The Nuclear Industry's Contribution to the U.S. Economy

PREPARED FOR

NUCLEAR MATTERS

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This report was prepared for Nuclear Matters. All results and any errors are the responsibility of the authors and do not represent the opinion of The Brattle Group, Inc. or its clients.

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I. Executive Summary

Nuclear power currently accounts for 19% of U.S. power production, but several factors are at play that may threaten some nuclear generators and could diminish the nuclear industry's contribution to our electricity supply and the U.S. economy. These factors include limited recognition of carbon as a social cost, as well as market factors such as low natural gas prices, flat electricity demand growth, and transmission constraints. At the request of Nuclear Matters, The Brattle Group has estimated the value of the entire nuclear industry to the U.S. economy, and its contribution to limiting greenhouse gas emissions, to inform the discussion of whether and how these factors should be addressed.

Our analysis of the incremental effect of the U.S. nuclear industry has determined that it:

- **contributes approximately $60 billion annually to gross domestic product** (GDP) ($103 billion annually in gross output).
- **accounts for about 475,000 full time jobs** (direct and secondary).
- **helps keep electricity prices low** – without nuclear generation, retail rates would be about 6% higher on average.
- is responsible for nearly $10 billion annually in additional federal tax revenues, and $2.2 billion in additional state tax revenues, because of the boost it gives to the economy.
- **prevents 573 million tons of carbon dioxide emissions**, worth another $25 billion annually if valued at the federal government's social cost of carbon estimate.
- prevents over 650,000 tons of nitrogen oxides (NO_X) and over one million tons of sulfur dioxide (SO_2) emissions annually, together valued at $8.4 billion based on the National Academy of Science's externality cost estimates.

These values reflect the incremental contribution of the nuclear industry to the economy, measured by comparing the performance of the U.S. economy with and without the nuclear fleet. This approach nets off the contribution of the alternative generation that would be necessary if the nuclear industry did not exist, to determine its incremental contribution. Without nuclear plants, the economy would rely more heavily on existing and new natural gas-fired generating plants, and to a lesser extent, additional generation from existing coal-fired plants. This greater use of fossil generation would mean higher electricity prices – wholesale prices would be 10% higher on average; retail prices would rise about 6%. It is this effect on electricity prices that accounts for the majority of nuclear's overall incremental economic impact.

Increased fossil use would also result in much higher carbon dioxide emissions and greater emissions of criteria pollutants such as NO_X and SO_2. Large-scale renewable energy would probably not substitute significantly for nuclear; intermittent renewable generation is not a direct substitute for the baseload profile of nuclear.

The magnitude of the power price effects, and ultimately the economic and jobs effects, could depend on movements in the price of natural gas, since it plays a primary role in setting power prices in most U.S. regions.[1] Lower natural gas prices are a primary reason for the current threat to some nuclear plants, of course, but the sensitivity of this analysis to gas prices also points out that nuclear plants help to protect consumers and the economy from the volatility of gas prices. These effects go well beyond what consumers pay for natural gas directly, and even beyond what they pay for electricity, since power prices have a significant effect on the larger economy, as is demonstrated by this study.

Absent nuclear, consumers would pay more for electricity, the economy would suffer both in terms of GDP and jobs, and we would face substantially higher emissions of CO_2 and other pollutants.

II. Background

Sixty two nuclear plants comprising 99 reactors operate in the United States, representing over 100,000 megawatts (MW) of capacity and almost 800 million megawatt hours (MWh) of annual generation, as summarized in Table 1.[2] These plants operate in 30 states, with many plants clustered in the Northeast, Midwest, and Southeast, as shown in Figure 1. Table 2 and the illustration in Figure 2 define the major electric generating regions in the U.S. Table 2 shows that nuclear accounts for approximately 9% of U.S. generating capacity (almost 20% in some regions), and provides 19% of total U.S. electricity generation.[3] PJM, MISO, and VACAR have particularly large amounts of nuclear, together accounting for over half of U.S. nuclear capacity, though nuclear power accounts for large shares in several other regions as well.

Table 1: Summary of Nuclear Generation in the U.S.

	Variable	Value
[1]	Number of nuclear plants	62
[2]	Number of nuclear reactors	99
[3]	Total capacity (MW)	100,430
[4]	Estimated generation (MWh)	798,400,000

The nuclear industry is an important economic engine both nationally and locally. Nuclear plants typically directly employ 400 to 900 workers, often making them major employers in their

1 For example, the economic and jobs effects could be up to twice the values shown here if gas prices were to return to levels seen just a couple years ago.

2 Data from Ventyx's Energy Velocity.

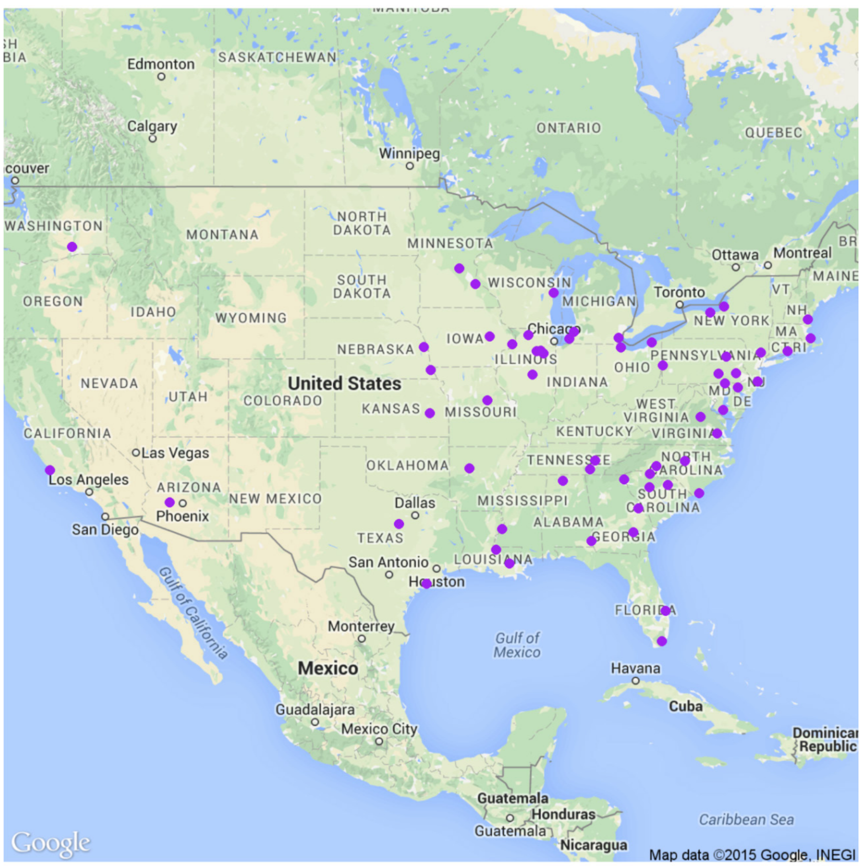
3 These regions, which are based on reliability assessment areas established by the North American Reliability Council (NERC), correspond to the major electricity markets in the U.S.

local communities.[4] According to the U.S. Bureau of Labor Statistics and the Nuclear Energy Institute, the nuclear electric power generation sector employs directly between 50,000 and 60,000 workers. Nuclear vendors and manufacturers add another 60,000 positions.

The nuclear industry, in addition to its contribution to economic activity, has also been recognized for providing reliable supply and for its carbon-free emissions profile. However, some plants are struggling financially at present, for reasons that include limited recognition of carbon emissions as a social cost, low natural gas prices, lack of electricity demand growth, and transmission constraints.

At the request of Nuclear Matters, and to inform the debate regarding whether and how these factors should be addressed, The Brattle Group has estimated the value of the U.S. nuclear fleet to the U.S. economy, as well as its contribution to limiting greenhouse gas emissions. This paper addresses the nuclear industry's contribution to economic activity as measured by its contribution to GDP, employment (direct and secondary), its role in moderating electricity prices, and its role in controlling carbon dioxide emissions.

Figure 1: Locations of U.S. Nuclear Plants



4 NEI Nuclear Factsheet, http://www.nei.org.

Table 2: The Importance of Nuclear Power by Reliability Region

	Region	Capacity		Generation	
		Share of U.S. nuclear capacity in region	Nuclear share of region's capacity	Share of U.S. nuclear generation in region	Nuclear share of region's generation
[1]	California	2%	3%	2%	6%
[2]	Central	8%	15%	8%	27%
[3]	Desert Southwest	4%	7%	4%	24%
[4]	ERCOT	5%	4%	5%	12%
[5]	Florida Reliability	3%	6%	3%	12%
[6]	New England	4%	11%	4%	24%
[7]	New York	5%	12%	5%	26%
[8]	Northwest Power Pool	1%	2%	0%	1%
[9]	MISO	13%	6%	13%	15%
[10]	PJM	30%	18%	31%	30%
[11]	Southeastern	6%	8%	6%	19%
[12]	Southwest Power Pool	2%	3%	2%	7%
[13]	VACAR	15%	18%	15%	50%
[14]	Basin	0%	0%	0%	0%
[15]	Rocky Mountain	0%	0%	0%	0%
	Total	100%		100%	
	Aggregate Share		9%		19%

Figure 2: Electric Reliability Regions of the U.S.

III. The Nuclear Industry Makes a Considerable Contribution to the U.S. Economy

We have estimated the nuclear industry's contribution using Regional Economic Models, Inc. (REMI), a widely-used dynamic input-output model of the U.S. economy, linked with a simplified Brattle model of the U.S. electricity sector to better capture the dynamics of power markets and prices.[5] By linking these models, we are able to measure the value of the U.S. economy with and without the nuclear industry, providing the most accurate picture of the fleet's incremental contribution to the economy.

This analysis indicates that the current nuclear industry makes a significant contribution to keeping electricity costs down, and this has a substantial effect on the economy. Netting off the value of the alternative electric generation mix that would substitute if it did not exist, the nuclear industry is responsible for substantial economic output and accompanying employment and tax revenues. Table 3 summarizes our high-level findings.

Table 3: Net Contribution of U.S. Nuclear Industry

	Average Annual (2015-2024)
Direct and Secondary Employment *(jobs)*	475,000
Direct and Secondary Output *(2015 dollars)*	$103 billion
Direct and Secondary GDP *(2015 dollars)*	$60 billion
Direct and Secondary State Tax Revenues *(2015 dollars)*	$2.2 billion
Direct and Secondary Federal Tax Revenues *(2015 dollars)*	$9.9 billion

The nuclear industry is responsible for contributing $60 billion annually to GDP ($103 billion to gross output) after netting off the contribution of alternative generation, and providing nearly 475,000 incremental primary and secondary jobs.[6] The nuclear industry also has a substantial

[5] For more information on the REMI model, see www.remi.com.

[6] We report both GDP and gross output since both are useful economic statistics. GDP is the most widely-used measure of national income. It reflects value added, which includes industry sales to other industries and to final users minus the value of its purchases from other industries. Gross output

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impact on federal and state tax revenues; the nuclear industry's effect on the economy leads to almost $10 billion more in annual federal tax revenues and another $2.2 billion in higher state tax revenues.

Below, we summarize the impact of the nuclear industry on:

- The electricity generation mix
- The cost of electricity
- Economic output and GDP
- Employment (direct and secondary)
- Federal and state tax revenues

Further details regarding our data, assumptions, and modeling results are presented in the technical appendix.

A. Impact on Electric Generation Mix

As shown in Figure 3, without nuclear power, electricity demand would be met mostly by increased reliance on natural gas-fired generation, and to a lesser extent, greater utilization of existing coal plants. The amount of energy provided by natural gas-fired generators would increase by almost half, from 26% to 39% of total energy in 2015, and coal generation would increase by 16%, from 38% to 44% of total generation. Large-scale renewable energy would probably not be significantly different; intermittent renewable generation alone is not a direct substitute for the baseload profile of nuclear, and at current capital and fuel prices (absent other policy changes), natural gas generation is generally more cost-effective. However, higher electricity prices might somewhat reduce demand for grid-based electricity, by inducing efficiency, conservation, and switching to alternative fuels or electricity sources.

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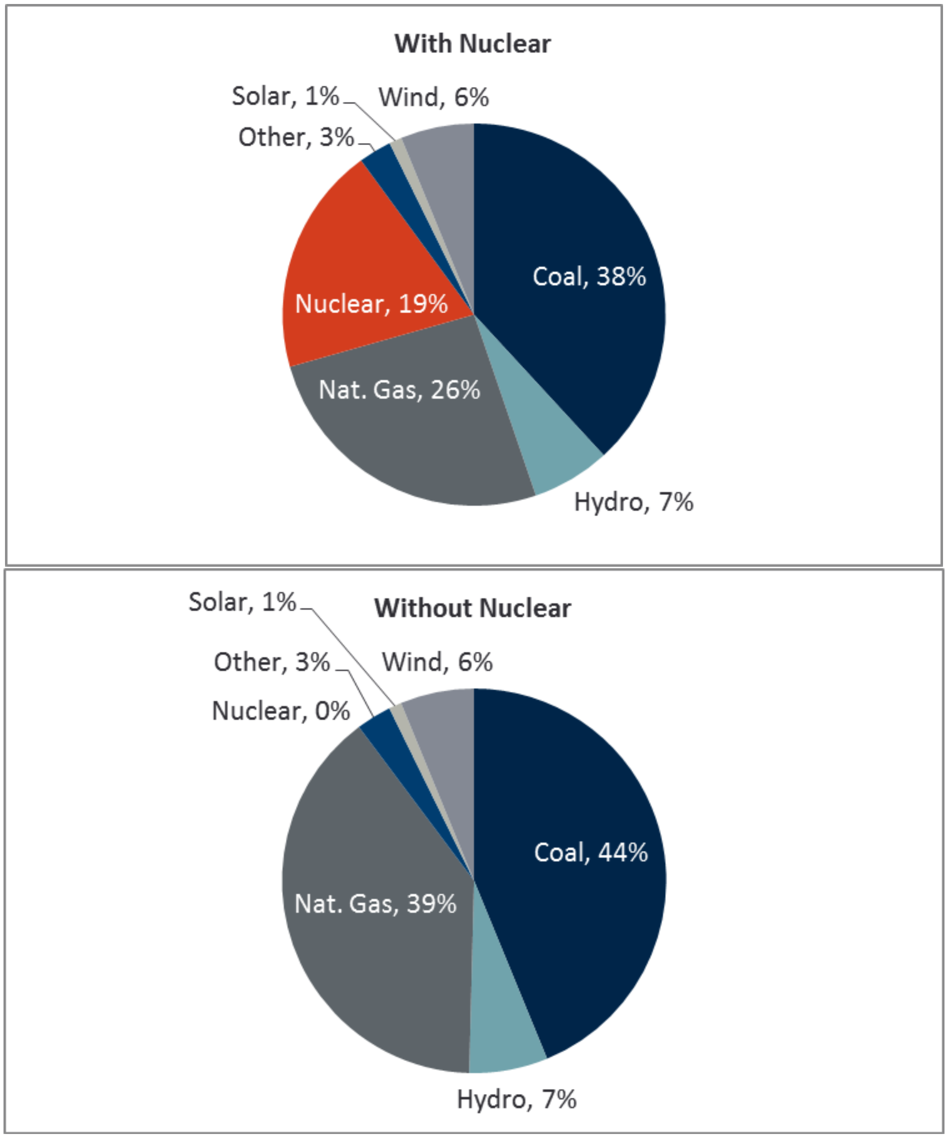
is a measure of industry sales, which includes sales to final users and intermediate sales to other industries. This results in a form of double counting, but does not prevent the measure from being a meaningful indicator of how individual industries perform relative to one another.

Figure 3: Generation Mix in the United States, 2015



B. IMPACT ON ELECTRICITY PRICES

Nuclear power's influence on the U.S. economy is primarily the result of the fleet's impact on electricity prices. Absent the nuclear industry, electricity demand would be met by increased development of natural gas-fired plants and higher utilization of existing gas- and coal-fired plants. This alternative generation mix would mean higher electricity prices across the country. As shown in Table 4, on average wholesale electricity prices would be 10% higher; this corresponds to about 6% higher prices at retail, on average.[7] Some regions would face a considerably higher impact because of their heavy reliance on nuclear generation, and/or low current power prices. Higher electricity prices hurt the economy primarily by reducing residential, commercial, and industrial spending on other goods and services.

Table 4: U.S. Nuclear Industry Avoids Higher Electricity Prices
(All-in Wholesale Electricity Prices with and without Nuclear, Average Annual $/MWh, 2015-2024)

	Region	Wholesale price with nuclear	Wholesale price without nuclear	Wholesale price change	% change in wholesale price
[1]	California	$45.28	$46.85	$1.57	3%
[2]	Central	$36.11	$41.80	$5.69	16%
[3]	Desert Southwest	$31.34	$33.18	$1.83	6%
[4]	ERCOT	$36.80	$37.57	$0.77	2%
[5]	Florida	$49.53	$52.15	$2.61	5%
[6]	New England	$56.95	$70.35	$13.40	24%
[7]	New York	$55.21	$63.26	$8.05	15%
[8]	Northwest Power Pool	$13.85	$18.57	$4.73	34%
[9]	MISO	$33.03	$36.14	$3.11	9%
[10]	PJM	$46.14	$51.16	$5.02	11%
[11]	Southeastern	$37.37	$41.20	$3.83	10%
[12]	Southwest Power Pool	$41.58	$44.65	$3.07	7%
[13]	VACAR	$34.85	$45.27	$10.43	30%
[14]	Basin	$32.24	$32.24	$0.00	0%
[15]	Rocky Mountain	$38.63	$38.63	$0.00	0%
	Weighted Average	$39.80	$43.98	$4.18	10%

The magnitude of the power price effects shown here and ultimately the larger economic effects depend on the price of alternative sources of electricity.[8] The price of natural gas is particularly

[7] The effect on the retail electricity price is estimated as the product of the change in wholesale electricity prices and the share of retail rates accounted for by the wholesale price. For this, we use a national average value of 60%, from EIA Annual Energy Outlook data.

[8] For example, the economic and jobs effects could be up to twice the amounts shown here if gas prices were to return to levels seen just a couple years ago. Of course, nuclear plants would not face the same economic threat at higher gas prices, but nuclear retirements are irreversible; once a nuclear plant retires, a gas price rebound will magnify the economic and jobs losses but will not revive the plant.

important since it plays a primary role in setting power prices in most regions of the U.S. Natural gas prices have been volatile in recent years, and have fallen significantly as a result of new shale gas production techniques. By changing the cost of the alternative to nuclear power, different natural gas prices would change the effect that nuclear has on power prices, and alter its effect on the larger economy. Lower natural gas prices are a primary cause of the current threat to some nuclear plants, of course, but the sensitivity of this analysis to gas prices also points out that nuclear plants help to protect consumers and the economy from the effects of gas price volatility. These effects go well beyond what consumers pay for natural gas directly, and also beyond what they pay for electricity, since power prices have a significant effect on the larger economy, as is shown in the next section. Although the drop in natural gas prices over the past few years has been positive for consumers and the economy, it also creates exposure to gas price volatility.

C. Impact on Economic Output

The nuclear industry contributes on average $60 billion to annual GDP and $103 billion to gross output, largely through the power price effects shown above. These figures include both direct and secondary economic activity attributable to nuclear plants, net of the economic activity associated with alternative generation that would be necessary in their absence.[9] Table 5 presents the net impact with respect to gross output and GDP for 11 states that rely on nuclear plants for a substantial share of electricity generation. Nuclear plants contribute the most to economic output in Texas and New York, followed by Illinois, Pennsylvania, and Ohio. In some states where nuclear is not a particularly large part of electricity supply, such as Texas, it can nonetheless have a large overall economic effect simply because of the size of the state's economy – a modest effect on a very large economy can result in a large absolute effect. The economic sectors most affected are shown in Table 6. The largest effect is found in the manufacturing sector, followed by the construction sector and real estate sectors. These three sectors account for 46% of the economic contribution attributable to nuclear power plants.

[9] In this context, secondary impacts include effects that are sometimes termed "indirect" and "induced."

Table 5: Net Economic Impacts by State (Average Annual Impacts, 2015-2024)

State	Direct and Secondary Output *(billions of 2015 dollars)*	Direct and Secondary GDP *(billions of 2015 dollars)*
Texas	8.8	5.0
New York	7.2	4.4
Illinois	5.4	3.3
Pennsylvania	4.5	2.5
Ohio	4.3	2.3
Michigan	3.4	1.8
Massachusetts	3.6	2.1
New Jersey	2.7	1.6
Maryland	1.7	1.0
Arizona	1.6	1.1
New Hampshire	1.0	0.6
Remaining states	59.2	33.9
Total	103	60

Note: Numbers may not sum due to rounding.

Table 6: Net Economic Output Impacts by Sector (Average Annual Direct and Secondary Impacts, 2015-2024)

Sector	Direct and Secondary Output *(billions of 2015 dollars)*
Manufacturing	26.4
Construction	11.6
Real Estate and Rental and Leasing	9.4
Finance and Insurance	8.7
Retail Trade	7.0
Professional, Scientific, and Technical Services	5.9
Health Care and Social Assistance	5.8
Wholesale Trade	4.9
Information	4.7
Mining	4.3
Other	14.7
Total	103

Note: Numbers may not sum due to rounding.

D. Impact on Employment

The nuclear industry accounts for nearly 475,000 direct and secondary jobs incrementally in the U.S. economy, as shown in Table 7. The employment sectors most influenced by the industry include sales and administrative support; construction; and management, business, and financial occupations, which together represent about 53% of jobs attributable to nuclear power. Cleaning and maintenance, production, health care, transportation, and installation, maintenance and repair make up another 33%. The largest contributions to employment are in Texas, New York, Ohio, and Pennsylvania, as shown in Table 8. Not surprisingly, the employment impact is distributed geographically in much the same way as the overall economic impact (comparing Table 8 to Table 5). As with economic impact, the jobs impact occurs mostly indirectly; not as employment within the nuclear sector itself, but as enhanced employment in other sectors primarily caused by the economic effect of lower power prices.

Table 7: Net Employment Impacts by Sector
(Average Direct and Secondary Impacts, 2015-2024)

Sector	Direct and Secondary Employment *(jobs)*
Sales and related, office and administrative support occupations	141,700
Construction and extraction occupations	56,100
Management, business, and financial occupations	51,300
Building and grounds cleaning and maintenance, personal care and service occupations	33,900
Production occupations	33,500
Healthcare occupations	32,500
Transportation and material moving occupations	31,700
Installation, maintenance, and repair occupations	24,400
Food preparation and serving related occupations	23,400
Computer, mathematical, architecture, and engineering occupations	21,700
Other	24,200
Total	475,000

Note: Numbers may not sum due to rounding.

Table 8: Net Employment Impacts by State
(Average Annual Direct and Secondary Impacts, 2015-2024)

State	Direct and Secondary Employment *(jobs)*
Texas	38,400
New York	26,800
Ohio	21,600
Pennsylvania	20,900
Illinois	19,300
Michigan	16,100
New Jersey	11,700
Maryland	9,800
Massachusetts	9,700
Arizona	5,700
New Hampshire	2,900
Remaining states	291,600
Total	475,000

Note: Numbers may not sum due to rounding.

E. Impact on Federal and State Tax Revenues

The nuclear industry is also responsible for substantial incremental federal and state taxes. Average annual federal tax payments are higher by almost $10 billion, and annual state tax payments higher by $2.2 billion, because of nuclear. This is due to the industry's contribution to economic activity ($103 billion in output; $60 billion in GDP), which results in substantially higher tax revenues across many sectors. These payments are summarized in Table 9.

Table 9: Net Annual Federal and State Tax Payments Attributable to
Economic Activity Related to the U.S. Nuclear Industry

	Average Annual (2015-2024)
Direct and Secondary State Tax Revenues *(2015 dollars)*	$2.2 billion
Direct and Secondary Federal Tax Revenues *(2015 dollars)*	$9.9 billion
Total Federal and State Tax Revenues *(2015 dollars)*	$12.1 billion

Note: Numbers may not sum due to rounding.

F. The Nuclear Industry Prevents Substantial Carbon Dioxide and Criteria Pollutant Emissions

The nuclear industry prevents substantial emissions of carbon dioxide (CO_2), SO_2, NO_X, and particulate matter (PM) compared to the additional natural gas and coal fired generation that would be necessary without it.[10] Average annual CO_2 emissions would be about 573 million tons higher absent nuclear power generation, which represents a 23% increase over power sector emissions with nuclear (Figure 4). Similarly, power sector SO_2 emissions would be one million tons higher, and NO_X emissions would be over 650,000 tons higher – about a 13% and 18% increase, respectively (Figure 5). Particulate matter emissions would be about 19% higher absent the nuclear industry (Figure 6). These reductions are summarized in Table 10.

Table 10: Emissions Prevented by the U.S. Nuclear Industry (Average Annual, 2015-2024)

Pollutant	Avoided emissions *(thousands of tons)*
CO_2	573,160
SO_2	1,055
NO_X	657
PM 2.5	64
PM 10	78

The social cost of these emissions can be estimated using the federal government's social cost of carbon dioxide emissions ($43.31/ton) and the National Academy of Science's externality estimates for SO_2, NO_X, PM-2.5, and PM-10.[11] Evaluated at these rates as shown in Table 11, the avoided social cost of CO_2 is almost $25 billion per year, and the avoided costs of SO_2 and NO_X are $7.2 billion and $1.2 billion, respectively. The avoided costs of particulate matter emissions are approximately $0.7 billion. These costs reflect environmental and human health damages and are independent of and in addition to the direct and secondary economic impacts addressed elsewhere in this report. They reflect costs incurred by society, not directly by the economy; the subsequent economic implications of these social costs are not reflected in the economic results above.

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10 Particulate matter is regulated at two sizes: 2.5 micrometers and 10 micrometers.

11 The cost per ton of CO_2 reflects a 3% discount rate assumption, expressed in 2015 dollars.

Table 11: Value of Emissions Prevented by the U.S. Nuclear Industry (Average Annual, 2015-2024)

Pollutant	Avoided emissions *(thousands of tons)*	Emissions cost per ton *($/ton)*	Avoided emissions value *(billions of 2015 dollars)*
CO_2	573,160	$43	$24.82
SO_2	1,055	$6,789	$7.16
NO_X	657	$1,873	$1.23
PM 2.5	64	$11,119	$0.71
PM 10	78	$538	$0.04
Total			$33.97

Sources:
Carbon costs come from the Interagency Working Group on Social Cost of Carbon, United States Government.
SO2, NOx, PM-2.5, and PM-10 costs come from "Hidden Cost of Energy: Unpriced Consequences of Energy Production and Use" by the National Research Council.

Figure 4: U.S. Nuclear Industry Prevents Higher CO_2 Emissions (Average Annual, 2015-2024)

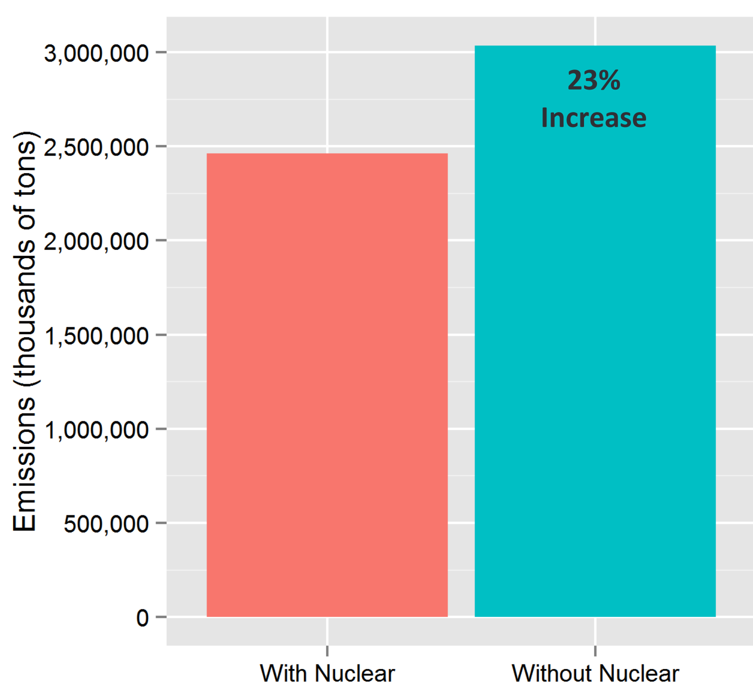

Figure 5: U.S. Nuclear Industry Prevents Higher NO_X and SO_2 Emissions (Average Annual, 2015-2024)

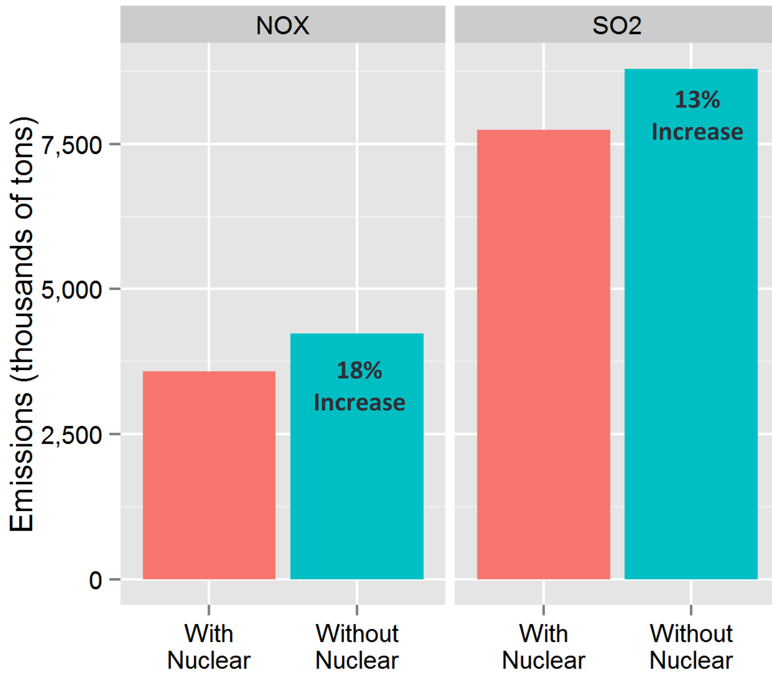

Figure 6: U.S. Nuclear Industry Prevents Higher PM Emissions (Average Annual, 2015-2024)

IV. Technical Appendix

A. Methodology

This appendix describes the electricity market and economic impact models that we use to determine the economic impacts of the nuclear industry. These impacts are calculated by comparing the performance of the economy with the current nuclear industry, to the performance that would be observed if the fleet did not exist (and alternative generation sources were to take the place of nuclear). The difference between actual output, employment, and tax revenue with the fleet in operation, and the levels that would prevail absent the fleet, gauges the net effect of the fleet on the economy. We rely primarily on two models to implement this comparison. First, we use REMI, a commercially-available dynamic input-output model of the U.S. economy, to estimate economic output, employment, and tax revenues.[12] In combination, we use a proprietary model of the electricity sector to estimate power system performance and the energy and capacity prices that would prevail in the absence of nuclear plants. Although this is a simplified model of the electric sector, it yields reasonable first-order measures of power sector effects, and linking it with REMI enables us to capture power sector effects that would not otherwise be captured in an input-output model of this type.

B. Overview of Model Interaction

Our electricity model allows us to estimate how electric generating capacity and utilization changes absent the availability of existing nuclear plants, and how electricity prices would differ as a result. Changes in capacity, utilization, and price are then introduced to REMI, a macro-economic model widely used to estimate economic impacts of large-scale projects and policy changes. The details of the model components are described below.

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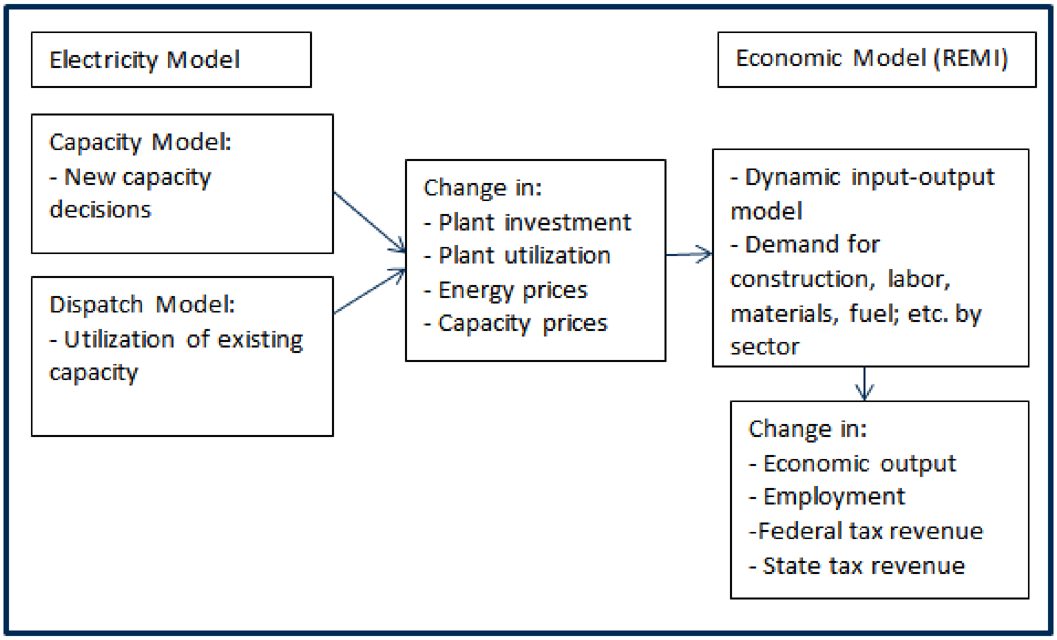
12 For more information about REMI, see http://www.remi.com/the-remi-model.

Figure 7: Model Layout



C. ELECTRICITY MARKET MODELING METHODOLOGY

The electricity market model includes two sub-models in order to estimate how generating capacity, capacity utilization, and electricity prices would change in the absence of nuclear plants in the United States. Although this is a highly simplified representation of the power system, these sub-models together give a reasonable characterization of the approximate power price effects of nuclear generation. The first sub-model is a capacity planning model where each region that does not have enough capacity to meet reserve margins adds capacity until reserve margins are met, from the available capacity types. Capacity is added in the way that achieves lowest overall cost, by minimizing discounted capital and operating costs in each region, subject to having enough capacity to meet reserve margins.

The second sub-model is an economic dispatch model for each region. We split each year into 96 representative hours – one for each season-hour combination (4 seasons x 24 hours = 96), assuming that each season-hour combination is representative. We adjust commodity prices for seasonality and location. For example, natural gas prices in New England are considerably closer to Henry Hub prices in summer than they are in winter (Henry Hub is a widely-used market reference pricing point for natural gas in the U.S.). The dispatch model assumes that plants will sell electricity at or above their marginal cost and plants are dispatched economically (i.e., total generation costs are minimized subject to the constraint that total generation is equal to demand in each hour). The dispatch model is characterized for each region-season-hour combination for each year from 2015 to 2024, estimating the electric energy price ($/MWh) in each market, and the amount of power generated by each power plant.

The dispatch model also includes a capacity market component, where each plant implicitly bids its fixed costs less expected energy revenue. The capacity market clears at the point where the total capacity secured is equal to expected peak demand in that region, plus reserve margin. This model estimates the capacity value ($/kW-yr) in each market.

Once we have obtained energy price ($/MWh), capacity price ($/kW-yr), plant-level generation, and plant-level capacity from the dispatch model for the baseline case, we remove all the nuclear plants from the system and run the model again. The results of the two model runs (with and without nuclear) are compared to determine the electricity market impacts of nuclear power, as measured by energy and capacity price changes and generation mix changes. These are then used as inputs to the dynamic macroeconomic model.

D. Economic Impact Modeling Methodology

In order to calculate economic impacts of the nuclear industry, we rely upon the REMI model. REMI is a dynamic input-output model that is widely used to measure policy impacts on economic output and employment. Our REMI model incorporates the following inputs:

- Change in electricity costs faced by consumers (caused by change in energy and capacity market prices faced by utilities, which comes from the electric market model);
- Elimination of revenue for nuclear generators;
- Change in energy and capacity revenues for non-nuclear generators; and
- Spending on construction of new plants as necessary to replace missing nuclear generation.

REMI uses these inputs to generate estimates of economic output and employment changes. Economic output changes, measured as GDP, are used to estimate tax revenue changes.

E. Key Assumptions and Data

Power plant operations data, planned plant construction and retirement data, hourly load data by planning area, and natural gas price data by hub are obtained from Ventyx's Energy Velocity data suite ("EV"). Economic plant retirements are not modeled. We do not simulate a carbon price or other climate policy, and also do not assume additional policies designed to encourage or promote renewable capacity such as further tax credits or advantageous rate designs. We also assume no policy changes that could improve the competitive position of solar and wind capacity.[13] Although local and possibly regional transmission needs might differ, perhaps significantly, in the absence of nuclear plants, we do not characterize changes in transmission investment levels.

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13 We allow for real solar and wind installation capital costs to decrease over time at a rate of almost 2%/yr. This decrease is consistent with the decrease shown in Black & Veatch, "Cost and Performance Data for Power Generation Technologies," February 2012.

Long-term commodity price forecasts, demand forecasts, and renewable energy capacity factors are obtained from the EIA. EIA commodity price forecasts for natural gas and bituminous coal are shown in Table 12 below.

Table 12: EIA Fuel Price Forecasts ($2015/MMBtu)

Year	Natural gas	Bituminous coal
2015	$3.86	$3.16
2016	$3.87	$3.21
2017	$3.98	$3.25
2018	$4.40	$3.27
2019	$4.76	$3.29
2020	$5.10	$3.31
2021	$5.25	$3.34
2022	$5.32	$3.37
2023	$5.49	$3.42
2024	$5.59	$3.45

Electricity demand forecasts are derived from a combination of EV data and EIA data. EV consumption data for 2014 is escalated at the growth rate given in EIA's regional electricity demand forecasts. We assume that load shape does not change over time. The demand growth rates assumed are presented in Table 13 below.

Table 13: Forecasted Electricity Demand Growth (2015-2024)

	Region	Average annual consumption growth rate (2015-2024)
[1]	California	1.06%
[2]	Central	1.19%
[3]	Desert Southwest	1.42%
[4]	ERCOT	1.12%
[5]	Florida Reliability	0.91%
[6]	New England	0.46%
[7]	New York	0.23%
[8]	Northwest Power Pool	1.28%
[9]	MISO	0.84%
[10]	PJM	0.69%
[11]	Southeastern	1.12%
[12]	Southwest Power Pool	0.99%
[13]	VACAR	1.10%
[14]	Basin	1.28%
[15]	Rocky Mountain	1.28%

Plant construction cost data is taken from Black & Veatch.[14] This data provides information on construction and operating costs for a variety of plants, including natural gas combined cycle, natural gas combustion turbine, solar, and wind.

We focus our analysis on fifteen electric regions in the United States, and we assume that each of these regions is operated independently from the others. The regions are identified in Table 2 and Figure 2 in the body of the report. We assume that each of these regions targets a reserve margin of 15%.[15] Additionally, we assume that all plants undergo scheduled maintenance during the spring and fall only and that unscheduled maintenance is equally likely to occur any time of day or year. Macroeconomic data used to determine economic output and employment impacts comes from REMI.

F. Electricity Market Impacts

In general, without the nuclear industry, consumers (residential, commercial, and industrial) would pay higher electricity prices. The figure below provides a visualization of the energy price impacts that would occur if there were no nuclear plants in PJM. The three vertical lines represent minimum, mean, and maximum hourly demand in PJM. The market clears, setting price and quantity, where the supply and demand curves intersect. Without nuclear plants, the PJM supply curve shifts to the left. This means that energy prices will be higher when nuclear generating sources are removed. The magnitude of the price changes at any point in time depends on the "steepness" of the supply curve in the region where demand intersects it at that time.[16]

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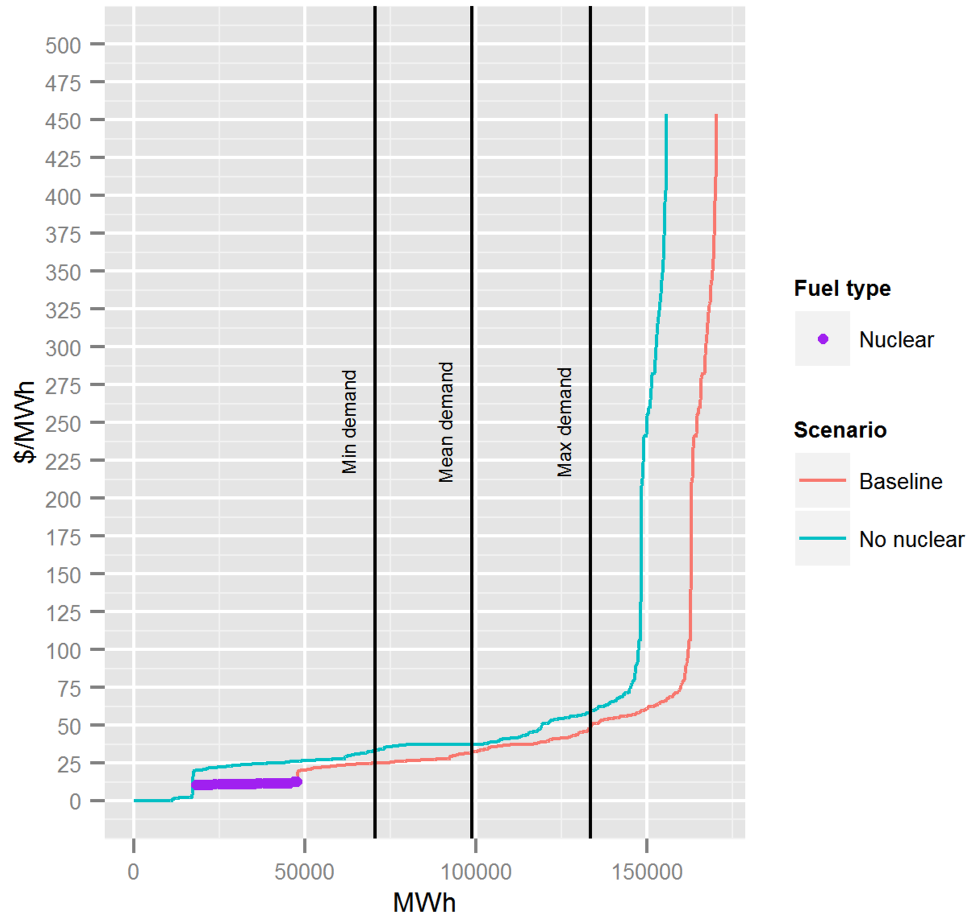
14 Black & Veatch, "Cost and Performance Data for Power Generation Technologies," February 2012.

15 This is consistent with the target reserve margins in many regions. See for example, http://www.eia.gov/todayinenergy/detail.cfm?id=6510.

16 The supply curve shown here is illustrative and the price effect is not exactly as shown. In any given hour, the supply curve is adjusted for plants on maintenance and the actual output of renewable generation. Further, if there is a shortage of generating capacity relative to reserve margin requirements, additional capacity would be added to maintain the reserve margin. This new capacity would typically be gas-fired (given current economics) and thus would have variable costs above those of nuclear; this means the supply curve would still shift upward.

Figure 8: PJM Supply Curve Shift Example



The effect on capacity price depends on whether nuclear plant closure leads to market entry, and also on how energy prices are impacted by nuclear plant closure. As described above, the value of capacity is set by the fixed costs of plants providing capacity, less their expected energy revenue. If new plants with lower fixed costs than nuclear plants enter the market after nuclear plants close, then capacity prices may face downward pressure (though note that the fixed cost of new capacity includes its full development cost; for existing capacity whose development cost is sunk, only fixed operating and capital addition costs are considered). If the fixed costs of new plants are higher than nuclear fixed costs, then capacity prices will face upward pressure. If energy prices increase, as they do when the supply curve shifts to the right, then capacity prices will face downward pressure (plants will earn more energy revenue, so their need for capacity revenue to cover their costs will be lower, all else equal).

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