Pennsylvania Nuclear Power Plants' Contribution to the State Economy

PREPARED FOR

Pennsylvania Building and Construction Trades Council

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Note:
This report is an update of a similarly-titled report that was published in September 2015. Relative to the previous report, the analysis underlying this report is updated to reflect current market conditions, and also uses a different and somewhat more sophisticated model to characterize the electric power system. The current model characterizes the entire Eastern Interconnection rather than just the PJM ISO, as well as incorporating the effects of some high-level transmission constraints between PJM sub-regions, and beyond PJM. The results found here differ from those of the previous report primarily because of changes in the underlying market conditions. In particular, the expected future price of natural gas (which is the primary substitute fuel in PJM, and is on the margin setting the electricity price in most hours) has changed significantly; there have also been changes in the environmental restrictions on electric generators, as well as recent updates to projected electric load, and generator additions and retirements.

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I. Executive Summary

At the request of the Pennsylvania Building and Construction Trades Council, the Pennsylvania Chamber of Business and Industry, the Allegheny Conference on Community Development, and the Greater Philadelphia Chamber of Commerce, The Brattle Group has estimated the value of the nuclear plants in Pennsylvania to the state's economy. We found that, absent Pennsylvania's nuclear plants, Pennsylvania consumers would pay significantly more for electricity, the economy would suffer both in terms of GDP and jobs, and there would be substantially higher emissions of CO_2 and other pollutants.

Our analysis has determined that the nuclear plants operating in Pennsylvania:

- **Contribute approximately $2 billion to state gross domestic product** (GDP) ($3.1 billion in gross output).
- **Account for 15,900 in-state full time jobs** (direct and secondary).
- **Help keep electricity prices low.** Pennsylvania consumers would pay $788 million more annually (2016$) and $6.6 billion more over the next ten years (on a present value basis) without these plants.
- **Are responsible for $69 million in net state tax revenues** annually.
- **Avoid over 37 million tons[1] of CO_2 emissions annually** over the next ten years, valued at $1.6 billion per year.
- **Avoid significant amounts of criteria pollutants annually,** valued at $260 million per year over the next ten years.

These measures reflect the significance of these nuclear plants for the Pennsylvania economy, found by comparing the performance of Pennsylvania's economy with and without its nuclear plants. This approach nets out the economic contribution of the alternative generation that would substitute for the Pennsylvania nuclear plants – both the greater utilization of existing plants and the construction of new plants, as necessary – to determine their incremental contribution. Absent the energy from these nuclear plants, Pennsylvania and the broader region would need to rely more heavily on natural gas and coal-fired generating plants, many of which are outside Pennsylvania, leading to greater reliance overall on out-of-state generation, and transforming Pennsylvania from a substantial net exporter of power to a net importer. The greater reliance on fossil generation would increase carbon and other air emissions, including in some current non-attainment areas of Pennsylvania. It would also raise electricity prices; without these nuclear plants, wholesale prices in Pennsylvania and throughout the broader region would be higher. The higher electricity prices would flow through to residential,

[1] Throughout this paper, references to tons are in metric tons; 1 metric ton = 1.10231 short tons. Here, 37 million metric tons is equivalent to approximately 41 million short tons.

commercial and industrial consumers as higher electricity bills. It is this effect on electricity prices that accounts for a large share of the overall incremental economic impact; the reduction in in-state generation and associated economic activity also plays a role. Note that these measures do not reflect the impacts outside Pennsylvania, although the absence of in-state nuclear plants would have significant additional negative consequences beyond the state's borders.

Emissions of carbon dioxide (CO_2) and criteria pollutants, such as nitrogen oxides (NO_X) and sulfur dioxide (SO_2), would also be much higher in the absence of Pennsylvania's nuclear plants, because the replacement generation would be almost entirely fossil-fired. Compliance with national ambient air quality standards (NAAQS), for ozone, nitrogen oxides (NO_X) and small particulate matter ($PM_{2.5}$), could become more costly for remaining generators, both in-state and out of state. It would likely be more difficult for Pennsylvania to achieve targeted CO_2 reductions under any future climate policy.[2] Further, the pollutant impacts are not limited to Pennsylvania, first because much of the replacement generation would come from outside Pennsylvania, and second because air pollution impacts can cross state borders – they are often regional in the case of criteria pollutants, and global in the case of carbon dioxide.

We examined the sensitivity of our results to a potential increase in natural gas prices, relative to current expectations, since natural gas is a key driver of electricity markets in the region. We found that in a higher gas price environment, the beneficial impact of Pennsylvania's nuclear plants on electricity prices would be significantly greater, as would their economic value. The emissions effect is, ironically, somewhat smaller. In a high gas price environment, higher-emitting coal plants are already generating closer to their full capacity even with the nuclear plants operating, and so have less ability to increase further to replace nuclear generation.

II. Background

Five nuclear plants, comprising nine nuclear reactors, operate in Pennsylvania; see Figure 1. These represent nearly 10,000 megawatts (MW) of generating capacity and over 79 million megawatt hours (MWh) of annual electricity generation, as shown in Table 1. Pennsylvania is within the PJM Interconnection, the electric region operated by the PJM independent system

[2] The Clean Power Plan, EPA's rule to limit greenhouse gas emissions from existing power plants, nominally takes effect in 2022. It has been stayed pending resolution of legal challenges, and the incoming administration has announced plans to rescind it. Since the ultimate fate of the Clean Power Plan is uncertain at this point, it is not considered in the analyses here.

operator.[3] PJM encompasses much more than just Pennsylvania, both geographically and electrically; Pennsylvania accounts for about 27% of PJM's total generation and 20% of its load. Within Pennsylvania itself, the Pennsylvania nuclear plants represent a significant share of capacity and generation at 22% and 38%, respectively, as illustrated in Figure 2.

Figure 1: Locations of Pennsylvania Nuclear Plants

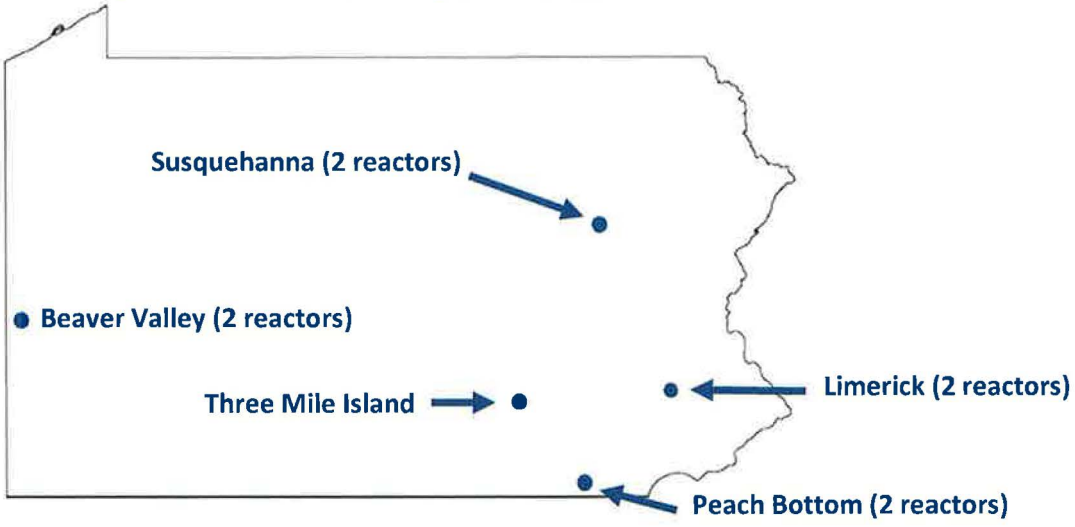


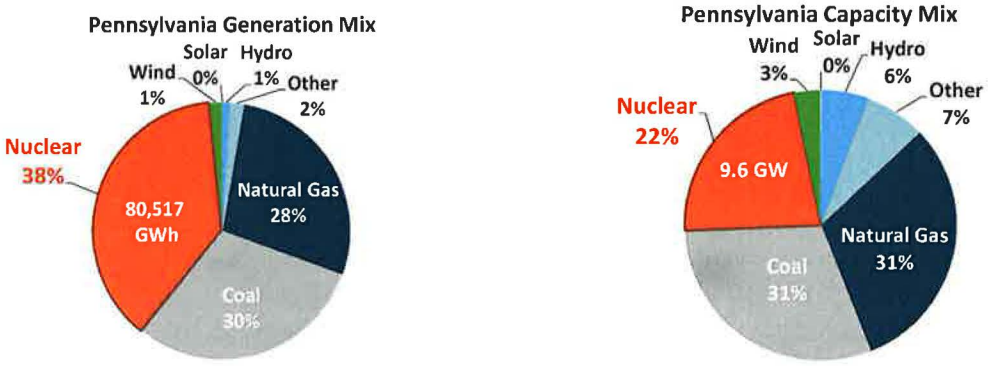
Table 1: Summary of Nuclear Plants in Pennsylvania

Item		Three Mile Island	Beaver Valley	Susquehanna	Limerick	Peach Bottom	**Total Pennsylvania Nuclear**
[A]		[B]	[C]	[D]	[E]	[F]	**[G]**
Number of Units	[1]	1	2	2	2	2	**9**
Total Net Summer Capacity (MW)	[2]	803	1,834	2,520	2,242	2,251	**9,649**
Average Annual Generation (GWh)	[3]	6,862	14,691	19,424	19,184	19,155	**79,315**

Sources & Notes: Data from Ventyx, Energy Velocity Suite. Average annual generation is the average of 2013 - 2015.

3 The PJM ISO operates the power system, as well as establishing and maintaining markets for electric capacity and energy.

Figure 2: Pennsylvania Electricity Generation and Capacity Shares by Fuel



Sources & Notes: Ventyx, Energy Velocity Suite. Generation is 2015 historical values; capacity is as of August 2016.

III. Pennsylvania's Nuclear Plants Make a Considerable Contribution to the State's Economy and Environment

We have estimated the economic value of Pennsylvania's nuclear plants to the state of Pennsylvania using REMI, a widely-used dynamic input-output model of the U.S. economy.[4] Nuclear power's overall effect on the Pennsylvania economy occurs through two main channels: first, electricity costs are lower for Pennsylvanians with nuclear power than they would be without it; and second, Pennsylvania is a significant net power exporter with its nuclear plants, but would become a net importer without them. The absence of Pennsylvania's nuclear plants would increase wholesale prices for energy and capacity in the region, since it would reduce the available supply of both, and this supply could not readily be replaced in terms of energy cost. Tighter supply will increase wholesale prices, which translates to higher retail prices, particularly in a state like Pennsylvania which has restructured and has retail access so that wholesale prices are readily reflected in customer costs.

Another major effect of the absence of the Pennsylvania nuclear plants would be higher emissions of CO_2 and criteria pollutants. Virtually all of the replacement power that would substitute for the output of these nuclear plants would be fossil-fired generation, at least until and unless strict environmental regulations on CO_2 emissions come into effect; these effects are discussed in Section III.6.

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[4] For more details on the REMI model, see www.remi.com.

To characterize the electricity market effects that drive the economic effects, we utilize a power market simulation model called Xpand, which models capacity planning and dispatch to capture the dynamics of power system operation, power markets and prices. By linking this power sector model with the REMI economic model, we are able to characterize the consumer power cost impacts and other power sector economic effects with and without the Pennsylvania nuclear plants. This allows us to develop the most accurate picture of their incremental contribution to the economy, in terms of economic output, employment, and tax revenues. Although we simulate the power system for the entire Eastern Interconnection to best capture the interstate electricity market effects, the economic impacts evaluated in this report are limited to those that occur within Pennsylvania. Since the Pennsylvania nuclear plants do have significant economic impacts well beyond the state's borders, the economic effects we estimate within Pennsylvania are a subset of the total economic impacts.[5]

We analyze the power sector and the economy both with and without the Pennsylvania nuclear plants, to determine the economic effects attributable to them. Our analysis indicates that these plants play a significant role in keeping electricity costs down in Pennsylvania, as well as the broader PJM region, and the resulting lower electricity costs create a substantial benefit to the Pennsylvania economy. Even after netting out the economic contribution of the alternative electric generation that would substitute if they did not exist, Pennsylvania's nuclear plants are responsible for economic output in the billions of dollars and accompanying employment and tax revenues. Table 2 summarizes our findings for the economic impacts within Pennsylvania for our Base Case, in the first column.

Under the Base Case,[6] Pennsylvania's nuclear plants contribute $2.01 billion to the state's GDP and account for 15,900 jobs (considerably more secondary jobs than direct jobs).[7] Much of the GDP and jobs effect is indirect, based on nuclear power's effect on electricity costs to consumers, rather than resulting from economic activity that is directly associated with the nuclear plants themselves. Because every sector of the economy depends on electricity, the power price effect is extraordinarily widespread, thus leading to a substantial overall impact.

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5 Estimating the overall economic impacts of Pennsylvania's nuclear plants would require a regional or national economic model.

6 Our Base Case analysis reflects current expectations for natural gas prices, as represented by the Reference natural gas price forecast from the U.S. Energy Information Administration's 2016 Annual Energy Outlook.

7 Table 2 reports both GDP and gross output since both are useful economic statistics. GDP is the most widely-used measure of economic performance. It reflects value added, which includes industry sales to other industries and to final users, net of the value of purchases from other industries. Gross output is an aggregate measure of total industry sales, which includes sales to final users and intermediate sales to other industries. This leads to a form of double counting when summed across industries, but the measure can nonetheless be a meaningful indicator of how individual industries perform relative to one another and in response to regulatory changes.

Table 2: Net Contribution of Pennsylvania Nuclear Plants to the Pennsylvania Economy (Annual Impacts, 10-Year Average)

	Base Case	High Gas Price Case
GDP and Output *(2016 dollars)*		
Direct and Secondary GDP	$2.01 billion	$2.43 billion
Direct and Secondary Gross Output	$3.10 billion	$3.79 billion
Direct and Secondary Employment *(jobs)*	15,900	18,800
Direct	4,685	4,685
Secondary	11,215	14,115
State and Federal Taxes *(2016 dollars)*		
Direct and Secondary State Tax Revenues	$69 million	$84 million
Direct and Secondary Federal Tax Revenues	$369 million	$444 million

Pennsylvania's nuclear owners also pay significant federal and state taxes, as do businesses providing goods and services to the plants and their employees. In addition, the nuclear plants' incremental contributions to the state's economy account for additional tax revenues to state and local governments – considerably more than the direct taxes paid by the plants. Pennsylvania plants' effect on the economy leads to about $69 million in additional state tax revenues and $369 million in federal tax revenues, beyond the tax revenues that would be provided by alternative in-state electric supply in their absence.

Natural gas prices are a key driver of power sector economics. If future natural gas prices are below current expectations, the cost of replacement power would be lower, thereby reducing the power price impact and economic benefits of the Pennsylvania nuclear plants. If gas prices are above current expectations, it would increase the cost of replacement power, amplifying the effect on power prices and the overall economic benefits of retaining these plants. To help illustrate this effect, in addition to the Base Case analysis, we also assess the contributions of Pennsylvania nuclear plants in a high gas price environment; these results are reflected in the second column of Table 2.[8] As expected, the economic impact of Pennsylvania's nuclear plants would be greater under high gas prices, contributing $2.43 billion to the state's GDP and

[8] The High Gas Price Case assumes delivered natural gas prices that are 35% above the reference gas prices used in the Base Case; this is based on Brattle's experience with the price volatility implied by financial options on natural gas, historical gas price variance and historical forecast errors.

accounting for 18,800 jobs. That is, their economic contribution increases by about 20% at a plausibly higher gas price trajectory.

Below, we provide further detail regarding the impact of Pennsylvania nuclear plants on:

- The electricity generation mix
- The cost of electricity
- Economic output and GDP
- Employment
- Federal and state tax revenues.

1. Impact on Electric Generation Mix

As shown in Figure 3: below, with the Pennsylvania nuclear power plants operating, the state is a net exporter of power, generating about 24% more power than its in-state demand. Absent the nuclear plants, Pennsylvania would become a net importer, importing about 12% of its total electricity needs. The state would generate considerably less electricity, experiencing a reduction in the economic activity associated with in-state generation, which contributes to the overall economic effect. The missing nuclear generation would be replaced by increased reliance on natural gas and coal-fired generation. Some of this additional fossil-fired generation would come from in-state, but the large majority of it would be imported from other states.[9] Large-scale renewable energy probably would not differ significantly in the near term; existing renewable generators already produce as much power as they can at virtually all times, constrained only by resource availability (wind or sun), and could not increase their output to substitute for missing nuclear generation. In a high gas price environment, the pattern is generally similar, though because of the high gas prices there is considerably less reliance on gas and more on coal regardless of whether the Pennsylvania nuclear plants are operating. This leaves coal with less additional flexibility to increase its output if the nuclear plants are absent, and thus gas-fired generation accounts for a somewhat larger share of the replacement power than in the Base Case.

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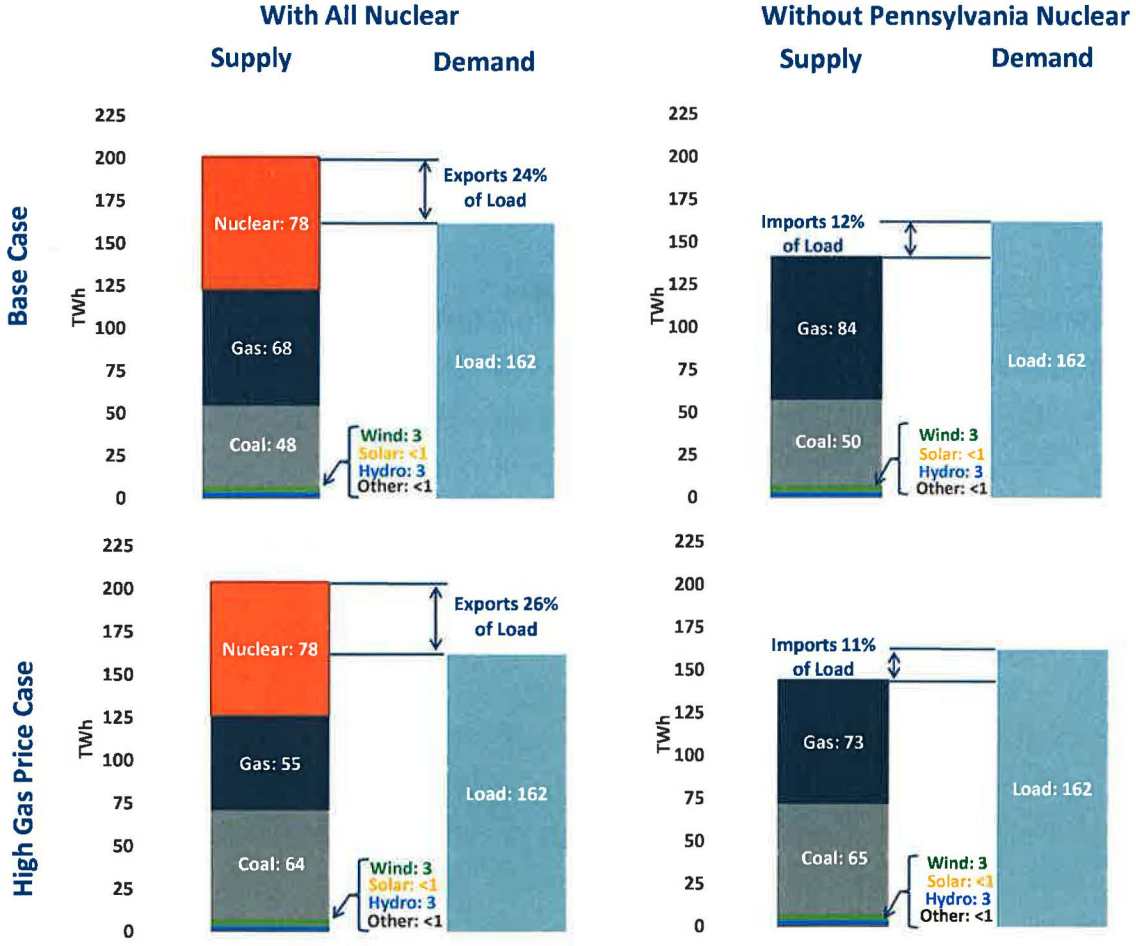
[9] The projected 2017 generation for gas and coal differ from the historical values in Figure 2 above, primarily because natural gas is expected to be cheaper in 2017 than it was in 2013-2015. This means that more natural gas and less coal will be utilized in the future (the generation in the High Gas Price projection is more similar to historical values).

Figure 3: Electric Generation and Load in Pennsylvania (2017 Projection)



2. Impact on Electricity Prices

As noted above, absent Pennsylvania's nuclear plants, electricity demand would be met by increased utilization of natural gas and coal-fired plants, some within Pennsylvania but most from outside the state. The reduction in supply would increase wholesale energy and capacity prices, which means higher electricity prices for customers in Pennsylvania and across PJM. As shown in Table 3, average power prices in Pennsylvania would be $4.78/MWh higher without the nuclear plants, with a somewhat smaller average effect across all of PJM.[10] This would be about $4.37 per month for a typical Pennsylvania residential ratepayer; across all Pennsylvania

[10] The electricity sector model used here depicts six sub-regions within PJM; one of these is entirely contained within Pennsylvania, and two are partly within Pennsylvania. The Pennsylvania average is the load-weighted average of the portions of the sub-regions that are in Pennsylvania; the PJM average is the load-weighted average across all six sub-regions.

consumers, this represents an increase of $788 million per year in electricity costs, or $6.6 billion in present value over ten years.[11] Across the state, about 37% of these increased costs would fall on residential customers, and 63% on commercial and industrial customers.[12] Preventing higher electricity prices is one of the primary means by which nuclear plants benefit Pennsylvania's economy. By keeping electricity prices lower, Pennsylvania's nuclear plants leave residential, commercial, and industrial consumers with more money to spend on other goods and services; this boosts jobs, output, and the overall economy.

The magnitude of the power price effects, and ultimately the economic and jobs effects, is sensitive to the price of natural gas, since gas plays a primary role in setting power prices in the region. In a high natural gas price environment, electricity prices would be higher, and thus the savings that result from retaining the nuclear plants would be larger. The lower panel of Table 3 shows that a high gas price environment magnifies the electricity price impacts of the Pennsylvania nuclear plants. Under high gas prices (characterized here as delivered gas prices 35% above the reference gas price), the Pennsylvania nuclear plants would save Pennsylvania consumers $1,065 million annually in electricity costs, about a third more than the electricity cost savings of the Base Case.

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[11] In addition to the effects of gas prices, electricity transmission requirements might also affect the level and the geographic distribution of electricity costs. Although local and possibly regional transmission needs could differ in the absence of nuclear plants, this report does not consider the effects on the transmission system nor potential changes in transmission investments. Transmission costs could, however, be substantial if a premature transition from nuclear to natural gas were to occur, as noted by a PJM study regarding the closure of nuclear plants in Illinois. See PJM Response to Illinois Commerce Commission (ICC) Request to Analyze the Impact of Various Illinois Nuclear Power Plant Retirements, 10/21/2014, http://www.icc.illinois.gov/electricity/hr1146.aspx. PJM found that premature retirement would require "substantial time to correct;" "would require substantial construction activity and could significantly inconvenience Illinois citizens;" and "[transmission] costs would be significant – in the hundreds of millions of dollars or more" (see page 7).

[12] Shares are proportional to customer class energy consumption, from 2014 EIA 861 filings.

Table 3: Pennsylvania Nuclear Plants Avoid Higher Electricity Prices
(All-in Power Price and Cost Differences due to Pennsylvania Nuclear Plants)

Region	% of Utility Load[1]	10-Year Average: Power Price Change without Nuclear ($/MWh)[2]	10-Year Average: Electricity Consumption (millions of MWh)	10-Year Average: Annual Electricity Cost Change (2016 $millions)	Total Electricity Cost Increase Over 10 Years (2016 $millions)[3]
Base Case					
Pennsylvania		**$4.78**	**165**	**$788**	**$6,617**
Residential	37%		61	$293	$2,458
Commercial/Industrial	63%		104	$495	$4,158
PJM		**$4.09**	**842**	**$3,447**	**$28,910**
Residential	37%		314	$1,284	$10,768
Commercial/Industrial	63%		529	$2,163	$18,142
High Gas Price Case					
Pennsylvania		**$6.46**	**165**	**$1,065**	**$8,954**
Residential	37%		61	$396	$3,327
Commercial/Industrial	63%		104	$669	$5,627
PJM		**$5.33**	**842**	**$4,493**	**$37,818**
Residential	37%		314	$1,674	$14,085
Commercial/Industrial	63%		529	$2,820	$23,733

[1]Load share by customer class is based on data from 2014, EIA Form 861.

[2]The reported Power Price Change includes only energy and capacity cost effects; does not include transmission costs, customer costs, etc. Power Price Effects are assumed to be the same, on an average per-MWh basis, for all customer classes; differences in load shape and billing determinants are not distinguished here.

[3]Present value for the 10-year period at a 3% discount rate.

3. Impact on Economic Output

Pennsylvania's nuclear plants contribute $2.01 billion to annual state GDP and $3.10 billion to gross output, in large part through the electricity price effects shown above. These figures include both direct and secondary economic activity attributable to Pennsylvania nuclear plants, and net out the economic activity associated with the provision of alternative generation in their absence, to the extent this replacement generation occurs in Pennsylvania. The largest effects are found in the utilities, construction, and manufacturing sectors, as shown in Table 4. These GDP and output effects increase by about 20% in the High Gas Price case.

Table 4: GDP and Gross Output Impacts by Sector in Pennsylvania (Annual Direct and Secondary Impacts in Millions of 2016 Dollars, 10-Year Average)

Sector	Base Case	High Gas Price Case
Utilities	$877	$971
Construction	$479	$593
Manufacturing	$414	$543
Mining	$156	$182
Retail Trade	$151	$191
Real Estate and Rental and Leasing	$145	$184
Professional, Scientific, and Technical Services	$138	$169
Health Care and Social Assistance	$114	$146
Finance and Insurance	$98	$125
Accommodation and Food Services	$80	$105
Other	$448	$577
Total Direct and Secondary Output Impact	$3,101	$3,786
Total Direct and Secondary GDP Impact	$2,014	$2,429

Note: The GDP effect is less than the sum of the output across sectors. Summing output can double count when the output of one sector is the input of another.

4. Impact on Employment

Pennsylvania's nuclear plants account for 15,900 direct and secondary jobs in the state's economy, as shown in Table 5. Direct jobs include those positions necessary for plant operations such as engineers and technicians as well as security and administration. Direct jobs also include positions necessary for refueling, plant repairs, and improvements that are completed during scheduled outages; these are often contractors or suppliers rather than plant employees.

As with the economic impact, the jobs impact occurs in large part indirectly; not necessarily as employment within the nuclear sector itself, but as enhanced employment in other sectors, caused largely by the economic effect of lower power prices. As shown in Table 5, the employment sectors most influenced are sales, construction, and business and financial occupations. These employment effects increase by almost 20% in the High Gas Price Case; because no additional workers are needed to operate the plants, all of this increase occurs in secondary employment outside the nuclear sector.

Table 5: Net Employment Impacts by Sector in Pennsylvania (Direct and Secondary Impacts, Number of Jobs, 10-Year Average)

Category	Base Case	High Gas Price Case
Sales and related, office and administrative support occupations	2,910	3,630
Construction and extraction occupations	2,170	2,650
Management, business, and financial occupations	1,240	1,530
Food preparation and serving related occupations	870	1,130
Installation, maintenance, and repair occupations	860	1,040
Transportation and material moving occupations	650	810
Building and grounds cleaning and maintenance, personal care and service occupations	640	820
Production occupations	640	790
Healthcare occupations	610	780
Computer, mathematical, architecture, and engineering occupations	550	670
Other	4,760	4,940
Total	15,900	18,800

Note: Numbers may not sum due to independent rounding.

5. Impact on Federal and State Tax Revenues

Pennsylvania's nuclear plants and the businesses providing goods and services to these plants pay substantial federal and state taxes. In addition, since these plants keep electricity prices lower, they create incremental economic output and associated tax revenues throughout the economy. Average incremental annual federal tax payments attributable to the plants total $369 million, and average annual state tax payments total $69 million, as shown in Table 6. These tax revenue effects increase by about 20% in the High Gas Price case.

Table 6: Net Annual Federal and State Tax Payments Attributable to Economic Activity Related to the Pennsylvania Nuclear Plants (Annual in 2016 Dollars, 10-Year Average)

	Base Case	High Gas Price Case
Direct and Secondary State Tax Revenues	$69 million	$84 million
Direct and Secondary Federal Tax Revenues	$369 million	$444 million
Total Federal and State Tax Revenues	$438 million	$528 million

6. Pennsylvania Nuclear Plants Prevent Substantial Carbon Dioxide and Criteria Pollutant Emissions within and outside the State

Pennsylvania's nuclear power plants prevent substantial emissions of CO_2, SO_2, NO_x, and particulate matter, compared to the alternative of natural gas and coal-fired generation that would replace it. Environmental rules such as the Clean Power Plan (CPP) or alternative greenhouse gas restrictions would likely interact with the emissions impacts of nuclear plants. But since the CPP has been stayed pending legal challenges, and the incoming administration has announced plans to rescind it, we have not modeled a national climate policy in our analysis; we do represent state-level policies such as Renewable Portfolio Standards.

To understand the potential emissions effects, it is helpful to characterize the differences in generation with and without the Pennsylvania nuclear plants. The entire Eastern Interconnection is an integrated power system and most of the power needed to replace the output of the Pennsylvania nuclear plants would come from outside the state. Because natural gas is typically the marginal fuel in the region, most of the replacement energy comes from gas. The location and type of the replacement generation are summarized in Table 7, which shows that 75% of the replacement generation comes from outside Pennsylvania, with 84% of the total being fired by natural gas. In a high gas price environment, the same general pattern holds, though ironically, the replacement power is even more dominated by gas, at 94%. This is because coal generation is already running closer to its full capacity even with the nuclear plants operating; more costly gas tends to be "on the margin" as the swing fuel. That is, since coal has limited ability to increase further, more of the replacement generation must come from gas.

Table 7: Changes in Generation to Replace Nuclear (Annual GWh, 10-Year Average, Base Case)

	Pennsylvania	Outside of Pennsylvania	Total
Gas	17,196	48,340	65,536
Coal	2,039	10,128	12,167
Wind	0	28	28
Solar	0	189	189
Other	5	-6	-1
Total	19,240	58,679	77,918

The resulting emissions reductions enabled by the Pennsylvania nuclear plants under the Base Case are summarized in Table 8. Average annual power sector CO_2 emissions would be about 37 million tons greater absent the Pennsylvania nuclear plants. To put this in perspective, this would be equivalent to adding about 8 million cars to the road, and represents 50% of the current power sector CO_2 emissions of Pennsylvania. Overall power sector SO_2 emissions would be 8,400 tons higher, and NO_x emissions would be 11,500 tons higher – about 7% and 19% of current

Pennsylvania values, respectively.[13] Particulate matter emissions, PM_{10} and $PM_{2.5}$, would increase by about 53% of current Pennsylvania emissions levels.[14] In a high gas price environment, the replacement generation consists of less coal and more gas, as noted previously. Since the emissions rates of all pollutants tend to be lower for gas plants, the incremental emissions effects are somewhat smaller with high gas prices.

Table 8: Emissions and Social Cost Prevented by Pennsylvania Nuclear Power Plants (Annual Impacts, 10-Year Average, Base Case)

Pollutant	Avoided Emissions (tons)	Social Cost ($/ton)	Avoided Emissions Value (2016 $millions)
CO_2	37,690,407	$42	$1,568
SO_2	8,479	$7,386	$63
NO_x	11,503	$2,038	$23
PM_{10}	16,630	$586	$10
$PM_{2.5}$	13,534	$12,099	$164
Total			$1,827

The overall social cost of these changes in emissions can be estimated using the federal government's social cost of carbon ($42/ton)[15] and the National Academy of Science's externality cost estimates for SO_2, NOx, PM_{10} and $PM_{2.5}$. Evaluated at these rates, which are shown in Table 8, the average annual avoided social cost of CO_2 is $1.57 billion, and the avoided costs of SO_2 and NOx are $63 million and $23 million, respectively. The avoided costs of PM_{10} and $PM_{2.5}$ emissions are approximately $10 million and $164 million, respectively. These costs reflect environmental and human health damages and are independent of and in addition to the direct and secondary

[13] The effect of the nuclear plants on SO_2 emissions is limited by the EPA's Cross-State Air Pollution Rule (CSAPR), which caps the allowed emissions of SO_2 from some units. This cap is binding even with the nuclear plants operating, and so in the absence of the nuclear plants, additional operational changes are required. These changes partly mitigate the direct effects on SO_2 emissions, which would otherwise be larger.

[14] In comparing these emissions increases with current Pennsylvania emission levels, note that although the emissions increase would be triggered by the missing nuclear generation in Pennsylvania, only part of the total emissions increase actually occurs within Pennsylvania, since most of the replacement generation comes from outside the state.

[15] The social cost of carbon used here, $42 per ton of CO_2, is the federal government's central value (which is based on a 3% discount rate) for 2015, converted from 2007 dollars to 2016 dollars. See the EPA Fact Sheet, Social Cost of Carbon, December 2015.

economic impacts that would result from higher power prices and reduced in-state power production. 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, but would be in addition to those values.

Because most of the replacement generation comes from outside Pennsylvania, most of the emissions increase also occurs outside the state. Even so, the criteria pollutants that are emitted in or near Pennsylvania may have substantial local impacts. In Appendix A, we discuss some of the potential local emissions effects of criteria pollutants, including how they may impact non-attainment areas in Pennsylvania – those areas that are currently in non-attainment for federal air quality standards for one or more of the criteria pollutants.

Appendix A: Local Environmental Impacts

Since criteria pollutants can affect local air quality, it is also important to consider the location of these emissions impacts. We have done so by mapping all of the power plants in Pennsylvania, locating them within Pennsylvania counties, and determining what change, if any, they would experience in generation and emissions in the absence of the state's nuclear plants. The locations of the plants are presented in Figure 4, and the plants are identified in Table 9.

Figure 4: Pennsylvania's Power Plants by Type

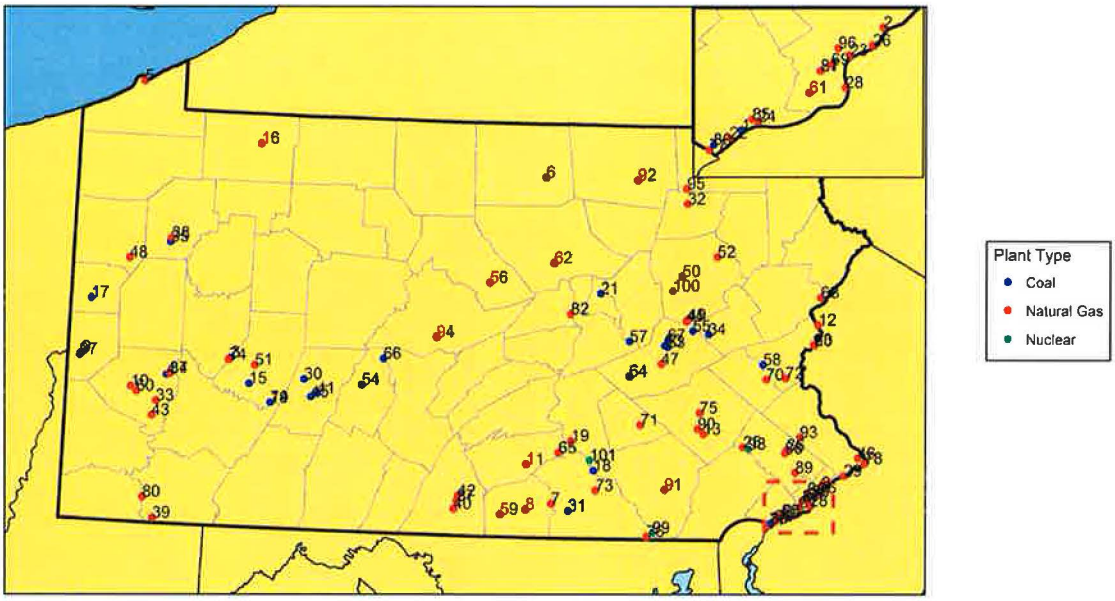


Table 9: Pennsylvania's Power Plant Key

Item	Plant Name	Plant Type	Item	Plant Name	Plant Type
1	Chester Ops	Coal	52	Jenkins	Natural Gas
2	Newman Co Inc	Natural Gas	53	John B Rich Memorial	Coal
3	Keystone (PA)	Coal	54	Juniata Locomotive Shop	Coal
4	Cheswick Power Plant	Coal	55	Kline Township Cogeneration Facility	Coal
5	Erie Coke Corp	Natural Gas	56	Lock Haven (PENNPOW)	Natural Gas
6	Blossburg	Natural Gas	57	Foster Wheeler Mt Carmel Cogeneration	Coal
7	Hamilton (PA)	Natural Gas	58	Northampton Generating Co LP	Coal
8	Hunterstown	Natural Gas	59	Orrtanna	Natural Gas
9	Bruce Mansfield	Coal	60	PPG Place	Natural Gas
10	Brunot Island	Natural Gas	61	Philadelphia Refinery	Natural Gas
11	Mountain	Natural Gas	62	Williamsport	Natural Gas
12	Portland (PA)	Natural Gas	63	Wheelabrator Frackville	Coal
13	Titus	Natural Gas	64	Westwood	Coal
14	Conemaugh	Coal	65	West Shore	Natural Gas
15	Homer City Station	Coal	66	Tyrone (PA)	Coal
16	Warren (PA)	Natural Gas	67	St Nicholas Cogeneration	Coal
17	New Castle Plant	Coal	68	Shawnee (PA)	Natural Gas
18	Brunner Island	Coal	69	Schuylkill Turbine	Natural Gas
19	PPL Martins Creek Harrisburg	Natural Gas	70	PPL Martin Creek LLC Allentown	Natural Gas
20	Martins Creek	Natural Gas	71	Ironwood	Natural Gas
21	Montour	Coal	72	Bethlehem Power Plant	Natural Gas
22	Chester Generating Station	Natural Gas	73	York Cogeneration Facility	Natural Gas
23	Delaware Generating Station	Natural Gas	74	Armstrong (PA)	Natural Gas
24	Eddystone Generating Station	Natural Gas	75	Ontelaunee Energy Center	Natural Gas
25	Moser Generating Station	Natural Gas	76	York Energy Center	Natural Gas
26	Richmond Generating Station	Natural Gas	77	Marcus Hook Refinery Cogeneration	Natural Gas
27	Schuylkill Generating Station	Natural Gas	78	Fairless Energy Center	Natural Gas
28	Southwark Generating Station	Natural Gas	79	Seward Generating Station	Coal
29	Croydon CT Generating Station	Natural Gas	80	Fayette Energy Facility	Natural Gas
30	Colver Power Project	Coal	81	Grays Ferry Cogeneration Partnership	Natural Gas
31	P H Glatfelter Co	Coal	82	Bucknell Univ	Natural Gas
32	Mehoopany	Natural Gas	83	Lower Mount Bethel Energy	Natural Gas
33	Uss Corp Mon Valley Works	Natural Gas	84	Allegheny Energy Units 3 4 & 5	Natural Gas
34	Panther Creek	Coal	85	Liberty Electric Power LLC	Natural Gas
35	Scrubgrass Generating Co	Coal	86	Marcus Hook	Coal
36	West Point Facility	Natural Gas	87	Orchard Park Generating Station	Natural Gas
37	Allegheny Energy Units 1 & 2	Natural Gas	88	Morris Road	Natural Gas
38	Handsome Lake Energy LLC	Natural Gas	89	Hill At Whitemarsh (The)	Natural Gas
39	Allegheny Energy Unit 8 & 9	Natural Gas	90	Reading Hospital Power	Natural Gas
40	Allegheny Energy Units 12 & 13	Natural Gas	91	Sight & Sound Theatre	Natural Gas
41	Cambria Cogeneration	Coal	92	Panda Liberty Project	Natural Gas
42	Chambersburg Diesel	Natural Gas	93	Panda Patriot Project	Natural Gas
43	Clairton Works	Natural Gas	94	East Campus Steam Plant	Natural Gas
44	Hazleton	Natural Gas	95	North Meshoppen II Project	Natural Gas
45	Ebensburg Power Co	Coal	96	Temple SEGF	Natural Gas
46	Falls (PA PECO)	Natural Gas	97	Beaver Valley Generating Station	Nuclear
47	Fishback	Natural Gas	98	Limerick Nuclear Power Plant	Nuclear
48	General Electric Co	Natural Gas	99	Peach Bottom Nuclear Generating Station	Nuclear
49	PPL Martins Creek LLC Harwood (PA)	Natural Gas	100	Susquehanna Steam Electric Station	Nuclear
50	Hunlock Power Station	Natural Gas	101	Three Mile Island Nuclear Generating Station	Nuclear
51	Indiana University of Pennsylvania	Natural Gas			

We also considered whether the county is in attainment with Clean Air Act standards for criteria pollutants, and checked for instances where a plant that is located within a non-attainment area for a particular pollutant would increase its emissions of that pollutant in the absence of the Pennsylvania nuclear plants. This analysis is illustrated in a series of maps below. Each map illustrates, for a given pollutant, the Pennsylvania generating plants, indicating whether their emissions increase (red dot), stay the same (black dot) or fall (blue dot), in the absence of the Pennsylvania nuclear plants. The size of the dot indicates the magnitude of the change in

emissions. We pay particular attention to those counties that are not currently in attainment with U.S. EPA standards under the Clean Air Act for one or more of the criteria pollutants; these counties are shaded on the maps.

This analysis revealed that absent the state's nuclear plants, there are a number of instances in which fossil plant emissions of a criteria pollutant would increase in a county that is already in non-attainment for that pollutant. This can be seen where there is a red dot within a shaded county, indicating that a power plant located in a non-attainment area is increasing its emissions. In fact, because those locations are already out of compliance, additional actions may be required to mitigate these emissions increases, including redispatch that would utilize more costly generation sources outside the non-attainment area, or potentially to add costly emissions controls to the affected plants. These additional actions could increase electricity costs beyond our estimates. Emissions increases in locations that are currently in compliance with federal standards could potentially push some of them into non-compliance, creating similar issues in additional locations.

Table 10 presents the aggregate change in emissions within Pennsylvania absent the state's nuclear plants. It is important to note that airborne transport of criteria pollutants could spread them to nearby and downwind locations; our analysis does not account for such transport and is thus only indicative of the types of problems that may arise. The table also does not present the increase in emissions at power plants that are outside of Pennsylvania, but might affect Pennsylvania air quality due to airborne pollutant transport. The table does show that criteria pollutant emissions within the state represent about $61 million in annual social costs (harm to health, the environment, etc.). Over half of this ($39 million) is attributed to $PM_{2.5}$.

Table 10: Emissions and Social Cost Prevented by Pennsylvania Nuclear Plants, in Pennsylvania (Annual Impacts, 10-Year Average, Base Case)

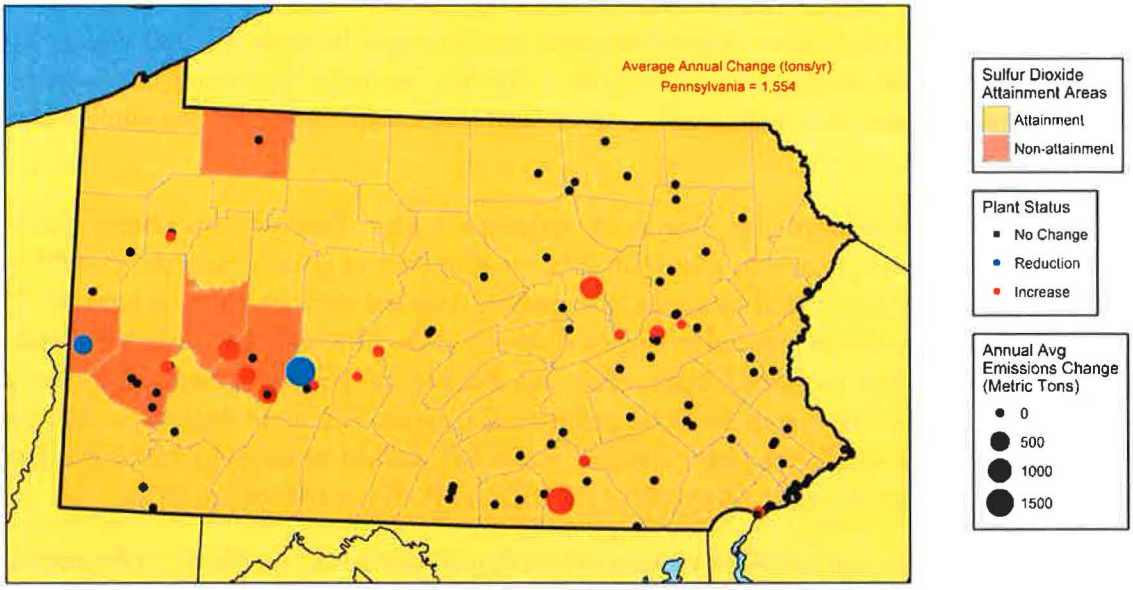
Pollutant	Avoided Emissions (tons)	Social Cost ($/ton)	Avoided Emissions Value (2016 $millions)
CO_2	8,773,878	$42	$365
SO_2	1,554	$7,386	$11
NO_x	4,136	$2,038	$8
PM_{10}	3,915	$586	$2
$PM_{2.5}$	3,201	$12,099	$39
Total			$426

The location and change in emissions by type and Pennsylvania county are discussed below.

SO_2

The SO_2 annual emissions increase of 1,500 tons presents an overall social cost of $11 million annually. At present, five Pennsylvania counties are in non-attainment for SO_2 (Allegheny, Armstrong, Beaver, Indiana, and Warren), as illustrated by shading in Figure 5. Absent the state's nuclear plants, net emissions would increase in three of these counties, making attainment more difficult and/or costly. Several other counties also experience a significant increase in emissions, which could result in non-attainment in some of those counties.

Figure 5: SO_2 Emissions Increase Absent Pennsylvania's Nuclear Plants – Base Case



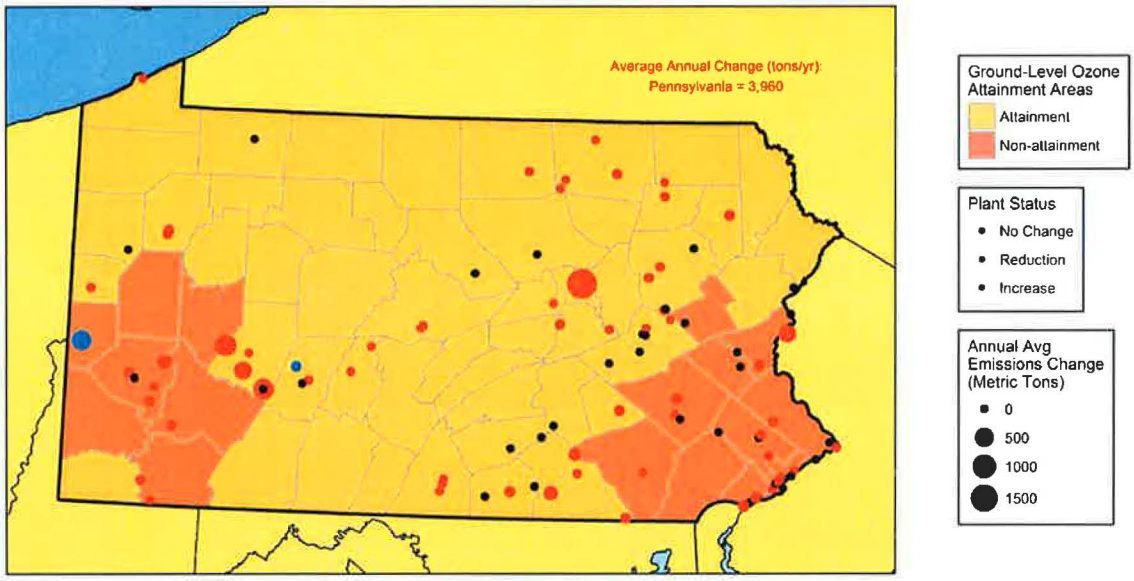
NOx

The overall social cost of the increase in NOx absent the nuclear plants is $8 million annually, but NOx is also a precursor of ground level Ozone.[16] At present, no Pennsylvania county is in non-attainment for NOx, but 17 are in non-attainment for ozone. NOx emissions in Pennsylvania are

[16] Ground level or tropospheric ozone occurs when nitrogen oxides (NOx), carbon monoxide (CO) and volatile organic compounds (VOCs), react in the atmosphere in the presence of sunlight. Ozone imposes social costs in the form of adverse health effects particularly to those with pulmonary system problems including asthma. Ground level ozone has also been found to negatively affect agriculture. Reducing NOx is generally the preferred means to lower ozone levels. Determining the impact of power plant NOx emissions on ozone levels is beyond the scope of this report, but increased NOx emissions is likely to compromise efforts to reduce ozone across much of the state.

projected to increase by more than 4,000 tons per year, absent Pennsylvania's nuclear plants. This increase may raise the cost of bringing many of these counties into attainment for Ozone. The locations of NOx increases are shown alongside the non-attainment areas for Ozone in Figure 6.

Figure 6: NO_X Emissions Increase Absent Pennsylvania's Nuclear Plants – Base Case



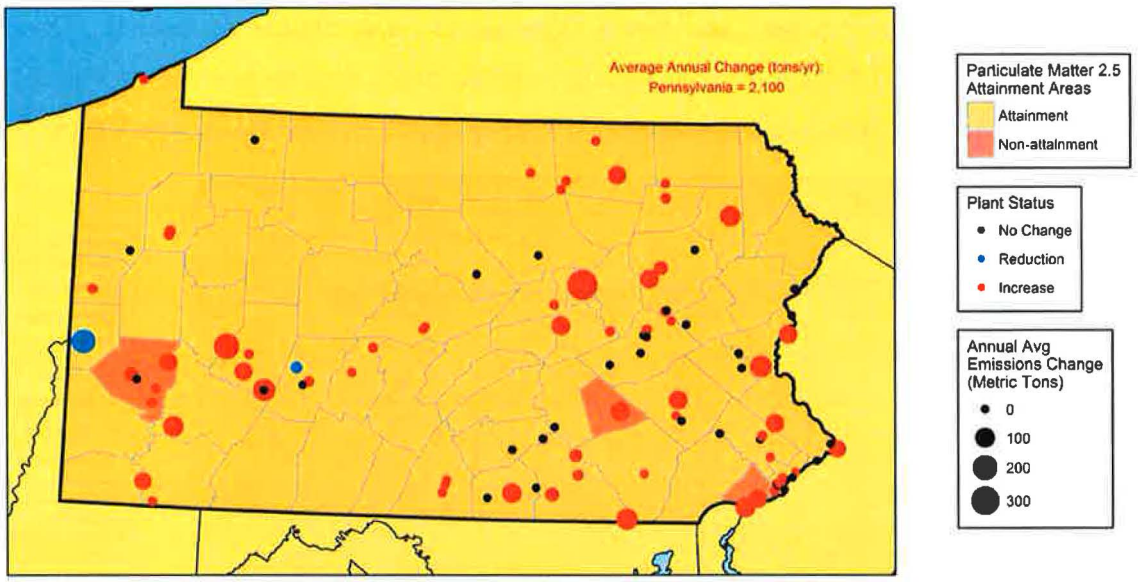
PM_{10}

The increase in PM_{10} emissions that would occur in Pennsylvania, absent the state's nuclear plants, is very modest, imposing social costs of $2 million annually. No counties were in non-attainment for PM_{10}.

$PM_{2.5}$

As Table 10 indicates, the $PM_{2.5}$ emissions increase of over 3,000 tons annually within Pennsylvania results in a social cost of $39 million, the highest among the criteria pollutants, reflecting its significant impacts on human health. At present, three Pennsylvania counties (Allegheny, Delaware and Lebanon) fail to meet air quality standards for $PM_{2.5}$. Without other actions, in the absence of the state's nuclear plants, $PM_{2.5}$ emissions would increase in all three of these counties due to increased fossil generation, as shown in Figure 7 (this does not account for airborne transport). Several other counties would also experience a substantial increase in $PM_{2.5}$ emissions that could place them into non-attainment with the Clean Air Act.

Figure 7: $PM_{2.5}$ Emissions Increase Absent Pennsylvania's Nuclear Plants – Base Case



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