TECHNOLOGY

SOLUTIONS FOR MAINTAINING THE EXISTING NUCLEAR FLEET

C2ES CENTER FOR CLIMATE AND ENERGY SOLUTIONS

by

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The Center for Climate and Energy Solutions (C2ES) is an independent, nonpartisan, nonprofit organization working to forge practical solutions to climate change. Our mission is to advance strong policy and action to reduce greenhouse gas emissions, promote clean energy, and strengthen resilience to climate impacts. Learn more at www.C2ES.org.

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EXECUTIVE SUMMARY

Nuclear power is responsible for around 20 percent of U.S. electricity generation and more than 50 percent of its zero-emission generation. However, these large sources of zero-emission power are being prematurely retired with respect to their operating licenses because of low wholesale electricity prices resulting from low natural gas prices, excess power generation capacity, declining renewable energy costs, and low growth in electricity demand. Unfortunately, nuclear generation is largely being replaced by fossil fuel-fired electricity, sending U.S. emissions in the wrong direction. With a finite amount of carbon dioxide that we can emit before we reach 450 ppm and increase the likelihood of serious climate impacts, we cannot afford such backsliding.

The existing U.S. nuclear fleet helps avoid the annual emission of at least 400 $MMtCO_2e$ and is a key component on the pathway to our nation's low-carbon future. In fact, most studies indicate that a diverse mix of renewables, increased energy efficiency, nuclear power, and fossil fuel with carbon capture utilization and storage is the least costly and least technically challenging path to achieve the mid-century goal of reducing U.S. greenhouse gas emissions more than 80 percent below 1990 levels. Other positive attributes of nuclear power include: reliability, fuel diversity within the broader generation portfolio, relatively small geographic footprint, and low air pollution (i.e., no sulfur or nitrogen oxides, or particulates). Additionally, preserving the existing fleet supports local jobs and provides significant tax revenue, maintains domestic nuclear expertise, benefits our national security, and could help promote safer nuclear power globally.

Expected transformational changes in our energy system are likely to create opportunities for existing nuclear power plants. Greater use of electricity across all sectors will likely lead to a resurgence in long stagnant electricity demand growth. This, in turn, will accelerate demand for power generation and energy storage to support expanding renewable generation. In the future, more flexible, load-following existing nuclear plants could complement expanding renewables. Additionally, new business models, including the production of clean water and hydrogen, represent opportunities for existing nuclear power plants in the coming decades.

However, existing nuclear plant owners face challenges which must be addressed, including declining revenue from wholesale power markets (i.e., a market that fails to reward generators for their environmental and other benefits) and an unresolved long-term waste storage issue, along with safety and proliferation concerns.

There are several potential policy options to address these challenges. A wide body of research shows an economy-wide carbon price that escalates at a predictable pace or a national clean energy standard (CES) would be the most effective way to promote lower- and zero-emission deployment. However, given current legislative priorities these policies are unlikely to gain traction in the next several years. Moreover, government action on carbon by agencies like the Environmental Protection Agency or Federal Energy Regulatory Commission is not likely in the near-term.

Therefore, the best remaining near-term options are through the states' targeted clean energy or zero emission standards. 12 reactors at nine nuclear plants have announced early retirements, and some reports estimate that more than half of the plants are operating at a loss; so, additional retirements are likely. In light of the urgency required, the following policy solutions offer the greatest promise to support the existing fleet and lay the groundwork for advanced nuclear reactors, as well as buying time for greater zero-emission deployments in general, and the systems and infrastructure to enable them:

- Targeted state policies, particularly zero emission credits (ZECs), are the best option right now as states are able to quickly adopt measures that directly support distressed facilities. ZEC policies have withstood initial legal challenges in New York and Illinois.

- Expanding state electricity portfolio standards like the Arizona proposal to include existing nuclear is a fair-minded, inclusive approach. At a minimum, they offer an opportunity to explore how nuclear and renewables can work together to one another's benefit.
- A price on carbon could preserve existing nuclear, but it may not be sufficient if the prices are too low. Carbon prices in California and Northeast markets did not prevent early nuclear retirements in those regions, most likely because they were too low.
- A meaningful price on carbon implemented in power markets, which seems to be a natural fit, would help level the playing field and provide additional revenue to non-emitting technologies like nuclear power and renewables. However, likely political and legal challenges could significantly delay implementation.
- Increasing the use of purchase power agreements for nuclear power with government agencies, cities, and businesses should be pursued.
- Second license renewals by the Nuclear Regulatory Commission, which would allow reactors to operate for 80 years would permit much of the existing U.S. nuclear fleet to continue to operate well beyond 2050, allowing new zero-carbon technologies (e.g. advanced reactors, fossil fuel with carbon capture, and renewables) to enter service and avoiding backsliding in emission reductions.

We believe that a broad-based clean energy coalition could help existing nuclear reactors, promote new renewables, and other necessary technologies to transform the energy sector. This is necessary now and essential for building toward a national market-based policy in the future.

I. INTRODUCTION

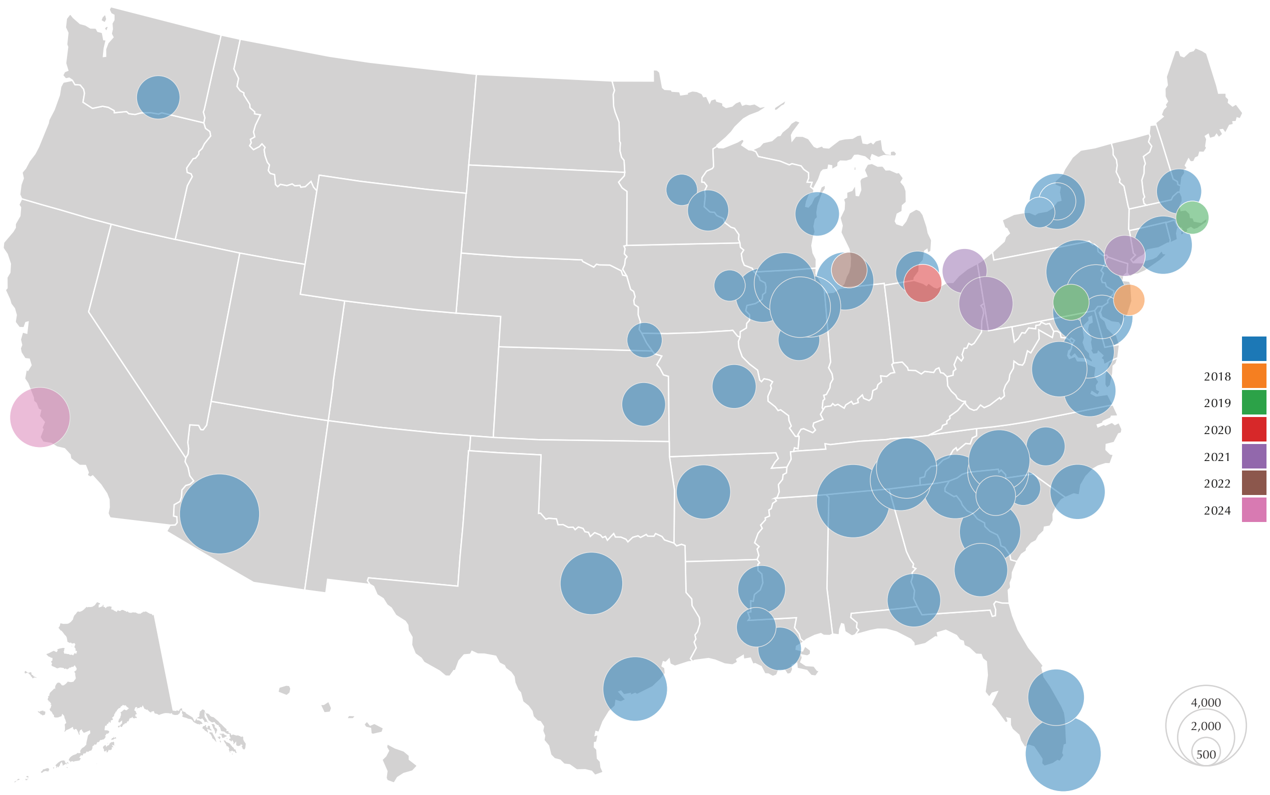
Since late 2012, five power companies retired six nuclear reactors in the United States as listed in **Table 1**. Across the country, an additional 12 reactors, seen in **Figure 1**, are scheduled to close by 2025. If this trend continues or accelerates, resulting emissions implications could be serious. Nuclear power supplies 20 percent of total U.S. electricity production, but more than 50 percent of zero-carbon electricity.[1] As all recent U.S. nuclear retirements have led to increased fossil fuel-fired generation, any additional loss of nuclear generating capacity could be expected to increase power sector carbon dioxide emissions as **Figure 2** illustrates.[2] Preserving the existing U.S. nuclear reactor fleet for as long as practical is a critical element in the transition to a low-carbon future. To that end, this report examines nuclear policies, implemented and proposed, that will maximize the existing fleet's lifespan until new, advanced zero-emission electricity sources can come on line to replace them.

TABLE 1: Recent Reactor Retirements

PLANT NAME, LOCATION	SIZE (MW)	OWNER	RETIREMENT DATE
Crystal River, Florida	860	Duke Energy	February 2013*
Kewaunee, Wisconsin	556	Dominion	May 2013
San Onofre, California	2,150 (2 reactors)	Southern California Edison	June 2013*
Vermont Yankee, Vermont	605	Entergy	December 2014
Fort Calhoun, Nebraska	476	Omaha PPD	October 2016

Total size of reactor retirements: 4,800 MW (4.8 GW).
*Date that retirement was announced; units stopped producing power earlier due to maintenance issues.

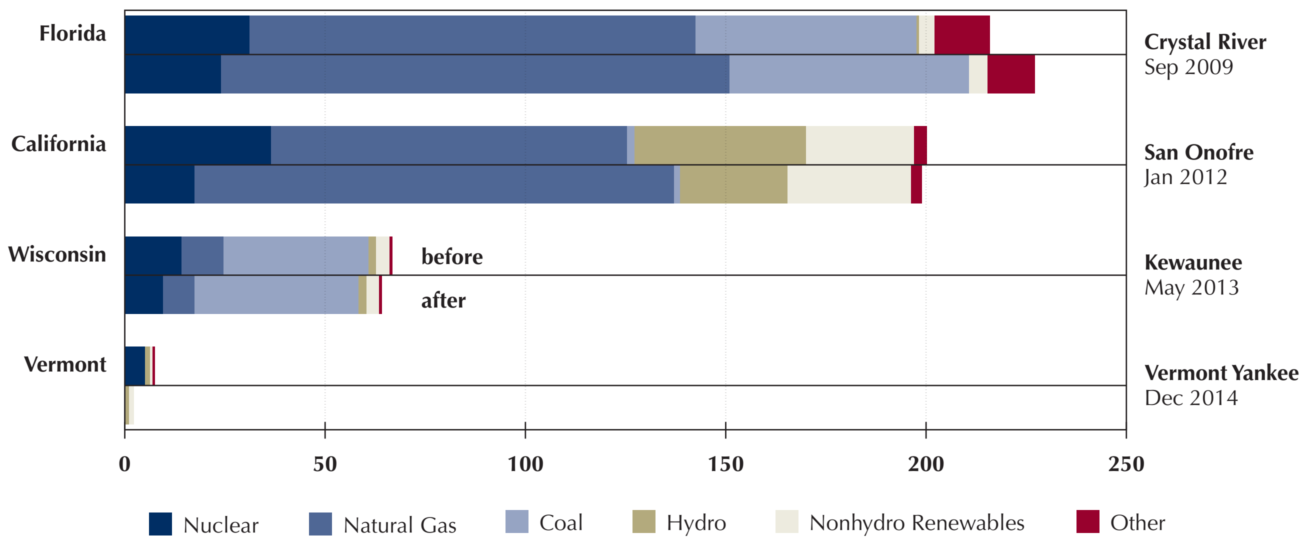
FIGURE 1: Announced Reactor Retirements



PLANT NAME, LOCATION	SIZE (MW)	OWNER	RETIREMENT DATE
Oyster Creek, New Jersey	636	Exelon	2018
Pilgrim, Massachusetts	685	Entergy	2019
Three Mile Island, Pennsylvania	837	Exelon	2019
Davis-Besse, Ohio	900	FirstEnergy	2020
Indian Point, New York	2,069 (2 reactors)	Entergy	2020, 2021
Perry, Ohio	1,260	FirstEnergy	2021
Beaver Valley, Pennsylvania	1,800 (2 reactors)	FirstEnergy	2021
Palisades, Michigan	811	Entergy	2022
Diablo Canyon, California	2,240 (2 reactors)	PG&E	2024, 2025

Total size of planned reactor retirements: 11,238 MW (11.2 GW).
Source: EIA (2016)

FIGURE 2: **In-State Electricity Generation in 12-month periods before and after nuclear retirements (billion kilowatt hours)**



California in-state electric power sector emissions rose by 10 million metric tons the year after San Onofre retired; as of 2015 they are still 9 million metric tons (21 percent) above the 2011 low. In Wisconsin, coal-fired generation largely replaced the missing electricity from the retired Kewaunee Power Station.

Source: EIA (2016); California Environmental Protection Agency (2018)

II. OVERVIEW

U.S. nuclear plants are being prematurely retired with respect to their operating licenses because of low wholesale electricity prices, resulting from low natural gas prices, excess power generation capacity, declining renewable energy costs, and low growth in electricity demand. Moreover, there is a clear market failure; wholesale power markets—a key source of revenue for many nuclear plant owners—do not explicitly reward power sources for being reliable or zero-emitting or place a cost on pollution from other sources. Additionally, there is short-sighted pressure from financial institutions to quickly retire money-losing assets. In the longer-term, the large quantity of emission-free generation from a nuclear plant is expected to become more valuable assuming a more electrified and lower carbon future. At the same time, total plant operating costs, though they have fallen in recent years, are higher than historically low wholesale electricity prices.

The electricity system is evolving with natural gas-fired generation now the largest source of U.S. electric power. Additionally, greater quantities of renewable power, distributed energy resources, and energy storage are being incorporated into the grid. As these trends continue, there is an increasing need for more sophisticated grid management systems and more flexible power plants, capable of ramping, i.e. dialing output up or down when necessary. However, nuclear power plants in the United States were designed to provide baseload power, i.e., reliable, dispatchable electricity sources that run 24 hours a day, seven days a week, to meet the continuous, minimum level of demand. At the same time, there are indications that long-stagnant electricity growth will need to expand rapidly to become the backbone of a low-carbon economy. For example, the transportation sector is already beginning its transformation from conventional liquid fuels to electricity and lower-emitting alternative fuels, which could ultimately require substantially larger quantities of electricity generation 10 to 15 years from now. Large, zero-emitting electricity sources like nuclear power plants are a logical component of this evolving and expanding power system.

To delve more deeply into this topic, this paper looks at the benefits that nuclear power provides. It summarizes the challenges and opportunities for nuclear power as markets evolve and as the world becomes increasingly carbon-constrained. Finally, it examines the pros and cons of policy actions, enacted and proposed, at the federal, state, and local levels as well as rule changes in wholesale power markets and programs that companies might advocate to support existing nuclear power plants.

BENEFITS OF NUCLEAR POWER

In addition to its climate benefit, other positive attributes of nuclear power include reliability, fuel diversity within the broader generation portfolio, a relatively small geographic footprint, low air pollution (i.e., no sulfur or nitrogen oxides, or particulates), rural job retention and sizeable local tax revenue, and enhanced national security.

Climate

Nuclear power is the largest source of zero-emission electricity in the United States. Individually, an average plant generates around 1,000 megawatts (MW). When one closes prematurely, it is not a simple matter to replace it quickly with non-emitting alternatives (e.g. wind, solar, hydro, energy efficiency). Siting new power plants and transmission lines can be challenging in populated areas, especially when a large amount of land is required and not all areas are necessarily suitable for various zero-emitting alternatives (e.g., average wind speeds are much lower in many East Coast states, which makes onshore wind less viable than throughout the central United States).[3] Since the carbon intensity of the electric power grid varies regionally as seen in **Table 2**, emission increases from a retiring 1,000 MW unit can range from 2 to more than 5 million metric tons of carbon dioxide equivalent (MMtCO_2e).[4] For reference, the United States emitted 6,587 MMtCO_2e in 2015. Since 2005, total U.S. emissions have fallen by 727 MMtCO_2e.[5] The entire U.S. nuclear fleet avoids the annual emission of at least 400 MMtCO_2e.[6]

TABLE 2: Annual Emissions Increase from a Hypothetical 1,000 MW Reactor* Retirement

BALANCING AUTHORITY	CARBON INTENSITY (LBS CO_2/MWH)	ANNUAL EMISSIONS INCREASE (MILLION METRIC TONS CARBON DIOXIDE)
NY ISO	538	1.93
PJM	1,100	3.94
MISO	1,444	5.17

*Reactor is assumed to have a 90 percent capacity factor.
Source: EPA eGRID (2017)

Reliability

Electricity service must be reliable—in other words, it must be available all day, every day. Nuclear power plants are a critical component of electrical system reliability, with plants generally running continuously at full capacity, except during brief refueling and maintenance periods every 18 to 24 months. By constantly improving management and operations since 1990, capacity factors (actual generation divided by maximum possible generation) have increased from 66 percent to over 90 percent, giving nuclear reactors the highest average utilization rate of any electricity source in the United States.[7] These gains have notably improved the cost per megawatt-hour (MWh) of power produced by these plants.

Fuel diversity

Fuel diversity is critical to managing system risk and helps to increase grid reliability. Additionally, relying on a broad combination of sources lowers the risk of fuel price volatility, fuel availability risk, and regulatory risks. Conversely, relying on too few fuel sources elevates these risks. Historically, coal and uranium prices have been relatively low and stable compared to oil and natural gas, but price spikes are not without precedent.[8] Relying on a basket of generation technologies and fuels can help minimize delivery disruptions, whether they are caused by physical, technical, weather, cyber or other threats. For example, having assets like nuclear with long-term fuel availability on site can mitigate the risk of outages (e.g., if there is a disruption to the natural gas pipeline system) and increase system resiliency.

Electric generation type is an important component of fuel diversity too as dispatchable sources (i.e., coal, natural gas, nuclear, geothermal, biomass and often conventional hydro) are essential to support variable sources (i.e., wind, solar and sometimes conventional hydro) in the absence of energy storage systems.

As the United States transitions to a cleaner energy system, it needs electricity from a variety of zero- and low-emitting sources, including nuclear, renewables and fossil fuels with carbon capture. The ideal generation mix, which will vary by region, is challenging to define, and there are risks associated with any electricity generation source; diversification is just as wise a strategy for an electricity generation portfolio as it is for an investment portfolio.[9]

Relatively small footprint

The amount of land area used for U.S. nuclear plants varies but is generally very small relative to the amount of power it produces. The largest plant, Palo Verde, which generated around 32 terawatt-hours (TWh) in 2016 (with a capacity of 3,937 MW) in the Arizona desert occupies 6.25 square miles.[10] However, the second largest plant, Salem and Hope Creek, with a capacity of 3,468 MW in Southern New Jersey uses only 1.15 square miles.[11] The smallest site in the United States is associated with the now shuttered San Onofre Nuclear Station in Southern California with a capacity of 2,150 MW on a 0.13 square mile coastal strip.[12] A 2014 study found that just 0.04 square miles (0.1 square kilometers) is required to generate 1 TWh of electricity with nuclear power. For comparison, natural gas would require 0.42 square miles (1.1 square kilometers), and in 2016, total U.S. power generation was 4,079 TWh.[13] For states in which land use is a concern, either due to high-population density or where a great deal of land is under protected status, retaining existing nuclear plants is a good option to achieve or maintain low carbon goals.

Uranium is the most energy dense fuel currently in use.[14] A single uranium fuel pellet (about the size of your fingertip) has as much usable energy for a typical reactor as three barrels of oil, around one ton of coal or 17,000 cubic feet of natural gas.[15] With U.S. electricity demand in 2050 expected to be between 4,900 TWh and 7,400 TWh, nuclear could supply one-third of U.S. power on 63 to 95 square miles of land.[16]

Low air pollution

When generating electricity, nuclear power plants emit no sulfur oxides, nitrogen oxides, or particulate matter, which can lead to health issues and environmental damage.[17] In areas where nuclear plants have been prematurely retired and replaced by fossil fuel generation, increased nitrogen oxides and particulate matter emissions raises the potential for Clean Air Act nonattainment, i.e., not meeting clean air standards.

Rural jobs

Since 2000, rural employment has dropped. Two trends have contributed to the fall. First, manufacturing jobs have declined, primarily due to trade competition and rising labor productivity.[18] Second, rural America's young, educated population has been migrating to greater opportunities in growing cities, stripping communities of their future leaders.[19]

Rural communities tend to be more reliant on a single industry.[20] Nuclear power plants, often located in rural communities are typically the largest employer. When a nuclear power plant retires, its financial impacts are profound with the loss of good-paying jobs, lost tax revenue and subsequent tax increases to make up for the shortfall. Additionally, city services are typically scaled back, property values decline, and with higher taxes and fewer services, small towns find it difficult to attract new businesses and revive their economies.[21]

National security

With regard to national security, nuclear power is growing globally, and the U.S. is ceding development and leadership to others, particularly Russia and China. National security is improved by having a robust domestic nuclear industry because it enables technology exports to foreign countries, bringing along the high U.S. standard of safety and ensuring non-proliferation of nuclear materials. Also, a shrinking U.S. nuclear sector reduces American enrollment in university programs, which has implications for the future work force as well as diminishing the talent pool for national security roles.[22] Additionally, having a well-functioning nuclear supply chain, infrastructure, and experienced workforce helps to set the stage for small modular reactors (SMRs) and the next generation of advanced nuclear reactors that are necessary for our low carbon future. The next generation technology is expected to be superior in terms of cost, safety, and proliferation risk.

CHALLENGES FOR THE EXISTING FLEET

Existing nuclear plant owners face challenges with declining revenue from wholesale power markets (i.e., a market that fails to reward generators for their environmental and other benefits), an unresolved long-term waste storage issue, along with safety and proliferation concerns. Note that nuclear power plants in regulated states are funded through "cost-of-service" regulation, which allows utility owners to recover costs and earn a reasonable rate of return. Generally, the financially challenged plants are the ones that operate in states with deregulated, competitive electricity markets and depend on wholesale market revenue determined by the supply/demand balance. These plants are also known as merchant generators.

Wholesale power markets

More than half of all nuclear power plants rely on revenues from wholesale power markets, where energy prices have trended downward and are currently at historical lows due to low natural gas prices, market oversupply, and anemic demand growth.[23] In New England (ISO-NE), New York (NYISO), PJM (a wholesale power market covering 13 states and the District of Columbia), and Texas (ERCOT) energy prices continued to decline in 2016 with average prices mostly below $30/MWh (Figure 4).[24]

In order to avoid retirement, plant revenues must exceed their costs. At $33.93/MWh, total generating costs for nuclear power are relatively low across the U.S. fleet as shown in **Table 3**.[25] Costs are lower for multi-unit plants and for fleet operators versus operators with a single plant. In addition to energy prices, some wholesale power markets provide further remuneration for capacity, uplift, and ancillary services.[26] Still, on average, nuclear plant costs exceed the revenue they are receiving from wholesale power markets where prices are largely determined by plants fueled by natural gas. A 2016 analysis found that 34 of the nation's 61 plants are collectively losing about $2.9 billion a year.[27]

The U.S. nuclear industry is currently focused on reducing total plant operating costs by 30 percent by 2018 through program and process efficiency improvements.[28] It is unclear how much further plant costs can fall; they have dropped nearly 16 percent since 2012 and are currently aided by falling uranium prices. Additionally, after completing the majority of mandatory post-9/11 and post-Fukushima safety enhancements in 2015, capital spending across the fleet dropped from $8.07/MWh (in 2015) to $6.74/MWh.[29]

Also, some in the industry advocate for a reduction in U.S. Nuclear Regulatory Commission (NRC) fees—the agency receives 90 percent of its funding from the industry—as a way to help lower plant costs.[30]

Long-term storage

After many years of study, a long-term storage solution for spent nuclear fuel has yet to emerge. At the end of 2017 there was an estimated 78,800 metric tons of spent fuel stored at U.S. nuclear plants, increasing by around 2,000 metric tons per year.[31]

Currently, spent fuel rods are stored onsite at nuclear power plants, initially in specially designed pools which cool the waste for several years, and later in dry storage containers. The U.S. NRC is confident that spent fuel is safely stored in pool and cask storage for "at least 60 years beyond the life of any reactor without significant environmental effects."[32] Still, the long-term storage of these wastes is a major public policy issue. Fourteen states prohibit building new nuclear until the long-term waste issue is resolved.[33]

While this represents a problem primarily for new nuclear builds, it also has ramifications for the existing fleet. Individual plant sites were not intended to provide interim storage. Although, it is stored safely and inspected regularly, the accumulation of spent fuel has upset some, who see the fuel adding to plant costs or as a potential terror target.[34] Finding a policy solution to this issue would help existing reactors and future construction of nuclear plants. Consent-based storage is a potential long-term policy solution and start-ups like Deep Isolation have proposed innovative, new storage solutions.[35]

Safety

While nuclear power emits no greenhouse gases, it has unique challenges, including how to prevent the release of radioactivity from a damaged reactor. Since the dawn of the nuclear age in the 1950s, the global nuclear energy industry has experienced only three serious nuclear reactor accidents—most recently in 2011 at Fukushima Daiichi in Japan—and several fuel cycle facility incidents. Nuclear power plants are designed and operated to minimize the chances of accidents and limit the impacts if they do occur. Overall, they have one of the safest performance records of any power source.[36] For example, deaths (among the public and to workers) resulting from the coal fuel cycle are at least five times greater than for the nuclear fuel cycle.[37] Among other things, the U.S. NRC ensures that existing U.S. reactors continue to operate safely.

TABLE 3: 2016 Nuclear Power Plant Cost Summary ($/MWh)

CATEGORY	NUMBER OF PLANTS / SITES	FUEL	CAPITAL	OPERATING	TOTAL OPERATING (FUEL + OPERATING)	TOTAL GENERATING (FUEL + CAPITAL + OPERATING)
All U.S.	60*	6.76	6.74	20.43	27.19	33.93
Plant Size						
Single-Unit	25	6.77	8.67	25.95	32.72	41.39
Multi-Unit	35	6.75	6.15	18.73	25.48	31.63
Operator						
Single	12	7.18	8.19	21.20	28.38	36.57
Fleet	48	6.63	6.32	20.21	26.84	33.16

*Costs exclude shutdown plants, are in 2016 dollars, and do not include reserves to cover operational and market risk.

Source: Electric Utility Cost Group (EUCG)

Proliferation

Globally, there is concern about the spread of nuclear weapons, also known as nuclear proliferation. Technologies and materials associated with civilian nuclear energy can be adapted and used to make nuclear weapons; this risk is actively managed by organizations like the International Atomic Energy Agency (IAEA). The IAEA monitors nuclear programs around the world to ensure safety, security, and transparency. U.S. policy regarding reactor designs, fuel infrastructure, and international agreements have been devised to mitigate proliferation risks.[38] Future advanced reactor designs directly address this issue. Six reactor technologies have been chosen for future development by the Generation IV International Forum in part because they offer opportunities to provide greater resistance to diversion of materials for weapons proliferation.[39]

OPPORTUNITIES FOR THE EXISTING FLEET

A likely resurgence in electricity demand growth, a growing need for energy storage to support expanding renewable generation, flexible nuclear generation to support expanding renewables, and new business models represent potential opportunities for existing nuclear power plants in the coming decades.

Demand growth

U.S. electricity demand growth has largely flat-lined over the last decade. The drivers of this trend have been upgrading to more efficient equipment, implementing efficiency standards (light bulbs and appliances), slowing population growth, and a shift away from energy-intensive industries to a more service-oriented economy.[40] However, in the mid- to long-term, assuming deep decarbonization policies are put in place (see **Box 1**), electricity generation could increase by more than 75 percent by 2050.[41] In most decarbonization studies, scenarios show that nuclear power has an even larger role to play in the future electricity generation mix.[42]

Energy storage

As we shift to a low-carbon energy system and deploy greater quantities of variable resources (e.g., wind and solar), we will need increasing quantities of electric energy storage to maintain reliable system operation; nuclear power can provide an additional storage solution.[43] Pumped storage, conventional hydropower with reservoir, and large batteries typically come to mind as sources of electric energy storage, but creating hydrogen and storing it for later use is also a form of energy storage.

How is hydrogen created? Electricity can be used to separate water into hydrogen and oxygen in a process known as electrolysis.[44] The hydrogen can be stored and used later to generate electricity in fuel cells, burned in combined cycle plants, or used as a transportation fuel or as a feedstock in industry.[45]

The hydrogen is considered to be green if it is created using electricity or heat from zero-emission sources like nuclear and renewable power. Since the future electricity generation mix could contain high levels of inflexible generation (e.g., variable wind and solar and conventional nuclear), there are likely to be periods where significant overgeneration could occur.[46] Instead of curtailing this generation (which happens today), it would be more cost-effective to create fuels (or other products) to store for future consumption. U.S. national laboratories have been collaborating to find ways to integrate nuclear reactors and intermittent zero-carbon emission renewables like wind and solar.[47] In the future, with the creation of new software tools and techniques, these sources could optimize their output. Surplus thermal or electric energy could be diverted to create a range of products, including emission-free hydrogen or liquid fuels for the transportation sector, the largest source of U.S. greenhouse gas emissions.[48]

Flexible nuclear generation

For regulatory and economic reasons, existing nuclear plants in the United States generally run at full power (i.e., 100 percent of rated capacity) when they are operating. Since their fuel costs are very low, it makes economic sense to operate in this manner. However, with greater deployment of wind and solar, more frequent periods of overgeneration are expected, particularly during the middle of the day or in the overnight period when demand is lower. Overgeneration creates zero or even negative pricing in wholesale power markets.

However, nuclear power plants in France and Germany demonstrate that plants can and do operate in a load following mode and at times reduce their output to as low as 30 percent of the reactor's rated capacity.[49]

BOX 1: Deep decarbonization

In order to meet the 2-degree Celsius (3.8-degree Fahrenheit) target agreed to by the international community and avoid the worst effects of climate change, global net greenhouse gas emissions must be approaching zero by the second half of this century.[118] Pathways to deep decarbonization generally focus on three, equally important strategies for our energy system: (1) increasing deployment of energy efficiency, (2) decarbonization of the energy supply, and (3) fuel switching as described in **Figure 3**.[119] Among the energy supply decarbonization strategies, there are many possible ways (i.e., combinations) to decarbonize the power sector. However, most studies indicate that a diverse mix of renewables, nuclear power, and fossil fuel with carbon capture utilization and storage is the least costly and least technically challenging path to achieve the mid-century goal.[120]

This is sub-optimal from an economic and technical standpoint, but feasible in the United States. For example, maintenance costs could increase for nuclear plants as a result of operating at less than full power. However, wholesale power markets could compensate nuclear power for reducing power (i.e., providing a valuable market service) by responding to overgeneration signals. This would enable nuclear and renewable power to complement one another in power markets and retain more zero-emission generation.

Further study by operators will be necessary (likely on a plant-by-plant basis) to determine whether using excess generation for practical purposes (e.g., creating hydrogen, see previous section) or investing capital to allow flexible operation makes more sense.

New business models

Traditionally, nuclear power's revenue is tied to the energy and services it provides to wholesale power markets or, in regulated markets, the funding it receives from a "cost-of-service" determination. However, there are other potential revenue streams. Nuclear reactors operate at very high temperatures, creating economic opportunities to utilize the heat.[50] Therefore, nuclear power could provide process heat (and electricity) for creating fresh drinking water (i.e., desalination), oil refining and other industrial or district heating applications.[51]

Practically speaking, however, non-trivial investments would be necessary to realize these new revenue streams, which require financial decisions weighing the costs and overcoming certain regulatory barriers, particularly where the technology has not been previously employed.

FIGURE 3: Decarbonization Strategies

Energy-Efficiency	Energy Supply Decarbonization	Fuel Switching
Making final energy consumption more efficient in buildings, industry and transport.	Low-carbon electricity generation mixes that include renewable, nuclear, and fossil with CCS. Pipeline gas supply and liquid fuels decarbonization.	Electrifying end-uses and greater use of low-CO_2 alternatives like hydrogen where possible.

Source: U.S. Deep Decarbonization Pathways, E3, LBNL, PNNL, 2015.

III. POLICY PATHWAYS

The challenges faced by existing nuclear power plants can and are being addressed to a limited extent by actions at the federal, state, and local level as well as by wholesale power market operators and businesses. Additionally, several actions have been proposed to preserve the existing nuclear fleet. In this section, we examine who has done what, what is being proposed and consider the pros and cons of each.

FEDERAL-LEVEL ACTION

Policy leadership at the highest levels is required to send the correct signals to all states, businesses and markets. Broadly speaking, stable policies that promote a long-term movement toward a low carbon future by mid-century and beyond are necessary to stimulate the high level of investment required. Since power plant infrastructure investments are expensive and long-lived, today's decisions are locked in for decades. So, it is even more critical that we make the right decisions today. Toward this end, Congress and federal agencies like the Environmental Protection Agency (EPA), Federal Energy Regulatory Commission (FERC), Nuclear Regulatory Commission (NRC) and others could adopt measures including carbon pricing, clean energy standards (CES), tax credits, agency specific regulations, and wholesale power market reform to help support existing nuclear power plants.

Congress

Though this issue has been prominent for several years, and nuclear power enjoys bipartisan support in Congress, a national response has failed to emerge. Congress has put forth proposals addressing the long-term waste storage issue and legislation that would cap NRC fees for existing reactors, though to date none of these has been passed into law.[52] However, actions that would more directly address the financial challenges faced by the existing nuclear fleet have not gained traction. Congressional actions that could help address this specific issue and correct the wholesale power market failure (to internalize the carbon pollution externality) include putting a price on carbon dioxide, instituting a national CES, and providing tax credits for investments in the existing reactor fleet.

Carbon pricing

Carbon pricing policy can be implemented in many forms; two basic approaches are carbon taxes or cap-and-trade programs. Each system has key parameters that must be established, which will determine the ultimate stringency and effectiveness of the policy.[53] For example, with a carbon tax, the point of taxation, the initial level of the tax (i.e., dollars per ton emitted), the amount that it will increase each year, and what to do with the revenue received are some of the variables that need to be determined. In a cap-and-trade program, an emissions cap is set, which provides more certainty about future emissions, but less certainty about the price of those emissions. In the United States, cap-and-trade programs for carbon dioxide have been employed only in California and in nine northeastern states, known as the Regional Greenhouse Gas Initiative (RGGI).[54]

Under a cap-and-trade program or a carbon tax, nuclear power does not receive direct support, but market price takers (i.e., nuclear and renewables) benefit when price makers (i.e., fossil fuel generators) pay for their carbon dioxide emissions. Under a cap-and-trade program, large carbon dioxide emitters must purchase sufficient allowances to cover their emissions. All other things equal, this increases their variable operating costs and wholesale power market offers. Similarly, a carbon tax implemented on fossil fuels far upstream (i.e., at the coal mine or wellhead for oil and natural gas) increases fuel costs for fossil fuel-fired power plants, which increases their market offers.[55] Higher market offers lead to higher market clearing prices, which benefit nuclear and other zero emission electricity sources who are price takers in power markets but do not have to bear the cost of the carbon tax or purchasing allowances.

While total emissions have trended downward marginally in California and collectively among the RGGI states, it is becoming clear that merely establishing a price on carbon in a particular region is not sufficient to preserve existing nuclear reactors if that price is very low.[56] In California, Diablo Canyon, the state's last remaining nuclear power plant, will close its two reactors in 2024 and 2025. In RGGI, the Vermont Yankee Nuclear Power Plant closed in 2014, the Pilgrim Nuclear Power Station is scheduled to close in 2019, the Indian Point Energy Center will shutter in 2021 and 2022 (Figure 1), and other reactors are at-risk of premature retirement. In both of these regions, carbon prices have been very low. Since California's cap-and-trade began in 2013, the price per ton of carbon has remained generally below $16/ton.[57] Similarly, RGGI allowance prices have remained generally below $6/ton; all other things equal, a more stringent (i.e., lower) cap would elevate prices.[58]

Historically low natural gas prices coupled with (the requirement to purchase) low-cost allowances have not notably increased market clearing prices. Increasing allowance prices (e.g., reducing the cap or retiring allowances) or establishing a higher carbon tax would increase market prices. Meaningfully increasing market prices would benefit nuclear power, but would also increase electricity prices for consumers, which could be offset somewhat by returning carbon pricing revenue to end-users or via allowance allocations to electric distribution companies to act as a price buffer for electricity consumers. Still, this can be a challenging political tightrope for policymakers to navigate. Expectations matter as well. So, designing a program where long-term, future prices are transparent is important.

Clean energy standard

A CES is a policy that seeks to increase the share of electricity demand met with clean energy by specific target dates, e.g. 50 percent clean energy by 2025.[59] Twenty-nine states and the District of Columbia have enacted some form of electricity standard, though typically these have been geared toward increasing renewable (i.e. wind and solar) generation.[60] Depending on its design and definition of clean energy, a national CES could explicitly include nuclear power.

Under a CES, electric utilities would be required to supply a certain percentage of their total electricity sales from clean sources. Utilities demonstrate compliance with the CES by obtaining the mandated amount of clean energy credits (CEC) for a given year and surrendering those credits to the program administrator. Utilities acquire clean energy credits by either owning or contracting for delivery from clean energy sources, or by purchasing tradable credits.[61] Key decision variables in designing a CES include defining which electricity sources are clean and how much credit they receive as shown in **Table 4**. Since fossil fuel-fired electricity sources are typically the market price setters, providing them partial credit in a CES is likely to further reduce wholesale power prices and make clean generation more costly to procure.

An ambitious CES would support existing nuclear power plants; because they produce such a large quantity of zero-emission power (e.g., around 8 TWh/year for a 1,000 MW plant), they would be difficult to replace quickly by other emission-free sources if they were to close.[62]

Tax credits

Federal tax credits for investments and capital spending on existing nuclear power plants could provide some relief to merchant nuclear operators. In December 2017, a bipartisan group of ten House members introduced H.R. 4416, the Nuclear Powers America Act.[63] This legislation would create an investment tax credit for capital spending at existing nuclear plants. Modeled after existing tax law for solar investments, the bill would provide a 30 percent credit for capital expenditures through 2021 and would phase down to 10 percent in

TABLE 4: Illustration of a Simple Approach to Crediting Clean Energy Generation under a CES

ELECTRICITY GENERATION TYPE	NUMBER OF CECS PER MWH OF GENERATION
Renewables	1
Nuclear	1
Coal with CCS (50-90% CO_2 capture)	0.5
Coal with CCS (90+% CO_2 capture)	1
Natural gas combined cycle (<800 lbs. CO_2/MWh)	0.5

Source: C2ES (2011)

2024. A tax credit would put nuclear, the largest source of emissions-free generation, on par with other non-emitting sources.

In summary, action in the 115th Congress, particularly if it is climate-focused, is unlikely given the current legislative priorities. However, congressional action, particularly a market-based, economy-wide carbon-pricing program would be the best, least cost approach and would be even more impactful than merely addressing power sector emissions.[64] Continued educational efforts and outreach with Congress are necessary to advance carbon-pricing, CES, and tax credit policies that will benefit all zero-emission technologies (e.g., nuclear, renewable, fossil fuel with carbon capture, energy storage, and so on) in the months and years to come.

Federal agencies

Actions by federal agencies like the EPA, FERC, NRC and others (e.g., Department of Energy (DOE), Department of Defense (DOD), and the General Services Administration (GSA)) could help to preserve the existing nuclear fleet.

Environmental Protection Agency

The Clean Air Act requires the EPA to work with states to reduce greenhouse gas emissions, including carbon dioxide and methane.[65] To that end, in August 2015, the EPA adopted carbon pollution standards for existing power plants, known as the Clean Power Plan, which was expected to reduce power sector emissions 32 percent below 2005 levels by 2030. The Clean Power Plan set unique targets (rate- and mass-based) for each state and granted states a great deal of flexibility in how they chose to construct their implementation plans.[66]

The Clean Power Plan was never implemented due to a Supreme Court stay issued in February 2016, and its replacement (currently under development) is expected to look very different in both scope and stringency. Had the original Plan gone into force, however, its impact on the existing fleet would likely have been minimal. A C2ES examination of the findings of six economic modeling studies of the Clean Power Plan found no material impact on nuclear power generation versus the 2030 business-as-usual outlook.[67]

Notably, unlike the treatment of existing reactors, the original Clean Power Plan did provide a clear incentive for new and additional zero-emission electricity sources, which would have included power uprates at existing nuclear plants, the construction of new nuclear plants, along with other new renewables (e.g., hydro, wind, solar).[68]

New regulations for existing power plants from the EPA are not expected to be as wide-reaching as the original Clean Power Plan. However, EPA's authority to monitor and regulate greenhouse gases is not going away. Even though this is not a high priority for the current administration, it is highly likely that a future administration will resurrect some of the good elements of the original Clean Power Plan absent congressional action on climate. This represents an important opportunity for existing nuclear reactors. Along with promoting options that enable long-term decarbonization in general, any future EPA regulation should more explicitly consider at-risk reactors in the development of a final rule (as was considered in an earlier draft version of the Clean Power Plan). Policy incentives should be crafted such that backsliding (i.e., emission increases) cannot easily occur in states operating under a rate- or mass-based system.

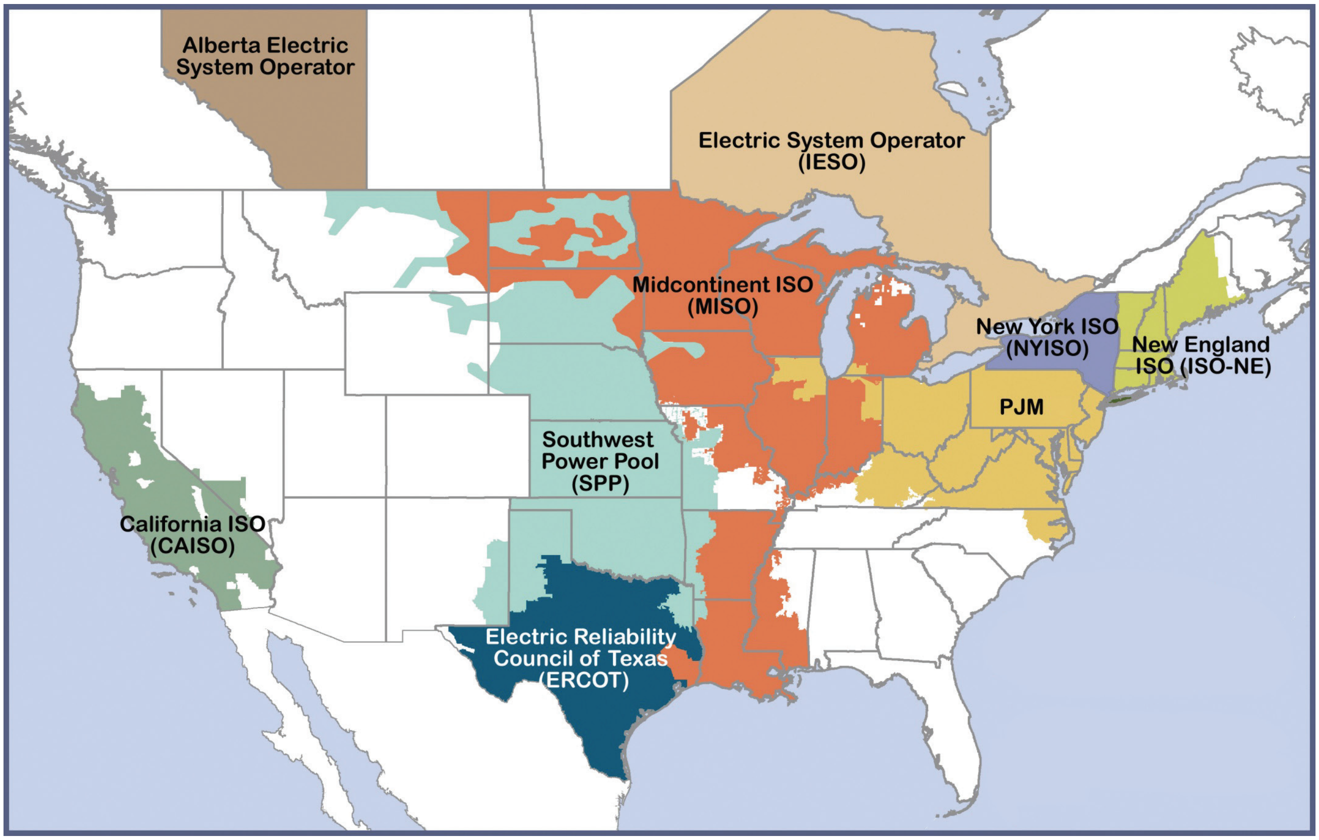
That said, existing nuclear facilities need near-term solutions. While there is promise that a constructive policy can be developed through the EPA in the coming years, for now, most attention is focused toward more immediate channels, i.e., FERC and the states.

FERC and wholesale power market operators

The Federal Energy Regulatory Commission (FERC) and the wholesale power markets that it overseas (seen in **Figure 4**) could play an important role helping existing nuclear power plants. Since the wholesale power markets are the primary source of merchant nuclear power's revenue decline, it makes sense to examine these markets for potential solutions.

Wholesale power markets were established to increase efficiency in the electric power sector and deliver affordable, reliable electricity. Largely, these markets have been functioning as designed. Recently, the New England market (ISO-NE) saw its lowest average prices in 13 years due to low natural gas prices and weak demand—a result of mild weather.[69] While low prices are great for consumers in the short term, they have been a challenge for nuclear plant operators. Markets are technology-agnostic and do not consider environmental benefits (a market failure) like low carbon dioxide emissions when rewarding generation sources. Therefore, nuclear and renewable power sources provide zero-emission

FIGURE 4: **North American Independent System Operators and Regional Transmission Organizations**



Source: FERC (2015) https://www.ferc.gov/market-oversight/guide/energy-primer.pdf.

electricity to the grid but receive no compensation from the market for this aspect of their service. Federal tax credits (i.e., production tax credit and investment tax credit), a policy intervention, provide out-of-market support for renewable generation but are being phased out, while renewable portfolio standards remain. Out-of-market subsidies are payments received by a generator that participates in an organized electricity market (e.g., ISO New England, PJM, MISO, NY ISO) outside of normal market operations. These include renewable energy credits (RECs), zero-emission credits (ZECs) and the federal production tax credit (PTC), among others.

At the same time, as states have become more concerned about greenhouse gas emissions, they have promulgated policies (i.e., renewable portfolio standards, zero emission credits—See State-Level Action section of this report) to encourage and preserve lower carbon technologies. Arguably, these efforts can affect market price formation as well as regular market participant entrance and exit.[70] FERC held a technical conference in May 2017 to gather information on these out-of-market payments, focusing on ISO-NE, NYISO, and PJM. During the conference, Commissioner Cheryl LaFleur said she hoped that FERC would be able to preserve the markets that have functioned well and that a system would emerge that would be able to accommodate states' aspirations (e.g., achieve their clean energy targets).[71] FERC's ongoing work on wholesale electricity price formation to more accurately compensate generators for the services they provide is a potential pathway to maintaining existing reactors. There may be an opening to test ideas in the resilience docket that was opened in January 2018.

FERC has already sanctioned some market changes from the organizations it oversees. Independent system operators (ISOs) and regional transmission organizations (RTOs) have demonstrated the ability to adapt to changing market circumstances (e.g. increasing quantities of intermittent generation and incorporating new technologies like energy storage). In 2015, FERC approved PJM's capacity performance proposal, which provides a financial incentive for units to improve their future performance but has only had a minimal impact on capacity prices.[72] Additional changes are being considered as part of FERC's resilience docket that could value the fuel security provided by nuclear plants and others with fuel on site. PJM has also offered a proposal that would correct market flaws that result in nuclear plants operating during times when market prices are below their cost of operation. But these changes are not expected to be made in time, if at all, to address the pending premature retirement announcements.

Some ISOs and RTOs have introduced the idea of carbon pricing at the wholesale market level. ISO stakeholder groups are currently discussing some of these proposals. Notably, the New England Power Pool, an advisory group to ISO-NE, has been looking into integrating markets and public policy for more than a year. NYISO is also looking into the feasibility of pricing carbon into its wholesale market.[73] There are regional differences across the country in terms of available resources for electricity supply and distinct patterns of end-user demand. Therefore, it is unlikely that a one-size-fits-all solution exists; rather, tailored, regionally-based solutions are more likely to emerge.

A key question remains. Does the Federal Power Act (FPA) allow FERC to put a price on carbon, i.e., insert a carbon adder into a wholesale power market? Several law review articles argue that it would be permissible. The framework of the FPA has enabled FERC to transform the transmission and electricity service that it oversees in novel ways without additional congressional authorization. For example, it has shifted from cost-of-service to market-based rates, implemented open-access transmission, and developed the RTOs/ISOs and energy markets. So, while the FPA does not explicitly authorize FERC to regulate pollution or put a price on carbon, the courts have upheld reforms (e.g., demand response) that enhance the wholesale market. As long as FERC concludes that a carbon adder proposal from an RTO (or a proposal of its own design) results in just and reasonable rates, the courts are likely to be deferential.[74]

Legal challenges are likely, and these could be time consuming; many reactor operators don't have a lot of time to wait out these legal proceedings.

Nuclear Regulatory Commission

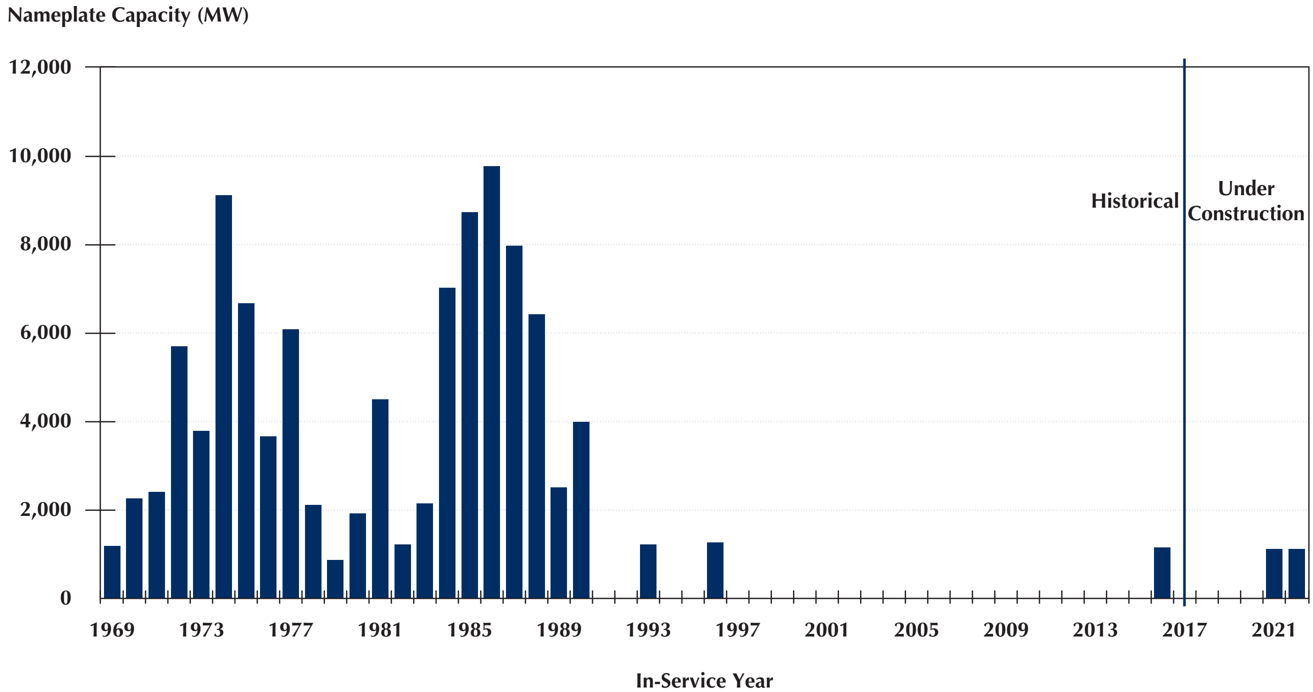
Nuclear power plants began coming online en masse in the 1970s and 1980s as shown in **Figure 5**. Initially, plants were licensed to operate for 40 years. In the late 1990s, operators began applying for 20-year license extensions, increasing the total operational lifespan to 60 years. Currently, 84 of the 99 operational reactors are licensed to operate for 60 years, and a further 13 intend to apply for the license.[75] Presently, this implies that much of the fleet will begin to retire in the period from 2029 through 2050.

However, the NRC has finalized guidelines by which it will evaluate nuclear plants in what is being called second or subsequent license renewals (SLR), which will extend existing licenses an additional 20 years—bringing the total operational lifespan of a reactor to 80 years.[76] Note that much of the equipment used to generate power, particularly the parts of the plant that move, is continually replaced. Among other things, the guidelines include detailed monitoring processes, inspections of aging equipment, and identification of components that require additional maintenance. SLRs would enable plants to continue to operate into the 2049 to 2070 range seen in **Figure 5**, depending on which plants decided to pursue the licenses, extending the life of much of the fleet well beyond mid-century. Critically, this would buy additional time to deploy new advanced reactors, other zero-emission electricity sources, and the necessary infrastructure (i.e., transmission and management systems) to meet the deep decarbonization challenge (see **Box 1**).

Florida Power & Light became the first operator to seek an SLR in February 2018 for its Turkey Point plant in South Florida.[77] According to records with the NRC, Exelon and Dominion intend to submit applications for SLRs for a total of 6 reactors at 3 facilities.[78] A survey conducted by a nuclear industry trade group found that as many as 20 facilities are currently planning for SLRs.[79] With a likely cost of around $30 to $50 million per plant, most profitable facilities are expected to apply for the SLR.[80]

In addition to avoiding carbon dioxide emissions further into the future, extending a nuclear plant's life creates additional opportunities. Plant operators are more likely to consider performing maintenance (e.g., turbine upgrade) that would not have otherwise been considered for a plant planning to retire in a few years, which would further improve the efficiency of

FIGURE 5: Nuclear Fleet Capacity and In-Service Year*



*Retired units have been removed

Source: EIA (2017)

the nuclear power plant. Thereby avoiding even greater quantities of carbon dioxide emissions, when they are offsetting other emitting sources.

However, all of this policy work is moot unless the reactors have an economic path forward.

This is why the policies (e.g., carbon pricing, clean energy standards, wholesale power market reform, state zero-emission standards and power purchase agreements, etc.) discussed in this report are so important—to extend the life of as many reactors as possible.

Other agencies

The DOE has established many programs to help support energy projects, including its loan program and the Advanced Research Projects Agency-Energy (ARPA-E), but these programs are primarily for new projects, near-commercial projects and basic science. They are not a support mechanism for existing facilities, namely the existing nuclear fleet. However, government agencies like the DOE, DOD and GSA are large consumers of electricity for their various laboratories, bases, and buildings. As such, the government has a great deal of purchasing power and establishing long-term power purchase agreements with nuclear facilities can be one option to help financially struggling nuclear units.

Power Purchase Agreements

Power purchase agreements (PPAs) are contracts to procure electricity. They allow the buyer to pay a fixed price and the seller to receive a guaranteed stream of revenue for a particular volume of electricity over a specified time period, removing uncertainty for both parties. According to data provided to the Congressional Research Service, at least six nuclear plants have some type of PPA in place for either a portion or all of their output as shown in **Table 5**.[81]

For nuclear plant owners, having in place a long-term PPA of 10 years or more provides a hedge, reducing power market price risk and guaranteeing a fixed level of revenue. In a 2005 order regarding a PPA, the Iowa Utilities Board found that the Duane Arnold Energy Center provided a host of benefits (including fuel diversity, cost stability, zero-emissions, and economic benefits), contributes to reliability, and plays a critical role in

TABLE 5: Nuclear Plants with PPAs

PLANT NAME	LOCATION	MAJOR OWNER	CAPACITY (MW)	PPA CONTRACTED POWER (%)
Cooper	Nemaha, NE	Nebraska Public Power District	768	3
Duane Arnold	Linn, IA	NextEra Energy	601	70
*Ginna**	Wayne, NY	Exelon	576	100
Palisades	Van Buren, MI	Entergy	805	100
Point Beach	Manitowoc, WI	NextEra Energy	1,184	100
Seabrook	Rockingham, NH	NextEra Energy	1,246	4

*Ginna was under a reliability support services agreement (RSSA), which supports continued operations of power generators that want to retire but are needed to ensure system reliability. That agreement expired more than one year ago.

Source: Congressional Research Service (2016)

the local transmission system.[82] The Duane Arnold Energy Center renewed its PPA in 2013.[83] However, with declining renewable prices, its PPA is not expected to be renewed in 2025.[84] In places like Iowa with excellent renewable resources, the downward price pressure from a combination of sustained, low natural gas prices, falling renewable prices and federal renewable subsidies (in the short-term) challenge the economics for nuclear operators. In other regions with constrained (e.g. high-population or developed) or protected land access or where renewable energy performs less well, PPAs with existing nuclear facilities can help ensure the local electricity mix remains low carbon. In these regions in particular potential PPA customers could include large government agencies (e.g., DOE, DOD, GSA), cities, and energy-intensive businesses including technology companies with data centers and large industrial consumers.

STATE-LEVEL ACTION

In the absence of significant federal policy support, states like New York, Illinois, Connecticut, New Jersey, Ohio, Pennsylvania, and Arizona are exploring options to preserve their existing nuclear power stations. The concept of renewable energy certificates or credits (RECs), which represent electricity produced using renewable resources emerged around two decades ago. Markets for RECs were created for utilities to comply with renewable portfolio standards (RPS), which were established by states to expand the use of renewable energy. In a similar vein, the concept of zero-emission credits (ZECs), representing electricity produced by nuclear power plants has recently emerged. States like New York, Illinois, and Connecticut are creating zero emission standards (ZES) to preserve their zero-emission nuclear generation.

New York

New York, which gets nearly a third of its electricity from nuclear, adopted a so-called CES in August 2016 that included, among other things, compensation for its economically challenged reactors—specifically for the zero-emission, environmental benefit they provide.[85]

The New York CES mandates that 50 percent of New York's electricity come from renewable energy sources, including hydro, wind, and solar by 2030. The CES is divided into two separate parts—a renewable energy standard (RES) and a ZEC requirement for existing nuclear power. The RES represents a continuation of the state's renewable portfolio standard (RPS). The ZEC requirement is a wholly independent component of the CES, and is designed to ensure the continued operation of the state's nuclear facilities by expressly valuing their environmental contribution. Maintaining the nuclear fleet, in addition to the RES, will help the state achieve its economy-wide goal to reduce greenhouse gas emissions 40 percent below 1990 levels by 2030.

In its *Order Adopting a Clean Energy Standard*, the New York Public Service Commission (PSC) cited the premature closure of nuclear power plants and the subsequent increased reliance on existing and new fossil fuel generation as a key rationale for establishing ZECs.[86] The order also articulates that ZECs are purely a mechanism for compensating nuclear power for its environmental attribute, an aspect that wholesale power markets currently fail to reward.

ZEC payments will be made to qualifying facilities that meet public necessity criteria. Public necessity is determined by the New York PSC on a plant-by-plant basis, considering the adequacy of the facility's current revenue streams to sustain its zero-emission value, its historic contribution to the state's clean energy mix, and its impact on ratepayers, among other things. Only upstate reactors (i.e., FitzPatrick, Ginna, and Nine Mile Point) were considered for receiving benefits (i.e., ZECs) because the owner of Indian Point did not assert that its facility was at risk.[87] Indian Point has subsequently announced retirement as part of a settlement of an environmental permit issue.

Qualifying facilities will receive ZEC payments from April 1, 2017, through March 31, 2029.[88] The ZEC price for the first of six, two-year periods was set at $17.48/MWh as seen in **Table 6**. The ZEC price was calculated as: (1) the projected average social cost of carbon (SCC) over the tranche period ($42.87/short ton) minus (2) a fixed baseline portion of that cost that is captured through RGGI over the same period ($10.41/short ton), which is $42.87—$10.41 or $32.47/short ton. A conversion factor (i.e., $/ short ton to $/MWh) of 0.53846 is applied (i.e., $32.47 times 0.53846) to arrive at the $17.48/MWh ZEC price.[89] The conversion factor is based on the mix of resources avoided (i.e., natural gas, coal and oil on the margin) by preserving nuclear power, and is derived from a 2015 study on net energy metering.[90]

Future ZEC payments for tranche 2 through tranche 6 are to be determined, but will be based on the same general methodology, (i.e., projected average SCC over the tranche period minus the baseline RGGI effect minus the "amount that the Zone A forecast energy price and rest of state (ROS) forecast capacity price combined exceeds $39/MWh" is equal to the ZEC price.)[91] Estimates of the total cost of the ZECs over the 12-year period depend on future energy prices and range from a high of $7.6 billion to as low as $2.86 billion.[92]

New York's CES is not a standard CES, as described earlier in this report; renewables and nuclear are explicitly segregated and other sources of lower emission generation are not eligible for credits. Under New York's approach, nuclear directly benefits as it is being transparently rewarded for its environmental benefit. Clearly, the policy is a remedy for the wholesale market's failure to appropriately price environmental benefits of zero carbon electricity. It would be more appropriate and efficient if it were accounted for within the market (i.e., as a carbon adder in the NYISO). However, since that is a more challenging feat to accomplish, this limited and targeted approach is novel and should be commended. Already, this approach has successfully withstood legal scrutiny, but additional challenges are forthcoming.[93]

Illinois

Illinois is home to the largest number of nuclear reactors in the United States—11, with more than 12 GW of capacity. Annually, just over half of the state's electricity is generated by nuclear power. In December 2016, Illinois passed the Future Energy Jobs Act (FEJA), which, among many other things, created a ZES; both the Clinton and Quad Cities nuclear facilities (i.e., three of the eleven reactors) are expected to qualify for the program.

The ZES went into effect in June 2017 and will expire on May 31, 2027.[94] The total annual volume of ZECs will remain constant for the duration of the program at approximately 20,100,000. Due to programmatic cost caps and a first-year price of $16.50/ZEC, around 5,900,000 ZECs will be unpaid. However, unpaid ZECs will be eligible for payment in future years in which the

TABLE 6: New York ZEC Periods and Pricing

TRANCHE	START DATE	END DATE	PRICE
1	April 1, 2017	March 31, 2019	$17.48 per MWh
2	April 1, 2019	March 31, 2021	TBD
3	April 1, 2021	March 31, 2023	TBD
4	April 1, 2023	March 31, 2025	TBD
5	April 1, 2025	March 31, 2027	TBD
6	April 1, 2027	March 31, 2029	TBD

Source: Order Adopting a Clean Energy Standard (2016) cost cap does not come into effect.[95] The Illinois Power Agency is responsible for procuring enough ZECs from zero-emission facilities to meet the ZES, while the Illinois Commerce Commission is responsible for determining that ZECs are cost-effective. The price for ZECs is based on the SCC (as in New York), and downward price adjustments are made based on the amount that the actual market price exceeds a baseline price in a given 12-month period.[96] If the price adjustment equals or exceeds the SCC, then there is no ZEC payment, i.e., the market price is sufficiently high to support the zero-emission facility without subsidy. The cost of the ZES portion of the bill is capped at $235 million per year with assurances that average monthly residential rates will not increase significantly.[97]

In addition to the ZES, the FEJA expands state energy efficiency measures and programs, and it sets annual energy savings mandates out to 2030.[98] Also, the Act remedies policy flaws in the existing renewable portfolio standard, providing more than $200 million annually for renewable projects. Around 1,300 MW of new wind and 3,000 MW of solar (more than half of which will be rooftop, community solar, and solar built on brownfields) are expected to be built by 2030.[99] Additionally, the Act contains provisions for job training and support for low-income communities.[100]

What started out as a narrow and negative debate around subsidies for nuclear power plants, grew over more than three years into a larger discussion involving more stakeholders and a broader-based solution. Ultimately, the resulting legislation will strengthen the RPS, support jobs in nuclear, support jobs and new investment in energy efficiency and renewables, and provide support for low-income communities. Notably the Act garnered support from a broad array of groups across the political spectrum that do not often agree on issues. The Natural Resources Defense Council (NRDC) praised the Act for its forward-thinking energy efficiency measures, the Sierra Club applauded the FEJA for the pathway that it creates toward a "stronger, more inclusive clean energy economy, and the Nuclear Energy Institute called the passage of the Act a "remarkable moment" that recognizes the unique value of nuclear in meeting Illinois clean energy goals.[101]

Measures taken by Illinois, New Jersey, and New York can serve as models to other states looking to preserve their existing nuclear fleet. New York was the first state to adopt ZECs for qualifying facilities. Illinois followed suit, creating a ZEC program and also using the social cost of carbon to value the environmental benefits provided by the zero-emission power plants.[102] Illinois' broad-based, multi-stakeholder solution is another key strategy to ensuring that existing nuclear is part of a long-term, clean energy future that is fair, inclusive and partners with renewables and energy efficiency.

There are opportunities to take these policy models even further. Currently, a New York ZEC is not equivalent to an Illinois ZEC. Standardization of ZECs across states opens the door to creating a national CES. Similarly, within a state, REC and ZEC programs, as currently designed, are completely separate. If the goal is to maximize zero-emission electricity production within a state, then combining the programs, i.e., converting an RPS to a true CES (as described earlier), could be a pathway toward achieving even greater reductions.

From a climate perspective, treating all zero-emission electricity sources (i.e., nuclear and renewables) equally is a reasonable approach. However, since nuclear represents such a large portion of zero-emission generation, the ambition of state electricity standards must be increased so that nuclear does not overwhelm the portfolio. Raising the state's clean energy target serves to preserve its existing nuclear generation and to encourage growth in other forms of zero-emission generation (i.e., wind, solar and small hydro), whether that is built within the state or procured through renewable energy credits (RECs).

However, there may be reasons to keep programs simple, targeted and transparent. New York and Illinois ZEC programs have already withstood legal challenges, but many more are pending.[103] Theoretically at least, more complex programs could be vulnerable to a greater array of legal arguments.

Connecticut

Connecticut, which gets nearly 45 percent of its electricity from its single nuclear plant (i.e., Millstone), enacted legislation in October 2017 that will permit its only nuclear power plant to participate in a competitive procurement process with other zero-emission electricity sources provided it is deemed to be in the best interest of ratepayers.[104] As a further condition of participation, the operator must accede to a state examination of the facility's financial situation. A report prepared by the Connecticut Department of Energy and Environment (DEEP) and the Public Utilities Regulatory Authority

(PURA) in January 2018 found that the financial viability of Millstone's continued operation could be at risk. The report also noted the negative impacts of early retirement, including an increase in electricity price volatility, significant decrease in fuel diversity, and an increase in New England's carbon dioxide emissions of more than 6 million metric tons per year on average.[105] Prior to May 1, 2018, Connecticut's DEEP will conduct its competitive procurement process for new and existing zero carbon generation to meet its Global Warming Solutions Act targets.[106] Millstone's ultimate success in the process will likely depend on its owner providing additional financial information to DEEP and PURA to conclusively deem the generation facility an "existing resource confirmed at risk." If Millstone is successful in the auction, it is likely to receive a three to ten-year contract, (e.g., PPA) to help support its continued operation.[107]

Politically, as a condition of receiving support (i.e., PPAs or ZECs), states should be able to examine existing reactors' financial records to confirm that they are truly at-risk. But states, must also make best endeavors to maintain the confidentiality (i.e., ensure that it does not become public) of key competitive data supplied to regulating agencies. Ideally, whether or not a plant is at-risk should not be a determinant; nuclear power plants and other zero-emission resources should be compensated for the environmental benefits they provide.

New Jersey

New Jersey, which gets around 40 percent of its electricity from nuclear, is looking to preserve and expand its clean energy portfolio. After a narrowly focused nuclear subsidy bill died in the recent lame duck session, a new bill which includes provisions for solar, offshore wind, energy storage and energy efficiency emerged.[108]

In April 2018, the New Jersey legislature passed two separate bills, a nuclear and renewable bill, with identical content to the joint bill crafted earlier in the year.[109] The nuclear bill establishes a ZEC program, which represents the zero-emission, fuel diversity, and air quality attributes of eligible nuclear power plants. By including fuel diversity and air quality, the New Jersey ZEC recognizes additional unpriced attributes of nuclear power beyond other state's environmental-only ZECs. Like Illinois, New Jersey's legislative process achieved success when it built a broader clean energy coalition.

Ohio

Unlike the other states discussed here, Ohio has been unable to gather sufficient momentum for any of the bills it has proposed over the past couple of years to support its two, Perry and Davis-Besse, nuclear power plants.[110] Recently, FirstEnergy, the plants' owner, entered into an agreement with private investor groups, which are looking into restructuring its regulated and money-losing unregulated (i.e., FirstEnergy Solutions) businesses.[111] Restructuring could lead to early plant closures, plant sales, or a shift of the plants to regulated status, which would protect them from wholesale market competition.

Subsequently, FirstEnergy Solutions, declared bankruptcy and announced the early retirement of the Ohio plants (as well as Beaver Valley in nearby Pennsylvania).[112]

Hypothetically, re-regulation would have kept the plants on-line and helped to avoid increasing fossil fuel emissions. However, re-regulation could establish a bad precedent and potentially undermine the benefits of wholesale power markets, which have generally functioned well by delivering lower cost power than what they would have otherwise been able to produce before the creation of the markets, while reliably delivering electricity to consumers. Focusing on fixing those markets would be the best approach, but without the luxury of time, Ohio had limited choices.

Arizona

Arizona is looking at a broad-based energy strategy that would, among other things, include the existing Palo Verde Nuclear Power Station in the state's clean energy requirement. The Arizona Corporation Commission is proposing a "Clean Resource Energy Standard and Tariff" that would see 80 percent of the state's electricity coming from clean sources, including nuclear, by 2050. Notably, the proposal also focuses on energy efficiency, electric reliability and resilience.[113]

Within the state, there is also a proposal to increase the RPS to 50 percent renewables by 2030 through a ballot initiative, which excludes nuclear.[114] The competing proposals represent an opportunity to discuss how all non-emitting technologies can work together. With thoughtful planning, there can be room for existing nuclear and growth in renewable technologies. If total decarbonization is the ultimate goal, nuclear, and renewables together is the answer.

Pennsylvania

Pennsylvania is home to the second largest number of nuclear reactors in the United States. The owner of the Three Mile Island plant announced in early 2017 that the plant was losing money and will close early (i.e., in 2019) without financial support. Pennsylvania legislators formed a nuclear caucus in 2017 but have not yet proposed legislation to support troubled reactors.[115]

Cities and businesses

Many cities and businesses enthusiastically support renewable electricity, primarily for its air quality and climate benefit. They support wind and solar power through financial contractual relationships like PPAs and RECs, while some are now building and owning renewable electricity.

Generally, cities and business do not support nuclear power in the same way unless the nuclear facility is located near or in the city. In fact, a U.S. Conference of Mayors "100% Renewable Energy in American Cities" resolution, adopted in June 2017, explicitly excludes nuclear as an acceptable energy source, putting it alongside fossil fuels and new large-scale hydro.[116] Further education and building awareness about what nuclear retirements mean today (i.e., increases in fossil fuel generation and increases in carbon dioxide emissions), and elaborating on the mid-century challenge to decarbonize the entire economy could help shift the conversation. But solving the long-term waste challenge will likely be important to win support for nuclear power from cities and businesses. Developing a broad coalition to support clean energy, which could include nuclear, large hydro, fossil fuel-fired electricity incorporating CCS and renewables might encourage some companies and cities to act to support nuclear. It could also spur action from Congress and state legislatures to provide appropriate incentives (e.g., tax credits) for cities and businesses to enter into PPA's for nuclear power.

TABLE 7: High-Level Summary of Policy Solutions

POLICY	CONSIDERATIONS	RATIONALE
FEDERAL LEVEL		
Clean Energy Standard	Directly credits nuclear. However, might be challenging to harmonize state and federal standards, and difficult to harmonize with carbon pricing policies beyond electricity sector.	Equal treatment of all zero-emission technologies. Higher levels of carbon free generation could be achieved sooner with nuclear remaining in the mix.
Carbon Adder (FERC/RTOs)	Directly increases wholesale market prices. Therefore, it helps nuclear and other zero-emission (price taker) technologies. The impact of higher wholesale prices on retail customers needs to be considered. Additionally, it's a novel policy with little precedent—lengthy legal challenges could delay implementation.	Wholesale markets are the pinch point for merchant nuclear plants. It makes sense to look for a solution in the context of these markets.
Carbon Tax	Carbon price is specified. A meaningful price could elevate wholesale markets prices enough to provide the necessary support for merchant reactors. Other zero-emission technologies and energy efficiency would benefit. Revenue recycling (dividends) can help compensate or shield consumers from this impact.	Goes beyond the power sector to meaningfully reduce emissions economy wide.
Cap-and-Trade	Emission level is specified. If the cap is stringent enough, a meaningful price could develop and elevate wholesale markets prices enough to provide the necessary support for merchant reactors. Other zero-emission technologies and energy efficiency would benefit. Revenue recycling (dividends) can help compensate or shield consumers from this impact.	Goes beyond the power sector to meaningfully reduce emissions economy wide.
Tax Credits	Directly encourages investment and efficiency improvements in the nuclear fleet. Higher efficiencies would likely reduce total costs for plants. However, other measures might be necessary.	Targeted at improving fleet efficiency. Could be a helpful short-run policy fix.
STATE LEVEL		
Zero Emission Credits	Direct support for nuclear within a state, ZECs explicitly capture and compensate for the environ-mental value of nuclear.	This policy pathway has withstood legal challenges. It appears to be sufficient to keep at-risk reactors operating.
Clean Electricity Standards	Directly supports nuclear and renewables. The standard can support higher levels of clean generation at an earlier date.	Equal treatment of all zero-emission technologies. Higher levels of carbon free generation could be achieved sooner with nuclear remaining in the mix.
Power Purchase Agreements	Direct support for nuclear for the contract term. Relies on willingness of a buyer to lock into nuclear and market fundamentals.	

IV. CONCLUSION

Responsible for around 20 percent of U.S. electricity generation and more than 50 percent of its zero-emission generation, the existing U.S. nuclear fleet avoids the annual emission of at least 400 MMtCO_2e and is a key component on the pathway to our nation's low-carbon future. In fact, most studies indicate that a diverse mix of renewables, increased energy efficiency, nuclear power, and fossil fuel with carbon capture utilization and storage is the least costly and least technically challenging path to achieve the mid-century goal, i.e., reducing greenhouse gas emissions more than 80 percent below 1990 levels.

There is a wide body of research that shows an economy-wide carbon price that escalates at a predictable pace or a national CES would be the most effective way to promote lower- and zero-emission deployment.[117] Additionally, a national market-based policy would be preferred for the long-term stability and transformation of the power sector. However, given current legislative priorities these policies are unlikely to gain traction. Moreover, government action on carbon by agencies like the EPA or FERC is not likely in the near-term. Therefore, the best remaining near-term options are through the states' targeted clean energy or zero emission standards. The basic building blocks of a workable model (e.g., New York ZEC program) for states to maintain and increase the level of non-emitting generation are in place, but there is scope to improve these state programs. Moving forward, nuclear and renewable power must ally and focus on working together. Stakeholders must collaborate to maximize the benefits of all zero-emission sources and develop complementary policies that allow existing nuclear to continue to operate through the end of their licenses and at the same time allow renewable power to grow its market share to the greatest extent practicable. Given the need to continually reduce greenhouse gas emissions and not even temporarily increase those emissions, retaining existing zero-emission electricity is essential.

In light of the urgency required—12 reactors at nine nuclear plants have announced early retirements and some reports estimate that more than half of the plants are operating at a loss (i.e., additional retirement announcements are likely), the following policy solutions offer the greatest promise to support the existing fleet and lay the groundwork for advanced nuclear reactors:

- Targeted state policies, particularly ZECs are the best option right now as states are able to quickly adopt measures that directly support distressed facilities; ZEC policies have withstood initial legal challenges in New York and Illinois.
- Expanding state electricity portfolio standards like the Arizona proposal to include existing nuclear is a fair-minded, inclusive approach. At a minimum, they offer an opportunity for nuclear and renewables to explore how they can work together to one another's benefit.
- A price on carbon could preserve existing nuclear, but it may not be sufficient if the prices are too low. Carbon prices in California and Northeast markets did not prevent early nuclear retirements in those regions, most likely because they were too low.
- A meaningful price on carbon implemented in power markets, which seems to be a natural fit, would help level the playing field and provide additional revenue to non-emitting technologies like nuclear power and renewables. However, likely legal challenges could significantly delay implementation.
- Increasing the use of PPAs for nuclear power with government agencies, cities, and businesses should be pursued.
- Second license renewals by the NRC, which would allow reactors to operate for 80 years would permit much of the existing U.S. nuclear fleet to continue to operate well beyond 2050, allowing new zero-carbon technologies (e.g. advanced reactors, fossil fuel with CCS and renewables) to enter service and avoid backsliding in emission reductions. There is a finite amount of carbon dioxide that we can emit in order to limit global temperature rise.

We believe that a broad-based clean energy coalition could help existing nuclear reactors, promote new renewables and other necessary technologies to transform the energy sector. Additionally, preserving the existing fleet supports local jobs, maintains domestic nuclear expertise, benefits our national security and could help promote safer nuclear power globally.

Preserving the existing U.S. nuclear reactor fleet for as long as practical is a critical element in the transition to a low-carbon future. There is no silver bullet to preserving existing nuclear plants. It will take a combination of policies, and a broad coalition of support. These actions can help set the stage for advanced nuclear, more renewables and a much cleaner second-half of this century. We cannot be short-sighted; we need a comprehensive long-term strategy in order to realize our low-carbon future.

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The Center for Climate and Energy Solutions (C2ES) is an independent, nonpartisan, nonprofit organization working to forge practical solutions to climate change. We advance strong policy and action to reduce greenhouse gas emissions, promote clean energy, and strengthen resilience to climate impacts.

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