CLIMATE SOLUTIONS: THE ROLE OF NUCLEAR POWER

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Since late 2012, four power companies have announced the retirement of five nuclear reactors in the United States. Coming amidst increasing debate over nuclear power in countries such as Japan and Germany, these announcements, the first since 1998, have led some Wall Street analysts and academics to forecast a wave of U.S. reactor retirements in the coming years. If these predictions are correct, the result could have serious climate change implications. Nuclear power supplies 19 percent of total U.S. electricity production with essentially zero greenhouse gas emissions. As renewables such as wind and solar do not provide reliable baseload power, any additional loss of nuclear generating capacity would result in increased carbon dioxide emissions, making it more difficult for the United States to achieve both its 17 percent emissions reduction pledge by 2020, and greater reductions in the future. Preserving the existing U.S. nuclear reactor fleet for as long as possible is a critical element in the transition to a low-carbon future.

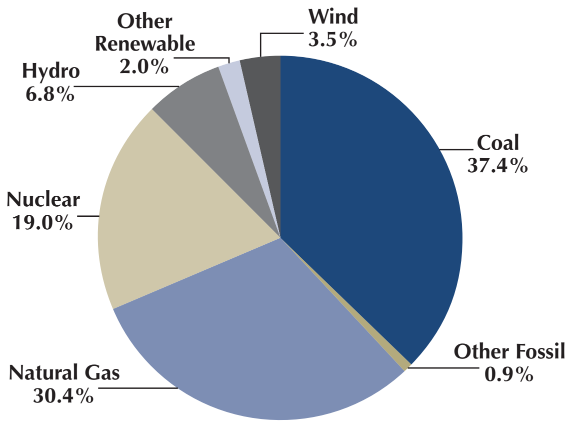
INTRODUCTION

Fossil fuels generate around 70 percent of electricity in the United States. As a result, the electric power sector is responsible for around 40 percent of U.S. carbon dioxide (CO_2) emissions. Zero-emissions power sources such as hydro, wind, solar, and nuclear power generate the remaining 30 percent of U.S. electricity.[1] In 2012, nuclear contributed 19 percent of overall U.S. generation (**Figure 1**) and over 60 percent of the nation's zero-emissions electricity—more than four times the amount provided by wind and solar combined. Nuclear also generates constant baseload power, 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.

If nuclear were not part of the electricity generation mix, the use of fossil fuels would increase, as most new renewable sources are intermittent and not suitable for generating baseload power. Without nuclear power, depending on the assumptions made for replacement technologies, U.S. emissions would be 289–439 million metric tons higher in 2014, and 4–6 billion metric tons higher over the period of 2012 to 2025.[2] To provide context for the scale of nuclear power's contribution to our long-term climate goals, U.S. Environmental Protection Agency (EPA) greenhouse gas standards for light-duty vehicles are predicted to achieve 6 billion metric tons of emissions reductions during the same timeframe.[3]

Yet nuclear power faces significant headwinds. Though five new reactors are under construction, since October 2012, four power companies have announced the retirement of five other reactors representing nearly 4,200 megawatts, or 4.2 percent of the total U.S. nuclear generating capacity of 101,000 megawatts. These retirements alone could result in the release of an additional 12–18.25 million metric tons of carbon dioxide per year—equal to the annual emissions from around 2–3.6

FIGURE 1: U.S. Electricity Generation, 2012



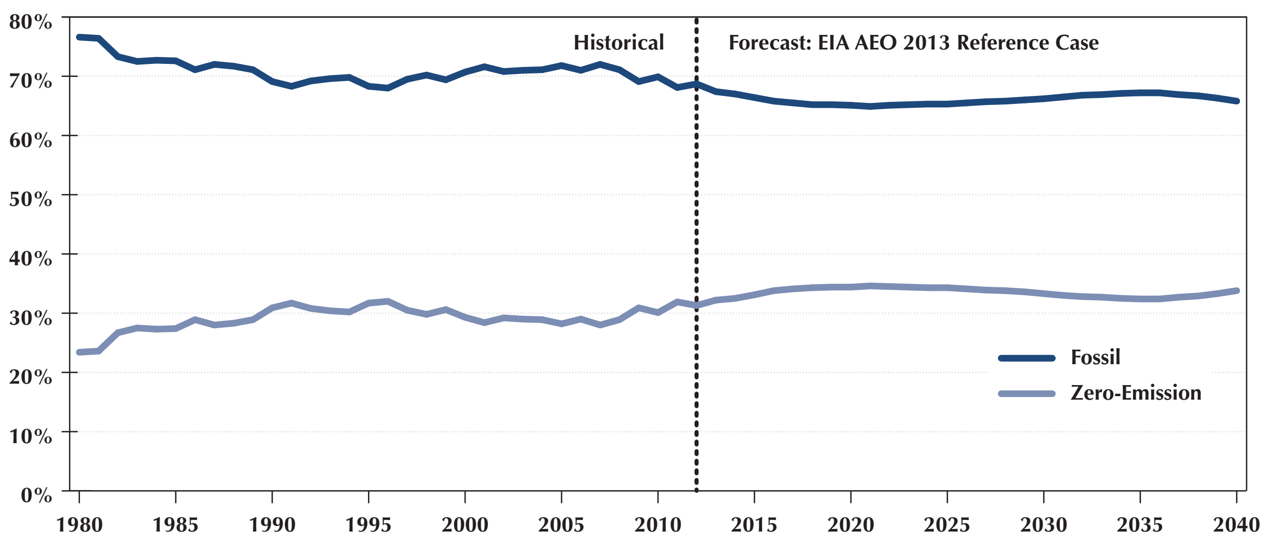
Source: Energy Information Administration 2013.

million passenger vehicles.[4] Thus, each nuclear retirement makes it more difficult to achieve the United States' international pledge to reduce emissions 17 percent below 2005 levels by 2020, and to achieve the even greater reductions necessary over the longer term.[5]

Many factors pose economic challenges to nuclear power, including plummeting natural gas prices, renewable energy policy, decelerating load growth, power market structures, and the absence of a price on carbon. Additionally, life-extending capital investments, mandated post-Fukushima safety enhancements and other maintenance activities are adding to plant cost structures.

This paper discusses the pressures on the nation's existing nuclear fleet and the possible climate implications of further nuclear retirements. It looks first at the history and forecast for zero-emissions electricity sources in the United States. Next, it explores the significance of baseload electric power, electricity markets, and policy decisions. Finally, the paper considers the future of nuclear power in the United States, including new builds, climate regulation, and related greenhouse gas implications. While safety, waste, and proliferation concerns are important in considering the future of nuclear power, they are beyond the purview of this paper.

FIGURE 2: U.S. Electricity Generation, 1980–2040



Source: Energy Information Administration 2013.

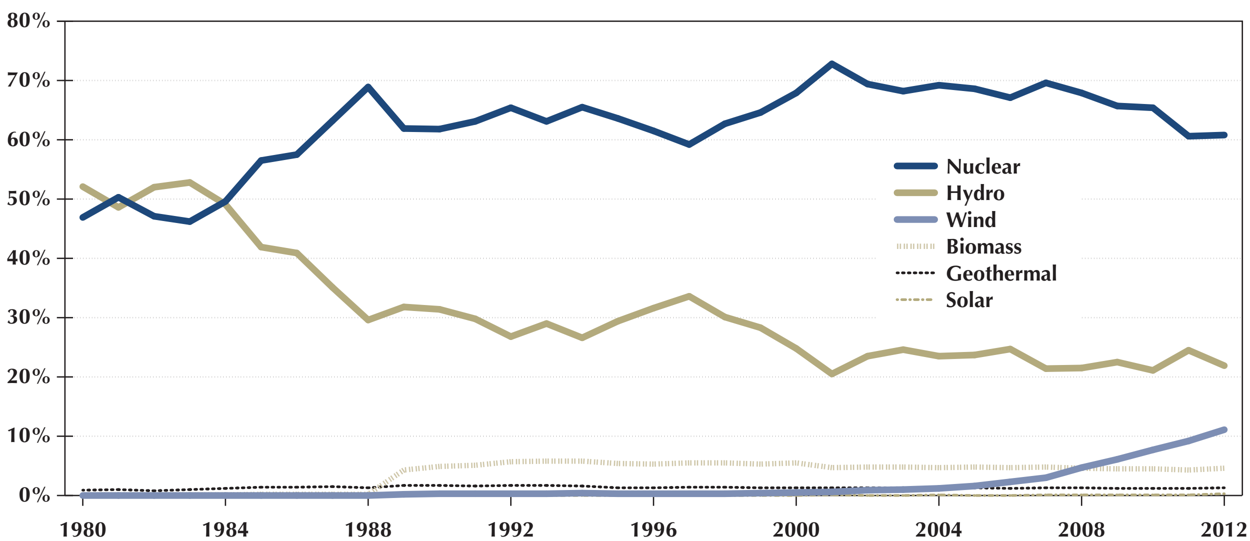
THE IMPORTANCE OF ZERO-EMISSION POWER GENERATION

The latest assessment of the Intergovernmental Panel on Climate Change (IPCC) reaffirms with greater certainty than ever that human activity is warming the planet, and that unabated greenhouse gas emissions threaten to irreversibly alter the climate. In the United States, electricity generation is responsible for roughly 38 percent of total U.S. CO_2 emissions,[6] as nearly 70 percent of electricity in the United States is generated by fossil fuel sources—primarily coal and natural gas. In the absence of significant policy changes, fossil fuels are projected to continue to generate more than 65 percent of electricity through 2040.[7] Sources of electricity that produce no greenhouse gases, such as nuclear, hydro, wind, biomass, geothermal and solar, are considered "zero-emission," and together these make up just over 30 percent of the fuel mix (**Figure 2**).[8]

There have been a few notable shifts in zero-emission electricity sources over the past 30 years, and the contribution of each is shown in **Figure 3**. In the early 1980s, nuclear power surpassed hydropower as the largest zero-emission electricity source, and since the late 1980s it has represented around 60 to 70 percent of the total. Since 2005, wind power capacity has increased dramatically, contributing 11 percent of total zero-emission electricity in 2012, while solar power remains a very small contributor at just 0.3 percent.

Since 2005, U.S. CO_2 emissions from the electric power sector have fallen by 15 percent, largely due to a shift from coal- to natural gas-fueled power generation, the economic recession, and increases in energy efficiency, demand response, and wind generation.[9] However, as **Figure 2** shows, the relative proportion of fossil fuel and zero-carbon sources is currently predicted to remain relatively stable (in the absence of new policies) to 2040, even amidst a backdrop of a growth in renewables from 10.4 percent of overall generation in 2010 to 16.5 percent in 2040. Yet, in order to achieve the dramatic CO_2 emissions reductions needed over the next several decades to avoid the worst potential effects of climate change, it will be essential not only to increase substantially the share of zero-carbon electricity production, such as nuclear, renewables, and fossil-fuel sources with carbon capture and sequestration (CCS), but also to maintain our current zero-carbon fleet.

FIGURE 3: Zero-Emission Fuel Sources for Electricity Generation, 1980–2012



Source: Energy Information Administration 2013.

NUCLEAR POWER AND THE ELECTRICITY MARKET

Baseload Power

Electricity service must be reliable—in other words, it must be available all day, every day. To this end, electricity system coordinators make use of three power plant categories to manage the minute-to-minute variability in demand. First, baseload power plants run 24 hours a day, seven days a week, to meet the continuous, minimum level of energy demand. Next, operators use "load-following" power plants, which are also known as "intermediate" or "mid-merit" power. These plants, typically fueled by natural gas, are able to increase or decrease electricity production more quickly than nuclear or coal plants, and typically supply power during the day as demand increases. Some intermediate plants may operate as baseload units, particularly during the summer, when the continuous minimum demand is likely to be higher than average for all hours of the day. Lastly, peaking capacity power plants, or "peakers," run for just a few hours each day when demand peaks.

The defining characteristics of baseload power plants are low operating costs and the ability to be run at nearly full power around-the-clock for extended periods. Historically, most baseload plants have been nuclear and coal-fired, as they both meet these criteria. Additionally, these plants are not designed to be efficiently powered up and down, so once they are running it makes sense to keep them operating at full load as long as possible. While baseload plants like nuclear units have lower marginal costs, they also have higher fixed costs than gas-fueled units, for example. It is economically efficient for these plants to operate at full power as long as the revenues they are receiving are greater than their marginal costs. Recently, in some regions, when natural gas prices have been exceptionally low, combined cycle gas turbine (CCGT) plants have also run as baseload units, dispatching at a lower cost than coal units.[10]

Among zero-emission sources, certain hydropower, biomass, and geothermal power can also provide reliable baseload power. However, other zero-emission energy sources, such as wind and solar, are intermittent—in other words, their output is variable across a given time period depending on local weather conditions. Since utility-scale electricity storage is not yet commercially available, they cannot be reliably used as baseload power. An example of this challenge came during the first week of August 2011 in Texas. At the time, more than 10,000 megawatts (MW) of wind capacity was installed, but the maximum generation output achieved was only around 5,700 MW. This occurred at night (when the wind often blows harder), and thus coincided with a period of lower demand. During the peak daytime hours of this same hot summer week, however, when demand for electricity was highest and winds tends to be calmer, wind generation was consistently less than 2,000 MW, or just 20 percent of capacity.[11] (While this example highlights the negative effect of relying on an intermittent source to meet demand, it should be noted that there are situations where having a diverse electrical supply, including wind generation, is beneficial for the grid.)

Electricity Markets

Electric power in the United States is supplied by utilities (public, municipal-owned, investor-owned or cooperatives) and independent power generators not affiliated with a particular utility.[12] Regulated utilities recover their costs via retail rates established by public utility commissions (PUCs). On the other hand, independent power producers typically operate as merchant generators, selling their power into competitive wholesale markets at the prevailing market price. Approximately one half of U.S. nuclear reactors operate as merchant generators.[13]

The United States has seven wholesale power markets that serve around two-thirds of U.S. electric power customers.[14] Each market has its own set of rules, yet there are many similarities in how they operate. Offers to supply electricity are bid into the market based on production costs, which are driven primarily by fuel prices and plant efficiency. Because they have no fuel costs, renewable technologies such as hydro and wind have the lowest production costs (**Figure 4**), and can be bid into a market at relatively low prices. Next in the price order is nuclear power, followed by lignite, an inexpensive, soft coal with higher moisture content than the hard coal used in many plants. Hard coal and natural gas combined-cycle plants (NGCC) are in the middle of the supply curve, though at very low natural gas prices combined-cycle plants become less expensive than most coal units.[15] Finally, single-cycle natural gas turbines; the older, smaller and least efficient coal units; oil; and diesel plants are the most expensive to run and are generally used only during times of extremely high demand.

Electricity system operators employ a least-cost dispatch (supply) methodology—in other words, power from the least expensive electricity plants is transmitted to the grid first. The plant that falls at the intersection of the amount of electricity demanded and the market price supply curve is known as the marginal generator, and the cost of power from this generator sets the market price (**Figure 4**). This is not much different from the theoretical manner in which most commodity markets operate—prices are set at the intersection of supply and demand. Because coal- or natural gas-fired plants are generally in the middle of the supply curve, they are typically the marginal generator in most competitive power markets. Even though other suppliers such as wind and nuclear have bid into the market at a price lower than the marginal generator, all units receive the marginal or market price for that time period. When operating in these markets, a merchant generator with high fixed costs may or may not be able to recover its long-term total costs and, as a result, may be forced to leave the market if wholesale prices are too low for too long a period.

Cheaper natural gas prices and greater quantities of low variable-cost renewables (e.g., wind) are contributing to lower prices in competitive electricity markets. For example, in **Figure 4**, as natural gas prices have fallen over the past several years, the production costs of CCGT 1 and CCGT 2 have fallen (not shown in the figure), which has lowered the market price that all generators receive. If the price of natural gas should fall further, the offers from CCGT 1 and CCGT 2 will decrease, which will reduce the market price further. The second graph in **Figure 4** provides an example of what happens when new wind power is added to the system. The addition of wind capacity shifts the supply curve to the right, and for the same level of demand, the market price drops as the marginal generator shifts from CCGT 2 to CCGT 1.

These factors contribute to independent power producers and baseload generating units receiving lower compensation than they did just a few years ago for their generation. About half of existing nuclear facilities operate as merchant generators, and these units must find other ways to absorb these losses or face retirement. Plants in regulated markets are better able to recover costs through rates set by their PUCs based upon a cost-of-service model. Indeed, lower market prices were cited as one of the reasons behind the recent decisions to shut down the Wisconsin-based Kewaunee nuclear power station as well as the Vermont Yankee reactor, both of which are merchant units.[16,17] Additionally as the margins are squeezed, costs from impending maintenance activities (or previous maintenance investments) add to the overall plant cost structure, and have the potential to make even more existing units uneconomic.[18] If this occurs and leads to additional reactor shutdowns, further increases in power sector greenhouse gas emissions may result.

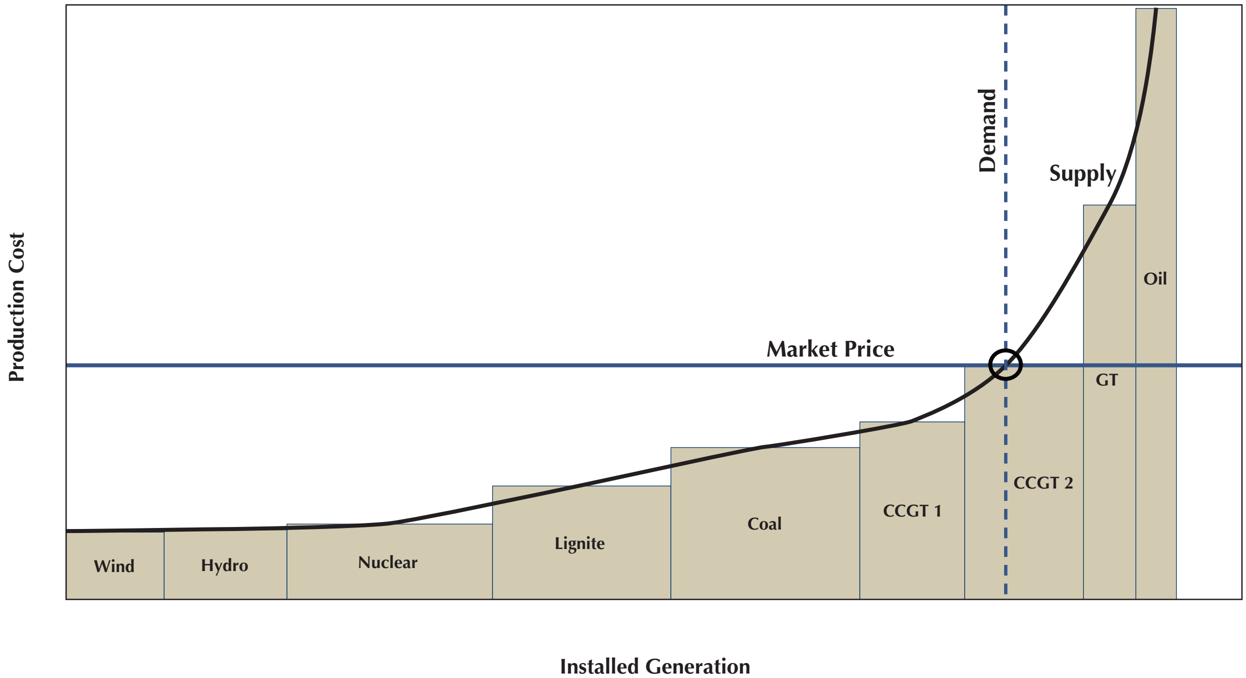
A further challenge comes from "capacity markets," which have been established as a complementary measure to some power markets to help ensure that adequate capacity is available in the future to supply reliable electricity generation. The basic idea is to compensate power plants today for investments they make in additional capacity to supply the electrical grid at some point in the future, thereby providing forward pricing signals to retain current resources and encourage the development of new resources.[19] Not unlike the power market, a capacity market is technology-agnostic. It does not place a premium on baseload versus intermittent generation, often compensates plants with high and low capacity factors equally, and does not explicitly value or encourage zero-emission generation. Entergy referenced flaws in power and capacity market design as one of the reasons it decided to retire its Vermont Yankee reactor this year.[20] So far, as baseload units have retired, the impact on electric system reliability has been minimal because reserve margins have been adequate. However, each additional retirement increases the risk that electric system reliability may become impaired.

The Intersection of Nuclear and Renewables

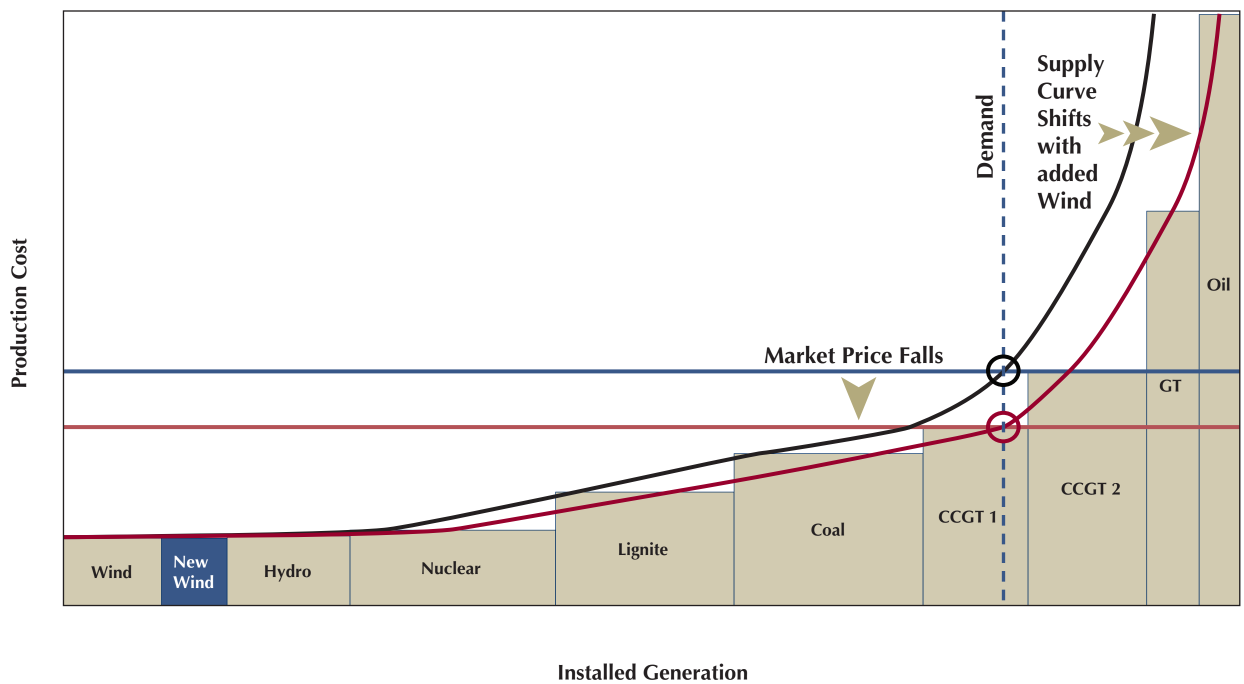
The federal renewable production tax credit (PTC), first enacted in 1992, has played a critical role in building the U.S. wind energy industry. The PTC allows a wind project to claim a $22/MWh credit for its first 10 years of operation.[21] In addition, wind projects are also able to sell renewable energy credits (RECs) that utilities in many states need to comply with renewable portfolio standards.[22] The combination of zero fuel costs, the PTC, and RECs, has led in certain conditions to wind generation setting very low, or even negative prices in market regions.[23]

In a wholesale power market, negative prices are a signal that a particular location is over-served by generation. In the short term, negative prices essentially send generators an economic signal to shut down. However, there may be very short-term circumstances when a power company would actually want to pay a system operator

FIGURE 4: Illustrative Competitive Power Market



Illustrative Effect of Adding New Wind Capacity



The lower chart illustrates the potential effect of adding new wind generation to the available supply. Demand is held constant, the remaining supply (also held constant) shifts to the right, and the market price (intersection of supply and demand) falls. Note that the width of each box indicates the quantity of generation offered and the height indicates its production cost. In recent years, as the price of natural gas has decreased, the height or production cost for this technology (e.g., CCGT) has decreased, which has also led to lower market prices.

Source: Adapted from Rawls, Patricia, U.S. Department of Energy: National Energy Technology Laboratory, "The PJM Region: A GEMSET Characterization for DOE." December 13, 2002. Available at http://www.netl.doe.gov/energy-analyses/pubs/200220DecPJMregionHandout.pdf.

to take its power, such as when it would be more costly for a coal or nuclear plant to power down completely and restart than to pay the operator for a short period of negative prices. When low and negative prices persist over time, it can be a signal not only that investment in new generation in this location is unnecessary, but also that it may not be profitable to keep a current generation source in operation. Failure to anticipate the need for new generation capacity due to flawed market signals could jeopardize future system reliability.

Additionally, a two-party power purchase agreement (a bilateral contract between the purchaser and the generator) is a widely used hedging strategy against electricity price volatility. Since these agreements are typically negotiated based on historical wholesale prices, when persistently low and negative prices exist at a particular market location, it becomes difficult for a generator to obtain a power purchase agreement. For instance, the expectation that it would be unable to renew its power purchase agreements during a time of low regional wholesale power prices led to Dominion Power's decision to close its Kewaunee Power Station.[24]

In summary, policies like the PTC and state renewable portfolio standards have been critical in spurring necessary increases in renewable generation, particularly wind power. However, as greater quantities of these renewables are bid into competitive wholesale power markets, prices are likely to become very low or negative more often, which could remove the incentive to build new electricity generation of any type—including renewables. These policies, in addition to other factors such as low natural gas prices and market structures, will continue to put pressure on existing nuclear power, which is also a zero-emission source. Furthermore, swapping renewables for nuclear, it is not a zero-sum trade of zero-emissions sources. As explained in the section above, since renewables are intermittent and not currently appropriate for baseload generation, they must be backstopped by a consistently available electricity source, which is usually a fossil fuel source with associated greenhouse gas emissions. In order to preserve and expand the nuclear fleet while continuing to encourage the development of other new zero-emission sources, it may become necessary to reconsider the way in which wholesale markets function.

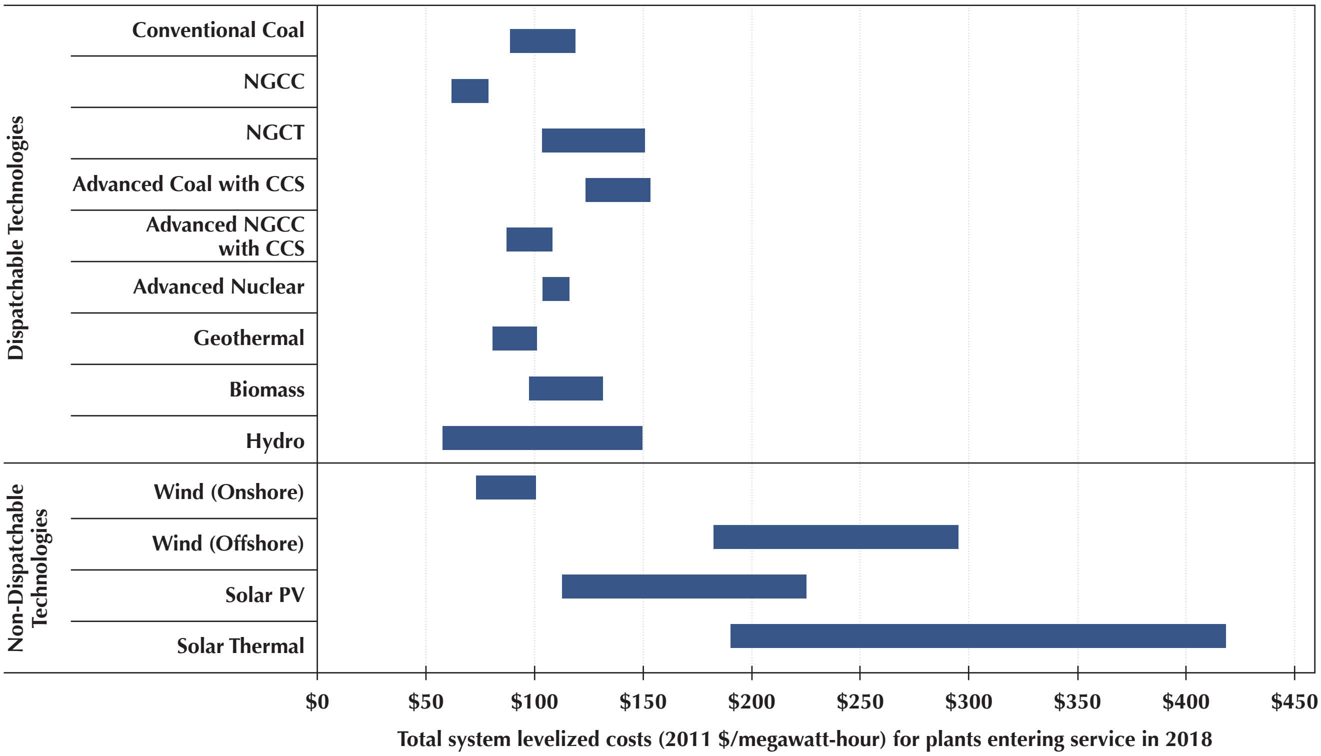
THE FUTURE OF NUCLEAR POWER IN THE UNITED STATES

The utilization of the existing nuclear fleet has been expanded greatly in the last two decades. Since 1990, nuclear has consistently supplied around one-fifth of U.S. electric power generation, even while total generation increased 33 percent since that time. As more than 90 percent of the currently operating U.S. reactors became operational in the 1970s and 1980s, with the last reactor coming on line in 1996, most nuclear generation increases have been achieved through power uprates (plant modifications that increase the electrical output of existing reactors), shorter refueling outages, and other efficiency improvements. Uprates alone have added over 6,000 MW of generating capacity since 1977, which is about the equivalent of six new reactors. Nuclear capacity factors (actual output divided by maximum possible output) have also increased from 66 percent to around 90 percent over the last two decades, and nuclear reactors now have the highest average utilization of any electricity source in the United States. These gains have notably improved the cost per MWh of power produced by these plants.

Uprates have been a key strategy for expanding nuclear generation since new large (1,000 MW or greater) nuclear plants require a large amount of upfront capital and take around 8–10 years to plan and construct. The U.S. Nuclear Regulatory Commission (NRC) currently lists combined construction and operation license applications for 28 new reactors; however, 10 of these have been suspended, 14 are under review, and only four have been issued. These four include the two new reactors under construction at the Southern Nuclear Operating Company's Vogtle plant in Georgia, and the two reactors South Carolina Electric and Gas is building at its Virgil C. Summer Nuclear Station, all of which are scheduled to enter into service in 2017 and 2018. A fifth reactor, whose construction was halted in 1988 and resumed in 2007, is being built by the Tennessee Valley Authority at Watts Bar, with expected completion in 2015. Importantly, these utilities operate in regulated states and will be able to recover their costs through retail rates established by their respective public utility commissions.

In its Annual Energy Outlook 2013, the DOE's Energy Information Administration forecasts no additional nuclear reactors beyond these five units between now and 2030.[25] This is at least in part due to the fact that natural gas-fired combined-cycle (NGCC) is projected

FIGURE 5: Levelized Cost of Electricity



According to the Energy Information Administration: Electric generating units whose output can be controlled (adjusted by system operators) to follow demand (dispatchable technologies) generally have more value to a system than less flexible units (non-dispatchable technologies) or those whose operation is tied to the availability of an intermittent resource. The levelized costs for dispatchable and non-dispatchable technologies are listed separately because caution should be used when comparing them to one another.

Source: Energy Information Administration 2013.

to be the least expensive generation technology in the coming years based on levelized costs (**Figure 5**), a measure for making an apples-to-apples comparison of diverse technologies. In this instance, the levelized costs represent the present value of the total cost of building and operating a generating plant over an assumed financial life and duty cycle.[26] They reflect overnight capital cost, fuel cost, fixed and variable operation and maintenance costs, financing costs, and an assumed utilization rate for each plant type. The availability of various incentives including state or federal tax credits can also impact the calculation of levelized cost.[27] The range of values shown do not incorporate any such incentives, nor do they include potential costs such as a price on carbon, but do include an array of other assumptions.[28]

Retirements

Since October 2012, four power companies announced the retirement of five nuclear reactors (**Table 1**). In February 2013, Duke Energy announced the retirement of Crystal River unit 3 near Tampa, Florida. In May 2013, Dominion powered down its Kewaunee nuclear plant in Wisconsin after it was unable to sell the unit. This was immediately followed in June by Southern California Edison's announcement that it would not restart units 2 and 3 at the San Onofre Nuclear Generating Station (SONGS). Finally in August, Entergy announced that it would retire its Vermont Yankee plant in late 2014.

Two of these retirements, Kewaunee and Vermont Yankee, were attributed to low natural gas prices and power market structures, while the other three were

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	Fall 2014

Total size of reactor retirements: 4,171 MW (4.2 GW); Total U.S. generation capacity (2011) 1,051 GW, nuclear capacity 101 GW.

the result of maintenance issues, specifically problems related to steam generator replacements. Steam generator replacement is a common maintenance practice around the world for extending the life of pressurized water nuclear reactors (PWR),[29] and most are completed successfully. However, these three closures are a reminder that there are issues beyond market economics that can affect the future of this zero-carbon electricity source.

CONCLUSION

In order to achieve the emission reductions necessary to avoid the worst potential consequences of climate change, it is necessary to obtain increasing quantities of electric power from zero-emission sources. Nuclear power is the largest source of zero-emission power in the United States, and it provides stable and steady baseload power, which helps ensure electric grid reliability. Currently, only nuclear, natural gas, coal, and hydro facilities can provide steady baseload power at the necessary scale. As the United States considers options for a low-carbon future, the importance of the current fleet of nuclear reactors should not be forgotten.

Power markets have generally functioned well in the past, delivering low-cost electricity to consumers and effectively signaling where generation and transmission are needed. However, low natural gas prices and policies that promote the development of low production cost renewables are putting pressure on the ability of existing nuclear reactors to compete in the marketplace. Another growing weakness is that most power and capacity markets neither explicitly value zero-emission electricity sources, nor adequately value baseload generation sources. While adding renewable capacity is an important goal, it is also critical that the United States maintain its existing zero-emissions generation assets while it works to grow its overall zero-emissions generation—a scenario that is not necessarily assured under the current circumstances.

With the exception of California and the nine states in the Northeast Regional Greenhouse Gas Initiative (RGGI), U.S. fossil fuel generators can emit greenhouse gases without cost, yet society is incurring increasing costs from climate change. The establishment of appropriate greenhouse gas regulations can both internalize the social cost of these emissions and increase the demand for low- and zero-emission sources. There are several ways that this can be achieved, but market-based polices that establish a price on carbon, such as emissions trading, a clean energy standard, or a carbon tax, can harness the power of market forces to reduce emissions at the lowest costs. While a comprehensive, legislated, market-based climate policy is not likely in the United States in the near term, as EPA considers proposals to regulate greenhouse gas emissions from existing power plants, it will be critical to consider the effect such regulations will have on the country's current zero-carbon sources, including nuclear.

There are risks associated with any electricity generation source, and diversification is just as wise a strategy for an electricity generation portfolio as it is for an investment portfolio.[30] To balance all of the risks, it makes sense to be able to utilize as wide a variety of future baseload power sources as possible, including nuclear, natural gas, coal with CCS, and renewables. However, until utility-scale electricity storage for renewables is a reality and they can serve as reliable baseload power, the loss of nuclear plants from the electricity grid would likely lead to millions of tons of additional carbon dioxide in the atmosphere each year. This is a prospect the global climate cannot afford.

ENDNOTES

1 Nuclear and hydropower are zero-emission sources in the sense that they emit no greenhouse gases from their primary generation activities. These sources can have very low levels of emissions from operation of emergency generators, heating, ventilation and air conditioning (HVAC), etc. The terms "zero-emission" and "zero-carbon" are used interchangeably in this brief and signify zero carbon dioxide emissions.

2 The *eGrid* average emissions rate of 1,216 lb CO_2/MWh is equivalent to 4.83 million metric tons of CO_2 per 1,000 megawatts (http://www.epa.gov/cleanenergy/energy-resources/egrid). If natural gas were assumed as the replacement fuel instead of the eGrid average, emissions would be 3.18 million metric tons of CO_2 per 1,000 megawatts (the average emissions rate of a natural gas CCGT is 800 lb CO_2/MWh). The calculated emissions are based on the current nuclear fleet of 101,000 megawatts, and assumes a 90% capacity factor, which is the average over the past seven years according to figures from the Nuclear Energy Institute: http://www.nei.org/Knowledge-Center/Nuclear-Statistics/US-Nuclear-Power-Plants/US-Nuclear-Capacity-Factors.

3 Emissions comparison is with the combined National Program for Model Years (MY) 2012–2016 and MY 2017–2025. U.S. Environmental Protection Agency, "EPA and NHTSA Set Standards to Reduce Greenhouse Gases and Improve Fuel Economy for Model Years 2017–2025 Cars and Light Trucks." August 2012. Available at: http://www.epa.gov/otaq/climate/documents/420f12051.pdf.

4 U.S. Environmental Protection Agency, "Greenhouse Gas Emissions from a Typical Passenger Vehicle." December 2011. Available at: http://www.epa.gov/otaq/climate/documents/420f11041.pdf.

5 Since the five new reactors will provide additional generation capacity and are in different regions from the retired reactors, they should not be considered as direct replacements for the retired reactors.

6 U.S. Environmental Protection Agency, "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2011," 2013. See Tables ES-7 and 2-1. Available at: http://www.epa.gov/climatechange/ghgemissions/usinventoryreport.html.

7 U.S. Energy Information Administration. 2013. Annual Energy Outlook 2013. Available at: http://www.eia.gov/forecasts/aeo.

8 Biomass is often considered to be carbon dioxide neutral because the carbon dioxide released into the atmosphere when it is burned is absorbed by the growth of new biomass.

9 U.S. Energy Information Administration, "Total Energy: Table 12.6." February 2014. Available at: http://www.eia.gov/totalenergy/data/monthly/#environment.

10 William M. Mohl (President, Entergy Wholesale Commodities). March 5, 2013. Testimony before U.S. Congress. House Energy and Commerce Committee. "American Energy Security and Innovation: The Role of a Diverse Electricity Generation Portfolio."

11 Electric Reliability Council of Texas, "Wind Integration August 2011 Archive." August 2011. Available at: http://www.ercot.com/gridinfo/generation/windintegration/2011/08/index.

12 Regulatory Assistance Project. March 2011. "Electricity Regulation in the US: A Guide." Available at: http://www.raponline.org/document/download/id/645.

13 World Nuclear Association, "Power Plant Purchases." July 2009. Available at: http://www.world-nuclear.org/info/Country-Profiles/Countries-T-Z/Appendices/Nuclear-Power-in-the-USA-Appendix-2-Power-Plant-Purchases/#.UnFJjxBuHVQ.

14 ISO/RTO Council. Available at: http://www.isorto.org.

15 The list of plant types is not exhaustive.

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22 Monitoring Analytics, LLC. March 2013. “State of the Market Report for PJM: Volume 1.” p 33.

23 Brown, Phillip, Congressional Research Service. November 2012. “U.S. Renewable Electricity: How Does Wind Generation Impact Competitive Power Markets?”

24 PR Newswire, “Dominion To Close, Decommission Kewaunee Power Station.” October 2012. Available at: http://www.prnewswire.com/news-releases/dominion-to-close-decommission-kewaunee-power-station-175225341.html.

25 U.S. Energy Information Administration, “Annual Energy Outlook 2013,” January 2013. Available at: http://www.eia.gov/forecasts/aeo.

26 U.S. Energy Information Administration, “Annual Energy Outlook 2013,” January 2013. Available at: http://www.eia.gov/forecasts/aeo/electricity_generation.cfm.

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