REPORT | ENERGY

# When Nuclear Ends: How Nuclear Retirements Might Undermine Clean Power Plan Progress

By Samuel Brinton and Josh Freed | Published: 08/19/15 | Updated: 08/21/15

## TAKEAWAYS

Third Way partnered with MIT-trained researchers to answer the question, "What happens if the United States shut down nuclear power plants?" We found:

- In the worst case, emissions would revert to peak levels in 2005, basically eliminating a decade of progress in carbon reduction.
- Natural gas predominately replaces the nuclear power plants when they go offline.
- Under the current policies, renewables growth has been strong but can't keep up to replace the lost nuclear power.

Nuclear power provides electricity for one in five homes in the U.S. But this zero-emissions power source faces extreme economic challenges led by badly designed energy markets that are leading to the premature closure of reactors. Five have already closed, and at least another nine are in danger of being retired soon.

This begs a critical question: **What will happen to carbon emissions if more reactors shut down?** In coordination with MIT-trained researchers*, Third Way modeled that question, and, regardless of the scenario we ran, the answers were dire:

1. **In the worst case, emissions would revert to their peak levels in 2005, basically eliminating a decade of progress in carbon reduction.**
2. **Natural gas would predominately replace the nuclear plants when they go offline.**
3. **Renewables growth has been strong but wouldn't keep up to replace the lost nuclear power given the current policies.**

* Jesse Jenkins and Fernando de Sisternes performed this research in an independent capacity and their findings and views do not reflect the views of the Massachusetts Institute of Technology. The views and opinions expressed in this

report are those of Third Way and do not necessarily reflect the position of MIT, the MIT Energy Initiative, or any other institution to which the researchers that participated in this study are affiliated.

# Nuclear Energy Today

## 1 in 5 Homes

Nuclear power currently provides 20% of the electricity in the United States, and more than 65% of our emission-free electricity.[1] The nearly 100 nuclear plants in the U.S. generate enough electricity for 73 million American households.[2] And nuclear is the only always available, constant, consistent source of zero-carbon electricity, making it an important compliment to renewable energy sources like solar and wind – and in some states, the only significant source of zero-carbon electricity.[3]

Nuclear power in the U.S., however, has come under increasing economic and policy pressure in recent years. Third Way partnered with a team of researchers at the Massachusetts Institute of Technology (MIT)[4] to see what impact a reduction or the elimination of nuclear energy in the U.S. would have on emissions. Using the Electric Power Capacity and Investment Model[5] we found that under any of our three scenarios, the overwhelming majority of U.S. nuclear energy capacity would be replaced by natural gas, resulting in a significant *increase* in carbon emissions. American policymakers need to recognize that nuclear is at a crossroad. And for anyone concerned about climate change, it is particularly important to understand the impact that a shift away from nuclear energy would have on carbon emissions.

## The Economic Challenge

The boom in natural gas that began in 2008 has been good for the overall economy and has led many carbon-intensive coal plants to be replaced by cleaner natural gas power plants, contributing to U.S. emissions reductions. At the same time, however, nuclear plants in many parts of the country have struggled to compete with cheap gas.[6] This has been compounded by a slowdown in demand due to energy efficiency, the lingering effects of the Great Recession, and state and federal policies that promote new renewable electricity capacity while failing to credit nuclear for producing carbon-free electricity.[7]

When you consider the market conditions, you can see why some nuclear power plants are finding it hard to maintain their economic viability in current energy markets. Already, five plants have closed, and at least nine more are threatened with closure.[8] In Illinois, nuclear power plants are competing with negative electricity prices from renewable energy sources caused by the distorting influence of subsidies. Elsewhere, plants like Kewaunee in Wisconsin and New England's Vermont Yankee have both had to end operation because they could not compete in this new energy landscape, which does not produce a sustainable price incentive for nuclear plants. The emissions impact of closure, however, does not factor into the decisions to close these large producers of clean power.

# The Study

## The Model

Third Way worked with MIT-trained researchers to model three different scenarios on how the retirement of portions, or the entirety, of the U.S. nuclear power fleet might impact carbon emissions. For each scenario, we examined what would happen in 2025 and 2035 if a specific portion of the nuclear power currently providing electricity to 73 million American households were retired. The scenarios were:

- **Scenario 1 (Optimistic Case):** All reactors currently operating remain online for 60 years, having received 20-year license extensions beyond their initial 40-year lifetime. This maintains all reactors through 2025. This is optimistic, but it would be consistent with maximizing the climate contribution of our nuclear investments and the continued safe operation of existing reactors.[9]
- **Scenario 2 (Middle Case):** All reactors shut down after their 40-year lifetime with no license extensions given. This leaves only about 40 reactors in 2025 and only a handful by 2035. This is consistent with widespread retirements due to the economic headwinds currently facing U.S. reactors.
- **Scenario 3 (Worst Case):** A complete phase-out of nuclear power, as began in Germany in 2011, with no reactors left operating by 2025 (other than the five new reactors currently under construction). This is a worst-case scenario.

In each of these scenarios, we forecast renewables would nearly double from their current generation and that all states would fully comply with existing renewable portfolio standard (RPS) requirements. We explored a wide range of fuel prices for natural gas, oil, and coal consistent with scenarios developed by the U.S. Energy Information Administration (EIA).[10] Since electricity is traded and consumed across interconnected grids that span large regions, the modeling examined each of the three electricity interconnections in the country, the Eastern, Western, and Texas Interconnects, rather than the impact on either a plant-by-plant or national level.

In Scenario 1, the 60-year operation of nuclear power is based on extending the license of nuclear operators from their initial license term of 40 years. According to the NRC, it has renewed the operating licenses of more than 70 reactors and is reviewing renewal applications for 12 reactors, with another 17 considering renewals. This represents the entire fleet of nuclear reactors renewing or considering renewing their licenses to keep the power on for another 20 or more years. Model results using the 60-year nuclear lifespan assumptions largely align with the reference case projections in the EIA Annual Energy Outlook 2014 edition, validating the model's performance.[11]

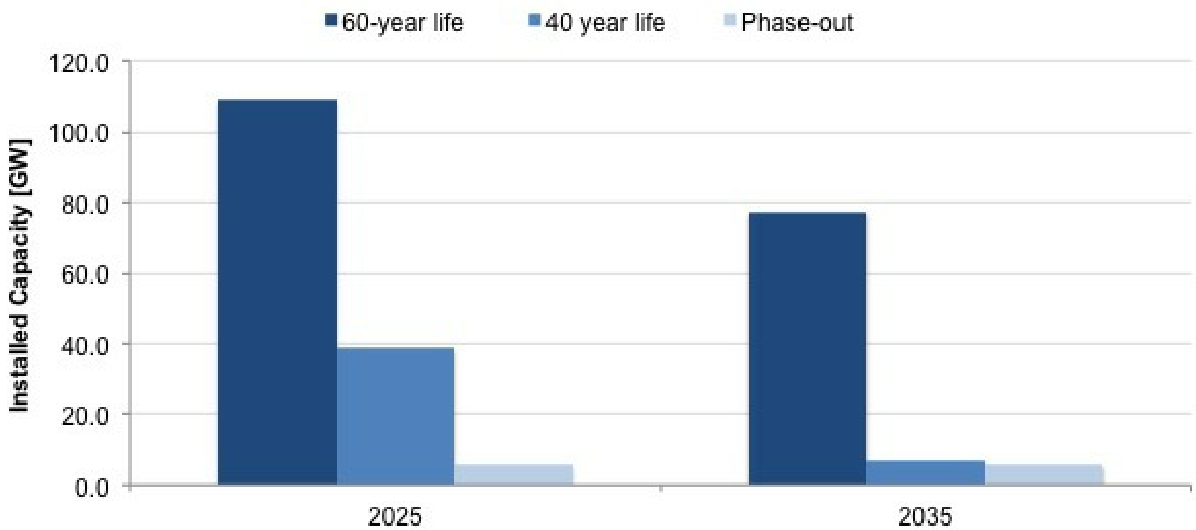
Scenario 2 assumes each of the reactors in operation today ceases operation at the end of the 40-year license granted by the NRC when a reactor is first allowed to operate. Congress specified the 40-year license in the Atomic Energy Act of 1954. In this case, nearly two-thirds of nuclear capacity would be retired by 2025. Only 40 reactors would remain operational in 2025, and this would dwindle to just a handful by 2035. It should be noted that some reactors have already received 60-year license extensions and so this scenario assumes these reactors are shut down even more prematurely due to economic considerations.

Scenario 3 envisions a complete nuclear phase-out. This may be the least likely scenario, but it is an important benchmark in understanding the full impact nuclear power has on emissions in the U.S. Indeed, Germany's nuclear energy policies are leading them toward a phase-out of domestic nuclear power.[12] That country now gets 43% of its electricity from coal, and Germany's nuclear phase-out will result in at least a short-term spike in emissions. A similar phase-out of nuclear in the U.S., as Scenario 3 models, could also make electricity markets more reliant on natural gas and coal, further exposing the market to fuel price fluctuations and potentially impacting on the final price that consumers pay for electricity. This is especially true for high-stress events, such as an extended heat or cold wave, like the East Coast saw with the 2014 Polar Vortex.

## Nuclear Generation in Three Scenarios

In 2015, nuclear power can provide roughly 104 Gigawatts (GW) of electricity capacity in the U.S. With the completion of five new reactors under construction at Vogtle (Georgia), Summer (South Carolina), and Watts Bar (Tennessee) and preservation of the existing reactor fleet, nuclear capacity increases to 109 GW by 2025 in our Scenario 1. Under Scenario 2, with reactors retired early after 40-year lifespans, only 38.6 GW of generating capacity would be provided by nuclear by 2025. In Scenario 3, just 5.7 GW of generating capacity from the five reactors currently under construction would remain (we assumed that these new reactors would not be immediately shutdown). Figure 1 shows the reductions at two snapshots in time: the years 2025 and 2035. Notice that by 2035, even Scenario 1 sees some reduction because reactors have begun to hit the 60-year lifespan, while the reactor fleet dwindles to a small handful of plants with 7 GW of capacity by 2035 as most plants reach the 40-year lifespan and retire in Scenario 2.

**Figure 1: The Nuclear Power Capacity Under Three Scenarios**




# The Results*

## Emissions Go Up

* The Results section was revised for clarity on August 21, 2015.

Under either the early retirement or phase-out scenario, U.S. emissions would *go up dramatically*, even under compliance with the existing renewable portfolio standards (which could be more ambitious). Emissions increases due to nuclear retirements would sabotage the carbon reductions targeted by the EPA's Clean Power Plan and, in the worst case, could wipe out a decade's worth of progress by effectively returning U.S. electricity sector emissions to 2005 levels.[13]

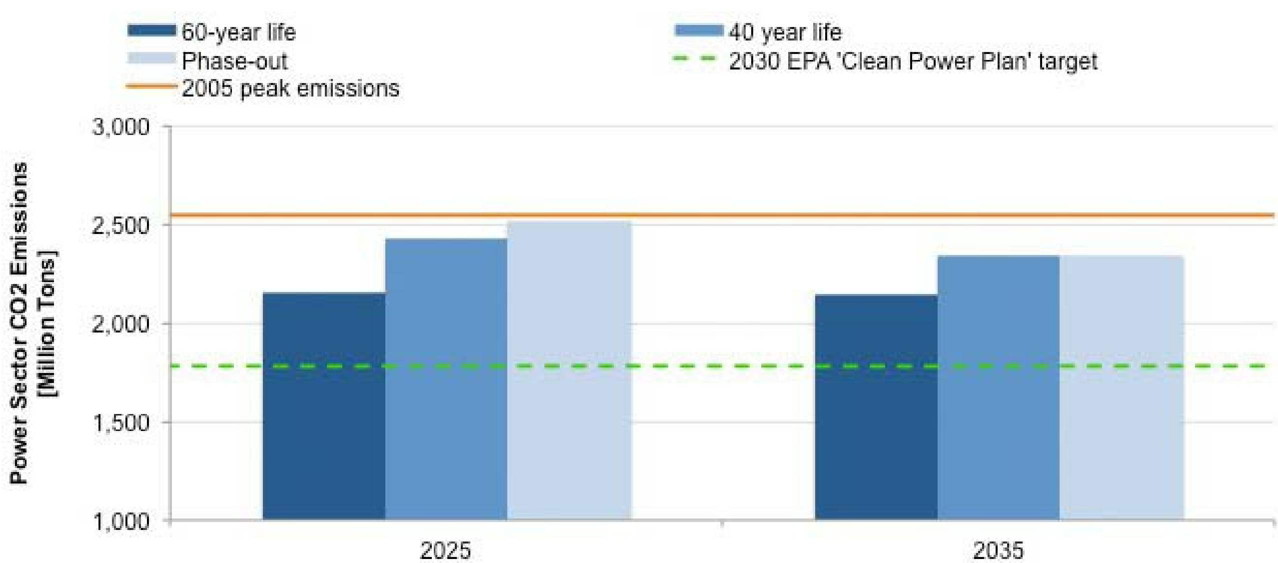
In our most optimistic scenario (Scenario 1), where all 99 currently operating nuclear reactors, including those at economic risk, are maintained for 60 years of operation, emissions would fall short of the Clean Power Plan's targets. [We use this scenario as reference case to compare to other scenarios, since it is the most consistent with the President's climate goals, though it is only realistic with changes in economic and public policy conditions.] Emissions would grow about 5.5% from 2012 levels under this scenario, due to growth in U.S. electricity demand, which is supplied by a mix of new natural gas and renewable energy. That would leave U.S. emissions roughly 20% above the Clean Power Plan's draft rule target. We note that we did not model compliance with the Clean Power Plan in these scenarios, but these results show that even if we continue operating the full U.S. nuclear fleet, more aggressive reductions are needed to meet the EPA's emissions goals.

If America's nuclear plants begin retiring in droves, achieving the Clean Power Plan emissions reductions could be impossible. Under Scenario 2, in which reactors retire after their initial 40-year license expires, emissions would be 12.5% higher in 2025 than if we preserved the nuclear fleet. If the U.S. nuclear fleet were phased out entirely (Scenario 3), emissions would be 17% higher in 2025. Those increases translate to an additional 269-360 million metric tons of CO2 compared to Scenario 1. Those are enormous increases, equivalent to adding up to 76 million cars to the road, or about 30 percent of vehicles registered in America today.[14] Under both scenarios, 2025 emissions would revert to close to 2005 levels, undermining progress towards a lower-carbon energy system.

By 2035, nearly the entire U.S. nuclear fleet would be shut down under either Scenario 2 or 3, as all but a few existing reactors would be at least 40 years old by that date. Replacing those retiring reactors would drive emissions up 9% compared to operating nuclear plants for a full 60-years. That translates to 190 million metric tons of additional CO2 emissions in 2035, enough to wipe out three-quarters of the reductions the Clean Power Plan aspires to achieve. While we project overall emissions will fall from 2025 to 2035 due to existing coal plants being retired and replaced by natural gas, the headwinds created by widespread nuclear retirements would prevent attainment of the EPA emissions goals. Emissions would be about 30 percent above the Clean Power Plan's emissions target in 2035 under both Scenario 2 and 3.

Figure 2 compares the different scenarios' effect on the emissions increase we will see if nuclear shuts down.

Figure 2: Impact of Nuclear Retirement on U.S. Power Sector CO2 Emissions



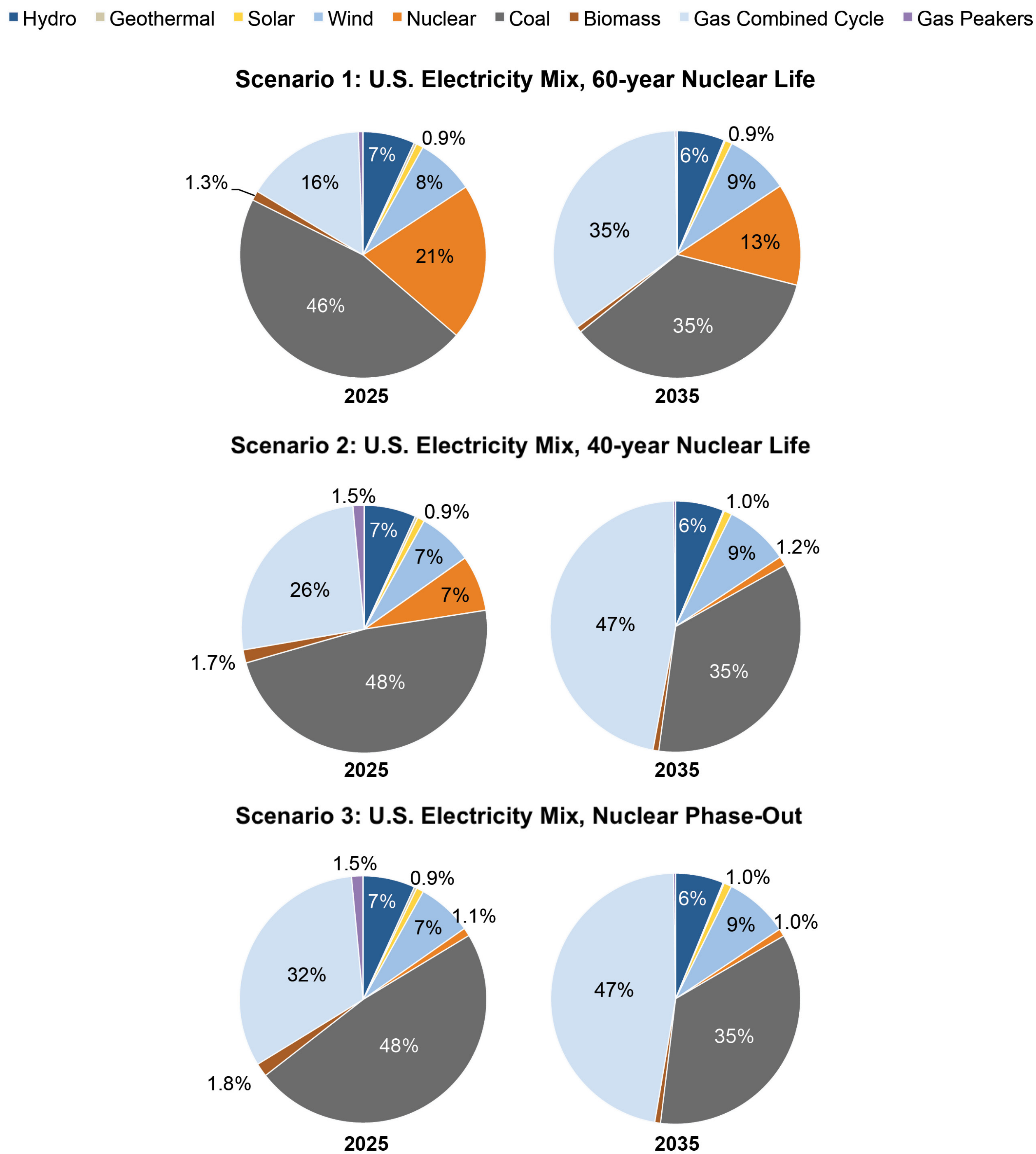
Under the EPA's Clean Power Plan,[15] the Agency assumes nuclear power will retain its current share of electricity generation through 2030. Unfortunately, the plan does not include any steps to prevent the retirement of existing reactors. As these results indicate, any widespread retirement of America's nuclear power plants would make it extremely difficult if not impossible for the Clean Power Plan15 to reach its emissions targets of 32% below 2005 levels. Preserving America's nuclear fleet is essential to the nation's carbon reduction goals.

## Nuclear Is Replaced With Natural Gas

Our modeling found that nuclear is predominately replaced by new natural gas-fired power plants (with a small increase in utilization of existing coal). This finding is consistent with recent real-world experience.[16] For example, EIA found that when the Vermont Yankee nuclear plant closed in 2014, the electricity it provided would likely be replaced by electricity generated from natural gas plants. This reflects the fact that natural gas grew from providing 30% of the electricity generated in New England in 2001 to 52% in 2012. Our model reflected this growth in natural gas going forward to 2025 and 2035, as the objective of the model was minimizing the cost of electricity to the consumer (subject to reliability and RPS policy constraints).

The following figures show an increasing drive to use natural gas as nuclear goes offline. Natural gas's share of 2025 electricity generation increases from roughly 17% if nuclear plants run for 60-years to 33.5% if nuclear is retired entirely. In 2035, gas generation increases from 35% to 47% if nuclear is phased out.

**Figure 3: The Increasing Role of Natural Gas as Nuclear is Phased Out**




## Renewables Can't Keep Up

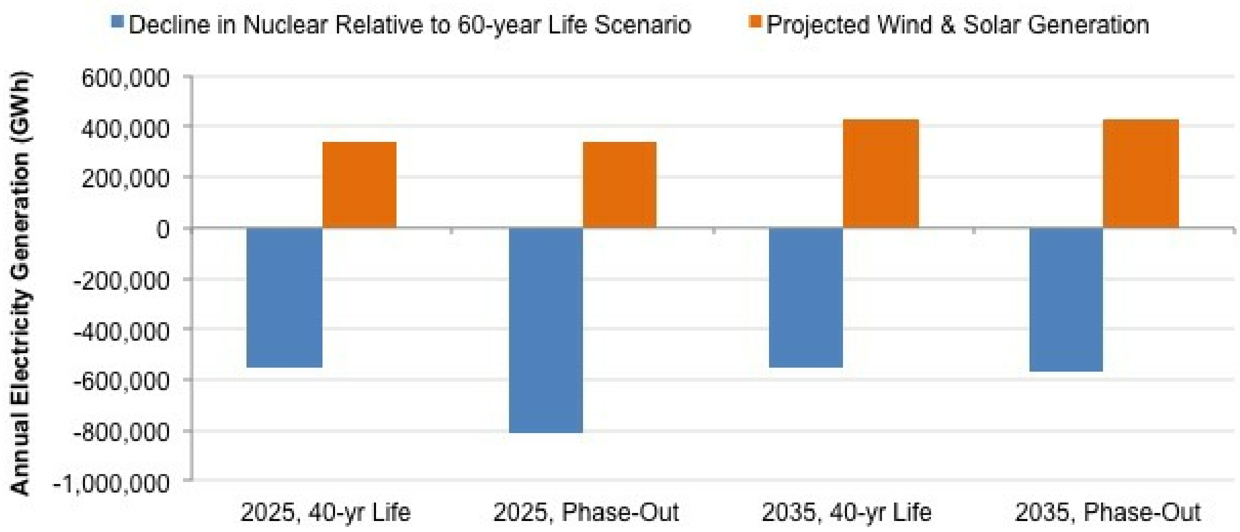
The growth of renewable energy in the United States, particularly wind and solar, is one of the most promising trends in the electricity sector in the last decade. The growth of renewables has helped reduce electricity costs in many markets, provided more choices for business and consumers, and most significantly from a climate perspective, helped reduce carbon emissions. Third Way supports policies that continue to encourage the expansion of renewable energy in the U.S.

Unfortunately, our models found that renewable electricity sources grow primarily to satisfy state RPS requirements, rather than for purely economic reasons. Renewable electricity capacity is largely unaffected by nuclear retirements and comes nowhere close to offsetting the lost nuclear energy generation in any early-retirement scenario. This isn't because renewables don't play a critical role in reducing emissions. By 2035 our model has over 425,000 Gigawatt hours (GWh) of wind and solar generation, which would double current renewable generation. In most states and at the federal level, tax and other incentives for renewables are at best holding steady, not increasing. Federal incentives were not used in this model for various reasons: the PTC has already expired, and the ITC is set to phase down to 10% for commercial projects and expire for residential solar in 2017. As a 2013 study by the National Renewable Energy Lab found, "Renewable energy development, to date, has mostly been in response to state mandates."[17] For these reasons, we only include state RPSs as the lasting policy measures currently in place. If federal incentives were extended or expanded for renewables, they could grow faster. But even in this case, it is unlikely that renewables could pick up all the slack left by retiring nuclear units. As the National Renewable Energy Lab warned, without increases in renewable portfolio standards or incentives, growth will not continue at nearly the level enjoyed since 2008.

The greater challenge is that the generation dropping off in the nuclear phase-out scenario is too much for renewables to replace. If reactors are only allowed 40 years of operation, renewable energy generation in the United States would need to grow 164% by 2025 and grow by 400% from 2014-2035. To replace the entire nuclear fleet, which would be required in our full phase-out scenario, wind and solar energy would have to grow 5.9 times from 2025 to 2035. These scenarios only consider the growth in solar and wind that would be needed to replace nuclear electricity generation, which if achieved, would have zero net impact on carbon emissions—replacing nuclear with renewables is like running to stay in one place. Even faster growth in wind and solar would be needed to displace any carbon-emitting natural gas or coal. Due to constraints in the supply chain, siting issues, the limitations of how much variable solar and wind electricity many parts of the grid can absorb, this would be very difficult, even for a sector that has enjoyed enormous growth over the past decade.[18]

Figure 4 compares the decline in carbon-free nuclear generation under the early-retirement scenarios with the projected growth in wind and solar. Wind and solar would have to growth much faster just to replace nuclear and keep carbon emissions from rising above today's levels. If wind and solar are to contribute to carbon reductions, far better to have them replace old coal and natural gas plants than our existing fleet of carbon-free nuclear.

**Figure 4: Renewable Generation Gained Cannot Fill the Gap Where Nuclear Generation is Lost**




## Nuclear Energy Tomorrow

In 2010, President Obama proclaimed, "To meet our growing energy needs and prevent the worst consequences of climate change, we'll need to increase our supply of nuclear power. It's that simple."[19] The president is right. But with market forces buffeting the U.S. nuclear sector, more and more reactor operators are contemplating shuttering existing plants rather than opening new ones. The consequences of a ramp-down of nuclear energy in the U.S. would be dire. Nuclear energy should be recognized as the carbon-free source of electricity that it is. There is widespread agreement among climate advocates that the U.S. must cut emissions in the power sector to zero by 2050 or sooner.[20] But to accomplish this, we must understand the contribution the U.S. civilian nuclear fleet has had on keeping emissions down and the devastating consequences we would face if this energy source were to gradually fade away, let alone rapidly disappear. The Clean Power Plan has paved the way for emissions reductions in the United States power sector. Shutting down nuclear power plants is a sure fire way to undermine these goals.

# Endnotes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4 Jesse Jenkins and Fernando de Sisternes performed this research in an independent capacity and their findings and views do not reflect the views of the Massachusetts Institute of Technology. The views and opinions expressed in this report are those of Third Way and do not necessarily reflect the position of MIT, the MIT Energy Initiative, or any other institution to which the researchers that participated in this study are affiliated.

5 In coordination with a team of researchers at MIT, Third Way sought such decision-support tool. The Electric Power Capacity and Investment Model (CANDI) is a heuristic-based optimization model that determines the lowest cost brownfield capacity mix compliant with renewable portfolio standard requirements for a power system at a specified year in the future. To do so, the model first generates on the optimal greenfield capacity mix, then compares this mix to the existing legacy capacity mix resulting from applying a retirement schedule to existing plants. Finally, a cost-effective mix of new generators is installed that bridges the gap between the legacy mix and the greenfield mix. The main features of CANDI are: i) generate a greenfield capacity expansion of both thermal and renewable technologies using hourly data resolution; ii) guarantee compliance with state renewable portfolio standard policies; and iii) generate an economically efficient brownfield capacity expansion based on the legacy and greenfield capacity mixes. CANDI uses hourly data to represent the demand and the wind and solar resources in the region modeled. Electricity capacity and generation decisions are made for each of the three U.S. electricity interconnections: the Eastern, Western and Texas interconnections. Different existing and future generation technologies are modeled using their expected future fixed costs (annualized capital costs fixed operation and maintenance), expected future variable costs (heat rate * fuel price variable operation and maintenance), and expected future emission rates based on the plants’ efficiencies.


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8 David Biello, “Nuclear Power Seems Doomed to Dwindle in the U.S. [Infographic]”, *Scientific American*, May 13, 2015. Accessed July 9, 2015. Available at: http://www.scientificamerican.com/article/nuclear-power-seems-doomed-to-dwindle-in-the-u-s-infographic1/.


9 It should be noted that we didn’t consider an even greater license extension from 60 years of operation to 80 years of operation. These license extensions are being studied by the Nuclear Regulatory Commission and future research by Third Way may address such a scenario.

10 Coal costs range from $2-4.5/million British thermal units (mmBTU) in 2035 with a central case of $3.14 (all prices in 2014 constant dollars). Natural gas prices range from $5-9/mmBTU with a central case of $7.52. Fuel oil prices range from $17.10-38/mmBTU with a central case of $27.51/mmBTU. Prices derived from U.S. EIA Annual Energy Outlook “high oil” “low oil” and “reference” cases. See note below for citation.


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