficit over ten hours (similar to the polar vortex event referenced in Figure 3), would amount to approximately $100 billion. This cost could in principle be a good value if the power it provided to

5 See Ivan, "California Expresses Frustration," and Wolfram, "Are There More Blackouts."

6 U.S. EIA, "Battery Storage in the United States."

7 Cole & Frazier, "Cost Projections for Utility-Scale Battery Storage."

the grid was available at a competitive price, but that is unlikely to be the case. Unlike nuclear power plants, which can generate revenue and recoup capital costs through regular daily use, grid storage facilities can only earn revenue when they are operating. Because large disruptions on the scale of the polar vortex are currently rare,[8] the full supply capacity of such a grid storage facility would only be used sporadically. This necessarily implies an extremely high cost of electricity.

Presume, for instance, that the functional lifetime of a storage system is twenty years, and there is one 1 TWh generation insufficiency event per year. In order to recoup its investment (thus, not even accounting for operational costs and profit), such a storage system would need to charge an electricity cost of $5/kWh, to be compared with the maximum LACE of carbon-free generation currently estimated to be $0.04091/kWh (solar photovoltaic), $0.04813/kWh (onshore wind), and $0.04135/kWh for nuclear power.[9] This argument strongly suggests that utility-scale grid storage is best used to deal with much more frequent, much smaller, and more geographically compact supply insufficiencies that can be handled by smaller, more affordable, local storage facilities.

It should also be noted that the polar vortex illustrated in Figure 3 was an extreme shock both because of its severity and because it extended over a spatial scale of continental dimensions. It covered the entire northeast quadrant of the United States, stretching from Chicago to Washington, DC, to Maine. While rerouting renewable power from other areas of the country on a national grid could address some of that insufficiency, Figure 3 suggests it is highly unlikely that strategy could cope with a disruption on this scale.

Extreme supply insufficiencies of the kind illustrated in Figure 3 should therefore be dealt with by deploying large generation resources. A fleet of modern nuclear

8 The probability of occurrence of events such as the polar vortex event of 2019 remains unknown. Extant climate models suggest that the probability of extreme weather events will increase with time over the next few decades, but the science remains uncertain (cf. Mann, et.al., "Projected changes in persistent extreme summer weather events", 2018). In other words, tail events will become more common, but scientists are uncertain about the specifics of their frequency.

9 U.S. EIA, "Levelized Cost and Levelized Avoided Cost of New Generation Resources." All estimates for new generation sources in 2025 are in 2019 $/kWh. Note that decreasing the probability or scale of such supply insufficiency events simply increases the associated cost of electricity from grid storage.

Much of the U.S. nuclear fleet is reaching the end of its licensed service life. Replacing those plants with others fired by fossil fuels would significantly increase U.S. GHG emissions.

power plants capable of dispatching 100 GW, and a grid able to shift this supply around the country, would secure the energy supply, even during such extreme weather events. Modern nuclear plant designs are capable of ramping production up and down on the basis of demand, and thus can—unlike most existing plants—be readily used as peakers. Furthermore, such plants may be used for ancillary zero-carbon emission power needs (such as powering desalination plants[10] or providing process heat[11]), and could be temporarily dispatched to resolve grid power insufficiencies in emergencies. Thus, modern nuclear power plant designs have the advantage over large-scale grid storage of being able to earn revenue when not dealing with grid power deficiencies.

The preceding discussion assumes that the United States has transitioned to a fully decarbonized electricity sector, but it must be noted that the Department of Energy's (DOE) current (2020) reference case[12] for 2050 does not project full decarbonization of the grid by mid-century. As illustrated by Figure 1, these projections show that fossil fuel-powered generation would only decrease to 49 percent of the total power generated, from its 2019 contribution of 61 percent, assuming a continued decline of nuclear power in the United States. Whatever the target date for full decarbonization of the electricity sector might be, a grid fully powered by renewables will still need ancillary infrastructure in place—either grid storage or fully dispatchable power—to deal with the kind of serious long-term power supply deficits illustrated in Figure 3. It is in this context that nuclear power can play an important role.

10 World Nuclear Association, "Desalination."

11 World Nuclear Association. "Nuclear Process Heat for Industry."

12 U.S. DOE, *Annual Energy Outlook*

How We Got Here

Federal policymaking on nuclear power has varied substantially with time. Strong federal support for nuclear research and development throughout the 1950s established the first civilian nuclear research facilities in the country as well as the first functioning nuclear power plant. While nuclear power capacity and generation continued to grow through the 1960s and 1970s,[13] driven in large part by investment by utilities, federal support for the industry waned substantially following the Three Mile Island and Chernobyl nuclear plant accidents in 1979 and 1986, respectively, leading to substantial cuts in federal support for nuclear power research and development (R&D).

The drop in federal support was driven in no small part by rising public opposition to the nuclear industry. Accidents like Three Mile Island raised public fears of inadequate oversight of power plant operations by the Nuclear Regulatory Commission (NRC), stoking both local and national resistance to the industry. In 1989, local opponents succeeded in shuttering a brand new, fully functional plant in Shoreham, NY, before it had ever been operated. Public concerns about nuclear waste disposal, meanwhile, have thwarted plans to open a used fuel repository in Yucca Mountain, NV for decades.

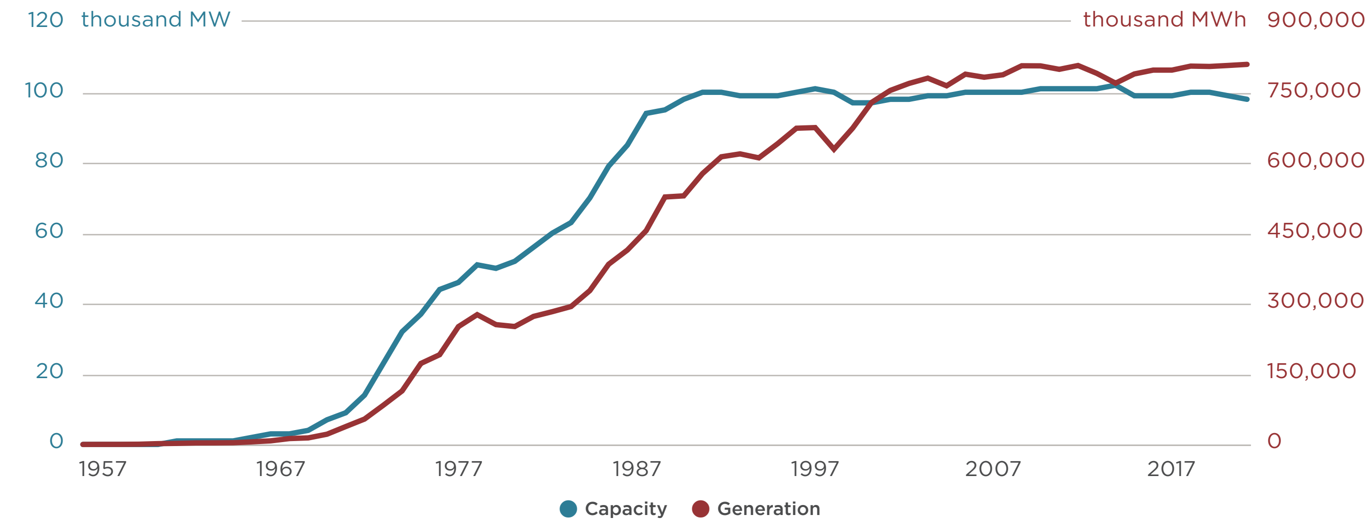
While both Democratic and Republican administrations continued relatively modest R&D support, mostly in the direction of new reactor designs, construction of new nuclear power plants ceased almost entirely after 1996, leaving a twenty-year gap during which no new nuclear plants were put on-line (Figure 4).

Not only has that resulted in an aging nuclear fleet, but also in a serious decay of U.S. industrial capacity to construct new nuclear power plants. It is only within the last decade that federal efforts aimed at supporting the design and construction of small modular nuclear power plants has led to efforts to address these critical deficiencies. As a result, the cost overruns encountered by Westinghouse and its collaborators building four gigawatt-scale nuclear power plants in Georgia and South Carolina should not have been a surprise—these efforts were effectively "first-of-a-kind" projects, with the attendant risk premium, given the relative inexperience of the contractors working on these plants.

13 U.S. EIA, "Nuclear explained."

FIGURE 4

U.S. Nuclear Electricity Generation Capacity and Generation, 1957-2019



Note: Capacity is net summer; MW is megawatts; MWh is megawatthours.

Source: U.S. Energy Information Administration, Monthly Energy Review, Table 8.1, March 2020, preliminary data for 2019.

The net result of these dynamics is that the actual cost of nuclear power based on gigawatt-scale plants is well above the LACE estimates provided by the EIA. Without concerted action now, the United States risks taking nuclear power off the table as a significant electric power source into the latter part of this century.

Furthermore, if the United States remains on its present course to exit nuclear, but still aims to decarbonize by mid-century or earlier, it will face the rising risk of extensive power shortages during extreme weather events such as the polar vortex instability, extremes that global climate models suggest are likely to increase in both frequency and severity. Since such power shortages are not likely to be politically acceptable, the United States will need to continue to rely heavily on fossil fuel-based backup power—unless it makes a substantial effort to introduce new nuclear power plants.[14] Thus, if the United States does not change course, it is almost certain that it will fail to achieve significant decarbonization by mid-century—an unthinkable result given the threat of climate change.

14 It is important to note here that modern nuclear power plants, including small modular nuclear reactors, can be designed to function as peaking power plants, an ability that current gigawatt-scale nuclear power plants do not have.

What To Do

Each of the three critical issues nuclear power faces (cost of construction and competitiveness, the handling of spent fuel, and public concerns about safety) can and should be addressed. By doing so, the United States can achieve a technologically plausible path towards complete decarbonization of its electricity sector by the end of this century—and possibly even by mid-century if policymakers address these issues expeditiously.

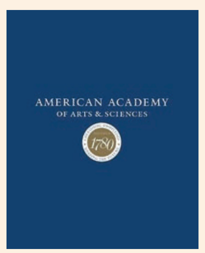
POLICY

High cost of building new nuclear power plants and obstacles to competitiveness

The high cost of building new nuclear plants can be dealt with by a concerted focus on the obstacles faced by the nuclear industry in the United States, such as designs that do not account for modern manufacturing technology; broken or non-existent supply chains for important system components; lack of sufficiently trained workforce; a nuclear regulatory regime with the

FURTHER READING

Nuclear Energy



Global Nuclear Future Initiative

American Academy of Arts & Sciences

As more and more countries seek the benefits of nuclear energy to respond to fast-paced industrialization and urbanization, the nuclear proliferation, security, and safety risks increase exponentially. Robert Rosner is a co-chair of The Academy's Global Nuclear Future Initiative, which seeks to guide domestic and international policymakers trying to balance the pursuit of a national nuclear energy program with the potential safety, security, and economic concerns.

dual focus on safety and security;[15] and a significant risk premium in financial markets.[16]

There are a number of steps that the Biden administration can take to address these issues. The DOE should strengthen its R&D programs in advanced reactor designs, as well as its collaborative programs with industry in transitioning new reactor designs to construction of test reactors and ultimately to commercial products. NRC and the Federal Emergency Management Agency (FEMA) should revisit regulations governing the operations of new reactor designs, including in particular the nature of Emergency Planning Zones (EPZs) and the impact that new design features (such as fully below-grade reactor vessels) have on these EPZs. The persistent degradation of the NRC's licensing capabilities for designs other than light water reactors—driven by consistent reductions in its budget[17]—needs to be reversed so that its technical capabilities for granting design and operating licenses for advanced nuclear plant designs can be restored. These changes can be effective in encouraging private industry to adopt new designs (of which small modular reactors—SMRs—are an example).

Modular designs in particular take advantage of highly automated—assembly line-based—manufacturing[18] pioneered in other high-technology industries such as the airframe industry, which has been shown to be effective in restraining manufacturing and construction costs. The current effort to build the first DOE-supported, NuScale-designed, modern SMR at Idaho National Laboratory is the first (necessary) step in this direction. Finally, to help staff these manufacturing facilities and build the new reactors, DOE could strengthen its partnership with industry and the nation's technical colleges to train a new generation of nuclear workers focused on plant construction.

15 The ultimate fate of the Shoreham nuclear power plant in Long Island, NY—which was completed but never put into operation, and led to the bankruptcy of its operator, LILCO—is illustrative of the corrosive effects of mixing regulatory uncertainty with public opposition (for more, see Wesselhoeft, "A Chronology of The Shoreham Plant").

16 Petti, et al., "Future of Nuclear Energy."

17 Enacted NRC budgets have decreased from $1.055 billion (2014) to $0.931 billion (2019), along with a staff reduction from ~3,800 (2014) to 3,106 (2019); see U.S. NEC, "Congressional Budget Justification: Fiscal Year 2020."

18 Indeed, such streamlined manufacturing processes have been credited with bringing down the costs of renewables, including solar panels and windmills.

But, focusing on design, manufacturing, and construction is not enough.[19] Regulatory reforms are also needed. For example, current Environmental Protection Agency (EPA) and NRC regulations set stringent limits on exposure to extremely low levels of radiation, which can considerably complicate the operation of nuclear facilities, raising operating costs. These constraints, especially the concept of limiting radiation exposure to "as low as reasonably achievable" (ALARA), are poorly grounded in science, because studies focusing on the biological effects of very low exposure levels have proven to be extremely difficult to carry out reliably. Thus, the cognizant federal agencies (especially the EPA) should launch a concerted research effort to finally settle the question of the biological effects at extremely low dosage levels, an effort that would establish scientifically informed regulations in this domain and provide clarity for workers, the industry, and the public.[20]

The non-competitive status of even existing nuclear power plants in the United States is the result of two policy failures. The first is the failure to price the damages caused by fossil fuel-based power production (most notably climate change and air pollution), which is a major factor in the current low LCOE of natural gas-powered electricity production. The second is the continued subsidization of non-hydropower renewables (e.g. wind and solar) without accounting for the costs of dealing with supply fluctuations from those sources. It is revealing that in Sweden, where nuclear power competes with hydroelectric power and other renewables (and where fossil fuels play no role in electricity generation), nuclear power and hydro show comparable generation costs, and lower generation costs than other carbon-free generation technology.[21] Thus, this issue can be resolved by (i) Congress, if it were to pass legislation that allowed for pricing carbon emissions appropriately (as discussed in "Put a Price on It: The How and Why of Pricing Carbon," page 50); (ii) the states, by eliminating renewable energy credits (RECs, which explicitly disadvantage nuclear power), and transition instead to clean energy standards (CES) and zero emissions credits (ZECs), both of which incentivize carbon-free electricity generation irrespective of technology; and (iii) state utility commissions, by accounting explicitly[22] for the costs of dealing with (non-hydropower) renewable power supply fluctuations.

A competitive market relies on the pricing of all externalities, including both carbon emissions and renewable intermittency.[23] Without placing an appropriate price on carbon emissions and the costs of managing intermittency,[24] like contracts with peaker plants, fossil fuel-based technologies and renewables, respectively, gain a cost advantage over nuclear. Hence, the low LCOE of natural gas-powered electricity production and non-dispatchable renewables does not properly represent their true costs to the electricity sector. This deficiency can be remedied if the Biden administration supports the passage of legislation that prices all such externalities.

While nuclear power's role for a decarbonized energy sector would serve primarily to support grid demand during an extreme weather, such nuclear power plants could also serve alternate energy needs (such as desalination of sea water or providing process heat) that are interruptible, so that they are able to earn revenue while they are not needed to support large-scale grid power insufficiencies. For this reason, the cost of nuclear power will compare quite favorably with the cost of providing comparable backup power via grid storage, viz., via grid-scale batteries, which earn no revenue when not used to deal with grid power insufficiencies.

POLICY

Safely disposing of nuclear waste

The Biden administration should revive the sensible roadmap for resolving the nuclear waste problem

19 Petti, et al., "Future of Nuclear Energy."

20 Cardarelli and Brant, "Move beyond the linear no-threshold theory."

21 With the elimination of the tax on nuclear power production, Vattenfall estimates its nuclear generation costs to be SEK 0.019/kWh (= $0.0228/kWh) in 2020; World Nuclear Association, "Nuclear Power in Sweden." See also Hong & Brook, "Costs of replacing nuclear."

22 There is considerable variability in how utilities allocate the costs of grid storage: in some cases, such costs are borne by the supplier (i.e., the wind or solar power generator); in other cases, such costs are incorporated into transmission costs. In the latter case, the result is to effectively hide from the consumer the additional costs associated with the variability of renewable energy production.

23 Though some would argue that the risk of a nuclear accident is also an externality, this risk has been internalized through regulatory oversight and multiple insurance premia mandated by The Price-Anderson Nuclear Industries Indemnity Act (1957).

24 Pricing the intermittency externality is of course related to the costs incurred by dealing with renewable power insufficiencies, e.g., the costs associated with grid storage and/or carbon-free "peaker" plants.

outlined by the Blue Ribbon Commission on America's Nuclear Future in 2012.[25] The principal components of that roadmap include the creation of a new federally charted corporation (a "fedcorp") with the unique charge of dealing with nuclear waste; moving forward with consolidation of all interim nuclear waste storage; and ultimately building a new nuclear waste repository, all predicated on a consent-based siting process for the interim storage and final repository facilities. Countries such as Canada, Finland, Sweden and Switzerland are already putting in place nuclear waste solutions similar to what the Blue Ribbon Commission recommended. These countries' successes using a transparent public, consent-based, siting process illustrate that interim storage sites and deep geological nuclear waste repositories are attainable.

POLICY

Public safety concerns

Nuclear power's public relations problem can be addressed—as it has been in Canada, Finland, Sweden and Switzerland—by increasing the transparency of the decision processes concerning nuclear power. In the United States, public skepticism regarding nuclear power has centered on the question of safety of nuclear power plants, and on the safety of ultimate disposal of the associated nuclear waste. The NRC's licensing process, followed in detail for the planned NuScale modular reactor in Idaho, is widely regarded as the gold standard for regulatory practice worldwide. This process has given regulators considerable opportunity to question the adequacy of NuScale's safety provisions, and to insist that this vendor respond satisfactorily before issuing design approval.[26]

However, there has been essentially no progress on dealing with civilian nuclear waste—in particular, there has been no progress in confronting the lack of public confidence in DOE's ability to deal with its mandated role in securing civilian nuclear waste. The aforementioned Blue Ribbon Commission's recommendation of a new fedcorp whose sole responsibility would be to deal with civilian nuclear waste would go a long way to address this difficulty. It would lift this responsibility out of the DOE, an agency widely mistrusted as a result of its past failures to deal with nuclear waste disposition, and establish a new body to set standards and field public concerns. Establishing this fedcorp would be a clear opportunity for the Biden administration to change public attitudes regarding nuclear power.

U.S. friends and allies have laid a path Washington can follow in this regard. In Canada, Finland and Sweden, initial efforts at dealing with the nuclear waste issue confronted opposition similar to that in the United States. But a clear turn towards total transparency—including consent-based siting that allows local communities a veto power over siting decisions—transformed their public relations problem. Their approach was similar to what the Blue Ribbon Commission recommended, but unfortunately has not been implemented in the United States. Implementing the findings of the 2012 Commission is important opportunity for the Biden administration.

Closing Argument

Significant changes in the U.S. electric power sector take an enormous effort to accomplish, in terms of time, money, and political focus; the electric power sector does not turn on a dime. If the United States postpones decisions regarding nuclear power until mid-century, hoping for the technological miracles that will usher in economically feasible significant grid storage capacity,[27] it will be too late to avoid the worst effects of climate change.

Building new nuclear power plants in sufficient numbers to replace the burning of fossil fuels to deal with supply shortages caused by an overreliance on renewable energy will take decades. Unless and until this is done, utilities will have little choice but to continue to dispatch fossil fuel-based backup power, in all likelihood vitiating the effort to decarbonize the energy sector. This point is understood not only by Canada, Finland and Sweden, but also by countries that are among the largest current users of fossil fuels, such as China and India; and the latter are implementing ambitious plans for expanding their nuclear power plant fleets during the balance of this century.

If the United States is to successfully decarbonize its economy, it needs to turn to the technology that is here, proven, and ready to deploy: nuclear energy.

25 Blue Ribbon Commission on America's Nuclear Future, "Report to the Secretary of Energy."

26 Burdick, "NuScale small modular reactor design."

27 Exactly what this means needs to be carefully defined, and this paper has only touched the surface of a complex problem. Historical data do exist on how long wind and solar outages have occurred in the past, and these data have already been used to both scale the required grid storage capacity and the restructuring of the national grid needed to allow large power transfers on the continental scale, as described in the text. Furthermore, large blackouts related to renewable source failures have also already occurred, perhaps most prominently in the UK as the result of a failure of a large offshore wind farm in August 2019 (BBC, "UK power cut"). The recent (August 2020) power outages in California have further illustrated the problems encountered when grid operators are insufficiently experienced to deal with extreme weather events (and associated heightened power demands) in a power supply environment that relies heavily on renewables and access to out-of-state power supply.

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