Nuclear Power and the Clean Energy Future

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This report was prepared for Nuclear Matters. The Horinko Group would like to recognize its author, Emily Hammond. Ms. Hammond serves as Senior Advisor at The Horinko Group and Professor of Law at The George Washington University Law School. The Horinko Group would also like to acknowledge the significant contributions of Cathryn Courtin and Sean McGinnis in preparing this report.

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Table of Acronyms

CO_2	Carbon dioxide
CO_2eq	CO_2 equivalent
CPP	Clean Power Plan
EIA	U.S. Energy Information Administration
EPA	U.S. Environmental Protection Agency
EGU	Electric Generating Unit
ERC	Emission Rate Credits
EM&V	Evaluation, Measurement, and Verification
GHG	Greenhouse gas
Gt	Gigaton
GWh	Gigawatt-hour
lb	Pound
MW	Megawatt
MWac	Megawatt alternating current
MWe	Megawatt electric
MWh	Megawatt-hour
NGCC	Natural gas combined cycle
TWh	Terawatt-hour

EXECUTIVE SUMMARY

Nuclear power—the largest source of clean, reliable, baseload power in the United States—is critical to a clean energy future. It provides nearly double the power of wind, solar, and hydroelectric combined, and accounts for 20% of the nation's electricity overall. It provides power 24 hours a day, 7 days a week regardless of the weather, with none of the greenhouse gas (GHG) emissions that come from fossil fuels.

GHGs contribute to climate change—the most pressing threat to public health and the environment of our time. The risks include increases in extreme weather causing flooding, droughts, and heat waves, sea-level rise, food- and airborne illnesses, and deaths. Among the most vulnerable to these threats are people living in cities, children, the elderly, and the poor.[1] The U.S. electricity sector emits 2.3 billion tons of the GHG carbon dioxide (CO_2) each year, but nuclear power emits *none*.

Under the Clean Power Plan (CPP), the United States expects to reduce CO_2 emissions from existing power plants to 32% below 2005 levels by 2030.[2] In absolute terms, that would mean an 870 million ton[3] reduction in CO_2 pollution compared to 2005 levels—an amount equivalent to removing 167 million cars from the road in a year, or approximately 70% of the nation's passenger vehicles.[4] Nuclear energy is critical to realizing that goal as well as to advancing other efforts to curb CO_2 emissions. But nuclear power's clean energy benefits are undervalued; as a result, some plants have already been lost and more are at risk, creating a major setback for achieving clean energy goals and responding to the climate change imperative.

In this report, The Horinko Group presents its analysis and findings with respect to two key issues: (1) nuclear power's significant contribution to minimizing the CO_2 emissions of the electricity sector; and (2) CPP compliance pathways that best value nuclear power's contribution for a clean energy future. Among our key findings are:

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[1] *See generally* Endangerment and Cause or Contribute Findings for Greenhouse Gases Under Section 202(a) of the Clean Air Act, 74 Fed. Reg. 66,496 (Dec. 15, 2009).

[2] Final Rule, Carbon Pollution Emission Guidelines for Existing Stationary Sources: Electric Utility Generating Units, 80 Fed. Reg. 64,662 (Oct. 23, 2015) [hereinafter "CPP Final Rule"]. As discussed in more detail in Part II, the CPP is currently under a stay pending resolution of litigation. However, many states are continuing to plan for compliance as well as updating their own clean energy policies. New York, for example, is currently working to implement its State Energy Plan, which would decrease GHG emissions by 40% of 1990 levels by the year 2050. *See* N.Y. State Energy Planning Bd., *The Energy to Lead: 2015 New York State Energy Plan* Vol. I (2015). Massachusetts has set a goal of 80% GHG emissions reductions by 2050. *See* Press Release, Exec. Offc. of Energy & Envtl. Affairs, *Massachusetts on Track to Meet 25% Greenhouse Gas Reduction Target for 2020* (Jan. 19, 2016). The United States has also made international commitments for reducing GHG emissions by 26-28% below its 2005 level in 2025. U.S. Cover Note, INDC, and Accompanying Information (Mar. 31, 2015), at http://www4.unfccc.int/Submissions/INDC/ (follow links to published documents and United States).

[3] Unless otherwise noted, "ton" refers to short ton, which is equal to 2,000 pounds.

[4] Assumes 5.2 tons CO_2 per year per vehicle. EPA, Greenhouse Gas Emissions from a Typical Passenger Vehicle (May 2014) (data converted from metric tons); *see also* EPA, Fact Sheet: Clean Power Plan by the Numbers (2015); EPA, Regulatory Impact Analysis for the Clean Power Plan Final Rule, at ES-8, Tbl. ES-4 (Oct. 23, 2015) [hereinafter "CPP RIA"].

- Nuclear power in the United States avoids over 531 million tons of CO_2 per year. Without nuclear power, the social cost of this carbon would total $85 billion by 2020 alone.[5]

- EPA estimates that the CPP will lead to annual CO_2 emission reductions of 413 million tons by 2030.[6] Without nuclear power—which avoids over 531 million tons of CO_2 per year—reductions expected under the CPP would be more than negated.

- Whether considering CPP compliance options or pursuing their own clean energy initiatives, states should preserve their existing nuclear power resources to ensure that emissions can be reduced while keeping costs low and maintaining the reliability of the power grid. Under the CPP, a mass-based plan that accounts for new sources of emissions best achieves these goals while offering significant additional benefits, including:
    - Familiarity and ease of administration,
    - Similarity to existing programs,
    - Reduced regulatory burden,
    - Best for existing clean generation, and
    - Best for the environment.

Part I begins with a brief overview of electric power sources, elaborating both their CO_2 impacts and how they fit into an interconnected power grid that must always balance supply and demand. Next, Part I elaborates the carbon benefits of nuclear power. It shows the contribution of nuclear power to overall power generation, discusses the CO_2 emissions that nuclear power avoids, and quantifies the value of those avoided emissions.

Part II presents pathways forward. First, it gives a brief overview of the CPP, including the flexibility the CPP affords states in choosing compliance options. Second, it demonstrates why non-emitting renewables—while important parts of a low-carbon future—are inadequate to replace nuclear power. Finally, Part II demonstrates why mass-based approaches that account for new sources of emissions are best for achieving clean energy goals.

Following a brief Conclusion, Appendix 1 to this report details our methodology, which incorporates a series of conservative assumptions. All data in this report are drawn from the Energy Information Administration (EIA) and the Environmental Protection Agency (EPA); the specific sources are noted throughout as well as in Appendix 1. Appendix 2 presents a table comparing the state CPP emission targets and nuclear power's avoided emissions by state.

Throughout the report, we use italics to highlight key terms and issues that are further discussed in call-out boxes. For additional information, readers are referred to the footnotes in this report.

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[5] Cumulative 2017 through 2020 value, applying EPA modeled state-specific baseline emission rates for 2020 (without CPP) to state-specific three-year historical average nuclear power generation. Social cost of carbon values reflect 2011 dollars and 3% discount rate. For details, see *infra* Part I.B.2 and methodology in Appendix 1.

[6] See CPP RIA, *supra* note 4, at ES-6, ES-7, and Tbl. ES-3 (presenting mass-based approach). Throughout the report, we use "mass-based approach" when referring to published values that do not include a new source complement.

I. NUCLEAR POWER'S CLEAN AIR BENEFITS

Of all the electricity sources, only nuclear power can deliver large-scale, always-on electricity without emitting GHGs. This section describes the differences between the major electricity fuels, paying particular attention to their operating characteristics and environmental attributes. We demonstrate the importance of nuclear power in terms of its significant contribution to meeting electricity demand without emitting CO_2. Next, this section quantifies nuclear power's clean air benefits. Overall, nuclear power provides 20% of total U.S. electricity—amounting to 63% of the country's clean electricity and avoiding over 531 million tons of CO_2 per year.

> The U.S. power sector emits 2.3 billion tons of CO_2 per year. Nuclear power's CO_2 emissions are *zero*.

A. Comparison of Electricity Fuels

Each type of electricity fuel—coal, natural gas, nuclear, hydroelectric, wind, and solar—differs in scale, operating characteristics, and environmental impact. Scale and operating characteristics contribute to each source's ability to provide sufficient power when needed, but those characteristics do not necessarily correlate with environmental impact. Nuclear energy is unique in its ability to provide reliable *baseload power* without emitting CO_2.

> ***What is Baseload Power?***
>
> Demand for electricity varies seasonally and within each 24-hour period, traditionally reaching its highest peaks on summer afternoons and its lowest levels overnight in the fall and spring. Even with these fluctuations, there is always some minimum amount of demand for electric power. That amount is baseload. Nuclear power is a critical source of baseload power.

Nuclear and many fossil-fueled power plants are capable of running continuously to meet baseload demand, but nuclear power plants are the only ones that do so without emitting *greenhouse gases* (GHG).[7] Natural gas-fired power plants emit about 580 million tons of CO_2 annually, and coal-fired power plants emit over 1500 million tons per year.[8] Thus, although these sources of electricity can provide baseload power, they do so at a significant environmental cost. Furthermore, the CO_2 emission rates of fossil-fueled plants used to provide non-baseload power tend to be higher than those that provide baseload generation.

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[7] Nuclear power also avoids the significant emissions of criteria and toxic pollutants associated with fossil fuels. *See infra* note 23 (collecting sources).

[8] EIA, Frequently Asked Questions, How much of U.S. carbon dioxide emissions are associated with electricity generation? (last visited June 27, 2016) (reporting 2015 emissions data).

What is the Difference Between GHGs and CO_2?

GHGs include numerous gases, most prominently CO_2, methane, nitrous oxide, and fluorinated gases. Each of these gases has a different global warming potential (GWP) when measured over a period of time. Thus, the unit CO_2eq (carbon dioxide equivalent) is often used to show how much CO_2 would have the same GWP as a given mixture of GHGs over a specified time period. For example, over a 100-year period, methane has a GWP of 21, so one ton of methane is equivalent to 21 tons CO_2eq.

The CPP regulates only CO_2 emissions because those make up the largest share of GHGs from the power sector. For this reason, we typically refer to CO_2 throughout this Report. However, we refer to GHGs or CO_2eq as necessary for accuracy or in describing other studies that encompass more than CO_2.

What is Capacity Factor?

An electricity source's capacity factor reflects the ratio of what a power source actually produces to how much it is theoretically capable of producing. For example, nuclear power's high capacity factor—over 90%—means that its actual output per year is very close to its potential output; the next closest is NGCC at 56.3%, as depicted on Figure 1. Note that no source operates at 100%. Routine maintenance, reduced demand, and grid constraints all reduce capacity factors. In the case of wind and solar, low capacity factors are largely due to their inherent variability.

Some renewable energy sources—like wind, solar, and hydropower—offer similar environmental benefits to nuclear in that they do not emit GHGs when generating electricity.[9] Unlike nuclear power, however, these sources cannot be counted on to provide a steady output of around-the-clock power. Wind and solar are variable; they cannot produce when the wind is not blowing or the sun is not shining, and the storage technologies that might offset this variability are not yet economically viable on a large scale. Most hydropower generates electricity continuously, but its output is ultimately dependent on rainfall and thus susceptible to drought.[10] A smaller portion of hydropower is operated in storage mode or as pumped storage, making it effectively dispatchable on a small scale.

[9] The emissions of these sources are also similar to nuclear power on a full life-cycle emissions basis. *See* Nat'l Renewable Energy Lab., U.S. Dep't of Energy, *Life-Cycle Greenhouse Gas Emissions from Electricity Generation*, NREL.gov, http://www.nrel.gov/docs/fy13osti/57187.pdf (summarizing methodology and results of Life Cycle Assessment Harmonization Project). We distinguish GHG-emitting renewables like landfill gas, woody biomass, and biogas from non-emitting renewables like wind, solar, and hydropower. In the CPP, EPA includes geothermal energy as a non-emitting renewable source of power, but it is not widely available and is not addressed here.

[10] For further discussion, see Emily Hammond & Richard J. Pierce, Jr., *The Clean Power Plan: Testing the Limits of Administrative Law and the Electric Grid*, 7 GEO. WASH. J. ENERGY & ENVTL. L. 1, 13-14 (2016); Emily Hammond & David B. Spence, *The Regulatory Contract in the Marketplace*, 69 VAND. L. REV. 141, 163-66 (2016).

Typically, wind and solar send power to the grid whenever it is generated, regardless of real-time demand. If demand is too low for the additional power, other electricity sources must ramp down to accommodate the new influx of power. Conversely, the grid must be ready to provide supply when these sources stop generating power. As a result, additional sources of power, generally fast-ramping fossil sources, must be readily available to maintain the grid's balance.[11] Because of this variability, wind and solar sources have lower *capacity factors* than other sources of electricity, as depicted by Figure 1.

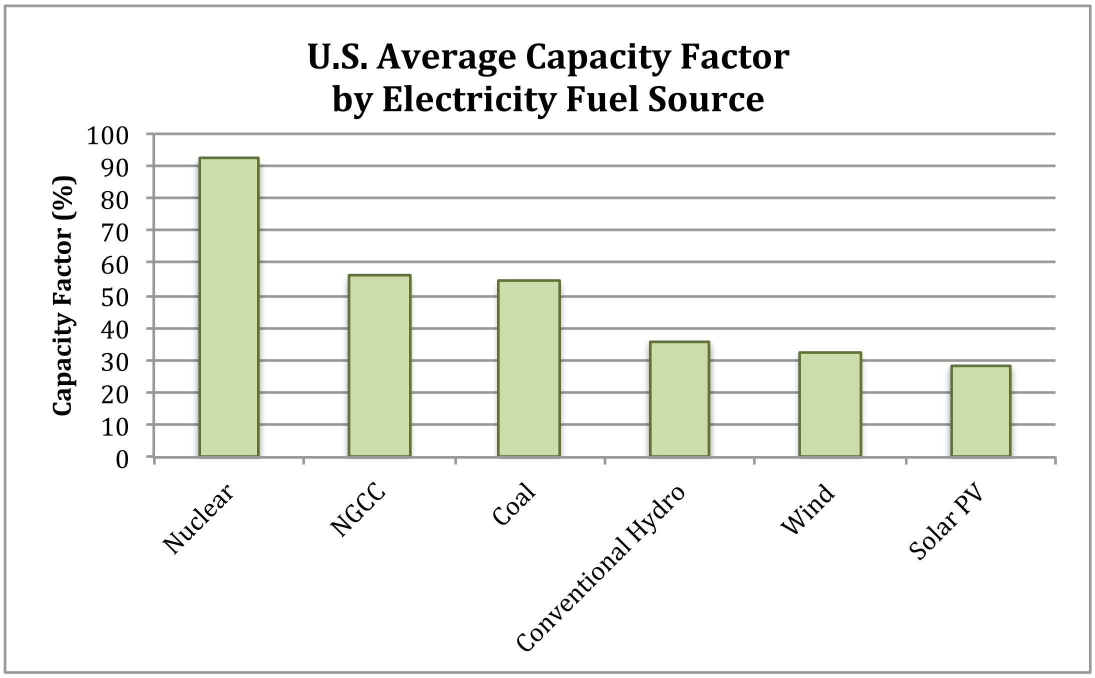

Figure 1. U.S. Average Capacity Factor by Electricity Fuel Source, 2015. ***Source*****: EIA.**[12]

Thus, the mix of electricity sources works together. Baseload sources of power like nuclear and some coal, natural gas, and hydropower meet the minimum level of demand. As demand increases, additional fossil-fueled sources (and some hydro) meet intermediate load, and as demand peaks, "peaker plants" like natural gas turbines, some hydropower, and older and higher-cost coal- or oil-fired plants, come online. Generally, lower-cost sources run first, leaving higher-cost sources to be called only in times of higher demand. However, wind and solar enter the power grid as produced, necessitating flexibility in the overall system to ensure the grid's stability. To be clear, grid operators are indifferent to the electricity fuel source when they dispatch power. Instead, power is dispatched based on what is available at the least cost to meet demand, subject to the technical needs of the power grid.

[11] Natural gas typically provides this capability. Without nuclear power's carbon-free baseload power, therefore, the electricity fuel mix would be increasingly reliant on natural gas both for baseload and for offsetting renewables' variability.

[12] EIA, Electric Power Monthly, Tbls. 6.7.A., 6.7.B (Apr. 28, 2016) (reporting 2015 utility-scale values on nationwide basis).

These rules of dispatch frequently happen to result in the order of electricity sources described here, especially in the *competitive wholesale markets*.[13] But as described in more detail in the call-out box, in the absence of CO_2 regulation, the costs bid into competitive wholesale markets do not reflect any generation differences based on CO_2 pollution, perpetuating a regulatory dysfunction that is putting nuclear power at risk.

What are the Competitive Wholesale Markets?

Two-thirds of the nation's wholesale electricity—that is, electricity sold for resale in interstate commerce—is sold in competitive markets operated by Regional Transmission Operators (RTOs) or Independent System Operators (ISOs). The RTOs/ISOs are responsible both for coordinating the sales of electricity and ensuring that the power grid's technical needs are met. They match offers to buy with offers to sell until all demand is satisfied. The price at which demand is met is called the market-clearing price; all bidders receive the market-clearing price. Electricity sellers bid into the market at a price reflecting the short-run marginal cost, that is, the cost of providing an additional unit of power.

Importantly, these markets do not directly include any value of avoided CO_2 emissions because these emissions have largely remained unregulated. The result is that nuclear power is undervalued. Nuclear power is reliable, dependable, and does not emit GHGs. But because it is always running, it must take the market-clearing price—whatever that price is (even if the price is negative). As a result, several nuclear power plants have shuttered years before the end of their available operating lives, and several more are at risk for early closure. For a detailed analysis, see generally Hammond & Spence, *supra* note 10.

B. Carbon Benefits Quantified

Nuclear power provides tremendous GHG benefits. It accounts for 20% of the nation's electricity and 63% of the nation's carbon-free electricity.[14] If nuclear power were not part of the electricity fuel mix, therefore, we would expect CO_2 emissions to be much higher than they are currently—adding over 531 million tons of CO_2 per year in the United States alone.

Building on the characteristics of the mix of electricity fuel sources set forth above, this section (1) provides an overview of existing literature on the carbon benefits of nuclear power; and (2) presents our estimates of the carbon value of nuclear power on both a national and state-by-state basis. Our methodology is set forth in Appendix 1.

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[13] Where wholesale electricity is not traded in a competitive market, dispatch may also vary according to utilities' schedules and power supply costs.

[14] EIA, State Historical Tables for 2014 (rev. Nov. 2015). Carbon-free generation includes the following non-emitting resources: wind, solar (both PV and concentrated), hydroelectric, and geothermal, in addition to nuclear power. Hydroelectric power includes both conventional and pumped. EIA reported categories "Other biomass," "Wood and wood derived fuels," "Other gases," and "Other are not included in carbon-free generation calculations.

Our key findings in this section are as follow:

- Past experience demonstrates that when nuclear power is lost, it is replaced by fossil-fueled power, which causes GHG emissions to increase.
- Further premature nuclear retirements will most likely continue to be replaced by fossil-fueled sources because of their comparable operating characteristics and scale.
- Nuclear power accounts for the majority of carbon-free generation in 26 of the 30 states that have nuclear power.
- Nuclear power avoids significant annual CO_2 emissions in every state—totaling over 531 million tons in the United States each year.
- Any state that loses nuclear power in the next several years to decades can expect an increase in CO_2 emissions.

1. *Lost Nuclear Power Means a Rise in GHG Emissions*

When nuclear power is lost, a rise in GHG emissions is to be expected. Consider the following examples:

- After years of declining GHG emissions, in 2015 New England's GHG emissions rose by two million tons after the Vermont Yankee nuclear plant closed.[15]

- In 2012, GHG emissions rose in California with the 2011 closure of the San Onofre Nuclear Generating Station (SONGS) and drought that reduced hydropower. In all, the state lost 33 TWh of clean electricity; the state relied on additional natural gas generation to meet electricity demand.[16]

- When Japan shuttered its nuclear power plants after the 2011 Tohuku earthquake and tsunami damaged the Fukushima Dai-ichi nuclear plant, GHG emissions rose significantly as coal-fired power stepped in to replace nuclear.[17]

- With decreasing reliance on nuclear power, Germany has seen a corresponding increased reliance on lignite coal-fired power. As a result, Germany has made little progress toward its emission reduction goals, despite significant expenditures on additional wind and solar.[18]

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[15] Patricio Silva, ISO NEW ENGLAND, Environmental Update, Planning Advisory Committee, at 17 (Feb. 17, 2016); *see also* William Opalka, *CO_2 Emissions Increase in ISO-NE; Loss of Nuclear Plant Reverses Trend*, RTO INSIDER (Feb. 22, 2016).
[16] CAL. AIR RESOURCES BD., 2014 EDITION: CALIFORNIA GHG EMISSION INVENTORY 6 (May 13, 2014).
[17] JOEL B. EISEN ET AL., ENERGY, ECONOMICS AND THE ENVIRONMENT 412 (4th ed. 2015).
[18] Andrew Follett, *Germany Abandons Nuclear Power, Increases CO_2 Emissions*, THE DAILY CALLER (Nov. 18, 2015); *see* Umwelt Bundesamt, Environmental Trends in Germany: Data on the Environment 2015, at 10 (depicting emission trends showing increase in 2012 and 2013, then projected decrease in 2014).

The climate benefits of nuclear power are indisputable. Every major study that has considered the issue predicts that lost nuclear power is most likely to be replaced primarily by fossil fuels because of scale, operating attributes, and cost considerations—including the lack of a price on carbon—just as has already happened in Vermont, California, Japan, and Germany. One study estimates that, if all nuclear power plants worldwide were to cease production, the world would see a cumulative increase of between 80 and 240 gigatons of CO_2eq over a forty-year period—equivalent to 14 to 41 times annual U.S. emissions.[19] Another study estimates that without nuclear power, U.S. CO_2 emissions would be 4.4 – 6.6 billion tons higher over the period of 2012-2025.[20] Still another estimates that without existing nuclear power, U.S. CO_2 emissions would be 17% higher by 2025, making Clean Power Plan goals nearly "impossible" to achieve.[21]

These figures starkly reveal the importance of nuclear power in avoiding CO_2 emissions.[22] The many other benefits of nuclear power are worth emphasizing, albeit beyond the scope of this report. First, nuclear power avoids not just GHG emissions, but also criteria and toxic pollutants directly harmful to public health.[23] Researchers Brook & Bradshaw, moreover, evaluated various electricity fuels according to metrics linked to biodiversity, and demonstrated that nuclear power is a strong option for biodiversity conservation.[24] The economic benefits of nuclear power—which include a $60 billion annual contribution to the gross domestic product, about 475,000 full-time jobs, lower electricity prices for consumers, and over $12 billion in federal and state tax revenues—are also widely documented.[25]

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[19] Pushker A. Kharecha & James E. Hansen, *Prevented Mortality and Greenhouse Gas Emissions from Historical and Projected Nuclear Power*, 47 ENVTL. SCI. & TECH. 4889, 4893 (2013). Scenarios assumed replacement by fossil fuels. Note units are in CO_2eq and metric tonnes (2,204 pounds) and refer to 2012 values.

[20] Doug Vine & Timothy Juliani, *Climate Solutions: The Role of Nuclear Power*, CTR. FOR CLIMATE & ENERGY SOLUTIONS 1 (Apr. 2014).

[21] Samuel Brinton & Josh Freed, *When Nuclear Ends: How Nuclear Retirements Might Undermine Clean Power Plan Progress*, THIRD WAY 5 (Aug. 19, 2015). This study assumed all states would meet existing renewable portfolio standards, renewables would double over current generation, and natural gas would be the primary replacement fuel. It assumed the Vogtle, Summer, and Watts-Bar plants would run as licensed.

[22] New nuclear power also has a critical role to play. The Brookings Institution estimates that new nuclear construction would avoid over 8,000 tons per MW per year of CO_2 if it displaced coal, and nearly 3,400 tons per MW per year of CO_2 if it displaced natural gas. Charles R. Frank, Jr., *The Net Benefits of Low and No-Carbon Electricity Technologies*, BROOKINGS INST., GLOBAL ECONOMY & DEVL'T WORKING PAPER 73 (May 2014).

[23] Kharecha & Hansen, *supra* note 19, at 4891-92; Mark Berkman & Dean Murphy, *The Nuclear Industry's Contribution to the U.S. Economy*, THE BRATTLE GROUP 13 (July 7, 2015).

[24] Barry W. Brook & Carey J.A. Bradshaw, *Key role for nuclear energy in global biodiversity conservation*, 29 CONSERV. BIOL. 702 (2014).

[25] Berkman & Murphy, *supra* note 23; *see also* James Conca, *Closing Vermont Nuclear Bad Business for Everyone*, FORBES (Sept. 29, 2014).

Indeed, states are recognizing that the clean energy and economic benefits of nuclear power are critical to ensuring both clean air and healthy economies.[26] As discussed in more detail in Part II, states that retain their nuclear power will also find it much easier to reduce CO_2 emissions from the power sector.

2. *Carbon Benefits of Nuclear Energy*

This section demonstrates and quantifies the clean energy impact of nuclear power: it provides large quantities of electric power, represents by far the largest share of clean electricity nationwide, and thereby avoids massive amounts of CO_2 emissions per year. These attributes mean billions of dollars in avoided costs in terms of climate impacts alone.

As detailed in our methodology (Appendix 1), we estimated the carbon value of nuclear energy in three steps. First, we used EIA's reported historical generation data to calculate average nuclear power generation by state over three years: 2013, 2014, and 2015.[27] Next, we applied to this average EPA's modeled state-specific CO_2 emission rate from the electricity sector for 2020 to estimate the carbon impact of replacing nuclear. As described in more detail in Appendix 1, these rates take into account each state's existing electricity mix but anticipate some near-term changes prior to the CPP's compliance deadlines; the rates themselves are set forth in Appendix 2. The rates range from 634 lb CO_2/MWh in Washington to 1950 lb CO_2/MWh in Missouri, and on average, the rates are lower in states with high proportions of hydroelectric power and higher in states that are heavily reliant on coal-fired power.[28]

In reality, *predicting a future CO_2 emission rate* without nuclear power is difficult. States with high hydroelectric penetration that currently have lower emission projections, for example, may be able to increase some of their hydropower output, but could not fully replace lost nuclear power with this non-emitting source. Thus, it is highly likely that without nuclear power, emissions would increase significantly because fossil fuels[29] would step in to provide the baseload power necessary to meet demand.[30] EPA's 2020 projected emission rates are inherently conservative and therefore conservatively yield additional tons of CO_2 per year in the absence of nuclear power, as described below.

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[26] *E.g.*, Letter from Andrew M. Cuomo, Governor of New York, to Audrey Zibelman, CEO, N.Y. State Dep't of Pub. Serv., Dec. 2, 2015 (directing proceeding to establish Clean Energy Standard); Ill. Comm. Comm'n et al., *Potential Nuclear Power Plant Closings in Illinois: Impacts and Market-Based Solutions* (2015) [hereinafter "Potential Closings"]. These policies extend to efforts to incentivize new nuclear construction. *See, e.g.*, The Georgia Nuclear Energy Financing Act, O.C.G.A § 46-2-25(c)(3) (2009) (permitting cost recovery of nuclear power's carrying costs of construction); *see also* Base Load Review Act, S.C. CODE ANN. § 58-33-220(2) (2011) (similar for base load plants); FLA. ADMIN CODE ANN. R. 25-6.0423(6) (2007) (Florida regulation permitting cost recovery for nuclear carrying costs of construction).

[27] Because the Kewaunee plant in Wisconsin ceased operations in May 2013, we excluded 2013 from Wisconsin's average.

[28] For comparison purposes, EPA reports the 2012 average national emission rate of NGCC to be 905 lb CO_2/MWh. EPA, Technical Support Document for CPP, Mitigation Measures 3-4 (Aug. 2015) [hereinafter "TSD Mitigation Measures"]. The emission rate for new NGCC is 1030 lb CO_2/MWh. Carbon Pollution Standards for New, Modified and Restructured Power Plants, 80 Fed. Reg. 64,510 (Oct. 23, 2016) [hereinafter "New Source Rule"].

[29] We explain why non-emitting renewables would be unlikely to factor into this estimate both below in Part II.B. and in Appendix 1. Consistent with EPA's approach in the CPP, our focus is on the renewable sources that, like nuclear power, do not emit GHGs. Note, however, that emitting renewables like landfill gas and woody biomass are typically very small-scale and could not replace nuclear power for this reason alone.

[30] Note that the EIA's projections—whether or not with the CPP in place—estimate substantial increases in natural gas-fired generation through 2040. EIA, Annual Energy Outlook 2016, Early Release: Annotated Summary of Two Cases 22 (May 17, 2016).

Predicting a Future CO_2 Emission Rate

If nuclear power were lost today, we would expect significant near-term increases in CO_2 emissions as fossil fuels stepped in to replace the lost power. Indeed, this result has been documented in Vermont, California, Japan, and Germany. But it is challenging to predict a future CO_2 emission rate because that value is dependent on a host of different variables.

As noted in the text, this study's methodology is to apply EPA's modeled, state-specific emission rates for 2020 to each state's nuclear generation. This approach is one of many options to estimate avoided emissions. The rates are state-specific in that they account for electricity fuel sources within each state as well as near-term projections. But other reasonable methodologies apply higher emission rates and yield correspondingly higher avoided CO_2 values, as the following example of New York demonstrates.

In states with high percentages of non-emitting renewables like New York's hydropower, it is not realistic to predict that these existing sources could simply step in to replace lost nuclear power. Instead, all of the studies to have considered the issue have concluded that fossil fuels are the most likely replacement for nuclear power, particularly in the near term. A conservative methodology would be to calculate CO_2 emission increases if all nuclear power were replaced with new NGCC at EPA's new source rate of 1030 lb CO_2/Mwh. This approach would yield:

- An increase of nearly 23 million tons of CO_2 per year.

The actual emissions increase, however, could be even higher. In the near term, if non-baseload sources of power were substituted for lost nuclear power at New York's non-baseload emission rate of 1223 lb CO_2/year, this approach would yield:

- An increase of nearly 27 million tons of CO_2 per year.

In-state replacement fuels are not the only uncertainty. If New York were to lose significant portions of its nuclear energy, supply could become scarce—leading to high prices and the need to import power. Given that regional electricity is highly dependent on fossil fuels, it is likely that imports would also cause net emissions increases for New York.

The bottom line is that a future without nuclear power involves many emissions risks. Although the uncertainties cannot be quantified, the risks themselves should not be ignored.

Finally, we applied to that amount a value representing the *social cost of carbon* for additional emissions from the four-year period from 2017 to the end of 2020 to help monetize the impact of lost nuclear energy.

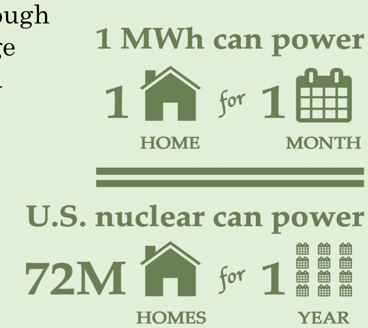
What is the Social Cost of Carbon?

The social cost of carbon is an estimate used by many federal agencies to incorporate the social costs associated with carbon dioxide emissions into cost-benefit analyses of major regulatory actions. Developed by an interagency working group using peer-reviewed models, these estimates reflect modeled costs to agricultural productivity, human health, property damage from flood risks, and changing energy needs for indoor climate control, among others. However, many costs are difficult to model and are not captured in these estimates. Moreover, because many of the costs of climate change are expected to be borne well into the future, the discount rate is one of the most important factors that can influence the present value of such costs. Appendix 1 includes a table presenting the current estimates. As further described in Appendix 1, this report uses estimates adjusted to short tons and 2011 dollars, which is in keeping with EPA's approach in the CPP.

Table 1 presents the results. First, the total summer capacity in each state helps show the scale of nuclear power; only NGCC, coal-fired power, and some large-scale hydro compare on a capacity basis, yet those sources' capacity factors are much lower than that of nuclear—meaning more generation capability is required of those sources to reach the same electricity production of nuclear power.

How Much is a Megawatt-Hour?

One megawatt-hour is enough energy to serve the average U.S. home for more than a month. In an average one-year period, nuclear reactors in the United States generate over 790 million MWh—enough electricity to power over 72 million homes for an entire year.



Second, each state's recent generation history helps further demonstrate the scale of nuclear power, as does the next metric provided for each state, nuclear generation as a percentage of carbon-free electricity. In the leading nuclear state—Illinois—nuclear energy generates enough electricity to power nearly 9 million homes annually[31] and provides 91% of the state's annual carbon-free electricity. In 26 of the 30 states with nuclear energy, it provides the majority of the state's carbon-free electricity—and more than 90% in 11 states. All told, nuclear energy accounts for 63% of the nation's clean power and serves over 72 million homes annually—a significant carbon-free contribution to Americans' energy needs.

Third, the avoided carbon contribution of nuclear power is impressive. For example, in Illinois, nuclear power avoids 83 million tons of CO_2 per year. Overall, nuclear power avoids over 531 million tons of CO_2 per year in the United States.

Finally, avoided CO_2 translates to a significant economic impact. The avoided costs of carbon range from $0.32 billion in Massachusetts to $13.3 billion in Illinois—totaling $85 billion nationwide before the Clean Power Plan's compliance period even begins.[32]

[31] Assumes U.S. average annual electricity use per home of 10,932 kWh. EIA, Frequently Asked Questions, How much electricity does an American home use? (Oct. 21, 2015) (reporting 2014 values).
[32] Calculated for 2017 through 2020.

Table 1. Nuclear Power's Clean Energy Benefits.

State	Total Summer Capacity (MW)	Average Annual Nuclear Electricity Generation (GWh)*	Percent of State's Carbon-Free Electricity**	Annual Avoided CO_2 (million tons)	Social Cost of CO_2 through 2020 (billions of dollars)***
Alabama	5,066	41,337	81	28.6	4.58
Arizona	3,937	32,092	77	22.6	3.62
Arkansas	1,820	13,420	84	10.4	1.66
California	2,240	17,801	25	6.3	1.01
Connecticut	2,123	16,777	97	7.2	1.15
Florida	3,572	27,505	98	16.1	2.57
Georgia	4,061	33,104	93	18.8	3.00
Illinois	11,564	97,436	91	83.1	13.3
Iowa	601	4,906	19	3.6	0.57
Kansas	1,175	8,119	44	7.6	1.21
Louisiana	2,133	16,522	94	10.2	1.63
Maryland	1,708	14,417	88	10.2	1.63
Massachusetts	678	5,032	86	2.0	0.32
Michigan	3,982	29,833	87	23.7	3.79
Minnesota	1,594	11,818	55	9.8	1.57
Mississippi	1,409	10,944	100	6.0	0.97
Missouri	1,193	9,361	83	9.1	1.46
Nebraska	1,243	9,097	72	8.8	1.40
New Hampshire	1,246	10,193	85	3.2	0.52
New Jersey	4,110	32,716	99	16.0	2.57
New York	5,431	44,132	59	19.9	3.18
North Carolina	5,094	41,102	88	26.2	4.19
Ohio	2,134	16,594	91	14.4	2.31
Pennsylvania	9,780	79,303	93	58.9	9.43
South Carolina	6,556	53,276	97	32.0	5.12
Tennessee	3,401	27,041	77	20.5	3.28
Texas	4,960	38,986	49	29.5	4.72
Virginia	3,568	29,202	100	14.0	2.24
Washington	1,158	8,706	10	2.8	0.44
Wisconsin	1,193	9,728	70	9.4	1.51
U.S. Total	**98,729**	**790,502**	**63**	**531.1**	**85.0**

* Average nuclear power generation over three-year period of 2013, 2014, and 2015. Wisconsin average is 2014 and 2015.

** Share of carbon-free generation in 2014.

*** SCC values are in billions of 2011 dollars at a 3% discount rate.

II. PATHWAYS FORWARD

Given nuclear power's carbon-free benefits, it is not surprising that nuclear energy stands to play a critical role in state climate policies—whether for CPP compliance or for meeting individual states' clean energy objectives. This section begins with an overview of the CPP, including the rule's major compliance pathways. As shown next, the threat of lost nuclear power has important implications for achieving GHG reductions, particularly because zero-emission renewables cannot be counted on to fill the gap. To best preserve nuclear power and meet CPP targets, states should choose mass-based compliance pathways that include new sources and are trading-ready.

A. Overview of the Clean Power Plan

Finalized by EPA in August 2015, the CPP sets CO_2 emission performance rates for existing fossil fuel-fired power plants.[33] It also sets CO_2 emission targets for each state based on the performance rates and the states' individual mixes of coal- and natural-gas-fired power, allowing states the discretion to determine how best to shape their compliance plans. Emission targets are set in three different ways: rate-based (tons of CO_2 per MWh); mass-based (tons of CO_2 per year); or mass-based with a new source complement (described in more detail below).

What is the Status of the Clean Power Plan?

A variety of interested parties have challenged the CPP in federal court. The case is currently before the U.S. Circuit Court of Appeals for the District of Columbia, and the Supreme Court has stayed the CPP while litigation is pending. Nevertheless, many states and energy companies are continuing to develop climate change mitigation plans—whether for compliance with the CPP or to proactively work toward a clean energy future.

As a result of the rule, EPA projects that CO_2 emissions will be about 32% less than 2005 levels by 2030. Overall, EPA illustrates the projected reductions under a rate-based and mass-based approach as shown in Table 2:

Table 2. CO_2 Reductions Under the CPP. *Source*: EPA, CPP Final Rule.[34]

Cumulative CO_2 Reductions by Year (million tons)			
	2020	**2025**	**2030**
Rate-Based Approach	69	232	415
Mass-Based Approach	81	265	413

[33] Existing plants are those in operation or which have commenced construction by January 8, 2016, and that are not otherwise exempt. *See* CPP Final Rule, 80 Fed. Reg. at 64,715-16 (providing details).
[34] Note that these are EPA's illustrations. They do not correlate to the compliance deadlines in the CPP.

Each state's emission targets are compiled in the table located in Appendix 2. EPA calculated the targets by applying the *best system of emission reduction (BSER)*, which is a term of art in the Clean Air Act (CAA). States must choose between two types of compliance pathways for their power plants—rate-based or mass-based approaches. Within each of these pathways, there are several possible variations. Further, states may develop their own pathways, called "state measures" approaches. This section provides a brief overview of the pathways and variations including trading among the states, while Part II.C. describes their relative merits.

What is BSER?

BSER stands for "Best System of Emission Reduction" and is a requirement of the Clean Air Act. To calculate BSER for the CPP, EPA applied three building blocks to existing fossil-fueled power. Building block 1 assumes that coal efficiency can be improved 2.1 – 4.3%. Building block 2 assumes that states can increase existing natural gas combined cycle (NGCC) utilization to 75%. Building block 3 involves a regional analysis and assumes an increase in non-carbon-emitting new generation that would replace coal and natural-gas-fired power on a pro-rata basis. Applying these reductions, EPA calculated that the average coal emission rate, adjusted for all three building blocks could drop to 1305 lb/MWh, while the average NGCC emission rate could drop to 771 lb/MWh.

Next, EPA applied these rates to the coal and NGCC mix in each state to yield state-specific targets. Notably, neither states nor power plants are limited to the building block assumptions when developing compliance approaches. They are free to adopt a wide variety of approaches, including credit trading, on-site abatement technology, fuel switching, and demand-side approaches, subject to EPA's approval. For details, see EPA, CO_2 Emission Performance Rate and Goal Computation Technical Support Document for CPP Final Rule (Aug. 2015).

Rate-Based Approaches. Using a rate-based approach, states can either (a) require coal- and gas-fired plants to meet the individual performance rates that correspond to BSER; or (b) adopt a state-specific average emission limit. Under either approach, state plans must require fossil fuel-fired plants to account for their CO_2 emission rates and adjust those rates for any emission credits obtained for additions of cleaner generation or efficiency. Any plants generating above the specified rates must purchase compliance credits in order to achieve a lower calculated emission rate, making those plants more expensive to run. Any qualified plants[35] generating below the specified rate will generate compliance credits that can be sold, making those plants less expensive to run. Overall, therefore, the higher emitters will be incentivized to operate less, and lower emitters will be incentivized to operate more.

[35] Existing nuclear power plants to do not qualify to generate rate credits. CPP Final Rule, 80 Fed. Reg. at 64,738.

Mass-Based Approaches. States may also adopt a mass-based approach. Such an approach would be similar to what states already use for several programs under the CAA, including the Acid Rain Program and the Cross-State Air Pollution Rule (CSAPR) for criteria pollutants. To comply with a mass-based approach, states must issue emission allowances, the cost of which fossil fuel-fired operators would factor into decisions about which plants would operate, facilitating the transition to lower-emission sources. All emitting generators would be required to hold allowances equal to their total emissions, making them somewhat more expensive to run. Zero-emitting generators would not require allowances. Over time, zero-emitting generators would be incentivized to run more at lower costs than those of emitting generators.

If states adopt mass-based approaches that apply only to existing sources, they must account for emission increases from *leakage* to new units. That is, states must guard against the possibility that generation from new fossil fuel-fired power plants not covered under the CPP will replace existing fossil fuel-fired power plants that are covered under the CPP, yielding an increase in overall emissions. As described in more detail below, to avoid both leakage and the administrative burden of addressing it, states may choose to include both existing and new sources of electricity in their mass-based plans.

State Measures Approaches. Finally, states may adopt "state measures" plans. These plans would involve a variety of actions to result in sufficient emissions reductions from existing power plants. For example, states could include other industries in a mass-based program, or they could use clean energy standards, renewable portfolio standards, and/or demand-side measures to achieve compliance. State measures plans would require enforceable back-up limits on CO_2 emissions from power plants.

Trading. The CPP contemplates that states may wish to trade emission rate credits or emission allowances. Indeed, EPA has proposed two different model state plans that include either rate-based or mass-based trading. Note that trading is permitted only among states with similar plan types (e.g., mass with mass and rate with rate). Finally, the agency has also proposed a back-up federal plan that it would implement should a state choose not to develop its own compliance plan; the proposed federal plan relies on trading.

What is Leakage?

The concept of leakage relates to the possibility that, because of how the CPP is structured, a state's plan might be in compliance with the CPP yet contribute to an overall increase in emissions. In the final CPP, EPA defined leakage as shifts in generation from existing fossil fuel-fired sources (which are covered by the CPP) to new fossil fuel-fired sources (which are not covered by the CPP). EPA explained that under a rate-based system, leakage is not likely to occur because existing NGCC plants are incentivized to increase their generation to improve average emission rates overall. Indeed, those existing NGCC sources would generate emission rate credits (ERCs), allowing them to out-compete new NGCC. Further, new renewables and new nuclear (including uprates) also generate ERCs, enabling them to similarly be competitive relative to new NGCC (CPP at 64,823).

In a mass-based system, however, all existing emitting generators must hold allowances, making new NGCC more competitive than existing NGCC. If generators relied on new NGCC as a substitute for existing NGCC with allowances, overall emissions could increase. To account for this possibility, EPA requires states adopting mass-based plans to take steps to guard against leakage. EPA offers either of two presumptively acceptable approaches (CPP at 64,889). Under the first approach—referred to as the mass-based plus new source complement approach—states would cover both new and existing sources under a mass-based cap that is slightly higher than a mass-based standard alone. Under the second approach, states would cover only existing fossil fuel-fired generators but adopt EPA's prescribed allowance distribution approach as set forth in the model rule—which limits states' options for how to use their allowances. States not adopting the model rule would be required to otherwise demonstrate that their plans would make leakage unlikely.

EPA acknowledged but did not address in the CPP other possible forms of leakage (CPP at 64,890). One is leakage across state lines. For example, if generation were shifted from a state with a lower rate standard to a state with a higher rate standard, overall emissions could increase. Or if a state with a mass standard imported electricity from a state with a rate standard, the former's emission may not decrease, while the latter's could increase for every increment it exports. Yet in both of these examples, both states would be in compliance.

But the shift could also happen within a state. If generation from a clean source like nuclear were replaced with generation from a new fossil-fueled source, overall emissions would increase. This is a major concern that could significantly undermine CPP goals.

B. Renewables: Important, But Not Enough

As described above, only nuclear energy and non-emitting renewables like wind, solar, and hydropower can generate electricity without GHG emissions. All of these sources of power play an important role in the clean energy future. But if nuclear power were lost, states would find it difficult if not impossible to meet their clean energy goals within the next several decades. Currently, renewable resources cannot supply steady baseload power at the scale provided by nuclear.

First, the scale of nuclear power is considerable. As depicted in Figure 2, even combining all of the non-emitting renewables' power generation in the top nuclear states, they amount to only a fraction of nuclear power plants' generation.

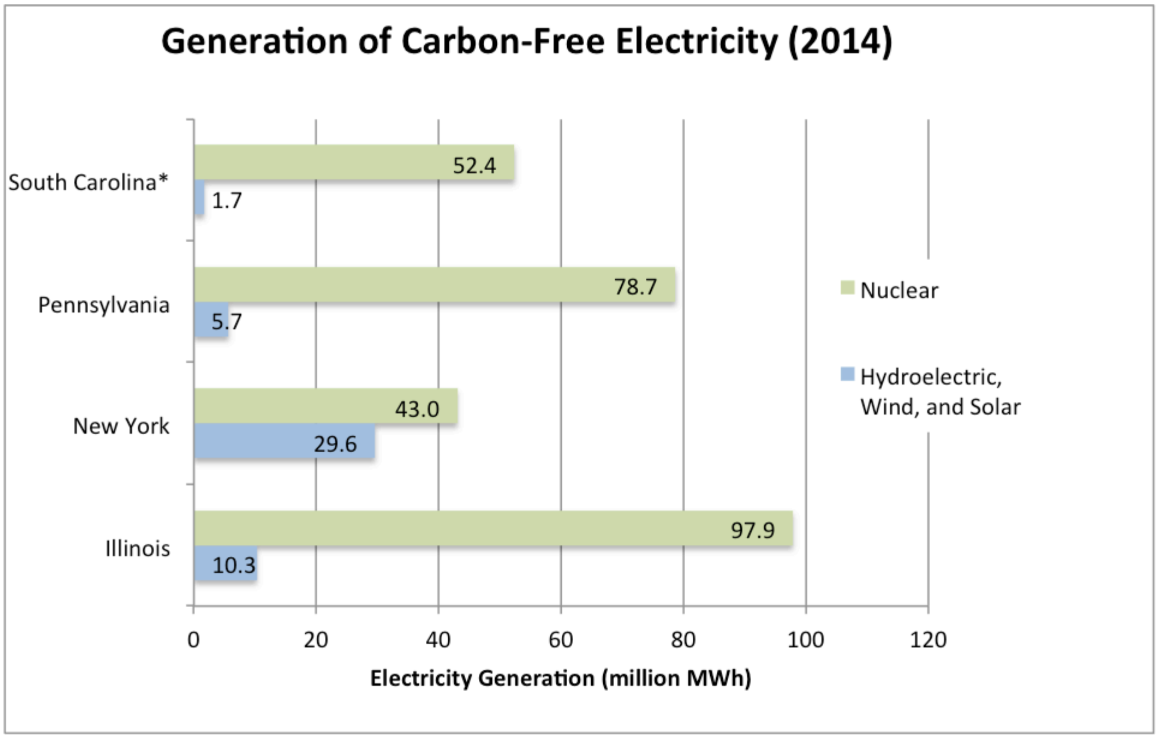


Figure 2. Generation of Carbon-Free Electricity (2014). ***Source*****: EIA.**
***South Carolina totals do not include new nuclear power under construction.**

Second, it is not possible to replace nuclear power with renewables because of their different performance characteristics. Nuclear power provides reliable baseload power—running around the clock regardless of the weather. But wind, solar, and hydropower are variable—they are incapable of providing always-on electricity. The capacity factors in Figure 1 in Part I.A. reflect these differences. Indeed, because of their capacity factors and scale, these non-emitting renewables have considerable *land-use implications*.

Land-Use Implications of Non-Emitting Renewables

Wind, solar, and hydropower are important resources for the low-carbon future. But their land-use implications are an important public policy consideration. In particular, wind and solar are small in both scale and capacity factor, requiring a substantial number of turbines, photovoltaic panels, or concentrated solar equipment to generate the same amount of power as one nuclear power plant. For example, the Indian Point nuclear power plant in New York is situated on 261 acres and generated over 16,400 GWh in 2015. In a study by the National Renewable Energy Laboratory (NREL) estimating the land-use requirements of utility-scale solar, the average total area for solar facilities on a capacity basis was reported at 8.9 acres per MWac. At a 20% capacity factor—which may be high for northeastern and midwestern regions of the country—this would require over 83,000 acres of land to generate the same amount of power as Indian Point, an area well over five times the size of Manhattan.

Source: NREL, Land-Use Requirements for Solar Power Plants in the United States (June 2013); *see also* NREL, Utility-Scale Energy Technology Capacity Factors (last updated Mar. 22, 2016).

Further, replacing nuclear power with renewables would mean a tremendous setback for the CPP because the CPP relies on new renewables to replace existing fossil fuels—not existing clean sources of power. As Figure 3 demonstrates, EPA has estimated that 540 GWh of renewable generation will be needed on the system to meet the CPP 2030 targets.[36] Nuclear generation represents far more power than all of that renewable energy combined. Without nuclear power, these renewable gains would be lost several times over.

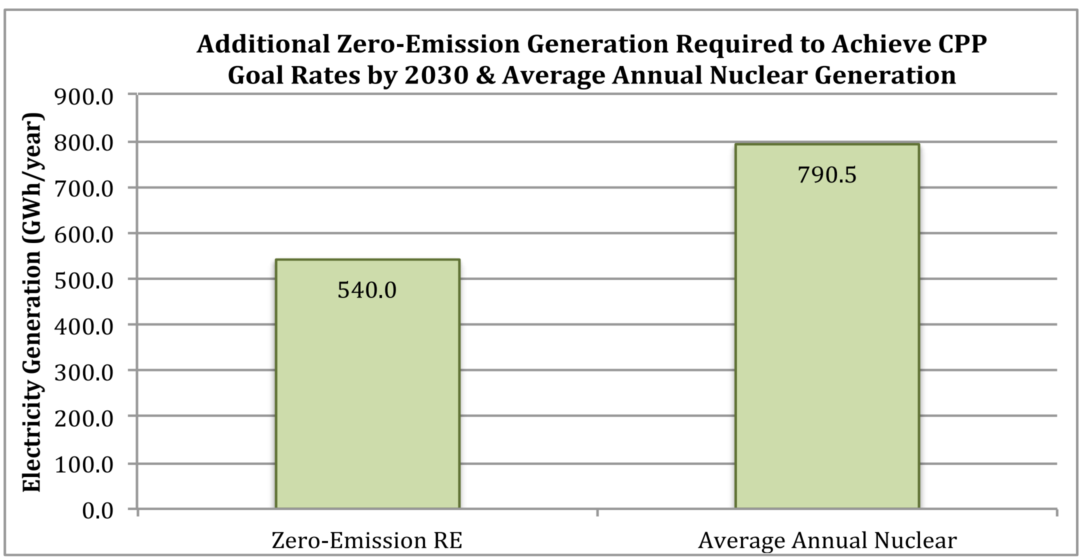


Figure 3. Additional Zero-Emission RE Generation Required to Achieve CPP Goal Rates by 2030 and Average Annual Nuclear Generation. *Sources*: EPA and Table 1 above.[37]

[36] As calculated for purposes of developing BSER. *See* TSD Mitigation Measures, *supra* note 28, at 4-10, Tbl. 4-10.

[37] EPA, Technical Support Document for CPP, Mitigation Measures Ch. 4 (Aug. 2015) [hereinafter "TSD Mitigation Measures"]. EPA conducted these calculations for purposes of developing BSER. For full methodology, see *id.*

EPA estimates that the CPP will lead to CO_2 emission reductions of 413 million tons by 2030.[38] Without nuclear—which avoids over 531 million tons of CO_2 per year—this expectation would be unobtainable.

C. Mass-Based Approaches that Account for New Power Plants Best Achieve a Low-Carbon Future

States should choose climate policies that recognize the value of clean energy and that avoid further distortion of the electricity markets. Moreover, given the necessity of nuclear power to ensuring real emissions reductions, state policies should ensure that existing nuclear power is preserved. As this section describes, the mass-based compliance option that incorporates new sources is the best approach for meeting these criteria.

Challenges Under a Rate-Based Approach. The rate-based compliance pathway—which is based on a lb/MWh limit on emissions—imposes more regulatory burdens on power generators and states than does the mass-based pathway. Rate-based compliance requires burdensome evaluation, measurement, and verification (EM&V) mechanisms. And numerous modeling efforts, including a recent evaluation by PJM, suggest that a rate-based approach will result in more CO_2 emissions in the long run.[39]

Indeed, the rate-based approach does not actually cap CO_2 emissions. Furthermore, although EPA estimated that leakage from existing to new NGCC is not a significant risk in a rate-based plan, it is still possible that leakage could result from new NGCC displacing existing nuclear power.[40] Consider this simplified Example 1:

Example 1: Leakage Under a Rate-Based Plan

Suppose the state's blended rate goal is 1030 lb CO_2/MWh.

- Existing NGCC plant A emits 1000 lb CO_2/MWh.
- Existing nuclear power plant B emits 0 lb CO_2/MWh.
- A new NGCC plant would emit 1030 lb CO_2/MWh.

For demonstration purposes, assume that each plant will generate the same amount of power. Under a rate-based approach where both A and B are operating, only A is counted for CPP purposes, so the rate is:

1000 lb CO_2/MWh = **complies with goal**

But what if the nuclear power plant B retired and was replaced by new NGCC? Each plant is at or below the rate goal and compliant with the CPP.

But actual emissions will have increased by 1030 lb CO_2 for every MWh generated.

If nuclear power plant B had generated 16 million MWh of clean electricity per year, and was replaced by the new NGCC, the state could see an increase of 8.2 million of tons of CO_2 emissions each year.

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[38] Mass-based approach. CPP RIA, *supra* note 9, at ES-6, ES-7, and Tbl. ES-3.
[39] *See* sources cited *infra* note 47.
[40] In this example, we use EPA's net-output rate of 1030 lb CO_2/MWh for new NGCC as set forth in the New Source Rule, *supra* note 28. Note that EPA reported a 2012 national average emission rate for NGCC of 905 lb CO_2/MWh. EPA, TSD Mitigation Measures, *supra* note 28, at 3-4.

Challenges Under a Mass-Based Approach. The mass-based compliance option improves significantly on the rate-based approach for several reasons. It is familiar to states, it is easier to administer, it is already the basis of trade in existing carbon markets, and it limits overall carbon emissions. However, a mass-based plan without a new source complement risks increases in actual emissions because an existing clean energy source, like nuclear, could retire and be replaced with new NGCC, as illustrated by the following simplified Example 2:[41]

Example 2: Leakage Under a Mass-Based Plan Without the New Source Complement

Suppose the state's mass goal is 1200 lb CO_2/year.

- Existing fossil-fueled plant A emits 1200 lb CO_2/MWh.
- Existing nuclear power plant B emits 0 lb CO_2/MWh.
- A new NGCC plant would emit 1030 lb CO_2/MWh.

For demonstration purposes, assume that each plant will generate 1 MWh of power per year. Under a mass-based approach in which both A and B are operating, the annual CO_2 emissions are:

1200 lb CO_2/year = **complies with goal**

But what if the nuclear power plant B retired and was replaced by new NGCC? Only the existing plant A counts, so the mass-based emissions comply with the goal. But the actual new emissions are:

1200 lb CO2/year + 1030 lb CO_2/year = 2230 lb CO_2/year = emissions actually increase.

As mentioned above, EPA offers states two presumptively compliant options for avoiding leakage: a mass-based plus new source complement option and a prescribed allowance distribution approach.[42] Otherwise, states must demonstrate, with supporting analysis, how they will avoid leakage—but it is unclear what showing states would need to make to satisfy EPA.

[41] In reality, it is likely that multiple NGCC plants would be required to replace one nuclear power plant, because of NGCC's lower summertime capacity and capacity factor. EIA, Electric Power Monthly (Apr. 2016) (reporting planned capacity for new NGCC and historic capacity factors).

[42] EPA has proposed a presumptively approvable allowance allocation method that ignores nuclear energy yet directly supports existing natural gas and new renewables. If finalized, these subsidies would lead to further market distortions and exacerbate the current conditions facing the nuclear fleet.

Why Choose Mass-Based Plus New Source Complement? A mass-based approach has numerous benefits for ease of implementation, efficiency, and achieving a clean energy future. Adding a new source complement best values existing clean resources, guards against unintentional increases in emissions, and reasonably accounts for future demand growth:

- *A familiar unit of measure*. States are already familiar with mass-based regulatory approaches under the CAA. These include the acid rain and cross-state air pollution programs. States can therefore take advantage of lessons learned from this method and more efficiently implement the new GHG program.

- *Matches existing trading*. States like California and those in the Regional Greenhouse Gas Initiative (RGGI)[43] already rely on mass-based trading programs for carbon reductions. Mass-based approaches are thus both convenient for working across state lines and familiar to state regulators. Under the CPP, states may trade with other states only if they have each adopted the same compliance option. Thus, states that may wish to join California's market or RGGI will need to use a mass-based approach, and states wishing to trade with those states will also need to use a mass-based approach. Further, all of these existing programs include new sources; a new source complement will provide further compatibility with existing programs.

- *Fewer regulatory burdens*. A mass-based program will involve less regulatory oversight, review processes, and reporting requirements than a rate-based program. Mass-based programs require accounting only for total emissions and allowances. By contrast, rate-based approaches require significant EM&V. Furthermore, including the new source complement further eases states' compliance burdens because it is presumptively approvable. States taking other options must either constrain themselves to EPA's model plan and allocation method, or devise a new, untested method of guarding against leakage.

- *The most certainty*. States, utilities, and regional market operators view mass-based approaches, combined with regional trading systems, as the most stable.[44] Moreover, this approach will result in the most fluid markets.[45] States that take other approaches risk isolation and higher compliance costs.

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[43] The nine RGGI states are: Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New York, Rhode Island, and Vermont—several of which benefit from nuclear energy.

[44] RGGI States' Comments on Proposed Federal Plan and Model Trading Rules for the Clean Power Plan 3, Docket No. EPA-HQ-OAR-2015-0199 (filed Jan. 21, 2016).

[45] Jeffrey Tomich, Clean Power Plan: State regulators, utilities see advantages in mass-based approach to EPA rule, E&E, Oct. 20, 2015.

- *Allows for load growth*. A mass-based cap on overall emissions permits load growth in the form of new low-and zero-emission resources and demand-side measures. Indeed, new nuclear power, like that under construction in Georgia, South Carolina, and Tennessee, provides large-scale clean energy that can meet future demand. In addition, EPA accounted for future demand in setting its new source complements, making the overall cap higher to ensure that states have flexibility in meeting future demand even with emitting generation.[46]

- *Better for preserving nuclear power*. The mass-based plus new source approach best values existing nuclear power for several reasons. First, it implicitly values the existing contribution of zero-carbon energy sources. Second, it values the compliance value of these sources in the future by guarding against leakage to new CO_2-emitting sources.

- *Best for the environment*. Recent modeling suggests that the new source complement reduces CO_2 emissions more than any other compliance pathway.[47] Although EPA has suggested several possible ways for states to guard against leakage, these studies show that the other alternatives do not result in equivalent emission reductions.[48]

III. CONCLUSION

Nuclear power is a critical part of America's clean energy future. It is unmatched in its ability to generate around-the-clock, large-scale, clean power. It avoids hundreds of millions of tons of CO_2 emissions per year, and it provides the largest portion of the nation's clean electric power. As states consider their clean energy policy initiatives for the future, they should adopt approaches that preserve nuclear energy so as to continue to reap the benefits of this clean power source for decades to come.

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[46] EPA, New Source Complements to Mass Goals Technical Support Document for CPP Final Rule (Aug. 2015).

[47] *E.g.*, PJM Interconnection, PJM Clean Power Plan Modeling, Preliminary Phase 1 Long-Term Economic Compliance Analysis Results (May 6, 2016); MISO's Phase II Analysis of the Draft CPP, Final Report (Aug. 2015); *see also* MISO, Results for MISO's Near-Term Analysis of EPA's Final Clean Power Plan (Jan. 20, 2016) (predicting lower costs with mass-based approach).

[48] M.J. Bradley & Assocs., EPA's Clean Power Plan: Summary of IPM Modeling Results 19 (2016); Dallas Burtraw et al., Resources for the Future, Approaches to Address CO_2 Emissions Leakage to New Sources under the Clean Power Plan (2016).

APPENDIX 1 – METHODOLOGY AND ASSUMPTIONS

I. Carbon Value of Nuclear Power

To estimate the carbon value of nuclear power, we used the following equation:

$$G_h \times R_{2020} \times 1 \text{ ton}/2000 \text{ lb} = E_r$$

Where:

- G_h = Average historic generation over the three years of 2015, 2014 and 2013 (MWh/year)
- R_{2020} = EPA's 2020 modeled emission rate for each state (without CPP) (lb CO_2/MWh)
- 1 ton/2000 lb = conversion factor
- E_r = Total emissions CO_2 to replace nuclear power (tons CO_2/year)

Using Pennsylvania as an example, which includes 5 nuclear power plants:

79,302,814 MWh/year x 1486 lb CO_2/MWh x 1 ton/2000 lb = 59.0 million tons CO_2/year

Details about our methodology, assumptions, and limits are presented here and in the body of the report.

The average historic generation values are calculated across the years 2015, 2014, and 2013 using values reported by the Energy Information Administration (EIA). Note that as of June 2016, EIA denotes the 2015 value as preliminary. For the State of Wisconsin, we calculated a two-year historic average over 2015 and 2014 because the Kewaunee nuclear power plant closed in May 2013.

We considered several approaches before selecting a CO_2 emission rate for replacing nuclear energy. Future rates are difficult to estimate because they hinge on a hypothetical electricity fuel mix, which in turn is highly sensitive to the price of natural gas. Moreover, eliminating nuclear power would alter the demand for, and cost of, replacement sources. Further, changes in electricity demand overall will also impact investors' construction decisions, market-clearing prices, and the availability of sources already in operation to replace nuclear power.

If all nuclear power plants were suddenly shut down, of course, we would predict significantly higher emissions (and market-clearing prices) in the near term as many non-baseload sources capable of running continuously would be required to step in and fill the place of nuclear power. Thus, one possible approach is to use non-baseload emission rates reported by the Environmental Protection Agency (EPA). This approach, however, would likely overestimate resulting emissions in the longer term because, among other reasons, it represents only an initial snapshot. We would expect newer, more efficient sources of power to be constructed in the medium-term such that emission levels would decrease somewhat from current non-baseload rates.

Moreover, it is realistic to assume that the future electricity mix will include a larger proportion of non-emitting generation and non-generating sources (such as storage, efficiency, and demand response). Current non-baseload values do not account for these developments. Overall, therefore, non-baseload emission rates would overestimate replacement generation emissions.[49]

Another approach would be to assume that natural gas combined cycle (NGCC) is the most likely candidate to replace nuclear power.[50] EPA has estimated that existing NGCC is capable of increasing its utilization rates to 75%, though the agency has assumed that its purpose for doing so would be to replace existing coal-fired power for CPP compliance.[51] Because existing NGCC will be used to replace existing coal, at least some new NGCC would likely replace nuclear power.[52] Under EPA's new source standards, the required emission rate for NGCC on a net-output basis is 1030 lb CO_2/MWh.[53]

The challenge of assuming new NGCC as a blanket approach across the United States, however, is that it does not account for variability among the states. For example, some states are constrained by lack of pipeline capacity in their ability to add new NGCC; others have higher non-emitting renewables penetration; and still others remain highly dependent on coal. To account for these differences, we chose EPA's projected 2020 emission rate for each state (without the CPP). These rates are presented in Appendix 2 along with the CPP emission targets for each state. Notably, EPA's model accounts for regulatory frameworks, continued capacity additions of renewables and natural gas, and the currently operating mix of electricity fuel sources that are projected to continue operation as of 2020.[54] As described in more detail in the body of this report, these values should be viewed as conservative.

[49] California provides an exception. Its 2012 non-baseload emission rate was 993 lb/MWh, which for comparison purposes is lower than a new NGCC replacement rate of 1030 lb/MWh. However, California's non-baseload electricity profile is heavily influenced by existing hydroelectric power.
[50] John Larsen et al., Rhodium Group, *Assessing the Final Clean Power Plan: Emissions Outcomes*, at 9 (Jan. 2016); *see also* Cmts. of the NEI on EPA's Proposed Rule, Docket No. EPA-HQ-OAR-2015-0199, at 7 (Jan. 21 2016) (applying this approach).
[51] *See generally* TSD Mitigation Measures, *supra* note 28, Ch. 3.
[52] EPA used this NGCC emission rate for calculating states' new source complements in the CPP. EPA, Technical Support Document, New Source Complements to Mass Goals (Aug. 2015).
[53] CPP Final Rule, 80 Fed. Reg. 64,510 (Oct. 23, 2015).
[54] EPA's Power Sector Modeling Platform, which includes documentation and assumptions, is available at https://www.epa.gov/airmarkets/power-sector-modeling-platform-v515 (last visited June 16, 2016).

II. Social Cost of Carbon

As described in the Report, the social cost of carbon is an estimate used by many federal agencies to incorporate the social costs associated with carbon dioxide emissions into cost-benefit analyses of major regulatory actions. Developed by an interagency working group and subjected to peer review, these estimates reflect modeled costs to agriculture, human health, property values, and indoor climate control, among others. Because many of the costs of climate change are expected in the future, the discount rate is one of the most important factors that can influence the present value of such costs. Moreover, competing models suggest much higher social costs of carbon than those used by regulatory agencies.[55] Thus, it is likely that our reported values are conservative on this basis as well. The following Table presents the estimates used by EPA for the CPP:[56]

Table 4-2. Social Cost of CO_2, 2015-2050 (in 2011$ per short ton)*

	Discount Rate and Statistic			
Year	5% Average	3% Average	2.5% Average	3% (95th percentile)
2015	$11	$35	$54	$100
2020	$12	$40	$60	$120
2025	$13	$44	$65	$130
2030	$15	$48	$70	$150
2035	$17	$53	$75	$160
2040	$20	$58	$81	$180
2045	$22	$62	$86	$190
2050	$25	$66	$91	$200

* These SC-CO_2 values are stated in $/short ton and rounded to two significant figures. The SC-CO_2 values have been converted from $/metric ton to $/short ton using the conversion factor 0.90718474 metric tons in a short ton for consistency with this rulemaking. This calculation does not change the underlying methodology nor does it change the meaning of the SC-CO2 estimates. For both metric and short tons denominated SC-CO_2 estimates, the estimates vary depending on the year of CO_2 emissions and are defined in real terms, i.e., adjusted for inflation using the GDP implicit price deflator.

Source: EPA, CPP RIA, Tbl. 4-2, at 4-8.

EPA used short tons and 2011 dollars for its cost-benefit analysis in the CPP, a method we employ here. The costs are $12, $40, $60, and $120 per short ton of CO_2 emissions in 2020 (respectively, at discount rates of 5, 3, 2.5, and 95th percentile of all three models at 3% rate).[57] These values were selected because they match those used in the CPP. This simplifies comparisons for interested readers and ensures consistency given our focus in Part III on CPP compliance. For simplicity, we report the 3% discount rate in Table 1 in the Report.

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[55] *See, e.g.*, Frances C. Moore & Delavane B. Diaz, *Temperature impacts on economic growth warrant stringent mitigation policy*, 5 Nature Climate Change 127 (Jan. 2015) (arguing for an order of magnitude higher).

[56] EPA estimated these SCC values using the estimates set forth in the Technical Support Document: Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12,866 (May 2013, revised July 2015). For further details, see CPP RIA, *supra* note 4, at 4-3 to 4-9. These values are frequently updated, and other estimates have used values adjusted differently for the year of interest. For example, the Brattle Group has applied a 2015 value of $43 per ton, expressed in 2015 dollars at a 3% discount rate. Berkman & Murphy, *supra* note 23, at 13.

[57] CPP Final Rule, 80 Fed. Reg. at 64,931; CPP RIA, *supra* note 4, at 4-8.

Appendix 2 – Table: State Targets Under Clean Power Plan and Nuclear Power's Avoided Emissions

State	2020 Projected Emission Rate *(without CPP)* *(lb CO_2/Net MWh)*	CPP Final Targets			CO_2 Avoided by Nuclear *(million tons)*
		Rate-Based *(lb CO_2/ Net MWh)*	Mass-Based *(million tons CO_2)*	Mass & New Source Complement *(million tons CO_2)*	
Alabama	1,386	1,018	56.9	57.6	28.6
Arizona	1,409	1,031	30.2	32.4	22.6
Arkansas	1,551	1,130	30.3	30.7	10.4
California	712	828	48.4	52.8	6.3
Connecticut	858	786	6.9	7.1	7.2
Florida	1,170	919	105.1	106.6	16.1
Georgia	1,135	1,049	46.3	46.9	18.8
Illinois	1,705	1,245	66.5	67.2	83.1
Iowa	1,456	1,283	25.0	25.3	3.6
Kansas	1,870	1,293	22.0	22.2	7.6
Louisiana	1,235	1,121	35.4	35.8	10.2
Maryland	1,411	1,287	14.3	14.4	10.2
Massachusetts	808	824	12.1	12.3	2.0
Michigan	1,588	1,169	47.5	48.1	23.7
Minnesota	1,658	1,213	22.7	22.9	9.8
Mississippi	1,107	945	25.3	25.7	6.0
Missouri	1,950	1,272	55.5	56.0	9.1
Nebraska	1,930	1,296	18.3	18.5	8.8
New Hampshire	636	858	4.0	4.1	3.2
New Jersey	981	812	16.6	16.9	16.0
New York	902	918	31.2	31.7	19.9
North Carolina	1,273	1,136	51.3	51.9	26.2
Ohio	1,742	1,190	73.8	74.6	14.4
Pennsylvania	1,486	1,095	89.8	90.9	58.9
South Carolina	1,202	1,156	26.0	26.3	32.0
Tennessee	1,517	1,211	28.3	28.7	20.5
Texas	1,515	1,042	189.6	198.1	29.5
Virginia	959	934	27.4	27.8	14.0
Washington	634	983	10.7	11.6	2.8
Wisconsin	1,940	1,176	28.0	28.3	9.4

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