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ECONOMIC CONSULTING

Assessing Economic Impacts of a Stricter National Ambient Air Quality Standard for Ozone

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EXECUTIVE SUMMARY

This report demonstrates analysis methods to assess the potential costs and impacts on the U.S. economy of a more stringent national ambient air quality standard (NAAQS) for ozone, and provides our estimates of the potential costs and economic impacts if the U.S. Environmental Protection Agency (EPA) were to set an ozone standard of 60 parts per billion (ppb). Our analysis is based on using the best available information on the emission reductions needed to attain a 60 ppb standard and the costs of those reductions; because that information is limited, we refer to our results as potential costs and economic impacts. Employing our integrated energy-economic model (N_{ew}ERA), we estimate that the potential emissions control costs would reduce U.S. Gross Domestic Product (GDP) by $270 billion per year on average over the period from 2017 through 2040 and by more than $3 trillion over that period in present value terms.[1] The potential labor market impacts represent an average annual loss of 2.9 million job-equivalents.[2]

A tighter ozone standard may also result in barriers to new energy production activity in areas that become in nonattainment. We therefore also consider a sensitivity case that includes constraints on new natural gas production in the U.S., leading to even greater estimated impacts in terms of energy costs for consumers and losses in economic output. In this sensitivity case, we estimate a GDP reduction of $360 billion on average and more than $4 trillion over the period from 2017 through 2040 in present value terms, and a projected average annual loss of 4.3 million job-equivalents.

These large potential impacts and the limited information now available to estimate them provide compelling arguments that EPA needs to provide more complete data and analysis as part of its forthcoming proposal to revise the ozone NAAQS, so that there can be better understanding of the economic impacts of the range of alternative ozone NAAQS levels. In particular, EPA needs to make a concerted effort to specify the full set of controls needed to achieve attainment of various ozone standards. A concerted effort is needed because currently EPA's "known" controls represent only one-third of the estimated reductions needed to achieve a 60 ppb standard, with the remaining two-thirds consisting of unspecified ("unknown") controls. EPA also needs to develop specific estimates of costs per ton for *all* of the needed controls, including a reliable means of extrapolating costs where cost information is not available. Finally, EPA needs to perform economy-wide modeling that accounts for both the emissions reduction costs

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[1] All dollar values in this report are in 2013 dollars unless otherwise noted. The present value reflects impacts from 2017 through 2040, as of 2014 discounted at a 5% real discount rate; this discount rate falls in the 3% to 7% range recommended in EPA's *Guidelines for Preparing Economic Analyses* (2010a, p. 6-19), and it is consistent with the discount rate used in the N_{ew}ERA model.

[2] "Job-equivalents" is defined as total labor income change divided by the average annual income per job. This measure does not represent a projection of numbers of workers that may need to change jobs and/or be unemployed, as some or all of the loss could be spread across workers who remain employed, thereby impacting many more that 2.9 million workers, but with lesser impacts per worker.

that the various states would face and the potential barriers to economic development due to other regulatory consequences of being designated as a nonattainment area.

Study Objectives

Our study had two principal objectives:

1. Assess the costs and economic impacts of a 60 ppb ozone standard using the best available information from EPA and other sources; and
2. Develop recommendations for additional and updated information and analyses EPA should provide in its regulatory impact analysis (RIA) of a proposed rule, so that such assessments can be more fully evidence-based.

The first objective was predicated on the large potential significance to the U.S. economy of a more stringent ozone standard as indicated by EPA's own prior partial estimate (excluding costs in California) that the annualized costs would be $90 billion per year in 2006 dollars ($102 billion in 2013 dollars) to achieve a 60 ppb standard using one of EPA's calculation methodologies (EPA 2010b, p. S2-19).[3] Unlike regulations that target specific sectors, an ozone standard would directly affect virtually every sector of the economy, because ozone precursors (oxides of nitrogen, or NO_X, and many types of volatile organic compounds, or VOCs) are emitted by a wide range of stationary, mobile, and area sources. Moreover, a tightened standard might result in other effects, notably potential constraints on domestic natural gas and crude oil development activity if nonattainment regions introduce permitting barriers or require emissions offsets to develop new wells and processing facilities.

The second objective of this study relates to EPA's process of updating its analysis as it prepares its RIA. Our analysis reveals major gaps in information on compliance technologies and their costs and in other important information. Our research thus puts us in a position to recommend information that EPA should develop and make available in order to provide comprehensive and reliable assessments of the economic impacts of a more stringent ozone standard.

Background on the Ozone NAAQS and Its Implementation

Under the Clean Air Act, EPA is instructed to select a primary NAAQS that protects the nation's public health with an "adequate margin of safety" (Section 109(b)(1)). In March 2008, EPA lowered the primary 8-hour ozone NAAQS from 80 parts per billion (ppb) to 75 ppb.[4] EPA is

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[3] Additional discussion of EPA's previous total cost estimates and differences from our cost estimates appears in Appendix C. The total estimated annualized cost of $90 billion is based on EPA's hybrid cost approach with the middle slope parameter.

[4] Due to rounding conventions, areas could comply with the ozone standard of 80 ppb with ozone levels as high as 84 ppb. The ozone primary standard is based upon the annual fourth-highest daily maximum 8-hour concentration, averaged over three years. There is also a secondary standard that presently is the same as the primary standard. We have not assigned any costs for a potentially-tighter secondary standard, should it be more stringent than the primary standard in some locations.

again reviewing the ozone NAAQS, including developing various assessment materials and obtaining advice from the Clean Air Scientific Advisory Committee (CASAC). The new NAAQS rule is expected to be proposed near the end of this year and promulgated in late 2015. EPA has stated its intention to consider tightening the standard to as low as 60 ppb in its most recent draft policy assessment for the ozone NAAQS, and CASAC has endorsed EPA considering a NAAQS in the 60 to 70 ppb range. Our study evaluates a new ozone standard of 60 ppb, one alternative standard that is likely to be included when EPA issues its proposed rule. It is intended to illustrate the types of data and analysis that EPA should undertake and present for each alternative standard that is included in its proposed rule.

After a NAAQS has been promulgated, states must review data from their ambient monitoring networks and identify areas that are not attaining the new NAAQS (called "nonattainment areas"). States must then develop state implementation plans (SIPs) that identify what sources of emissions will be reduced, and when, to achieve attainment on the regulatory schedule. For ozone, attainment will require reductions in both NO_X and many types of VOCs. In most of the U.S., NO_X reductions are presently more effective for reducing ozone formation than VOC reductions. Estimates of the cost of reducing emissions, such as EPA presented in its previous ozone NAAQS rulemakings, thus focus mostly on controls of NO_X. In the absence of any new information to the contrary, our cost analysis is also based mostly on NO_X emissions reduction needs – including what they will cost, and what sectors will pay for them.

Finally, being in nonattainment of a NAAQS triggers more regulatory burdens than just reducing emissions to achieve attainment. A number of regulatory programs are also imposed on nonattainment areas. Significant among these is a requirement that any economic entity that wishes to obtain a permit to establish a new facility that will emit the pollutant(s) of concern in a nonattainment area must first find an offsetting reduction of those same emissions from another facility that is exiting the area, or has voluntarily reduced its own emissions below its permitted level. Markets for these "offsets" often develop, but offsets can be exceedingly costly or difficult to find if there are few existing emitting facilities in the area to create a supply. A tightened ozone standard has the potential to cause nonattainment areas to expand into relatively rural areas, where there are few or no existing manufacturing facilities to generate a supply of offsets. If nonattainment expands into rural areas that are active in U.S. oil and gas extraction, a shortage of offsets may translate into a significant barrier to obtaining permits for the new wells and pipelines needed to expand (or even maintain) our domestic oil and gas production levels. Our analysis also considers the potential implications of this often-ignored aspect of nonattainment status.

Costs of Emissions Controls to Achieve Attainment

Methodology for Estimating Compliance Costs

Although EPA's review of the NAAQS for ozone is under way, EPA has not released any new ozone compliance cost estimates since its 2008-2010 analyses.[5] EPA has issued some updated information on projected baseline emissions, and there is updated monitored ozone concentration data that helps indicate the areas and states most likely to be designated in nonattainment with a 60 ppb standard. The updated information allows us to develop estimates of emissions reductions that might be required for these states to come into attainment. The cost information available from EPA, however, currently is very limited, and we explain ways that EPA needs to improve it. The data development and analysis needs that we highlight in this report will be the same whether EPA chooses to propose a standard of 60 ppb, as we analyze here, or some other level.

Our compliance cost estimates are based upon a synthesis of four major sources of information: (i) the most recent EPA information on projected 2018 baseline VOC and NO_X emissions (EPA 2014a) supplemented by baseline emission projections for electric generating units (EGUs) from N_{ew}ERA; (ii) our assessments (based upon earlier EPA analyses) of emission reductions that would be required for all regions of the United States to come into attainment; (iii) cost and emission reduction information that EPA has developed for what it refers to as "known" controls; and (iv) our estimates of the emission reductions and potential costs per ton of what EPA refers to as the "unknown" controls necessary to achieve attainment in each affected state.[6] The report and appendices provide details on our methodology. Although this report describes results for the United States as a whole and disaggregated to 11 regions,[7] the inputs and the results are built up using detailed state-specific and sector-specific cost information. The costs and impacts of a more stringent ozone standard differ substantially among states.

EPA's 2008-2010 ozone analyses identified many specific NO_X emissions controls that could be adopted by existing NO_X emissions sources in and around projected nonattainment areas. As noted, those "known" control options did not provide sufficient emissions reductions to attain a 60 ppb standard in most of the projected nonattainment areas. Indeed, the bulk of the estimated compliance costs for a 60 ppb standard in EPA's prior ozone analyses were based on extrapolations from "known" control costs to the costs of unspecified ("unknown") controls on

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[5] "EPA's 2008-2010 ozone analyses" refers to information in EPA's 2008 regulatory impact analysis (RIA) for the ozone NAAQS, including information on baseline future conditions and ozone standards of 80 (effectively 84) and 75 ppb (EPA 2008); EPA's 2010 supplemental regulatory impact analysis, including information on an ozone standard of 60 ppb (EPA 2010b); and data files in Docket No. EPA-HQ-OAR-2007-0225.

[6] EPA's 2008-2010 ozone analyses refer to various types of controls. We refer to the "known" costs as those EPA refers to as "known" and "supplemental." The "unknown" controls are not specified by EPA.

[7] "U.S." results are, formally, only for the lower 48 states, and exclude Alaska and Hawaii, as well as Washington DC. We refer to the lower 48 states as "U.S." hereafter.

the many other, mostly dispersed, sources of NO_X in the U.S. These extrapolations relied on information on the cost per ton of "known" controls—rather than potential costs for "unknown" controls—and on largely arbitrary assumptions about the maximum cost per ton that any area would incur. Extrapolations of any sort are fraught with a high degree of uncertainty. Such uncertainty is a particular concern when the resulting compliance cost estimates are very large, as is the case for a tightened NAAQS.

In this study, we demonstrate an evidence-based approach for estimating costs of the "unknown" controls that provides one template for developing reliable estimates of total compliance costs. To do so, we first assume that the "known" control measures identified by EPA in its 2008-2010 ozone analyses have not yet been adopted, and thus will still be part of the attainment effort to meet a tightened ozone NAAQS. We then identify the types of sources and activities that account for the remaining emissions of NO_X, and the extent to which they also will need to be reduced in order to attain a 60 ppb NAAQS. By directly characterizing what sources those "unknown" controls must come from, one can develop a more informed (albeit still uncertain) procedure for estimating the total costs of attainment.

As Figure S-1 illustrates, national NO_X emissions have already been reduced substantially, from about 25.2 million tons in 1990 to 12.9 million tons in 2013 (EPA 2014b). EPA presently is projecting that U.S. NO_X emissions will be further reduced to 9.7 million tons by 2018 (supplemented with EGU baseline emission projections from N_{ew}ERA) due to existing rules and regulations, some of which have not yet been fully implemented and will carry with them additional compliance costs on top of any compliance costs estimated in this study (EPA 2014a).[8] Economic activity (as measured by real GDP) in 2018 is projected to be more than double the level in 1990 (CEA 2014, Table B-3 and OMB 2013, Table 2), suggesting that U.S. NO_X sources will have been controlled by roughly 80% by 2018, even before the additional controls needed to attain a tighter ozone NAAQS.

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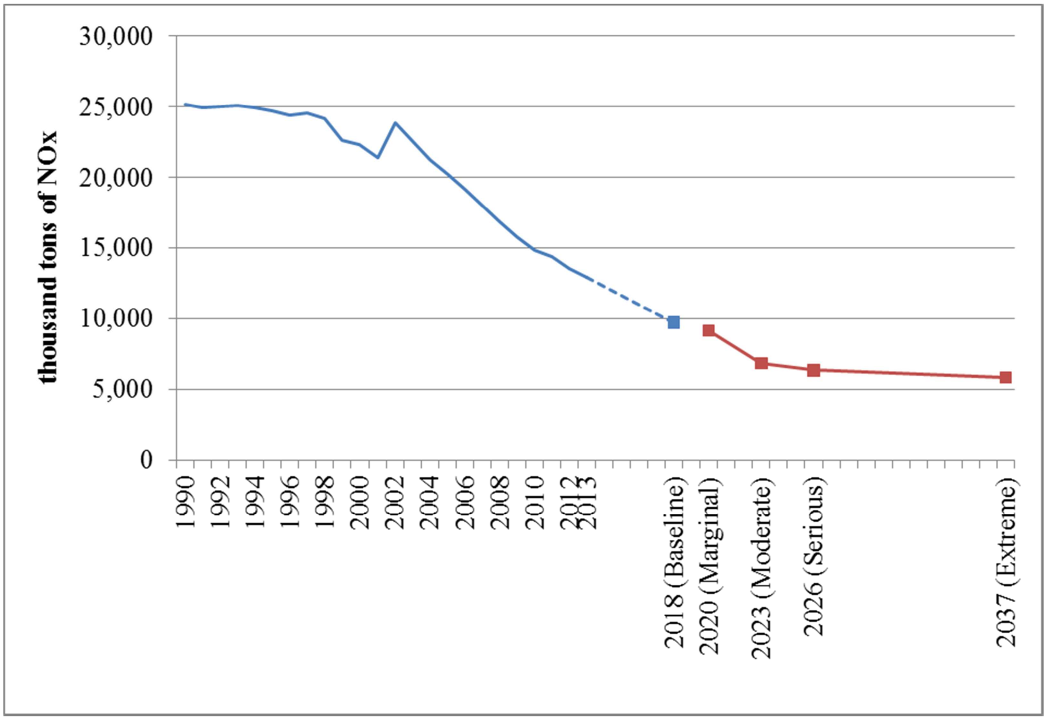
[8] These are national totals, but the reductions to get down to 9.7 million tons will have to occur primarily in states with nonattainment areas. As we will explain later, we estimate that 40 states will have at least some nonattainment for a new ozone NAAQS of 60 ppb. Among these 40 states, projected 2018 NO_X emissions are 8.9 million tons, and NO_X emissions need to be reduced to 5.0 million tons for attainment.

Figure S-1: U.S. NO_X Emissions to Attain 60 ppb NAAQS Compared to Historical NO_X



Notes: Blue solid line: estimated historical emissions; blue dotted line: projected further declines through 2018; Red line: emissions to attain 60 ppb on attainment schedule.
The slight increase in U.S. NO_X emissions from 2001 to 2002 primarily reflects changes in EPA's emission modeling methodology for onroad and nonroad sources (switching from MOBILE6 to the National Mobile Inventory Model and MOVES)

Source: NERA calculations as explained in text

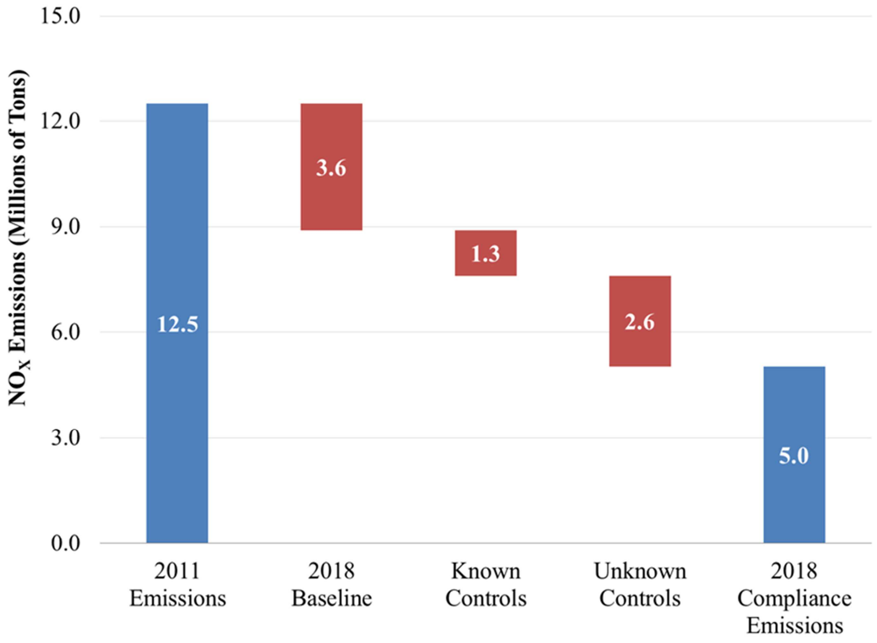
Based upon the 2008-2010 EPA review, total U.S. NO_X emissions would have to be reduced to about 5.8 million tons to meet a 60 ppb standard throughout the nation. This reduction appears as the red line above in Figure S-1, which also shows our projection of the timing of those reductions, based on our estimates of the likely severity classifications of the different states. Despite the extensive controls already expected to have occurred through 2018, we estimate that another 3.9 million tons (in aggregate) would need to be eliminated across the 40 states that our analysis indicates would not attain a 60 ppb standard under the 2018 baseline emissions, in order for those states to come into attainment. This is equivalent to another 45% reduction from those states' 2018 NO_X emissions, and it implies about 90% total reduction from all sizes and types of NO_X-emitting sources from the relatively uncontrolled emissions rates in 1990 (after adjusting for growth).

The EPA 2008-2010 analyses also imply that the EPA "known" control measures would reduce about 1.3 million tons of NO_X across those 40 non-attaining states. The remaining 2.6 million tons (two-thirds of the total necessary emission reduction) would need to come from the "unknown" controls that EPA was unable to identify in its 2008-2010 analyses. The waterfall chart of Figure S-2 summarizes the relative magnitudes of the three types of emissions reductions our analysis projects the 40 non-attaining states would rely on to get from their recent (2011) NO_X emissions to the estimated levels needed for attainment with a 60 ppb standard. In our analysis, we treat the first reduction block – which is reductions due to changes in activity and other non-ozone regulations presently being implemented – as costless (although we include the costs of controls that have not been implemented). While regulations now being implemented clearly have a cost, we do not attribute those costs to a tightened ozone NAAQS. For EPA's list of known controls, we use EPA's earlier cost estimates. For the block of controls that EPA called "unknown," we use additional data and analysis to develop our own cost estimate.

Answers to three key questions about these "unknown" controls will determine the overall costs (and, indeed the feasibility) of a 60 ppb ozone standard.

- What categories of emission sources would be potentially available to achieve these additional 2.6 million tons of "unknown" NO_X reductions?
- What types of control strategies would likely be used for these "unknown" NO_X emission reductions?
- What would be the costs of these "unknown" controls?

Figure S-2: NO_X Emissions and Categories of NO_X Reductions to Attain 60 ppb NAAQS (for 40 Non-Attaining States Only)



Note: Emissions and reductions include only states requiring emission reductions for compliance with a new ozone NAAQS of 60 ppb in this analysis.
Source: NERA calculations as explained in text

To address the first two of the above questions, we look at EPA's estimates of the categories of 2018 baseline emissions disaggregated down to the five categories that EPA identifies in its emissions inventories, and we allocate the reductions from EPA's list of known controls to these categories.[9] This information gives insights on what types of control strategies might be available to obtain further "unknown" reductions.

Figure S-3 shows the 2018 baseline emissions in states that will need to reduce NO_X emissions to meet a 60 ppb standard and the portion that would be eliminated by EPA's "known" controls for the five emission categories. (The total 2018 baseline emission for these states across all five categories is 8.9 million tons.) This information shows that most of the emissions that remain after EPA's "known" controls are from electricity generating units (EGUs) and the three types of non-point sources, while large industrial and manufacturing point sources are substantially controlled.

Detailed information on the list of known controls (described in the main report) indicates that the "known" controls seem to exhaust the options for retrofitting existing equipment with technology controls (e.g., installation of low-NO_X combustion devices and NO_X-destroying post-combustion devices). This explains why most of the known controls' effects are concentrated on the industrial and manufacturing emitters that comprise the "point source" category.[10] This evidence suggests that the bulk of the 2.6 million tons of "unknown" NO_X reductions will have to come various forms of capital stock replacement rather than further technology retrofits. While these replacements will likely include retirements of large coal-fired electricity generators, it also will likely become necessary to scrap and replace a wide array of very small sources, such as personal vehicles, individual pieces of construction equipment, and agricultural and landscaping equipment.

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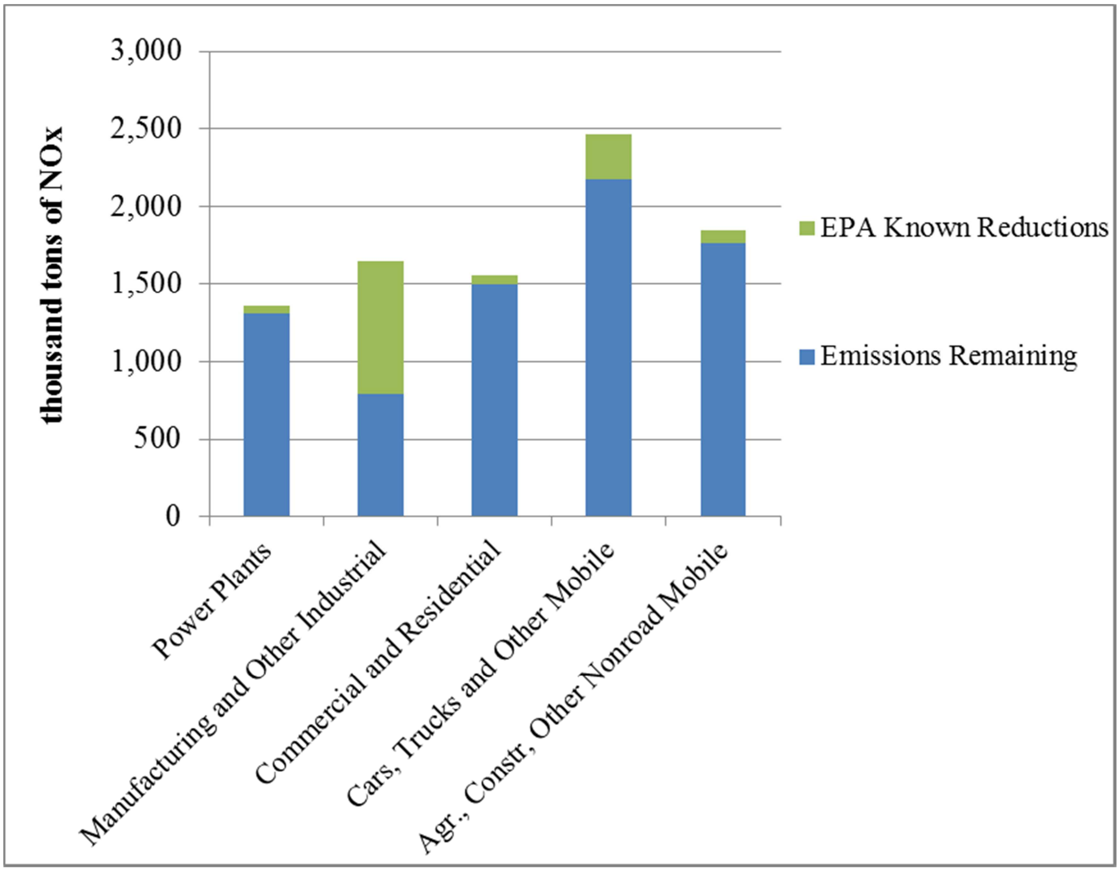
[9] The categories include two types of "point sources," which are large non-moving emitting equipment such as industrial boilers and electricity generating units (EGUs). The other three categories are "non-point sources," which means they are many small, diffuse sources. Of these "area sources" are non-moving equipment that are too individually small to be regulated as point sources are. Examples include commercial and residential water and space heaters as well as compressors along oil and natural gas pipelines. "Mobile sources" are small, diffuse and can be moved from place to place. Onroad mobile sources include cars and all sizes of trucks. Nonroad mobile sources include agricultural and construction equipment as well as transportation such as locomotives, airplanes, and boats.

[10] EPA's "known" controls for electric generation unit (EGU) sources (which are mostly from additional retrofits of selective catalytic reduction, SCR) have very little effect on EGU 2018 emissions. This is because almost all of the EGU point sources have already been retrofitted with NO_X controls in states projected to have nonattainment. Retirements rather than further retrofitting will be necessary to further reduce EGU emissions in these states and EPA did not consider retirements of equipment as a known control.

Figure S-3: EPA Known NO_X Reductions from 2008-2010 Analysis and Remaining Emissions by General Categories of Emissions Sources in the 40 Non-Attaining States



Source: NERA calculations as explained in text

To show how EPA can develop a more informed estimate of the costs of these remaining necessary types of NO_X reductions, we considered the costs of reducing emissions from two of the most significant categories of remaining NO_X emissions.

- *Retirement of coal-fired power plants.* If coal units are retired in states with large remaining NO_X reductions needs, and their generation is replaced by a cost-effective combination of natural gas and non-emitting generation, we estimate that an additional emissions reduction of about 1 million tons could be obtained. Our analyses indicate that these tons of reduction will cost an average of approximately $31,000/ton, but with costs ranging up to about $180,000/ton among the states. We replace the "known" power plant controls (retrofits) used in EPA's 2008-2010 analyses with these potential retirement controls in our analysis.

- *Scrapping of cars and light-duty trucks.* Cars and trucks will be much lower-emitting in 2018 than the fleet of vehicles on the road today, but in aggregate they account for a

> further potential reduction of 1 million tons, assuming every 2018 vehicle were to be scrapped in 2018 and replaced by either an electric vehicle (powered by natural gas generation) or a Tier 3 vehicle.[11] Using a model framework developed by an MIT researcher to evaluate an existing vehicle scrapping program (Knittel 2009), we estimate the marginal cost per ton of reducing light-duty vehicle NO_X emissions by 10% through the early replacement of the highest-emitting cars and trucks would be in the range of $100,000/ton, a figure that escalates to about $500,000/ton to achieve about a 50% reduction. Scrapping newer, lower-emitting cars would cost more and generate fewer reductions per vehicle, so the incremental cost per ton rises as increasing percentages of the vehicle fleet are scrapped.

Replacing coal-fired EGUs would reduce NO_X emissions by about 1 million tons. Replacing *all* 2018 cars and light-duty vehicles would provide another 1 million tons of reduction. But other types of equipment certainly would become cost-effective to replace before one would go so far as to scrap all cars and light duty vehicles. We assume that the marginal cost-per-ton for these other sources rise similarly to those we estimated for early turnover of different vintages of cars and light-duty trucks, as one indication of the potential costs that states would incur to control the other non-point sources.

Figure S-4 shows the resulting mix of reductions assumed in our estimates of the compliance costs needed to achieve a 60 ppb ozone standard. The dark green shows EPA's "known" controls and the light green shows NERA's evidence-based assumptions regarding where "unknown" controls will likely come from. The remaining sum (shown in the blue bars) is now 5.0 million tons—the aggregate limit to achieve attainment for the states projected to be in nonattainment under baseline 2018 emissions levels. NERA's estimates assume deep cuts in the EGU sector, where emissions are concentrated in a few sources and costs per ton are thus lower than for the many smaller sources among the non-point source categories (i.e., area, onroad mobile and nonroad mobile).[12] NERA's assumptions on "unknown" controls outside of the EGU sector involve much smaller incremental percentage reductions than from EGUs; but because these will require programs such as scrapping vehicles and other small sources, they are expected to come at a substantially higher cost per ton than the EGU controls—even though we assume that the scrapping programs only target the oldest, highest-emitting of each type of NO_X-emitting equipment.

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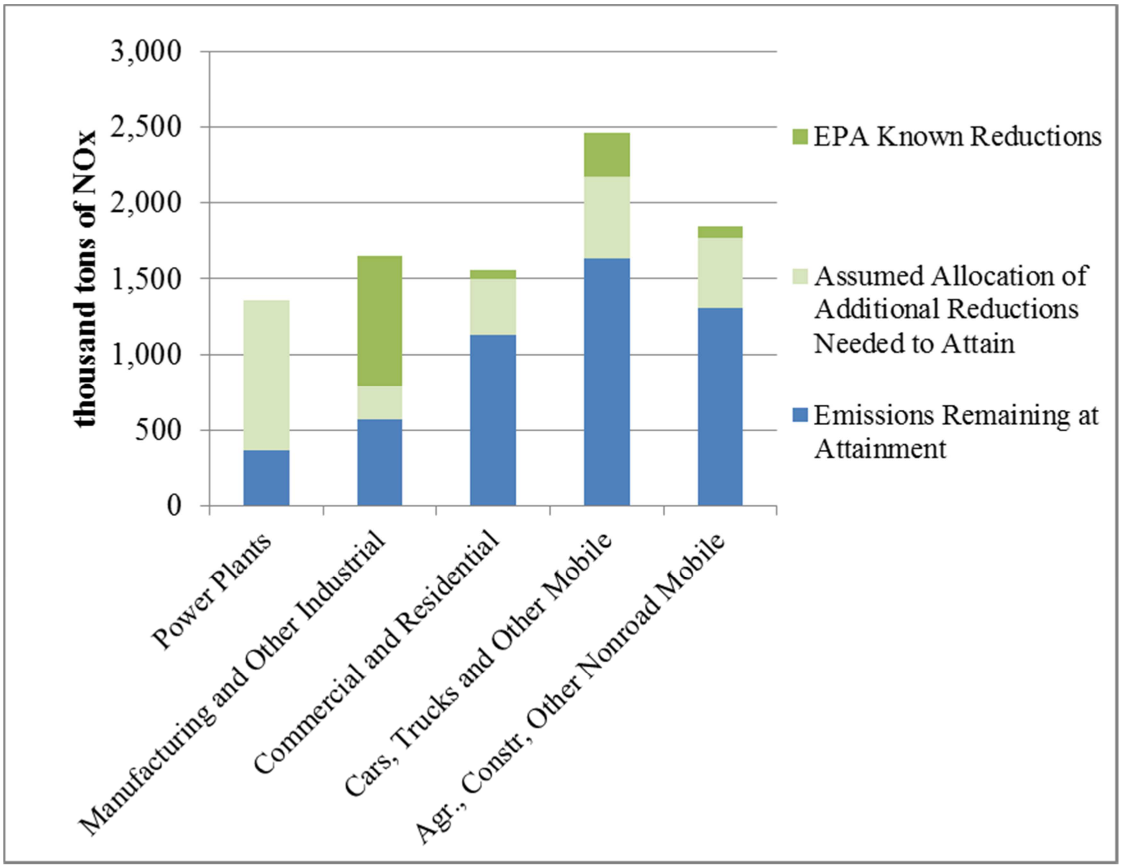
[11] The reduction is less than 1 million if one considers only vehicles in areas that contribute to nonattainment.

[12] As discussed below, EPA (2014d, pp. ES-6 and ES-7) estimates that its recently proposed power sector CO_2 rule would reduce annual NO_X emissions by approximately 300,000 to 400,000 tons (depending on regulatory option, state or regional compliance approach, and measurement year). Our modeling of potential changes to coal-fired power plants for compliance with a new ozone NAAQS of 60 ppb would lead to a significantly larger NO_X reduction (as shown in Appendix C). Thus, the proposed power sector CO_2 rule would not change our conclusion that a new 60 ppb ozone NAAQS would have significant impacts on the power sector (and other sectors of the economy).

Figure S-4: NERA Analysis's Allocation of Additional Reductions Necessary to Attain a 60 ppb NAAQS to Categories of Emissions Sources in the 40 Non-Attaining States



Source: NERA calculations as explained in text

On June 2, 2014, EPA released a proposed rule to limit CO_2 emissions from the power sector. Implementation of such a rule will almost certainly result in some amount of NO_X reduction (primarily because of a reduction in coal-fired generation needed to reduce state CO_2 emissions rates). EPA (2014d, pp. ES-6 and ES-7) estimates that the proposed power sector CO_2 rule would reduce annual NO_X emissions by approximately 300,000 to 400,000 tons (depending on regulatory option, state or regional compliance approach, and measurement year). Some of those NO_X reductions may overlap with NO_X reductions in our ozone cost analysis, and to the extent that this would occur, some of the cost estimates will be shared with the cost of the proposed CO_2 rule for the power sector. We have considered this issue and find that even if all of those overlapping costs were to be removed from our analysis, the costs and economic impacts presented in this report would not change in any meaningful degree because NO_X reductions from the power sector are estimated to be among the lowest cost-per-ton of the NO_X reductions in our ozone attainment scenario. In fact, even if all of the approximately 100 GW reduction in electric sector coal capacity (discussed in subsequent sections of this report) were treated as costless in our ozone analysis, our estimated GDP impact would only be reduced by about 8%, or about one-twelfth of the value we estimate. Moreover, our review of EPA's RIA for the power plant CO_2 rule indicates that the overlap of power sector costs is much less than 100%, as the proposed power sector CO_2 rule would lead to NO_X reductions in some areas that would not require reductions for compliance with a new 60 ppb ozone standard. Thus, uncertainty on how to attribute shared costs between the two regulations does not affect the major conclusions of this report regarding the costs and economic impacts of a tightened ozone NAAQS.

Estimates of Potential Compliance Costs

We estimate that the potential costs of achieving a 60 ppb ozone standard would have a present value of $2.2 trillion as of 2014 (based upon costs incurred from 2017 through 2040), as reported in Figure S-5. As a rough point of comparison, EPA's annualized cost estimate implies a present value of about $0.9 trillion.[13] The primary difference in our methodologies is the extrapolation method used to estimate the cost of "unknown" controls that were not identified in EPA's 2008-2010 analyses; we attempted to understand the kinds of controls that would be required after "known" controls and based our method on the estimated costs of one such control (vehicle scrappage), whereas EPA relied on an arbitrary extension from "known" control costs. As discussed in the report, our cost estimate is still subject to substantial uncertainty. We also note that our evidence-based approach could be extended to other types of equipment that, in aggregate, make substantial contributions to non-point source NO_X emissions. Given the importance of these additional controls to the compliance cost estimate, we conclude that it would be important for EPA to develop information before it releases its proposal to revise the ozone NAAQS.

Figure S-5: Potential U.S. Compliance Spending Costs for 60 ppb Ozone Standard

	Present Value (Billions)			Cumulative
	Capital	O&M	Total	Coal Retirements
Compliance Costs	$1,190	$1,050	$2,240	101 GW

Notes: Present value is from 2017 through 2040, discounted at a 5% real discount rate.
Cumulative coal retirements are incremental to baseline. These retirements are primarily due to assumed emission control measures but may also include indirect electric sector impacts of the ozone standards.
Source: NERA calculations as explained in text

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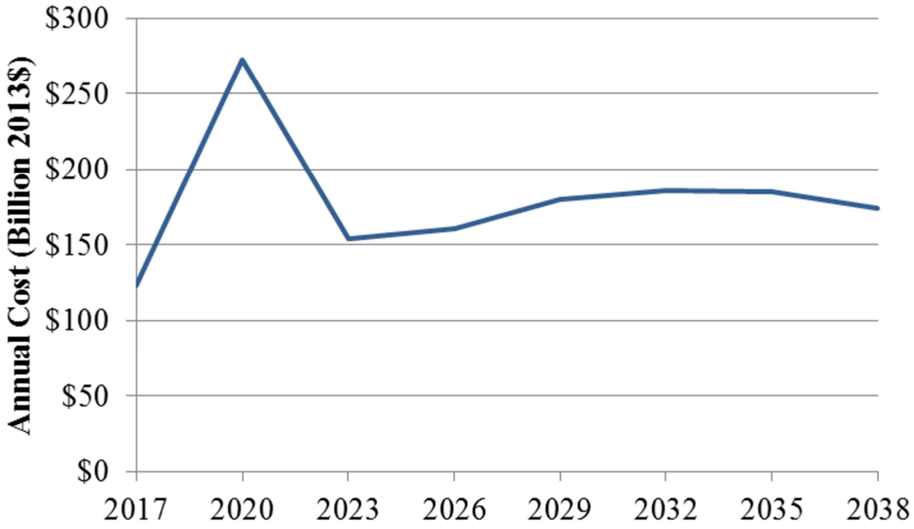
[13] The annualized cost of $90 billion in 2020 for EPA's hybrid cost calculation with the middle slope parameter has been converted to a present value over 20 years using a real annual discount rate of 5%, converted from 2006 dollars to 2013 dollars, and calculated as of 2014. Note that there are many differences in the EPA and NERA calculations so this figure is only designed to provide a rough comparison.

Allocating the estimated capital costs to spending in years prior to each state's projected compliance deadline, and allocating O&M costs to years after the respective compliance deadlines, Figure S-6 shows the pattern of annual compliance spending across all states (except for the endogenously-determined costs of coal unit idling.)

Figure S-6: Potential Annual U.S. Compliance Spending Costs for 60 ppb Ozone Standard



Notes: Figure does not include compliance costs associated control measures in the electric power sector (scrappage of coal-fired power plants), which are modeled in N_{ew}ERA.
Source: NERA calculations as explained in text

As was the case for EPA's 2008-2010 analyses, a large portion of our estimated compliance costs are for control actions that EPA has yet to identify. As we have shown, there are ways to identify what types of controls would be needed and to develop evidence-based estimates of those types of controls. We emphasize that EPA should more fully identify the likely control measures and their costs so that the costs and economic impacts of the rule can be estimated with more confidence. Our analysis also identified the need for updated information on the identify of potential non-attainment areas and the emission reductions required to achieve compliance—additional information gaps that EPA needs to fill in order to allow for a more reliable approximation of compliance costs than it produced in 2008-2010.

Market and Macroeconomic Impacts

The prior section explains how one can develop a reasoned estimate of the resource costs of attaining a tightened ozone NAAQS and how those costs are imposed on various sectors (including households). Developing a full picture of how those costs ultimately would affect various businesses and households requires an "economic impact analysis" that takes into account the complicated interactions in the economy. According to NERA's model, changes in costs for the various sectors directly affected by the tightened ozone standard can lead to changes in sector prices, which affect all consumers, whether households or other businesses. These regulatory costs—and the price changes they can induce—can lead to changes in the ways that sectors produce their outputs, which affects demand from existing suppliers as well as from other potential suppliers. The net effects of the compliance costs thus are potential changes in outputs and prices, with resulting effects on businesses as well as on households as workers and consumers. These impacts on businesses and households can differ dramatically by geography.

To assess these economic impacts of a regulation, the estimated compliance costs can be input into a model that includes linkages of how the directly regulated sector(s) interact with other parts of the economy. In addition to incorporating higher costs on sectors that reduce emissions, the model scenario should also reflect other types of constraints on choices or actions that the policy may impose. For example, if the regulation means that businesses cannot expand their production in certain locations, this constraint can affect the nature and location of a policy's economic impacts.

In the case of a regulation expected to have very large overall costs and to affect the costs of many sectors, a *full-economy*, macroeconomic model is needed to properly assess the overall impacts of compliance costs and other regulatory constraints. The tightened ozone NAAQS is such a situation. This study thus uses a detailed macroeconomic model to evaluate the economic impacts of a 60 ppb ozone standard.

Methodology for Analyzing Economic Impacts

We use NERA's N_{ew}ERA macroeconomic model to develop estimates of the potential macroeconomic impacts on the U.S. economy of our estimates of compliance costs for attaining a 60 ppb ozone standard. The capital costs are incurred from 2017 until 2036 (the last projected compliance date, for extreme areas), while O&M costs are incurred for all years after compliance. Our economic impact analysis includes the effects of costs incurred through 2040.

N_{ew}ERA is an economy-wide integrated energy and economic model that includes a bottom-up, unit-specific representation of the electric sector, as well as a representation of all other sectors of the economy and households. It assesses, on an integrated basis, the effects of major policies on individual sectors as well as the overall economy. It has substantial detail for all of the energy sources used by the economy, with separate sectors for coal production, crude oil extraction, electricity generation, refined petroleum products, and natural gas production. The model performs its analysis with regional detail. As discussed above, this particular analysis uses state-specific cost inputs, and N_{ew}ERA has been run to assess state-specific economic impacts. Appendix A provides a detailed description of the N_{ew}ERA model.

The analysis requires a baseline forecast that projects economic outcomes in the absence of the incremental spending to attain the tighter ozone NAAQS. For this study, N_{ew}ERA's baseline conditions were calibrated to reflect projections developed by Federal government agencies, notably the Energy Information Administration (EIA) as defined in its *Annual Energy Outlook*

2014 (*AEO 2014*) Reference case. This baseline includes the effects of environmental regulations that have already been promulgated as well as other factors that lead to changes over time in the U.S. economy and the various sectors.

Potential Impacts on the U.S. Economy and U.S. Households

The potential costs we estimated for a 60 ppb ozone standard are projected to have substantial impacts on the U.S. economy and U.S. households. Figure S-7 shows the potential macroeconomic effects as measured by gross domestic product (GDP) and U.S. household consumption. The 60 ppb ozone standard is projected to reduce GDP from the baseline levels by about $3.4 trillion on a present value basis (as of 2014) and by $270 billion per year on a levelized average basis (spread evenly over years but retaining the same present value) over the period from 2017 through 2040. Average annual household consumption would be reduced by about $1,570 per household per year.

Figure S-7: Potential Impacts of 60 ppb Ozone Standard on U.S. Gross Domestic Product and Household Consumption

	Annualized	Present Value
GDP Loss (Billions of 2013$)	$270/year	$3,390
Consumption Loss per Household (2013$)	$1,570/year	N/A

Notes: Present value is from 2017 through 2040, discounted at a 5% real discount rate. Consumption per household is an annualized (or levelized) value calculated using a 5% real discount rate.

Source: NERA calculations as explained in text

Figure S-8 focuses on several dimensions of projected impacts on income from labor ("worker income") as a result of the 60 ppb ozone standard. The projected impacts of the emissions reduction costs on labor income are substantial. Relative to baseline levels, real wages decline by about 1.2% on average over the period and labor income declines by about 1.9% on average, resulting in job-equivalent losses that average about 2.9 million job-equivalents. (Job-equivalents are defined as the change in labor income divided by the annual baseline income for the average job (see Figure S-8)). A loss of one job-equivalent does not necessarily mean one fewer employed person—it may be manifested as a combination of fewer people working and less income per worker. However, this measure allows us to express employment-related impacts in terms of an equivalent number of employees earning the average prevailing wage.[14] These are the *net* effects on labor and include the positive benefits of increased labor demand in sectors providing pollution control equipment and technologies.

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[14] The N$_{ew}$ERA model, like many other similar economic models, does not develop projections of unemployment rates or layoffs associated with reductions in labor income. Modeling such largely transitional phenomena requires a different type of modeling methodology; our methodology considers only the long-run, equilibrium impact levels.

Figure S-8: Potential Impacts of 60 ppb Ozone Standard on Labor

	Avg.
Baseline Annual Job-Equivalents (millions)	156
60 ppb Case:	
Real Wage Rate (% Change from Baseline)	-1.2%
Change in Labor Income (% Change from Baseline)	-1.9%
Job-Equivalents (Change from Baseline, millions)	-2.9

Notes: Average (Avg.) is the simple average over 20172040. "Job-equivalents" is defined as total labor income change divided by the average annual income per job. This measure does not represent a projection of numbers of workers that may need to change jobs and/or be unemployed, as some or all of the loss could be spread across workers who remain employed

Source: NERA calculations as explained in text

Potential Effects on U.S. Energy Prices

Emissions reduction costs of a 60 ppb ozone standard also would have substantial potential impacts on U.S. energy sectors, largely because the more stringent ozone standard is projected to lead to the premature retirement of additional coal-fired power plants. Figure S-9 shows average energy price projections under the baseline and the 60 ppb ozone standard. The average delivered residential electricity price is projected to increase by an average of 3.3% over the period from 2017 through 2040. Henry Hub natural gas prices would increase by an average of 9.9% in the same time period, while delivered residential natural gas prices would increase by an average of 7.3%. Part of the increase in delivered natural gas prices reflects the increase in pipeline costs due to control costs for reductions in NO_X emissions in the pipeline system that would be recovered through tariff rates.

Figure S-9: Potential Impacts of a 60 ppb Ozone Standard on Energy Prices

		Avg. Baseline	**Avg. 60 ppb Case**	**Change**	**% Change**
Henry Hub Natural Gas	$/MMBtu	$6.02	$6.65	$0.63	9.9%
Natural Gas Delivered (Residential)	$/MMBtu	$13.77	$14.79	$1.02	7.3%
Natural Gas Delivered (Industrial)	$/MMBtu	$8.43	$9.49	$1.06	12%
Gasoline	$/gallon	$3.56	$3.57	$0.01	0.4%
Electricity (Residential)	¢/kWh	14.5¢	14.9¢	0.5¢	3.3%
Electricity (Industrial)	¢/kWh	9.4¢	9.9¢	0.5¢	5.5%

Notes: Average is the simple average over 2017-2040.

Source: NERA calculations as explained in text

Potential Effects on U.S. Sectors and Regions

All sectors of the economy would be affected by a 60 ppb ozone standard, both directly through increased emissions control costs and indirectly through impacts on affected entities' customers and/or suppliers. There are noticeable differences across sectors, however. Figure S-10 and Figure S-11 show the estimated changes in output for the non-energy and energy sectors of the economy, respectively, due to the emissions reduction costs of a 60 ppb ozone standard.

Figure S-10: Potential Impacts of 60 ppb Ozone Standard on Output of Non-Energy Sectors (Percentage Changes from Baseline)

	Agriculture	Commercial/ Services	Manufacturing	Commercial Transportation	Commercial Trucking
Average (2017-2040)	-2.2%	-0.9%	-0.6%	-1.9%	-1.1%

Notes: Values are the simple average of percentage change over 2017-2040.
Source: NERA calculations as explained in text

Figure S-11: Potential Impacts of a 60 ppb Ozone Standard on Output of Energy Sectors (Percentage Changes from Baseline)

	Coal	Natural Gas	Refining	Crude Oil	Electricity
Average (2017-2040)	-52%	9.2%	-1.8%	-0.1%	-3.1%

Notes: Values are the simple average of percentage change over 2017-2040.
Source: NERA calculations as explained in text

Figure S-12 shows the average annual change in consumption per household for individual N_{ew}ERA regions. A region's attainment costs and its sectoral output mix determine to a large extent whether a region fares better or worse than the U.S. average, but all regions would experience lower household consumption.

Figure S-12: Potential Impacts of a 60 ppb Ozone Standard on Annual Consumption per Household by Region

Region	
Arizona and Mountain States	-$690
California	-$2,910
Florida	-$450
Mid-America	-$850
Mid-Atlantic	-$2,520
Mississippi Valley	-$1,550
New York/New England	-$2,490
Pacific Northwest	-$730
Southeast	-$1,060
Texas, Oklahoma, Louisiana	-$1,070
Upper Midwest	-$1,770
U.S.	**-$1,570**

Note: Values are the levelized average over 2017-2040, annualized using a 5% real discount rate. Maps of N_{ew}ERA regions are provided in the report body and Appendix A.
Source: NERA calculations as explained in text

Sensitivity Case with Limits on Natural Gas Production

The above results assume that the U.S. energy sectors would be able to increase production with no permitting delays or constraints (other than the higher production cost associated with emissions controls) in order to meet increased natural gas demand associated with ozone NAAQS attainment actions. This assumption allows for a large projected increase in U.S. natural gas production. However, natural gas producers in areas that become nonattainment under a tighter ozone standard might face new requirements – such as the need to obtain air permits as well as emissions reduction credits (“offsets”) for NO_X and/or VOCs – in order to develop new wells. Whether such permitting requirements will be applied to new oil and gas extraction nationally is a policy question that is in a state of flux at present; but some areas of the country already have these requirements and there are pressures for the EPA to make it a uniform requirement. Moreover, expansion of natural gas output will require additional gas processing facilities, which are already subject to the offsetting requirement if located in nonattainment areas. Obtaining offsets may be difficult and/or costly, particularly in relatively rural areas that are likely to face nonattainment issues that until now have been mainly faced by urban areas. Such rural areas will have few industrial emissions sources to create offset supply, so that a potential requirement of new sources in nonattainment areas to purchase offsets may become a substantial hindrance to growth. If such barriers to new well development do emerge, the projected economic impacts of a 60 ppb ozone NAAQS could be substantially increased.

To explore the ways that a constraint on new well development could change the economic impacts of a 60 ppb ozone standard, we developed a natural gas production sensitivity case. For this case we used the same emissions reduction cost inputs as in the 60 ppb case, but we also assumed that total U.S. natural gas production would not increase beyond its 2020 level as modeled in the 60 ppb scenario.[15] We project that lower 48 U.S. natural gas production would be 28.9 quadrillion Btus ("quads") in 2020 under a 60 ppb ozone standard without any natural gas constraints, so we limited lower 48 U.S. natural gas production to 28.9 quads after 2020 in the sensitivity case. Note that limits on natural gas production may also affect crude oil production, but we have not attempted to evaluate this possibility.

Figure S-13 shows the potential effects of a 60 ppb ozone standard in the natural gas production sensitivity case (which includes the effects of reduced natural gas availability as well as the estimated compliance costs) on the U.S. economy as measured by GDP and U.S. household consumption. The 60 ppb ozone standard with assumed natural gas production limits is projected to reduce GDP from the baseline levels by about $360 billion per year on a levelized average basis and by $4.5 trillion on a present value basis (as of 2014) over the period from 2017 through 2040, which is about 30% higher than for the 60 ppb case without natural gas production limitations. Average household consumption would be reduced by about $2,040 per household per year on average over the period.

Figure S-13: Potential Impacts of a 60 ppb Ozone Standard on U.S. Gross Domestic Product and Household Consumption (Sensitivity Case)

	Annualized	Present Value
GDP Loss (Billions of 2013$)	$360/year	$4,480
Consumption Loss per Household (2013$)	$2,040/year	N/A

Notes: Present value is from 2017 through 2040, discounted at a 5% real discount rate
Source: NERA calculations as explained in text

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[15] This scenario constrained natural gas production to be at or below 2020 levels throughout the model horizon, but this policy does not mean that no new wells could be drilled. If new wells were prohibited after 2020, U.S. natural gas production would actually start to decline after 2020, rather than hold steady as this case assumes.

Figure S-14 shows potential labor impacts as a result of the 60 ppb ozone standard with natural gas production constraints. In this sensitivity case, labor income would decrease (relative to baseline future levels) by an average of 2.7% over the period from 2017 through 2040, and in job-equivalents this would imply an average annual loss of about 4.3 million job-equivalents.

Figure S-14: Potential Impacts of a 60 ppb Ozone Standard on Labor (Sensitivity Case)

	Avg.
Baseline Job-Equivalents (millions)	155.7
Sensitivity Case:	
Real Wage Rate (% Change from Baseline)	-2.0%
Change in Labor Income (% Change from Baseline)	-2.7%
Job-Equivalents (Change from Baseline, millions)	-4.3

Notes: Average is the simple average over 2017-2040. "Job-equivalents" is defined as total labor income change divided by the average annual income per job. This value does not represent a projection of numbers of workers that may need to change jobs and/or be unemployed, as some or all of it could be spread across workers who remain employed.

Source: NERA calculations as explained in text

Figure S-15 shows potential energy prices under the baseline and the 60 ppb ozone standard with natural gas production constraints. In this sensitivity case, the average delivered residential electricity price is projected to increase by an average of 15% over the period from 2017 through 2040. Henry Hub natural gas prices would increase by an average of 66% in the same time period, while delivered residential natural gas prices would increase by an average of 32%.

Figure S-15: Potential Impacts of a 60 ppb Ozone Standard on Energy Prices (Sensitivity Case)

		Avg. Baseline	**Avg. Sensitivity**	**Change**	**% Change**
Henry Hub Natural Gas	$/MMBtu	$6.02	$9.97	$3.95	66%
Natural Gas Delivered (Residential)	$/MMBtu	$13.77	$18.16	$4.39	32%
Natural Gas Delivered (Industrial)	$/MMBtu	$8.43	$12.79	$4.36	52%
Gasoline	$/gallon	$3.56	$3.60	$0.04	1.3%
Electricity (Residential)	¢/kWh	14.5¢	16.6¢	2.1¢	15%
Electricity (Industrial)	¢/kWh	9.4¢	11.6¢	2.2¢	23%

Notes: Average is the simple average over 2017-2040.

Source: NERA calculations as explained in text

Figure S-16 and Figure S-17 show the estimated changes in output for the various sectors of the economy due to a 60 ppb ozone standard under the sensitivity case with natural gas production constraints. This case leads to substantial reductions in natural gas output relative to the baseline.

Figure S-16: Potential Impacts of a 60 ppb Ozone Standard on Output of Non-Energy Sectors (Percentage Changes from Baseline) (Sensitivity Case)

	Agriculture	Commercial/ Services	Manufacturing	Commercial Transportation	Commercial Trucking
Average (2017-2040)	-2.7%	-1.2%	-1.3%	-2.4%	-1.5%

Notes: Values are the simple average of percentage change over 2017-2040.
Source: NERA calculations as explained in text

Figure S-17: Potential Impacts of a 60 ppb Ozone Standard on Output of Energy Sectors (Percentage Changes from Baseline) (Sensitivity Case)

	Coal	Natural Gas	Refining	Crude Oil	Electricity
Average (2017-2040)	-52%	-11%	-2.3%	0.2%	-9.7%

Notes: Values are the simple average of percentage change over 2017-2040.
Source: NERA calculations as explained in text

Recommendations for Forthcoming Ozone Regulatory Impact Analysis

The large potential costs and economic impacts reported in this study—along with the substantial uncertainties involved in their estimation—suggest two major recommendations for EPA as it prepares the RIA for its forthcoming ozone proposal:

1. EPA should develop analyses of the overall costs and economy-wide impacts of more stringent ozone standards; and

2. EPA should provide updated information on critical parameters, including the potential permitting barriers on oil and gas production in nonattainment areas as well as updated and expanded estimates of the emission reductions and costs required to achieve alternative ozone standards.

We have developed estimates of the potential impacts of a 60 ppb ozone standard on the U.S. economy and on U.S. households using the best available information on emissions and controls, including the impacts of a sensitivity case in which we assume that U.S. natural gas production would be constrained after 2020 as a result of the ozone standard. It will be important for EPA to provide these types of assessments based upon its estimates of compliance costs and resulting impacts on the economy of alternative ozone standards. There are sound reasons to expect a revised ozone standard to be very costly to attain and these costs would likely have major adverse macroeconomic impacts.

It is important that the attainment cost and macroeconomic impact estimates be based upon reliable information. Our analyses uncovered numerous gaps that EPA should fill as it develops its RIA. Perhaps the most important gaps are the identity of control options and their costs to achieve the emissions reductions needed for attainment, although it is important to develop updated information on the specific emission reduction requirements as well. The bulk of compliance costs to meet a 60 ppb standard in EPA's 2008-2010 analyses are based upon "unknown" controls, *i.e.*, controls that are not attributed to particular control technologies or even to particular sectors. We have developed estimates of these "unknown" costs based upon an assessment of the available information, particularly the sources of the emissions remaining by 2018 that would need to be reduced to attain a tighter ozone NAAQS, as well as on costs of potential retirement of coal units and potential reductions from mobile sources and where they might fit in a marginal cost curve. But it would be important for EPA to update and expand its compliance cost information to provide a more comprehensive assessment of emission control options and compliance costs. Moreover, our sensitivity analysis including natural gas production constraints suggests the importance of this issue and thus the need for EPA to evaluate the potential impacts of a tighter ozone standard on domestic natural gas and crude oil production.

I. INTRODUCTION

This report provides estimates of the potential impacts on the U.S. economy of a more stringent national ambient air quality standard (NAAQS) for ozone and recommends updated and expanded information the U.S. Environmental Protection Agency (EPA) should provide when it issues a proposal. The analysis is based upon the most up-to-date information on projected ozone precursor emissions as well as the best available information on control costs. We use our integrated energy-economic model, N$_{ew}$ERA, to estimate the potential macroeconomic effects of complying with a more stringent standard. The limited information now available to assess these compliance costs and economic impacts provides a compelling argument that if EPA proposes a stricter standard, it needs to develop more complete data and analysis as part of its forthcoming proposal. We refer to our estimates as potential costs and economic impacts to reflect the substantial uncertainties in the underlying emission reduction and cost information.

A. Background

1. Policy Background

The U.S. Environmental Protection Agency (EPA) has responsibility under Sections 108 and 109 of the Clean Air Act to establish, to review and to revise (as appropriate) a primary NAAQS that protects the nation's public health with an "adequate margin of safety." This assessment is made by the EPA Administrator based upon a review of various EPA assessments as well as review of advice from the Clean Air Scientific Advisory Committee (CASAC). Once a national standard is revised, states have the responsibility to develop State Implementation Plans (SIPs), documents that describe how the states will ensure that regions within their jurisdiction will attain and maintain the standard. States typically are given attainment deadlines that vary depending upon the severity of nonattainment. EPA has set NAAQS for six principal pollutants.

The Clean Air Act instructs EPA to review the NAAQS every five years. The EPA in March 2008 set an ozone standard of 75 parts per billion (ppb), lowering the standard from 0.08 parts per million (effectively 84 parts per billion (ppb) due to rounding conventions). In 2010, EPA reconsidered the ozone standard and evaluated lower potential standards, including 60 ppb. EPA currently is reviewing the ozone NAAQS, including developing various assessment materials and obtaining advice from the CASAC. EPA has stated its intention to consider tightening the standard to as low as 60 ppb in its most recent draft policy assessment. Our study thus evaluates a new ozone standard of 60 ppb, one value that seems likely to be included when EPA issues a proposed rule.

Although EPA's review of the NAAQS for ozone is under way, EPA has not released any new ozone compliance cost estimates since its 2008-2010 analyses.[16] The Agency has issued some

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[16] "EPA's 2008-2010 ozone analyses" refers to information in EPA's 2008 regulatory impact analysis (RIA) for the ozone NAAQS, including information on baseline future conditions and ozone standards of 84 and 75 ppb (EPA

updated information on projected baseline emissions, however. In addition, there is updated information on monitored ozone concentrations that indicates the air quality regions and states most likely to be designated in nonattainment with a 60 ppb standard. The updated information allows us to develop estimates of the emissions reductions that would be required for these states to come into attainment, which we use to develop estimates of the costs of such a tightened NAAQS for ozone. The information EPA has currently made available is limited and, indeed, this analysis is provided in part to illustrate the approach and types of data that EPA should develop to provide a sound understanding of the economic impacts of a new ozone NAAQS when it releases its proposal. The approach and data development that are needed will be the same whether EPA chooses to propose a standard of 60 ppb, as we analyze here, or some other level.

2. Ozone Concentrations

a. EPA Recent Historical Information

EPA uses a network of air quality monitors to measure concentrations of ozone and other air pollution across the country. Figure 1 shows ozone readings for 2013 (measured as the fourth-highest level over an eight-hour period) in the 781 counties with ozone monitors that year; note that about three quarters of all U.S. counties did not have ozone monitors. Although some areas of the country were below (or at) 60 ppb, most areas with ozone monitors were above that level. Many states had areas with 2013 ozone concentrations above the 2008 standard of 75 ppb, and six states (California, Colorado, Connecticut, Nevada, Texas, and Utah) had areas above the 1997 standard of 80 ppb (effectively 84 ppb due to rounding conventions). As discussed above, states develop SIPs to bring nonattainment areas into compliance.

b. EPA Projections from 2008 Ozone NAAQS Review

Figure 2 shows EPA's projections from the 2008 ozone NAAQS review of baseline ozone concentrations in 2020 in the 661 counties that had ozone monitors when EPA performed this analysis. As shown in the figure, almost all states were projected to have an area with ozone concentration above 60 ppb under baseline conditions in 2020. EPA has not issued new ozone projections since its 2008-2010 ozone analyses

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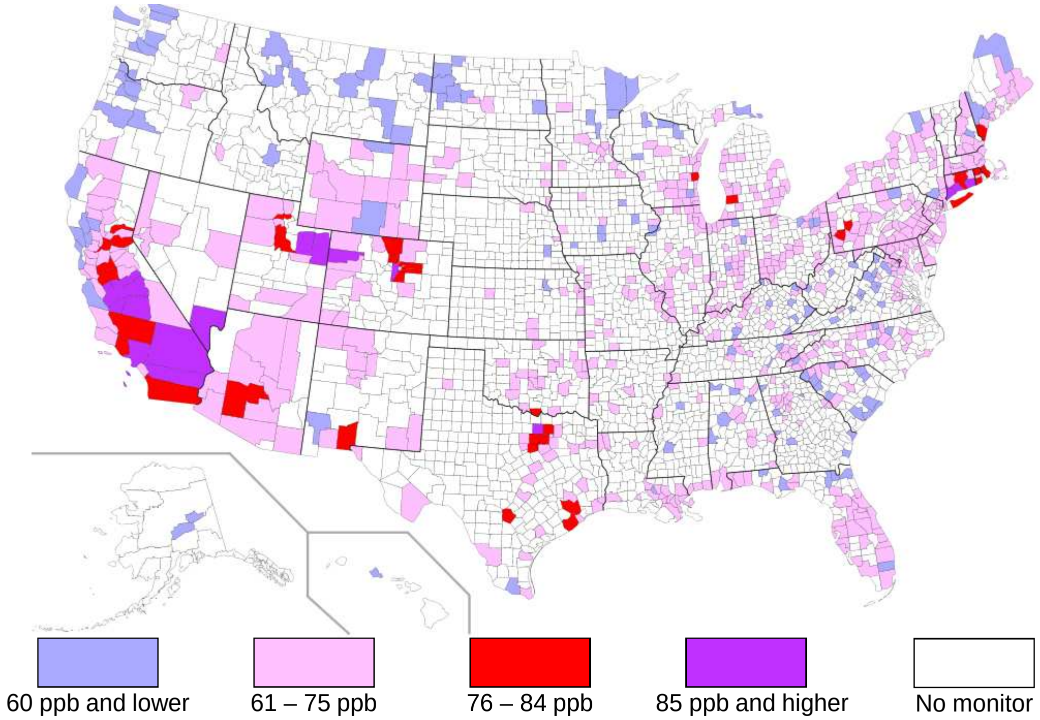
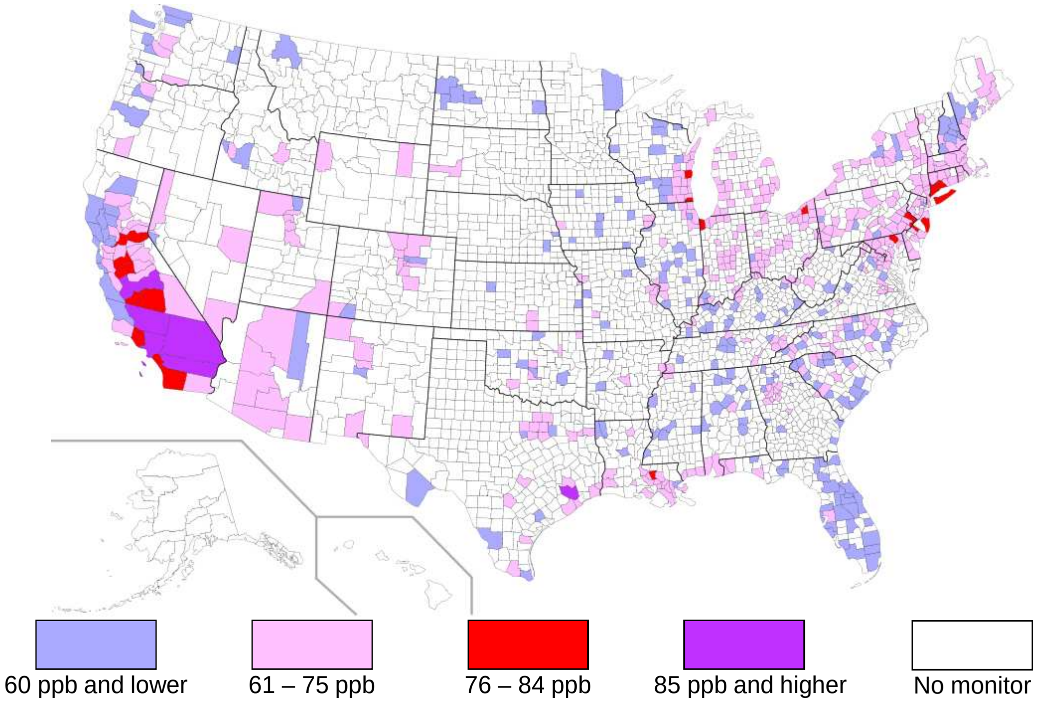
2008); EPA's 2010 supplemental regulatory impact analysis, including information on an ozone standard of 60 ppb (EPA 2010b); and data files in Docket No. EPA-HQ-OAR-2007-0225.

Figure 1: EPA 2013 Ozone Concentration Data



Source: NERA map using ozone concentration data from EPA (2014c)

Figure 2: EPA Projections of 2020 Baseline Ozone Concentrations from 2008 NAAQS Analysis



Source: NERA map using ozone concentration data in EPA (2008, pp. 3a-31 to 3a-45)

3. Energy Developments

Recent energy developments in the United States have important implications for ozone concentrations and air policy. Technological advances in oil and gas extraction (including improved horizontal drilling techniques) have significantly expanded the available resource base in recent years. Between 2005 and 2013, U.S. oil production increased 43% and U.S. natural gas production increased 34% (EIA 2014). Extraction and transportation of crude oil and natural gas produce emissions that contribute to ozone concentrations. A tighter ozone standard could introduce air permit and emissions offset requirements that might constrain new crude oil and natural gas activity in nonattainment areas. To provide an indication of the potential impacts, we performed a sensitivity case with constraints on natural gas production. Dramatic changes have occurred recently in domestic energy resources, and we provide this sensitivity analysis in part to indicate the types of data that EPA should develop when it releases its proposal in order to provide a sound understanding of the economic impacts of a more stringent ozone NAAQS.

B. Objectives of This Report

This report has two principal objectives:

1. Assess the costs and economic impacts of a 60 ppb ozone standard using the best available information from EPA and other sources; and
2. Develop recommendations for additional and updated information and analyses EPA should provide in its regulatory impact analysis (RIA) of a proposed rule, so that such assessments can be more fully evidence-based.

The first objective is predicated on the large potential significance to the U.S. economy of a more stringent ozone standard. Unlike regulations that target specific sectors, an ozone standard would directly affect virtually every sector of the economy since ozone precursors (oxides of nitrogen, or NO_X, and many types of volatile organic compounds, or VOCs) are emitted by a wide range of stationary, mobile, and area sources. Moreover, the analyses undertaken by EPA as part of its 2008-2010 ozone review make it clear that the overall costs would be very large. Indeed, as noted, the standard might result in other effects, notably potential constraints on domestic natural gas and crude oil development if nonattainment regions introduce permitting barriers or require emissions offsets to develop new wells and processing facilities. Our estimates show the potential costs and macroeconomic impacts of a more stringent ozone standard, impacts that are even greater under a sensitivity case that assumes nonattainment limits new natural gas wells.

The second objective relates to EPA's process of updating its analysis as it prepares its RIA. Our analysis reveals major gaps in data on compliance technologies and their costs and in other information. Our research puts us in a position to recommend information that EPA should develop and make available in order to provide comprehensive and reliable assessments of a more stringent ozone standard. EPA needs to provide updated data and analyses so that it can provide an adequate understanding of the economic impacts of a tighter ozone NAAQS. Recognizing the large uncertainties and gaps of currently available information from EPA, we refer to our results as potential costs and macroeconomic impacts.

C. Report Organization

The remainder of the report is organized as follows. Section II provides information on the methodology used in our study. Section III presents the empirical results of the study. Section IV summarizes our conclusions.

II. METHODOLOGY AND COMPLIANCE COSTS

This chapter provides an overview of the methodology that we use to evaluate the effects of a 60 ppb ozone standard on the U.S. economy. The first section includes an overview of N_{ew}ERA, the model we use to develop estimates of the macroeconomic impacts, as well as information on the compliance cost inputs we develop. The second section explains our methodology for computing compliance costs. The last section describes the sensitivity case, which considers a potential impact of the ozone standard on natural gas production.

A. N_{ew}ERA Model

1. Overview of the N_{ew}ERA Model

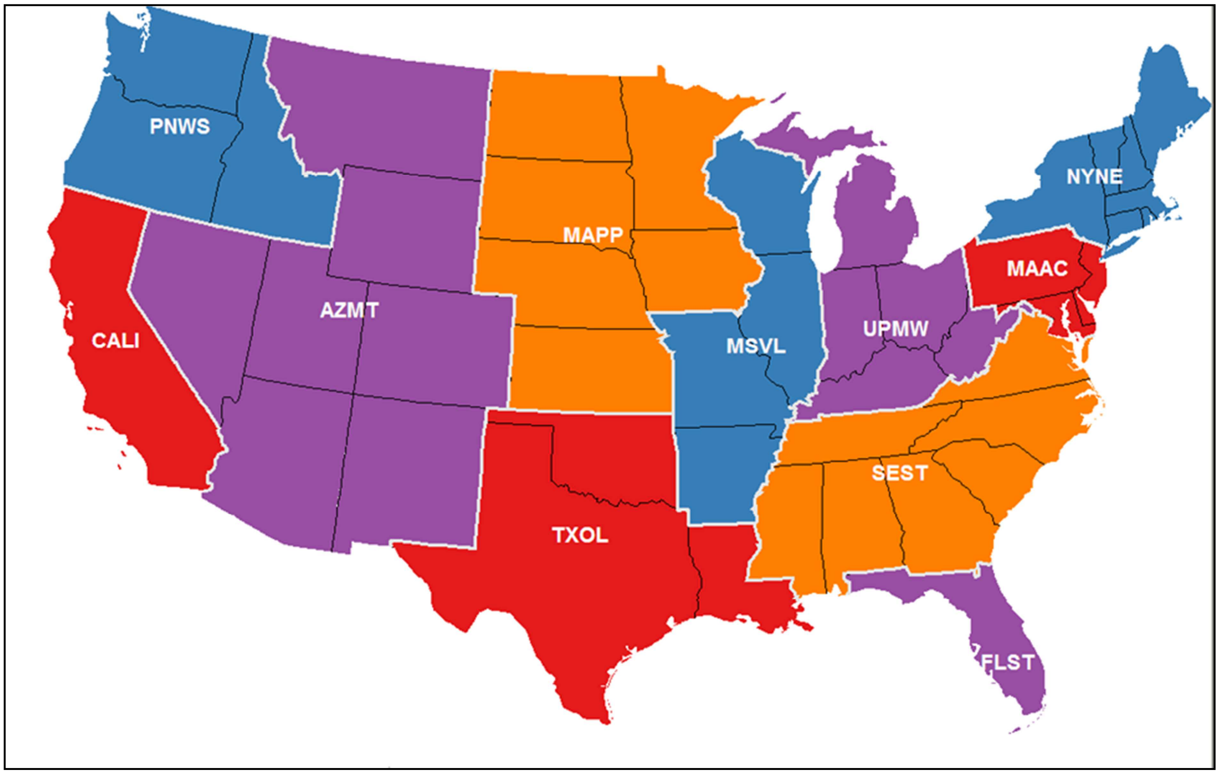
The N_{ew}ERA model is an economy-wide integrated energy and economic model that includes a bottom-up, unit-specific representation of the U.S. electricity sector, as well as a top-down representation of all other sectors of the economy and households. It assesses, on an integrated basis, the effects of major policies on individual sectors as well as the overall economy. It has substantial detail for all of the energy sources used by the economy, with separate sectors for coal, crude oil extraction, electricity generation, refined petroleum products, and natural gas production. The model performs its analysis with regional and state detail, accounting for over 30 electricity market regions and 11 macroeconomic regions in the lower 48 states for other economic activities (see Figure 3). The N_{ew}ERA model is a long-term model that includes the assumption that households and firms develop optimum decisions over the modeling period. Appendix A provides a detailed description of the N_{ew}ERA model.

We developed state-specific inputs for N_{ew}ERA and performed multiple modeling iterations to generate state-specific economic impacts. As an integrated model, N_{ew}ERA incorporates supply and demand connections among sectors of the economy. It is able to account for both the adverse effects of higher business costs and “unproductive” capital required by environmental regulations as well as the near-term gains to companies that manufacture pollution control equipment and other means of compliance with environmental regulations. For example, when sectors must incur capital costs for pollution control measures, these capital costs represent increased demand for manufacturing sectors goods that would produce the pollution controls.

2. Baseline Conditions

The baseline scenario is constructed from a version of the N_{ew}ERA model that is calibrated to the most recent *Annual Energy Outlook* (*AEO 2014)* Reference case forecast. That is, the model’s parameters and key inputs such as natural gas supply/prices are first set so that if we impose the same policies as are in AEO 2014, N_{ew}ERA will produce very similar projected fuel prices and consumption.

Figure 3: N$_{ew}$ERA Macroeconomic Model Regions



Source: N$_{EW}$ERA model definitions

The N$_{ew}$ERA and *AEO 2014* baseline forecasts incorporate current environmental regulations, including the following major programs:

- Regional Greenhouse Gas Initiative (RGGI);[17]
- California AB 32 greenhouse gas emission program;
- SO_2 and NO_X emission programs for the electricity sector;
- Mercury emission limits under the EPA Mercury and Air Toxics Standards (MATS); and
- Recent air emission standards for new passenger cars and light duty trucks.

Neither N$_{ew}$ERA nor the modeling behind the *AEO 2014* forecasts constrains air emissions for compliance with current NAAQS. In particular, air emission projections from the models under baseline conditions do not achieve compliance in all areas of the country with the current ozone standard of 75 ppb. The models do not incorporate state-specific controls that might be put in

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[17] *AEO 2014* did not include recent updates to make the RGGI policy more stringent over time. For consistency purposes, N$_{ew}$ERA also did not include these updates.

place to comply with this standard (the controls are currently under development as states continue to prepare and implement their SIPs for 75 ppb). In addition, the baseline excludes EPA's recently proposed rule to limit carbon dioxide (CO_2) emissions from the power sector because it is not part of current law. As discussed below, taking into account EPA's recent CO_2 rule would not change the major conclusions of our study.

On June 2, 2014, EPA released a proposed rule to limit CO_2 emissions from the power sector. Implementation of such a rule will almost certainly result in some amount of NO_X reduction (primarily because of a reduction in coal-fired generation needed to reduce state CO_2 emissions rates). EPA (2014d, pp. ES-6 and ES-7) estimates that the proposed power sector CO_2 rule would reduce annual NO_X emissions by approximately 300,000 to 400,000 tons (depending on regulatory option, state or regional compliance approach, and measurement year). Some of those NO_X reductions may overlap with NO_X reductions in our ozone cost analysis, and to the extent that this would occur, some of the cost estimates will be shared with the cost of the proposed CO_2 rule for the power sector. We have considered this issue and find that even if all of those overlapping costs were to be removed from our analysis, the costs and economic impacts presented in this report would not change in any meaningful degree because NO_X reductions from the power sector are estimated to be among the lowest cost-per-ton of the NO_X reductions in our ozone attainment scenario. In fact, even if all of the approximately 100 GW reduction in electric sector coal capacity (discussed in subsequent sections of this report) were treated as costless in our ozone analysis, our estimated GDP impact would only be reduced by about 8%, or about one-twelfth of the value we estimate. Moreover, our review of EPA's RIA for the power plant CO_2 rule indicates that the overlap of power sector costs is much less than 100%, as the proposed power sector CO_2 rule would lead to NO_X reductions in some areas that would not require reductions for compliance with a new 60 ppb ozone standard. Thus, uncertainty on how to attribute shared costs between the two regulations does not affect the major conclusions of this report regarding the costs and economic impacts of a tightened ozone NAAQS.

3. Modeling Years

For this analysis, we evaluate the economic implications of a 60 ppb ozone standard, with compliance in individual states staggered to reflect the degree of nonattainment (as discussed below). We model results for three-year periods beginning with 2017. Thus, we present results for 2017, 2020, 2023, 2026, 2029, 2032, 2035, and 2038. Each model year represents an average of three years, the stated year and the next two years; for example, 2017 represents the average of 2017 through 2019. These annual results are used to calculate present values for 2017 through 2040, as of 2014.

B. Compliance Cost Inputs to N$_{ew}$ERA

This section summarizes the steps we take to develop state- and sector-specific compliance cost estimates for an ozone standard of 60 ppb. The methodology consists of the following three major steps:

1. Estimate the NO_X reductions needed to achieve 60 ppb in each state;
2. Estimate the costs of achieving the required NO_X reductions in each state; and
3. Allocate compliance costs to years and N$_{ew}$ERA sectors.

The steps are based upon the most up-to-date information available from EPA, including information from the 2008 RIA as well as additional materials that EPA has released since then. We focus on NO_X emissions and emission reductions in our analysis because EPA indicates that NO_X is the critical precursor for ozone formation in most areas of the country, particularly for a tighter new standard of 60 ppb (EPA 2010, pp. S2-3 and S2-14); our compliance cost estimates, however, do include EPA's estimates of the costs of reducing volatile organic compounds (VOCs), the other major ozone precursor. We describe each of these major steps in the subsections below. Appendices B, C, and D provide details on the methodology and data and present state-specific information.

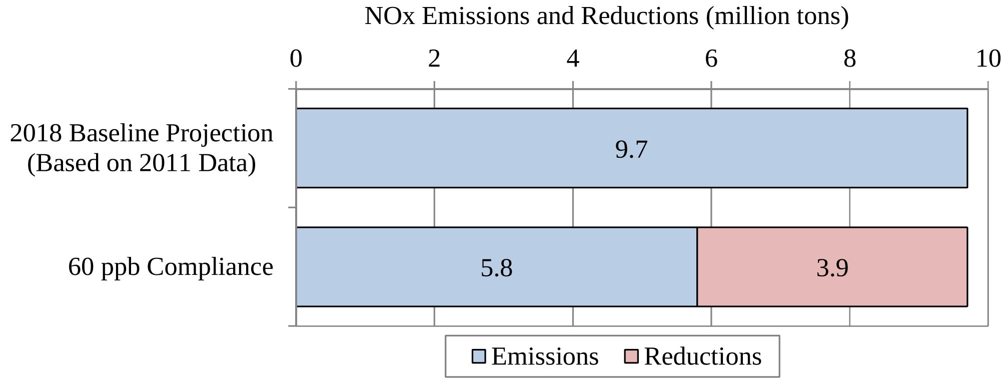
1. Step 1: Determine Necessary NO_X Reductions by State

The first step is to develop estimates of the NO_X reductions each state would need in order to meet a 60 ppb ozone standard. We developed these estimates using two sources of data: (1) recent EPA projections of future baseline NO_X emissions for 2018; and (2) estimates from EPA's 2008 RIA of the level of NO_X emissions consistent with meeting a 60 ppb standard.

The EPA in December 2013 released detailed estimates of projected 2018 NO_X emissions using its most recent projection platform, which is based upon historical emissions data from 2011 (2014a). In its 2008 RIA, EPA had developed estimates of projected 2020 NO_X emissions as well as estimates of the reductions that would be required to achieve a 60 ppb standard (among other standards) in 2020; the difference between these two values represents a set of estimates of the state-by-state emissions that would be consistent with national compliance with a 60 ppb standard ("compliance emissions"). The reduction requirements modeled in EPA's 2008-2010 ozone review (which we use to determine state-level compliance emissions) extended beyond the limited number of counties with ozone monitors shown in Figure 1 and Figure 2 since EPA assumed that non-monitored areas near nonattaining counties would also be required to reduce their NO_X emissions to achieve attainment. Note, however, that the number of nonattainment counties may be greater than EPA's existing monitoring sites, and thus the required emission reductions, compliance costs and economic impacts may be greater than based upon the current EPA monitoring information.

For each state, we calculated the NO_X emission reductions that would be required by subtracting the compliance emissions from the projected 2018 baseline emissions. Figure 4 shows national estimates of baseline emissions, compliance emissions, and required reductions. Based on information in the 2008-2010 EPA ozone review, U.S. NO_X emissions would have to be reduced to about 5.8 million tons to meet a 60 ppb standard in 2020. National NO_X emissions have been decreasing in recent years, from about 25.2 million tons in 1990, to 16.8 million tons in 2008, and to 12.9 million tons in 2013 (EPA 2014b). EPA presently is projecting that NO_X emissions will be reduced to 9.7 million tons by 2018 (supplemented with EGU baseline emission projections from N_{ew}ERA) due to existing rules and regulations (EPA 2014a), some of which have not yet been fully implemented and will carry with them additional compliance costs on top of the compliance costs estimated in this study. These emissions estimates mean that in 2018 another 3.9 million tons of NO_X will need to be reduced to get to the 60 ppb standard nationally (this reduction is equivalent to about 40% of baseline NO_X emissions for 2018).

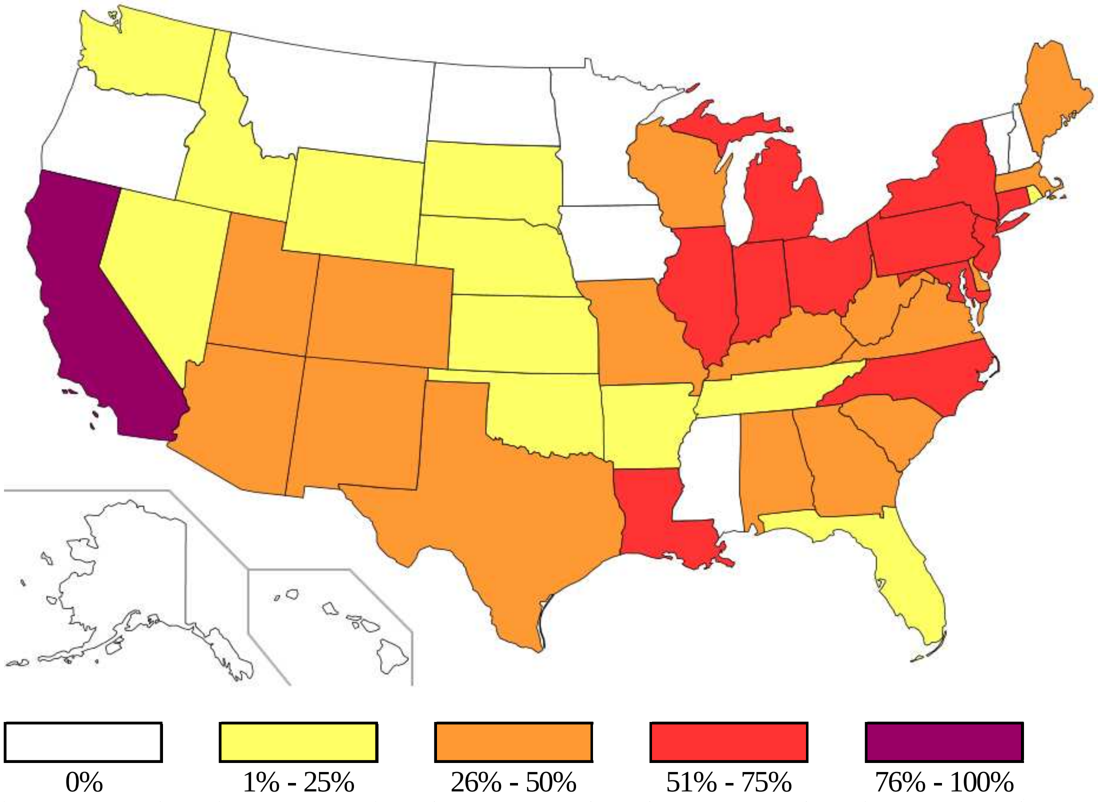
Figure 4: National 2018 Baseline NO_X Emissions, 60 ppb Compliance NO_X Emissions, and 60 ppb NO_X Required Emission Reductions



Note: NO_X emissions include only anthropogenic sources (*i.e.*, exclude fires and biogenic sources).
Source: NERA calculations based on EPA (2014a) and other inputs as explained in Appendix B

These values are stated on a national basis, but the actual emissions control requirements will be concentrated around projected nonattainment areas. Moreover, the emissions reductions needed in any particular nonattainment area will vary depending on the severity of its exceedance of the NAAQS level. Figure 5 summarizes state NO_X emission reductions for 60 ppb compliance (expressed as a percentage reduction from EPA 2018 baseline emission projections). Our analysis projects that 40 states would have at least one nonattainment area in 2018 under a 60 ppb ozone NAAQS and thus will have to reduce NO_X emissions. We also find that 12 of these 40 states will need to reduce their NO_X emissions by between 50% and 80% from their already-reduced levels projected in 2018 to attain the standard. Appendix B presents detailed state information on projected 2018 emissions, compliance emissions, and emission reductions required to achieve a 60 ppb ozone standard.

Figure 5: Necessary NO_X Emission Reductions for 60 ppb (Percentage Reduction from Baseline 2018 NO_X Emission Projections)



Note: Map shows necessary percentage reductions below 2018 baseline NO_X emission projections. States with 0% reductions would comply with a new ozone standard of 60 ppb in 2018 based on this analysis.

Source: NERA calculations as explained in text and Appendix B

2. Step 2: Determine NO_X Compliance Costs by State

The next major step in our analysis is to develop estimates of the compliance costs that would be incurred in each state in order to obtain the required NO_X emission reductions. We developed compliance cost estimates using the most recent data available from EPA, supplemented by estimates for controls not considered by EPA, and judgments about the nature of the marginal cost curve (*i.e.*, the relationship between the marginal costs of reducing NO_X emissions and the extent of NO_X reductions). As discussed below, we considered it important to develop an evidence-based assessment of the costs EPA described as “unknown” in their 2008-2010 analysis and for which they developed a largely arbitrary method of estimation, in part to provide a template for the type of detailed cost analysis EPA should do as part of its forthcoming RIA.

a. EPA Costs for “Known” and “Unknown” Controls

In its 2008-2010 ozone analyses, EPA presented state-specific information on “known” controls. These “known” controls represent specific control measures that regions and states could use to reduce their NO_X emissions. EPA identified controls from five categories of emission sources:

(1) Electric generating units (EGUs);

(2) Non-EGU point sources, such as industrial boilers, cement kilns, and petroleum refineries;

(3) Area sources, such as dry cleaners, commercial buildings, and residential buildings;

(4) Onroad mobile, such as passenger cars, light-duty trucks, and heavy-duty trucks; and

(5) Nonroad mobile, such as locomotives, aircraft, marine vessels, construction equipment, and agricultural equipment.

The RIAs and their supporting documentation include estimates of emission reductions and annualized costs by facility or state for “known” controls in these sectors.

After applying all “known” controls to the five categories of emission sources, EPA found that certain areas would not meet some of the alternative ozone standards, including 60 ppb. In these cases, EPA assumed that the areas would achieve the standards through installation of “unknown” controls. To estimate the potential total costs of alternative ozone standards, EPA developed a marginal cost curve (*i.e.*, curve showing relationship between the incremental or “marginal” cost of controls and NO_X emissions reduced) starting with the “known” controls in order from the lowest to the highest cost per ton reduced. The curve used a “slope” parameter based on “known” control costs and an arbitrary assumption on the maximum cost per ton in order to extend the curve beyond “known” controls to include the costs of “unknown” controls. EPA’s methodology and cost estimates are discussed in Appendix C.

We used EPA’s estimates of “known” controls as the starting points for the estimated marginal cost curves we developed for each state. For the United States as a whole, the “known” controls are projected to reduce NO_X emissions by about 1.3 million tons per year, or about one-third of the reductions required to achieve the 60 ppb ozone standard.

The following table summarizes the EPA “known” controls.

Figure 6: National Summary of EPA "Known" NO_X Controls (tons of reduction)

Point (Non-EGU)	**825,400**
Selective catalytic reduction (SCR) without low-NOx burner (LNB)	466,800
Low-emission combustion (for internal combustion engines)	82,000
Selective catalytic reduction (SCR) and low-NOx burner (LNB)	80,800
Non-selective catalytic reduction (NSCR)	70,300
Selective non-catalytic reduction (SNCR)	61,400
OXY-firing (for glass manufacturers)	33,800
Low-NOx burner (LNB) without selective catalytic reduction (SCR)	20,700
Biosolid injection (for cement kilns)	8,200
Other	1,300
Area	**27,800**
Low-NOx water and space heaters (for commercial buildings)	14,000
Low-NOx burner (LNB)	12,800
Switch to low-sulfur fuel (for residential buildings)	1,000
Onroad Mobile	**256,100**
Retrofit heavy-duty diesel with selective catalytic reduction (SCR)	137,700
Continuous inspection and maintenance	27,800
Eliminate long-duration idling	10,500
Commuting programs	4,400
Low Reid Vapor Pressure	1,000
Unspecified	74,800
Nonroad Mobile	**45,000**
Retrofit heavy-duty diesel with selective catalytic reduction (SCR)	45,000
No Details (Some Omissions in EPA Data for CA and TX)	**130,100**
Total	**1,284,400**

Note: Totals may not equal sum of rows due to independent rounding.
Source: NERA calculations as explained in text

These controls have a range of marginal costs up to $23,000 per ton (2006 dollars), the maximum assumed by EPA in its 2008-2010 analysis (EPA 2008, p. 5-3). For some states, these known controls were sufficient to achieve the NO_X emission reductions required to achieve a 60 ppb standard—and, indeed, as shown in Figure 5 above, eight states (excluding Alaska, Hawaii, and the District of Columbia) did not require any emission reductions.[18] But the bulk of states are projected to require emission reductions beyond the known controls, and in some states the additional emission reductions are very substantial. EPA's estimates of the costs of "unknown" controls provided in the 2008-2010 RIAs were based upon estimates of "known" control costs and an arbitrary maximum cost per ton, rather than on estimates of the additional controls that would be required.

b. NERA Cost Estimates for "Unknown" Controls

We developed estimates of the potential costs of "unknown" controls by developing answers to the following three questions

- What categories of emission sources would be potentially available to achieve these additional 2.6 million tons of "unknown" NO_X reductions?
- What types of control strategies would likely be used for these "unknown" NO_X emission reductions?
- What would be the costs of these "unknown" controls?

To address the first two of the above questions, we disaggregated EPA's estimates of 2018 baseline emissions down to the five categories that EPA identifies in its emissions inventories, and we allocated the reductions from EPA's list of known controls to these categories.[19] This information gives insights on what types of control strategies might be available to obtain further "unknown" reductions.

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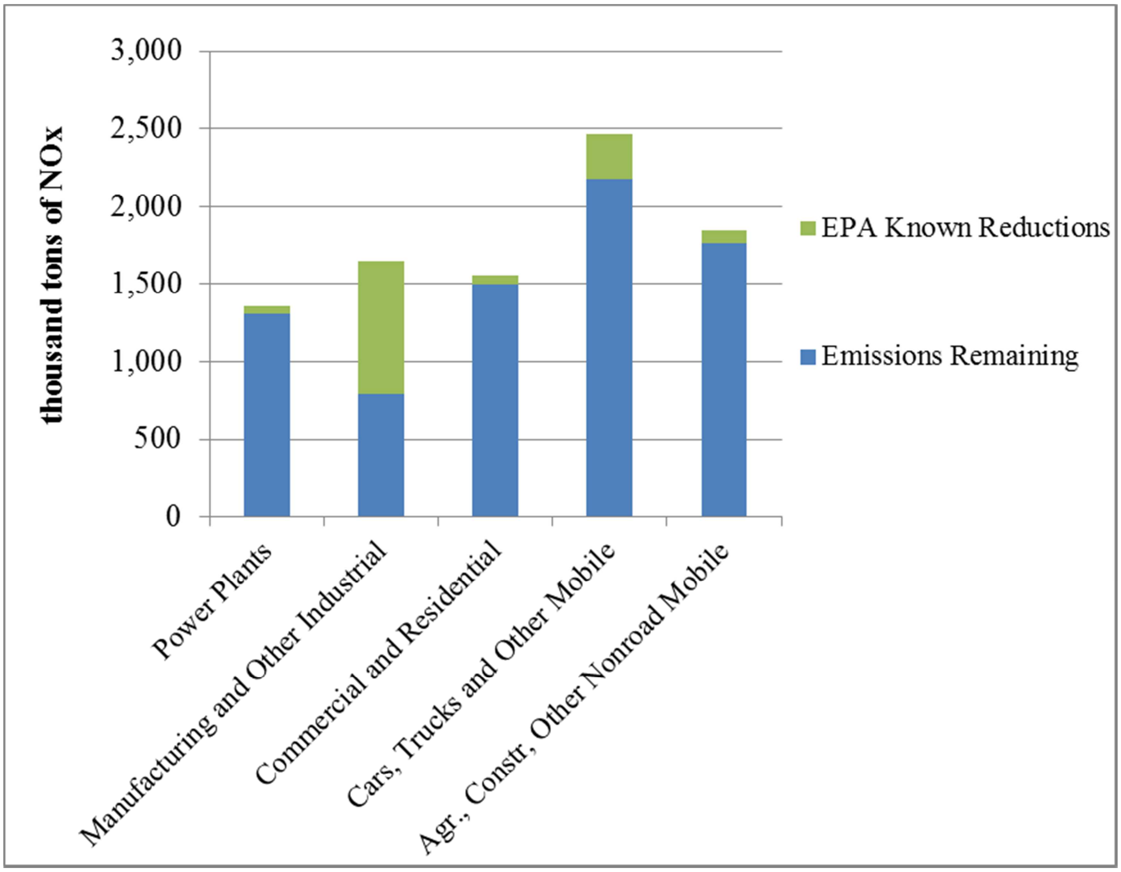
[18] The states without compliance costs would still have adverse economic impacts on net (despite competitive advantages relative to states with compliance costs) because of higher energy costs and reduced demand elsewhere in the country for their goods and services.

[19] The categories include two types of "point sources," which are large non-moving emitting equipment such as industrial boilers and electricity generating units (EGUs). The other three categories are "non-point sources," which means they are many small, diffuse sources. Of these "area sources" are non-moving equipment that are too individually small to be regulated as point sources are. Examples include commercial and residential water and space heaters as well as compressors along oil and natural gas pipelines. "Mobile sources" are small, diffuse and can be moved from place to place. Onroad mobile sources include cars and all sizes of trucks. Nonroad mobile sources include agricultural and construction equipment as well as transportation such as locomotives, airplanes, and boats.

Figure 7 shows the 2018 baseline emissions in states that will need to reduce NO_X emissions to meet a 60 ppb standard and the emission reductions due to EPA's "known" controls for the five emission categories. (The total 2018 baseline emission for these states across all five categories is 8.9 million tons). This information shows that most of the emissions that remain after EPA's "known" controls are from electricity generating units (EGUs) and non-point sources, while large industrial and manufacturing point sources are substantially controlled.

Figure 7: EPA Known NO_X Reductions from 2008-2010 Analysis and Remaining Emissions by General Categories of Emissions Sources in the 40 Non-Attaining States



Source: NERA calculations as explained in text

The list of known controls described in the previous section suggests that the "known" controls largely exhaust the options for retrofitting existing equipment with technology controls (e.g., installation of low-NO_X combustion devices and NO_X-destroying post-combustion devices). This explains why most of the known controls' effects are concentrated on the industrial and manufacturing emitters that comprise the "point source" category.[20] This evidence suggests that

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[20] EPA's "known" controls for electric generation unit (EGU) sources (which are mostly from additional retrofits of selective catalytic reduction, SCR) have very little effect on EGU 2018 emissions. This is because almost all of the EGU point sources have already been retrofitted with NO_X controls in states projected to have nonattainment.

the bulk of the 2.6 million tons of "unknown" NO_X reductions will have to come various forms of capital stock replacement rather than further technology retrofits. While these replacements will likely include retirements of large coal-fired electricity generators, it also will likely become necessary to scrap and replace a wide array of very small sources, such as personal vehicles, individual pieces of construction equipment, and agricultural and landscaping equipment.

To indicate how EPA could develop more informed and evidence-based estimates of the costs of these remaining necessary types of NO_X reductions, we developed information on the costs of reducing emissions from two of the most significant categories of remaining NO_X emissions.

- *Retirement of coal-fired power plants.* If coal units are retired in states with large remaining NO_X reductions needs, and their generation is replaced by a cost-effective combination of natural gas and non-emitting generation, we estimate that an additional emissions reduction of about 1 million tons could be obtained. Our analyses indicate that these tons of reduction will cost an average of approximately \$31,000/ton, but with costs ranging up to about \$180,000/ton among the states. We replace the "known" power plant controls (retrofits) used in EPA's 2008-2010 analyses with these potential retirement controls in our analysis.

- *Scrapping of cars and light-duty trucks.* Cars and trucks will be much lower-emitting in 2018 than the fleet of vehicles on the road today, but in aggregate they account for a further potential reduction of 1 million tons, assuming every 2018 vehicle were to be scrapped in 2018 and replaced by either an electric vehicle (powered by natural gas generation) or a Tier 3 vehicle.[21] Using a model framework developed by an MIT researcher (Knittel 2009), we estimate the marginal cost per ton of reducing light-duty vehicle NO_X emissions by 10% through the early replacement of the highest-emitting cars and trucks would be in the range of \$100,000/ton, a figure that escalates to about \$500,000/ton to achieve about a 50% reduction.[22] Scrapping newer, lower-emitting cars

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Retirements rather than further retrofitting will be necessary to further reduce EGU emissions in these states and EPA did not consider retirements of equipment as a known control.

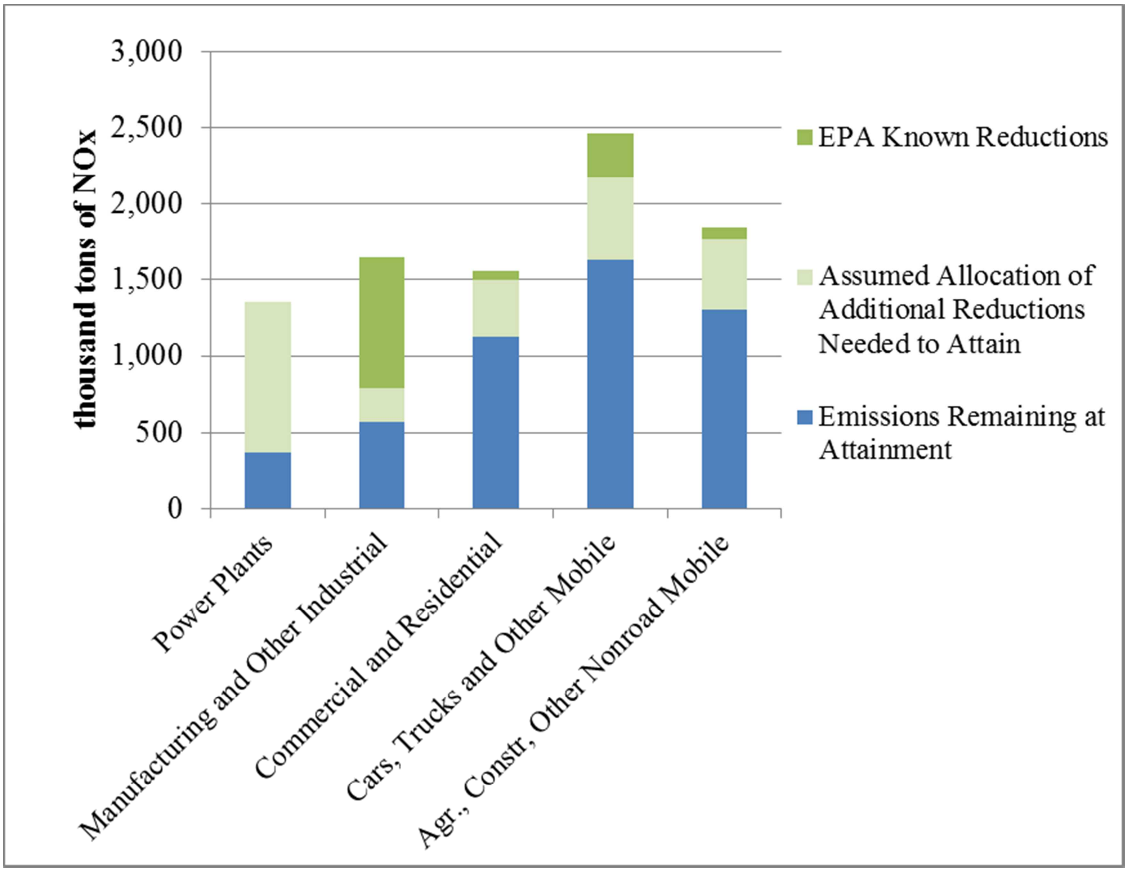
[21] The reduction is less than 1 million if one considers only vehicles in areas that contribute to nonattainment.

[22] We estimated this cost per ton removed for scrapping the marginal car that would achieve a 50% reduction of 2018 emissions from such vehicles following a methodology used in Knittel (2009) that is described in detail in Appendix C. Considering the subset of vehicle vintages making up 50% of light-duty vehicle emissions in 2020 (the first attainment year in our analysis), the newest vintage in the subset – or the marginal vehicles that would be scrapped in a program achieving 50% reduction – would have an average NO_X emission rate of 0.19 g/mile. Using an emission rate of 0.03 g/mile for replacement vehicles, along with an assumed average annual travel distance of 12,000 miles, the annual NO_X emission reduction of these marginal vehicles would be about 0.0022 tons per year for that vintage vehicle. We assumed the value of that vintage vehicle is \$4,200, which, when annualized over its remaining useful vehicle life of about 4 years at a 5% discount rate, implies an annualized lost capital value of about \$1,200 per year. Thus, the annualized cost per ton would be \$1,200 / 0.0022 tons, or about \$500,000 per ton. Sources and other information on these assumptions and calculations appear in Appendix C.

would cost more and generate fewer reductions per vehicle, so the incremental cost per ton rises as increasing percentages of the vehicle fleet are scrapped.

Replacing coal-fired EGUs would reduce NO_X emissions by about 1 million tons. Replacing *all* 2018 cars and light-duty vehicles would provide another 1 million tons of reduction. But other types of equipment certainly would become cost-effective to replace before one would go so far as to scrap all cars and light duty vehicles. We assume that the marginal cost-per-ton for these other sources rises similarly to the cost-per-ton we estimated for early turnover of different vintages of cars and light-duty trucks, as one indication of the potential costs that states would incur. Figure 8 shows the resulting mix of reductions assumed in our estimates of the compliance costs needed to achieve a 60 ppb ozone standard

Figure 8: NERA Analysis's Allocation of Additional Reductions Necessary to Attain a 60 ppb NAAQS to Categories of Emissions Sources in the 40 Non-Attaining States



Source: NERA calculations as explained in text

The dark green portions of the bars in Figure 8 shows EPA's "known" controls and the light green shows NERA's evidence-based assumptions regarding where "unknown" controls will likely come from. The remaining sum (shown in the blue bars) is now 5.0 million tons—the aggregate limit to achieve attainment for the states projected to be in nonattainment under baseline 2018 emissions levels. NERA's estimates assume deep cuts in the EGU sector, where emissions are concentrated in a few sources and costs per ton are thus lower than for the many smaller sources among the non-point source categories (i.e., area, onroad mobile and nonroad mobile) NERA's assumptions on "unknown" controls outside of the EGU sector involve much smaller incremental percentage reductions than from EGUs; but because these will require programs such as scrapping vehicles and other small sources, they are expected to come at a substantially higher cost per ton than the EGU controls—even though we assume that the scrapping programs only target the oldest, highest-emitting of each type of NO_X-emitting equipment.

We developed estimates of EGU control costs using the results from N_{ew}ERA. In particular, using N_{ew}ERA, we modeled reduced generation from existing coal-fired power plants and replacement with natural gas power plants (or another energy source if optimal) as a potential NO_X emission reduction measure in each state where "known" non-EGU controls would be insufficient for 60 ppb compliance.[23] The potential costs and NO_X reductions from this measure thus are calculated within the N_{ew}ERA model.[24]

The next task related to our analysis of "unknown" costs was to use the information on the potential costs of phasing out NO_X-emitting mobile source emissions, in particular on the costs of scrapping older, high-emission rate passenger cars and light duty trucks and replacing them with new low-emission vehicles. Such vehicle scrapping programs were developed in California in the 1990's and applied most recently in 2009 (Car Allowance Rebate System) as part of the federal stimulus program. The cost per ton to scrap older vehicles varies with the age of the vehicles, since scrapping is both more expensive and generates fewer emission reductions for newer, lower emission vehicles. We used a framework developed by an MIT researcher who had evaluated the cost-effectiveness of vehicle scrappage to develop our empirical estimates. As noted above and explained in more detail in Appendix C, we used that framework to estimate that the marginal cost of scrapping sufficient passenger cars and light duty trucks to reduce 50% of their expected NO_X emissions would have a marginal cost of roughly $500,000 per ton. This same information indicates that the marginal cost per ton increases as the percent reduction in NO_X emissions increases, providing motivation and evidence for an increasing marginal cost curve.

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[23] For convenience, in the report we sometimes refer to this option as "scrappage," although the specific assumption is that generation is not allowed (or is limited).

[24] As noted above, EPA (2014d, pp. ES-6 and ES-7) estimates that the proposed power sector CO_2 rule would reduce annual NO_X emissions by approximately 300,000 to 400,000 tons (depending on regulatory option, state or regional compliance approach, and measurement year). Our modeling of potential changes to coal-fired power plants for compliance with a new ozone NAAQS of 60 ppb would lead to a significantly larger NO_X reduction (as shown in Appendix C). Thus, the proposed power sector CO_2 rule would not change our conclusion that a new 60 ppb ozone NAAQS would have significant impacts on the power sector (and other sectors of the economy).

We used the information on vehicle scrapping to develop estimates of each state's marginal cost curve for "unknown" controls. In particular, as shown below, we assumed that the option of scrapping 50% of the vehicle fleet emissions would be undertaken at the part of each state's marginal cost curve corresponding to a 75% reduction from the baseline NO_X emission level. This anchor point, in combination with cost-per-ton information for "known" controls, determines our estimate of the slope of the "unknown" segment of each state's marginal cost curve. We estimated total annualized costs for "unknown" controls for each state using this slope and the necessary remaining tons of NO_X emission reductions after implementation of "known" controls.

Although the costs of "unknown" costs are highly uncertain and other data and assumptions could be used to derive state-by-state marginal cost curves, our calculations represent an effort to use evidence-based information—in particular, scrappage of existing coal-fired power plants and scrappage of existing vehicles of different vintages—to derive the marginal cost curve for the "unknown" controls. We emphasize that EPA needs to develop more specific information on control measures and their costs in order to reduce the enormous uncertainty in potential control costs due to the importance of "unknown" costs. Appendix C provides additional explanation and state-specific information based on these calculations.

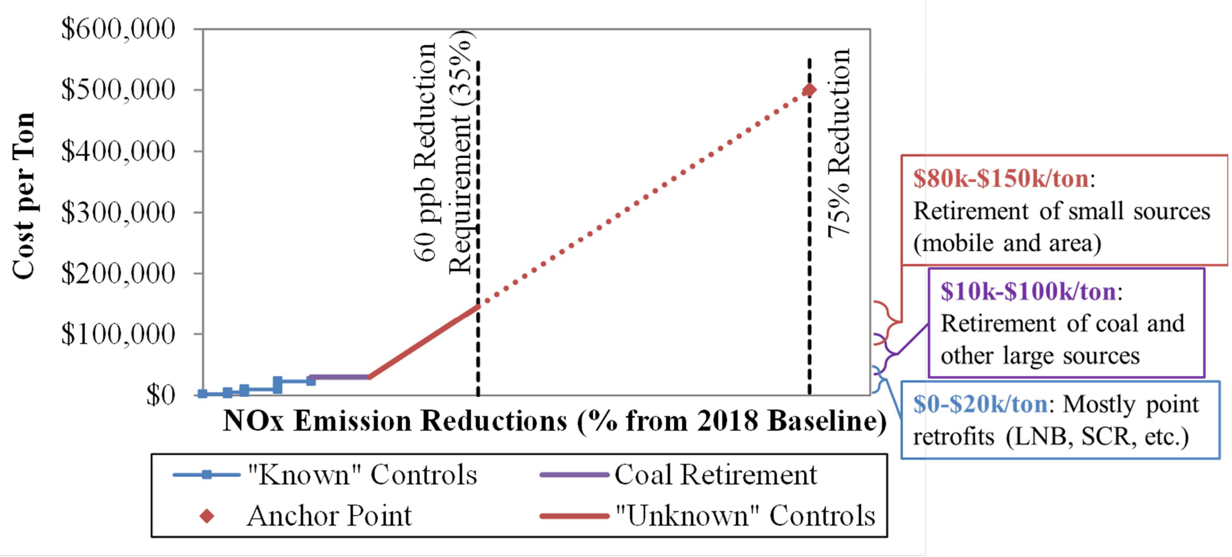
c. NERA Marginal Cost Curve

Figure 9 illustrates our methodology for constructing a state NO_X marginal cost curve including EPA "known" controls and an evidence-based approach to estimating costs of "unknown" controls. EPA "known" controls are shown in the lower left part of the curve. These controls generally are on point sources and are in a range up to about $20,000 per ton. The second segment of the curve reflects the costs of reduced generation from coal-fired power plants as estimated in N_{ew}ERA. State-level average costs of these generation controls range up to about $180,000 per ton; for purposes of developing the state-specific marginal cost curves, we only use generation controls in this segment of the cost curve if their costs are no greater than about $30,000 per ton; for more costly coal-fired generation controls, we incorporate the controls into the third segment of the curve.

The third segment of the curve reflects costs for additional "unknown" controls (beyond those related to retirement of coal-fired units). The evidence for this part of the curve is based upon the costs of scrapping existing motor vehicles. As discussed in Appendix C, we estimate that the marginal cost of scrapping 50 percent of NO_X emissions from light-duty motor vehicles is approximately $500,000 per ton. We also determined that the likely feasible emission reductions beyond the "known" controls would come from various non-point sources (including on-road sources such as cars and trucks, non-road sources such as trains, and area sources such as home and commercial heaters).

The slope for "unknown" controls in the illustrative marginal cost curve is based on two anchor points: the marginal cost per ton of reduced coal-fired generation (for the lower left point on the curve) and the marginal cost per ton of vehicle scrappage at the 50 percent level as discussed above (for the upper right point on the curve). (For ease of exposition, we refer to reductions in coal-fired generation as coal scrappage in the figure.) As shown in the illustration, the segment for “unknown” controls required in a particular state is the solid line representing the additional controls that would be necessary (beyond EPA “known” controls and coal scrappage) for 60 ppb compliance. The dashed part of the curve illustrates additional “unknown” emission reductions for this state assumed to be “available,” but not needed to achieve compliance. The estimated cost in each state is equal to the area under the solid segment of the curve, including “known” and “unknown” controls.

Figure 9: Illustration of a State NO_X Marginal Cost Curve Showing “Known” and “Unknown” Controls



$80k-$150k/ton: Retirement of small sources (mobile and area)

$10k-$100k/ton: Retirement of coal and other large sources

$0-$20k/ton: Mostly point retrofits (LNB, SCR, etc.)

Source: NERA illustration

The curve in Figure 9 provides a general illustration of our methodology for developing a marginal cost curve. As noted above, we use state-specific information on emissions and controls to develop our cost estimates. States differ substantially in their estimated marginal cost curve for several reasons. For one thing, in some states reduced coal-fired generation and replacement would cost more than $30,000 per ton, and in those cases we used the final EPA “known” control as the lower left end of the “unknown” control cost curve to estimate the slope. In addition, the share of controls represented by “unknown” controls required to achieve a 60 ppb ozone standard differs greatly among the states. Appendix C provides state-specific information related to the costs of reducing coal-fired generation and our estimates of “unknown” control costs.

A very large portion of our estimated costs of compliance at the national level is based on extrapolation beyond the list of the "known" control options that EPA prepared in its 2008-2010 analyses; as shown in Appendix C, the cost of "unknown" controls to achieve a 60 ppb ozone standard is about 60 times the cost of "known" controls (excluding reduced generation from existing coal-fired power plants). That such a large portion of the estimated compliance costs would be from controls that EPA has yet to identify highlights the dangers of implementing a policy for which most of the control options are unknown. As noted above, in its on-going NAAQS review, EPA should develop more complete information about additional controls to allow for a more reliable estimation of compliance costs than it produced in 2008-2010.

3. Step 3: Allocate Costs to N_{ew}ERA Sectors and Years

The third and final step in the development of the compliance cost inputs to N_{ew}ERA consisted of translating the annualized compliance costs into estimates of additional compliance costs in individual sectors and individual years.

a. Allocation to N_{ew}ERA Sectors

N_{ew}ERA models the economy using 10 sector aggregations (see Appendix A). Using EPA information from the 2008-2010 ozone review, including North American Industry Classification System (NAICS) codes for emission reductions from point sources, we matched the costs for "known" control measures to N_{ew}ERA sectors. The specific allocation of costs to sectors is based on state-level NO_X control information and baseline emissions and thus varies by state. Appendix D provides detailed allocation assumptions for each state.

For "unknown" control measures, we divided costs among four of the five EPA categories of emission sources (excluding the EGU category) based on the potential of each category for further emission reductions beyond the "known" controls.[25] Once associated with specific emission source categories, we matched costs for "unknown" controls to N_{ew}ERA sectors using the same logic and state-level calculations that were applied to the "known" control costs. Appendix D shows the cost information for "unknown" costs.

b. Allocation to N_{ew}ERA Modeling Years

The timing of costs in each state depends on when the state would be required to be in compliance with the 60 ppb standard as well as when different types of costs would be incurred. For states requiring NO_X emission reductions for 60 ppb compliance, we used EPA information on recent ozone monitor readings and the most recent EPA NO_X emission projections to develop

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[25] We divided "unknown" control costs using the state-level shares of emissions remaining in the non-EGU point, area, onroad mobile, and nonroad mobile source categories after applying the "known" controls. We assumed that no additional EGU reductions are available after the reduced generation from coal-fired power plants, so we did not allocate any "unknown" control costs to the EGU emissions source category.

estimates of the compliance deadlines. The deadlines reflect estimated designations for each state as “Marginal,” “Moderate,” “Serious,” “Severe,” or “Extreme” nonattainment areas, using the system specified in the Clean Air Act and used by EPA for previous ozone standards. As noted above, some states would comply with 60 ppb under baseline conditions and would not incur any costs in our modeling. Note too that although EPA designates nonattainment areas as parts of states, we use a single designation and compliance deadline for each state. Figure 10 summarizes the state designations and compliance deadlines. The deadlines reflect the assumption that EPA would finalize the new ozone standard in 2015 and would finalize state designations in 2017.

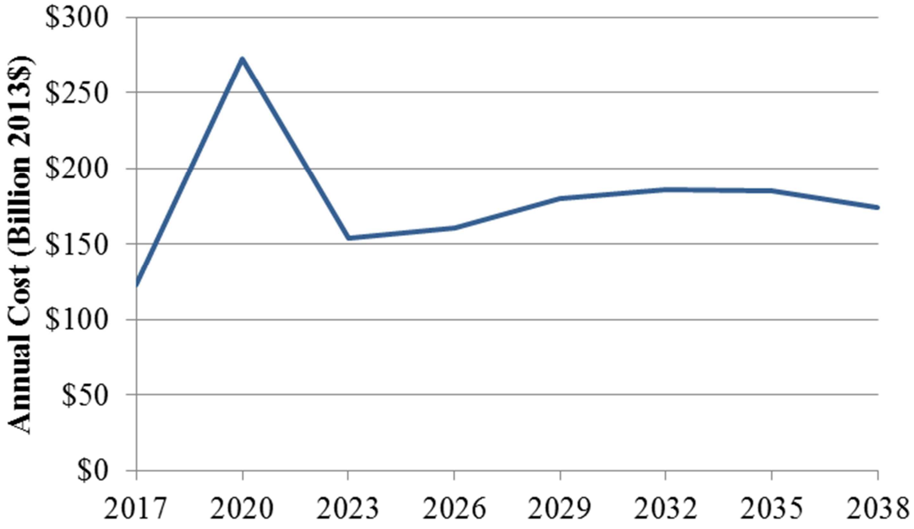
Figure 10: Classifications and Attainment Years for 60 ppb

Classification	Attainment Year	States
Compliant	N/A	8
Marginal	2020	5
Moderate	2023	32
Serious	2026	2
Severe-15	2032	0
Severe-17	2034	0
Extreme	2037	1

Notes: “N/A” denotes that attainment year is not applicable for compliant states.
State counts do not include Alaska, Hawaii, or the District of Columbia
Source: NERA calculations as explained in text

Based on these state designations and compliance deadlines, we developed estimates of the costs that would be incurred each year. We assumed that one-half of annualized costs represent capital costs that would be incurred before the compliance deadline and the other half represents operating costs that would be incurred each year from the compliance deadline onward. Figure 11 shows the resulting estimates of total potential compliance costs by year to achieve an ozone NAAQS of 60 ppb. The present value of the costs shown in this figure is \$2.2 trillion (in 2013 dollars, calculated as of 2014, excluding costs related to coal-unit retirements (which are modeled endogenously in N$_{ew}$ERA). Appendix D provides details on the cost estimates. We ran the N$_{ew}$ERA model with these costs assigned to specific states, sectors, and years to estimate the economic impacts of a potential 60 ppb ozone NAAQS.

Figure 11: Potential U.S. Compliance Costs for 60 ppb by Year (Billion 2013$)



Notes: National summary figure reflects sum of state-specific modeling inputs.
Annual values are the average for that year and the following two years (*e.g.*, 2017 value is the average for the 2017-2019 period).
Compliance cost inputs in the figure do not include the cost of reduced coal-fired generation.
Source: NERA calculations as explained in text

C. Natural Gas Production Sensitivity Case

The methodology outlined above assumes that the U.S. natural gas extraction sector would be able to increase production without any constraints to meet increased natural gas demand associated with ozone NAAQS attainment actions. This assumption results in a large projected increase in U.S. natural gas production. However natural gas producers in areas that become nonattainment under a tighter ozone standard might face new requirements – such as the need to obtain air permits as well as emissions reduction credits (“offsets”) for NO_X and/or VOCs – in order to develop new wells. Whether such permitting requirements will be applied to new oil and gas extraction nationally is a policy question that is in a state of flux at present; but some areas of the country already have these requirements and there are pressures for the EPA to make it a uniform requirement. Moreover, expansion of natural gas output will require additional gas processing facilities, which are already subject to the offsetting requirement if located in nonattainment areas. Obtaining offsets may be difficult and/or costly, particularly in more rural areas where there are few industrial emissions sources to create offset supply. If such barriers to continued new well development do emerge, the projected economic impacts of a 60 ppb ozone NAAQS could be substantially increased.

To consider the implications of possible constraints on energy production, we evaluated a natural gas production sensitivity case. This case was intended to provide an indication of the potential impacts if the 60 ppb standard effectively prevented additional natural gas production in nonattainment areas. For this case we used the same attainment cost inputs as in the 60 ppb case, but we also assumed that total U.S. natural gas production would not increase beyond its 2020 level (from the 60 ppb scenario).[26] The motivation for this sensitivity case is the possibility that the majority of the natural gas producing regions will find themselves as part of a nonattainment area for 60 ppb and may face new air permit and emissions offset requirements in order to site new wells. Crude oil and natural gas activity has been linked to increases in ozone concentrations in several areas of the country (*e.g.*, Lyman and Shorthill 2013, Wyoming Outdoor Council *et al*. 2013, Travers 2013, and Colorado Department of Public Health and the Environment 2014). Jacus (2011) summarizes legal issues and cases related to crude oil/natural gas activity and air quality.

Thus for the sensitivity case, we assumed that natural gas production could not exceed the 2020 levels of production in the 60 ppb case. This case does not reflect the specific constraints that might result in individual states. Note that the sensitivity case implicitly assumes some new natural gas wells are developed after 2020. Indeed, if new wells were prohibited entirely, production levels would likely decline because of the decline over time in production from existing wells. Note also that this case excludes constraints on crude oil production, which also could be affected. Our sensitivity analysis highlights the need for EPA to evaluate potential impacts on domestic energy production in its forthcoming ozone RIA.

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[26] Note that limits on natural gas production may also affect crude oil production, but we did not evaluate this.

III. STUDY RESULTS

This chapter summarizes the results of our analyses of the impacts of a 60 ppb ozone standard. The results are grouped into three major categories: (1) potential impacts on the overall U.S. economy and U.S. households; (2) potential impacts on the U.S. energy sectors; and (3) potential impacts on individual sectors and regions. As noted, we refer to our estimates as potential impacts because of the major uncertainties involved in the underlying estimates of compliance costs. The final section summarizes the major uncertainties in our results.

A. Potential Impacts on the U.S. Economy and U.S. Households

The potential effects of a 60 ppb ozone standard on the U.S. economy and U.S. households are substantial. This section presents estimated impacts of a 60 ppb standard on GDP, household consumption, the labor force, and total welfare.

1. Gross Domestic Product and Its Components

GDP is an economic measure of the entire economy. The components of GDP are consumption, investment, government spending, and net exports. Since the level of Federal government expenditures is assumed to remain constant, the changes in GDP are driven by changes in consumption, investment, and net exports. Figure 12 shows the estimated changes in GDP and its components due to the 60 ppb ozone standard. GDP declines from the baseline levels by an average of 1.2% per year during the period. Both consumption and investment decline as well.

Figure 12: Potential Impacts of 60 ppb Ozone Standard on U.S. Gross Domestic Product

	PV	2017	2020	2023	2026	2029	2032	2035	2038
GDP									
Baseline (Trillions)	$281	$18.3	$19.7	$21.2	$22.7	$24.4	$26.1	$27.8	$28.9
60 ppb Case (Trillions)	$278	$18.1	$19.5	$20.9	$22.4	$24.1	$25.7	$27.4	$28.6
% Change from Baseline	-1.2%	-0.8%	-1.2%	-1.4%	-1.3%	-1.3%	-1.3%	-1.2%	-1.2%
Consumption									
% Change from Baseline	-1.1%	-1.0%	-1.1%	-1.2%	-1.2%	-1.2%	-1.2%	-1.2%	-1.1%
Investment									
% Change from Baseline	-1.5%	0.5%	-1.7%	-2.4%	-1.9%	-1.5%	-1.6%	-1.7%	-1.8%
Net Exports									
% Change from Baseline	0.2%	0.5%	0.0%	-0.2%	0.3%	0.6%	0.4%	0.0%	-0.3%

Notes: Present value is from 2017 through 2040, discounted at 5% real discount rate. Government spending is also a component of GDP, but is unchanged from the baseline.

Source: NERA calculations as explained in text

2. Consumption per Household

One common economic metric of policy costs is the change in consumption per household (sometimes described as change in costs per household). It is important to note that, as with the other measures, the estimated change in consumption per household is a comprehensive figure that includes a large number of influences. This metric incorporates the financial gains due to increased demand for pollution control equipment. It also takes into account the many ways in which consumers and producers can change their behavior to limit financial losses from increases in prices due to the ozone standard. That is, this impact measure includes cost-minimizing adjustments to consumers' "market basket" of goods and services purchased and to their lifestyle/behavioral patterns. Similarly, the loss in consumption per household incorporates all the adjustments to inputs and production processes that businesses make to minimize the effects of compliance expenditures on the cost of their products or services. These adjustments can lead to non-financial losses and thus the change in consumption per household is not a complete measure of consumer losses. The full effects of the 60 ppb ozone standard include the qualitative effects of all such changes in personal choices and activities as well as the financial costs we report here.

Figure 13 shows the potential change in consumption per household over time. These results indicate that average potential household consumption would be reduced by about $1,190 in 2017 and by about $1,830 in 2038, with an average annual (present valued) reduction over the period from 2017 through 2040 of $1,570 per household.

Figure 13: Potential Impacts of 60 ppb Ozone Standard on U.S. Annual Change in Consumption per Household[27]

	Avg.	2017	2020	2023	2026	2029	2032	2035	2038
Change in Average Consumption per Household	-$1,570	-$1,190	-$1,430	-$1,590	-$1,640	-$1,760	-$1,830	-$1,850	-$1,830

Note: Average is the levelized average over 2017-2040, annualized using a 5% real discount rate.
Source: NERA calculations as explained in text

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[27] PV is a levelized value over the 2017 through 2040 time period.

3. Labor Market

Figure 14 focuses on several dimensions of projected impacts on income from labor ("worker income") as a result of the 60 ppb ozone standard. The ozone standard on balance would lower potential wage rates by an average of 1.2% over the period from 2017 through 2040. Wage rates decline because companies have higher costs and lower labor productivity due to compliance costs. Lower real wage rates reduce workers' incomes even if they continue to work the same number of hours. However, a lower real wage rate also decreases people's desire to work. With fewer hours worked, total labor income declines by a greater percentage than does the wage rate (an average of 1.9% over the period). These are the net equilibrium effects on labor in the aggregate, and include the positive benefits of increased labor demand in sectors providing pollution control equipment and technologies.

Figure 14: Potential Impacts of 60 ppb Ozone Standard on Labor

	Avg.	2017	2020	2023	2026	2029	2032	2035	2038
Baseline Job-Equivalents (millions)	155.7	145.2	148.4	150.3	153.5	157.2	160.6	163.7	167.0
60 ppb Case									
Real Wage Rate (% Change from Baseline)	-1.2%	-0.8%	-2.0%	-1.3%	-1.2%	-1.3%	-1.2%	-1.2%	-1.1%
Change in Labor Income (% Change from Baseline)	-1.9%	-0.7%	-2.2%	-2.0%	-2.0%	-2.1%	-2.1%	-2.1%	-1.9%
Job-Equivalents (Change from Baseline, millions)	-2.9	-0.9	-3.2	-3.0	-3.0	-3.3	-3.4	-3.3	-3.2

Notes: Average is the simple average over 2017-2040. Total job-equivalents equals total labor income change divided by the average annual income per job. This does not represent a projection of numbers of workers that may need to change jobs and/or be unemployed, as some or all of it could be spread across workers who remain employed.

Source: NERA calculations as explained in text

The total reduction in potential labor income is spread over many workers, most of whom may continue to work, but the dollar magnitude of the reduction in labor income can be placed in context by estimating the equivalent number of average jobs that such labor payments would fund under baseline wage rates. To state the potential labor income changes in terms of such "job-equivalents," we divide the change in labor income by the annual baseline income for the average job (see Figure 14). A loss of one job-equivalent does not necessarily mean one fewer employed person—it may be manifested as a combination of fewer people working and less income per worker. However, this measure allows us to express employment-related impacts in terms of an equivalent number of employees earning the average prevailing wage.[28] Note that the $\mathrm{N_{ew}ERA}$ model, like many other similar economic models, does not develop projections of unemployment rates or layoffs associated with reductions in labor income; modeling such largely transitional phenomena requires a different type of modeling methodology; our methodology considers only the long-run, equilibrium impact levels.

The projected impacts of a 60 ppb ozone standard on potential labor income are substantial. Potential labor income declines by about 0.7% to 2.2% throughout the period, resulting in potential annual job-equivalent losses that average about 2.9 million job-equivalents.

4. Economic Welfare

Economic welfare is a concept used by economists that relates to the overall utility that individuals experience from the economy. In $\mathrm{N_{ew}ERA}$, welfare is measured by the sum of the values of household consumption and leisure. The potential effects of the 60 ppb ozone standard lead to a potential average U.S. welfare loss over the entire modeling horizon of 0.90%, expressed as percentage changes relative to the baseline, over the time period of our study.

B. Potential Impacts on U.S. Energy System

The transformations required to meet a 60 ppb ozone standard could have substantial impacts on the U.S. energy system. These potential impacts include effects on fossil fuel markets and electricity prices.

1. Fossil Fuel Markets

We estimated controls to achieve a 60 ppb ozone standard include elimination of generation from coal-fired power plants in certain nonattainment states. These changes would lead to higher costs for consuming other fossil fuels and reduced production and consumption of coal in the long term. Figure 15 shows the potential impacts on coal and natural gas production due to the 60 ppb ozone standard. The significant potential declines in steam coal consumption reflect the reduced generation from coal-fired generators. Potential natural gas consumption increases substantially due to fuel switching from coal to natural gas in the electricity sector.[29]

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[28] Such a "job-equivalent" estimate is comparable to determining the minimum number of workers that would lose their entire income (their "job") if the full brunt of the regulation were concentrated on the smallest number of workers.

[29] Natural gas production decreases slightly in 2020 (before the retirement of coal units and the resulting increase in natural gas generation) due to reduced overall economic activity.

Figure 15: Potential Impacts of a 60 ppb Ozone Standard on Fossil Fuel Production

	2017	**2020**	**2023**	**2026**	**2029**	**2032**	**2035**	**2038**
Steam Coal (Quadrillion Btu)								
Baseline	17.0	17.0	18.0	18.6	18.9	19.1	19.4	19.4
60 ppb Case	15.4	14.8	8.2	6.0	6.0	6.0	6.0	6.0
Change	-1.6	-2.2	-9.8	-12.7	-12.9	-13.2	-13.4	-13.4
Natural Gas (Quadrillion Btu)								
Baseline	26.7	29.4	31.3	32.7	33.6	34.6	35.7	36.7
60 ppb Case	26.8	28.9	34.6	37.4	38.1	39.0	40.2	41.2
Change	0.17	-0.6	3.2	4.7	4.4	4.4	4.5	4.5

Source: NERA calculations as explained in text

Figure 16 shows the potential impacts on the prices of fossil fuels. The average Henry Hub natural gas prices would increase by an average of almost 10% over the period from 2017 through 2040. Delivered natural gas prices to residential and industrial customers potentially would increase on average by 7% and 12%, respectively, over the same time period. Note that part of the increase in delivered natural gas prices reflects the increase in pipeline transportation costs due to control costs for reductions in NO_X emissions in the pipeline system that would be recovered through tariff rates.

2. Electricity Sector

Figure 17 shows the residential and industrial sector delivered electricity prices in the baseline and under the potential impacts of the 60 ppb ozone standard. In the baseline, both residential and industrial electricity prices are projected to increase primarily due to increasing fuel prices over time. The 60 ppb ozone standard is projected to lead to a potential increase in average delivered residential electricity price of 3.3% over the period from 2017 through 2040. Average delivered industrial electricity prices are projected to increase potentially by 5.5% over the same period.

Figure 18 shows projected potential physical impacts on the electricity sector in terms of coal electricity unit capacity and overall electricity demand. Projected reductions in coal-fired power plant generation to reduce NO_X emissions in certain nonattainment states would lead to cost increases from the need to use more expensive sources of electricity. This would result in reductions in potential electricity demand shown in the table below. The average reduction is 3.1% over the period from 2017 through 2040.

Figure 16: Potential Impacts of a 60 ppb Ozone Standard on Fossil Fuel Commodity Prices ($/MMBtu for Natural Gas, $/gallon for Gasoline)

	Avg.	2017	2020	2023	2026	2029	2032	2035	2038
Baseline Prices ($/MMBtu for natural gas and $/gallon for gasoline)									
Henry Hub Natural Gas	$6.02	$4.42	$4.87	$5.25	$5.70	$6.18	$6.68	$7.29	$7.76
Natural Gas Delivered (Residential)	$13.77	$12.25	$12.56	$12.96	$13.46	$14.00	$14.51	$14.99	$15.43
Natural Gas Delivered (Industrial)	$8.43	$6.80	$7.15	$7.58	$8.11	$8.67	$9.21	$9.73	$10.19
Gasoline	$3.56	$3.19	$3.25	$3.40	$3.50	$3.59	$3.70	$3.86	$4.00
60 ppb Case ($/MMBtu for natural gas and $/gallon for gasoline)									
Henry Hub Natural Gas	$6.65	$4.47	$4.73	$6.02	$6.73	$7.05	$7.50	$8.12	$8.57
Natural Gas Delivered (Residential)	$14.79	$12.63	$12.74	$14.15	$14.96	$15.36	$15.82	$16.19	$16.45
Natural Gas Delivered (Industrial)	$9.49	$7.22	$7.39	$8.82	$9.66	$10.08	$10.55	$10.96	$11.24
Gasoline	$3.57	$3.20	$3.25	$3.41	$3.52	$3.61	$3.72	$3.87	$4.01
60 ppb Case (% Increase from Baseline)									
Henry Hub Natural Gas	9.9%	1.1%	-2.7%	15%	18%	14%	12%	11%	10%
Natural Gas Delivered (Residential)	7.3%	3.1%	1.4%	9.1%	11%	9.8%	9.0%	8.0%	6.6%
Natural Gas Delivered (Industrial)	12%	6.2%	3.3%	16%	19%	16%	15%	13%	10%
Gasoline	0.4%	0.3%	0.0%	0.5%	0.5%	0.5%	0.5%	0.3%	0.2%

Note: Average is the simple average over 2017-2040.
Source: NERA calculations as explained in text

Figure 17: Potential Impacts of a 60 ppb Ozone Standard on Delivered Electricity Prices (¢/kWh)

	Avg.	2017	2020	2023	2026	2029	2032	2035	2038
Baseline Prices (¢/kWh)									
Residential	14.5¢	12.9¢	13.3¢	14.0¢	14.4¢	14.8¢	15.3¢	15.6¢	15.4¢
Industrial	9.4¢	7.8¢	8.1¢	8.9¢	9.3¢	9.8¢	10.3¢	10.7¢	10.5¢
60 ppb Case (¢/kWh)									
Residential	14.9¢	13.2¢	13.7¢	14.6¢	15.1¢	15.4¢	15.8¢	15.9¢	15.8¢
Industrial	9.9¢	8.1¢	8.6¢	9.5¢	10.1¢	10.4¢	10.8¢	11.0¢	10.9¢
60 ppb Case (% Increase from Baseline)									
Residential	3.3%	2.3%	3.2%	4.4%	5.3%	4.1%	3.0%	1.8%	2.4%
Industrial	5.5%	4.2%	6.0%	7.5%	8.6%	6.7%	4.6%	2.9%	3.9%

Note: Average is the simple average over 2017-2040.
Source: NERA calculations as explained in text

Figure 18: Potential Impacts of a 60 ppb Ozone Standard on Electricity Sector

	2017	2020	2023	2026	2029	2032	2035	2038
Baseline								
Coal-Fired Capacity (GW)	262	259	257	257	257	257	257	257
Electricity Demand (TWh)	4,150	4,250	4,370	4,480	4,580	4,650	4,750	4,850
60 ppb Case								
Coal-Fired Capacity (GW)	229	221	166	160	160	158	158	156
Electricity Demand (TWh)	4,080	4,140	4,210	4,290	4,400	4,500	4,620	4,710
60 ppb Case (Change from Baseline)								
Coal-Fired Capacity (GW)	-34	-38	-92	-97	-97	-99	-99	-101
Electricity Demand (%)	-1.7%	-2.7%	-3.7%	-4.2%	-3.9%	-3.2%	-2.6%	-3.0%

Note: Average is the simple average over 2017-2040.
Source: NERA calculations as explained in text

C. Potential Impacts on U.S. Sectors and Regions

Although all sectors of the U.S. economy would be affected by a 60 ppb ozone standard, both directly through increased emissions control costs and indirectly through the overall impact on the economy, there are noticeable differences across sectors.

1. Potential Sectoral Impacts

Figure 19 shows the estimated potential changes in sectoral output for 10 sectors. The reduction in coal output and increase in natural gas output are largely results of the scrappage of coal-fired power plants in some nonattainment areas and the resulting shift toward natural gas generation. While agriculture and commercial transportation have the largest percentage reductions in output among the non-energy sectors, the largest absolute reductions over the period from 2017 through 2040 are in the commercial/services and manufacturing sectors since these are much larger sectors.

Figure 19: Potential Impacts of a 60 ppb Ozone Standard on Sectoral Output (Percentage Change from Baseline)

	Avg.	**2017**	**2020**	**2023**	**2026**	**2029**	**2032**	**2035**	**2038**
Non-Energy Sectors									
Agriculture	-2.2%	-0.1%	-2.7%	-2.6%	-2.3%	-2.6%	-2.7%	-2.6%	-2.3%
Commercial/Services	-0.9%	-0.4%	-1.1%	-1.0%	-0.9%	-1.0%	-1.1%	-1.0%	-1.0%
Manufacturing	-0.6%	1.7%	-0.9%	-0.9%	-0.7%	-0.9%	-1.2%	-1.2%	-1.1%
Commercial Transportation	-1.9%	-0.8%	-2.2%	-1.9%	-2.0%	-2.1%	-2.1%	-1.9%	-1.8%
Commercial Trucking	-1.1%	-0.1%	-1.4%	-1.2%	-1.1%	-1.2%	-1.3%	-1.2%	-1.2%
Energy Sectors									
Coal	-52%	-8.3%	-12%	-55%	-67%	-67%	-68%	-68%	-69%
Natural Gas	9.2%	0.6%	-2.0%	10%	14%	13%	13%	12%	12%
Refining	-1.8%	-0.5%	-1.5%	-1.9%	-2.0%	-2.3%	-2.4%	-2.1%	-2.0%
Crude Oil	-0.1%	0.4%	0.0%	0.1%	0.0%	-0.1%	-0.3%	-0.3%	-0.3%
Electricity	-3.1%	-1.7%	-2.6%	-3.6%	-4.2%	-3.9%	-3.2%	-2.6%	-2.9%

Note: Average is the simple average over 2017-2040.
Source: NERA calculations as explained in text

2. Potential Regional Impacts

The potential impacts of a 60 ppb ozone standard vary by region. Regions fare better or worse than the U.S. average primarily due to each region's attainment costs and sectoral output mix.

Figure 20 shows the estimated potential changes in gross regional product for the eleven regions in the N_{ew}ERA model. California, the Mid-Atlantic and Upper Midwest regions have the largest percentage impacts, though all regions experience some reduction in gross regional product. As noted above, total U.S. gross domestic product decreases by about 1.2% per year from baseline during the model period.

Figure 20: Potential Impacts of a 60 ppb Ozone Standard on Gross Regional Product (Percentage Change Relative to Baseline)

Region	PV	2017	2020	2023	2026	2029	2032	2035	2038
Arizona and Mountain States	-0.8%	-0.7%	-0.9%	-1.0%	-0.8%	-0.9%	-0.7%	-0.7%	-0.6%
California	-2.2%	-1.3%	-1.5%	-1.7%	-2.4%	-3.0%	-3.2%	-2.9%	-2.7%
Florida	-0.4%	-0.7%	-0.5%	-0.5%	-0.2%	0.1%	-0.1%	-0.3%	-1.0%
Mid-America	-0.6%	0.3%	-0.4%	-0.5%	-0.9%	-0.8%	-0.8%	-0.8%	-0.8%
Mid-Atlantic	-1.6%	-1.7%	-2.1%	-2.4%	-1.5%	-1.3%	-1.3%	-1.0%	-1.0%
Mississippi Valley	-1.3%	-1.1%	-1.4%	-1.6%	-1.3%	-1.3%	-1.3%	-1.1%	-1.0%
New York/New England	-1.4%	-1.5%	-1.6%	-1.9%	-1.3%	-1.3%	-1.2%	-1.2%	-1.1%
Pacific Northwest	-0.6%	-0.6%	-0.5%	-0.6%	-0.5%	-0.9%	-0.5%	-0.5%	-0.3%
Southeast	-0.9%	-0.7%	-1.1%	-0.9%	-1.0%	-1.1%	-1.0%	-1.0%	-0.9%
Texas, Oklahoma, Louisiana	-0.3%	0.0%	-0.6%	-0.6%	-0.1%	0.0%	-0.1%	-0.6%	-0.5%
Upper Midwest	-1.6%	0.4%	-1.3%	-1.9%	-3.2%	-2.2%	-2.0%	-1.8%	-1.9%
U.S.	**-1.2%**	**-0.8%**	**-1.2%**	**-1.4%**	**-1.3%**	**-1.3%**	**-1.3%**	**-1.2%**	**-1.2%**

Note: Present value is from 2017 through 2040, discounted at 5% real discount rate.
Source: NERA calculations as explained in text

Figure 21 shows projected potential changes in average consumption per household by region over the period from 2017 through 2040. The regional patterns are similar to gross regional product, and all regions experience a decrease in average consumption per household.

Figure 22 shows potential changes in job-equivalents by region (relative to baseline) due to the 60 ppb ozone standard. All regions experience a decrease in job-equivalents, though potential impacts vary considerably by region.

Figure 21: Potential Impacts of a 60 ppb Ozone Standard on Regional Consumption per Household – Change in Consumption per Household Relative to Baseline ($/HH)

Region	PV	2017	2020	2023	2026	2029	2032	2035	2038
Arizona and Mountain States	-$690	-$550	-$610	-$680	-$740	-$780	-$800	-$800	-$780
California	-$2,910	-$1,710	-$2,130	-$2,600	-$3,170	-$3,710	-$4,060	-$4,160	-$4,100
Florida	-$450	-$340	-$410	-$450	-$510	-$530	-$520	-$510	-$480
Mid-America	-$850	-$620	-$670	-$770	-$890	-$990	-$1,080	-$1,140	-$1,160
Mid-Atlantic	-$2,520	-$2,110	-$2,410	-$2,670	-$2,510	-$2,660	-$2,740	-$2,820	-$2,840
Mississippi Valley	-$1,550	-$1,230	-$1,450	-$1,610	-$1,590	-$1,690	-$1,750	-$1,780	-$1,790
New York/New England	-$2,490	-$1,870	-$2,380	-$2,610	-$2,550	-$2,680	-$2,800	-$2,890	-$2,950
Pacific Northwest	-$730	-$590	-$650	-$680	-$760	-$820	-$880	-$900	-$890
Southeast	-$1,060	-$880	-$1,020	-$1,070	-$1,080	-$1,150	-$1,190	-$1,200	-$1,180
Texas, Oklahoma, Louisiana	-$1,070	-$770	-$1,010	-$1,190	-$1,240	-$1,240	-$1,180	-$1,120	-$1,080
Upper Midwest	-$1,770	-$1,440	-$1,720	-$1,850	-$1,800	-$1,860	-$1,930	-$1,980	-$2,000
U.S.	**-$1,570**	**-$1,190**	**-$1,430**	**-$1,590**	**-$1,640**	**-$1,760**	**-$1,830**	**-$1,850**	**-$1,830**

Note: Present value is from 2017 through 2040, discounted at 5% real discount rate.
Source: NERA calculations as explained in text

Figure 22: Potential Impacts of a 60 ppb Ozone Standard on Regional Job-Equivalents - Change in Job-Equivalents Relative to Baseline (thousands)

Region	Avg.	2017	2020	2023	2026	2029	2032	2035	2038
Arizona and Mountain States	-86	-12	-96	-96	-88	-96	-100	-101	-98
California	-608	-123	-319	-408	-529	-762	-899	-926	-895
Florida	-53	-11	-47	-63	-57	-61	-66	-58	-57
Mid-America	-69	8	-62	-72	-68	-81	-90	-96	-87
Mid-Atlantic	-364	-175	-541	-387	-381	-367	-372	-351	-337
Mississippi Valley	-289	-94	-350	-329	-314	-319	-319	-302	-286
New York/New England	-333	-160	-468	-366	-346	-347	-333	-330	-312
Pacific Northwest	-54	-12	-49	-56	-49	-59	-68	-70	-65
Southeast	-303	-101	-378	-328	-302	-326	-343	-332	-311
Texas, Oklahoma, Louisiana	-313	-83	-319	-358	-385	-391	-344	-310	-314
Upper Midwest	-453	-136	-581	-539	-485	-486	-487	-467	-445
U.S.	**-2,920**	**-900**	**-3,210**	**-3,000**	**-3,000**	**-3,290**	**-3,420**	**-3,340**	**-3,210**

Note: Average is the simple average over 2017-2040.
Source: NERA calculations as explained in text

Figure 23 shows potential changes in economic welfare by region (relative to baseline) due to the 60 ppb ozone standard. All regions are projected to suffer negative economic outcomes, but some regions fare better or worse than the U.S. average depending on the quantity and cost of NO_X reduction required for compliance, along with their natural resource base (regions with natural gas have some benefits associated with increased production that offsets some of their compliance costs, while coal producing regions have negative consequences from reduced coal production on top of their compliance costs).

Figure 23: Potential Impacts of a 60 ppb Ozone Standard on Regional Welfare (Percentage Change Relative to Baseline)

Region	PV
Arizona and Mountain States	-0.44%
California	-1.41%
Florida	-0.34%
Mid-America	-0.46%
Mid-Atlantic	-1.28%
Mississippi Valley	-0.86%
New York/New England	-1.11%
Pacific Northwest	-0.47%
Southeast	-0.70%
Texas, Oklahoma, Louisiana	-0.64%
Upper Midwest	-1.12%
U.S.	**-0.90%**

Note: Present value is from 2017 through 2040, discounted at 5% real discount rate
Source: NERA calculations as explained in text

D. Sensitivity Case with Limits on Natural Gas Production

For the sensitivity case we used the same attainment cost inputs as in the 60 ppb case, but we also assumed that total U.S. natural gas production would not increase beyond its 2020 level (from the 60 ppb scenario). Figure 24 shows natural gas production under baseline conditions, with a 60 ppb ozone standard but no restrictions on natural gas production (“60 ppb”), and with natural gas production limited to 2020 production in the 60 ppb case. Natural gas production is 28.9 quads in 2020 in the 60 ppb case (without any natural gas constraints), so we limited natural gas production to 28.9 quads after 2020 in the sensitivity case.

Figure 24: Potential Impacts of a 60 ppb Ozone Standard on Natural Gas Production (Quadrillion Btu)

	2017	2020	2023	2026	2029	2032	2035	2038
Baseline	26.7	29.4	31.3	32.7	33.6	34.6	35.7	36.7
60 ppb	26.8	28.9	34.6	37.4	38.1	39.0	40.2	41.2
Production Sensitivity	26.8	28.9	28.9	28.9	28.9	28.9	28.9	28.9

Source: NERA calculations as explained in text

1. Potential Impacts on the U.S. Economy and U.S. Households

Figure 25 shows the estimated potential changes in GDP and its components due to the 60 ppb ozone standard with assumed limits on natural gas production. GDP declines from the baseline levels by approximately 1.6% per year during the period, a potential reduction roughly 30% higher than in the 60 ppb case without limits on natural gas production. Both consumption and investment decline as well.

Figure 25: Potential Impacts of a 60 ppb Ozone Standard on U.S. Gross Domestic Product and Components (Sensitivity Case)

	PV	2017	2020	2023	2026	2029	2032	2035	2038
GDP									
Baseline (Trillions)	$281	$18.3	$19.7	$21.2	$22.7	$24.4	$26.1	$27.8	$28.9
Sensitivity (Trillions)	$277	$18.1	$19.5	$20.8	$22.3	$23.9	$25.6	$27.3	$28.4
% Change from Baseline	-1.6%	-0.9%	-1.3%	-1.6%	-1.8%	-1.9%	-1.9%	-1.9%	-1.8%
Consumption									
% Change from Baseline	-1.5%	-1.1%	-1.4%	-1.5%	-1.6%	-1.7%	-1.7%	-1.6%	-1.6%
Investment									
% Change from Baseline	-2.5%	0.0%	-2.1%	-3.1%	-2.7%	-2.8%	-3.1%	-3.4%	-3.5%
Net Exports									
% Change from Baseline	-1.0%	2.6%	-0.7%	-1.3%	-1.2%	-0.3%	0.2%	0.0%	-0.6%

Note: Present value is from 2017 through 2040, discounted at 5% real discount rate. Government spending is also a component of GDP, but is unchanged from the baseline.

Source: NERA calculations as explained in text

Figure 26 shows the potential change in consumption per household over time in the sensitivity case. These results indicate that average household consumption would be reduced by about $1,370 in 2017 and by about $2,580 in 2038, with an average annual (present valued) reduction over the period from 2017 through 2040 of $2,040 per household.

Figure 26: Potential Impacts of a 60 ppb Ozone Standard on U.S. Consumption per Household (Sensitivity Case)

	Avg.	2017	2020	2023	2026	2029	2032	2035	2038
Change in Average Consumption per Household	-$2,040	-$1,370	-$1,710	-$2,000	-$2,210	-$2,430	-$2,550	-$2,590	-$2,580

Note: Annualized average is from 2017 through 2040, discounted at 5% real discount rate.
Source: NERA calculations as explained in text

Figure 27 shows projected impacts on income from labor ("worker income") as a result of the 60 ppb ozone standard with assumed limits on natural gas production. The ozone standard sensitivity on balance would lower wage rates by an average of 2.0% over the period from 2017 through 2040. Wage rates decline because companies have higher costs and lower labor productivity due to compliance costs. Lower real wage rates reduce workers' incomes even if they continue to work the same number of hours. However, a lower real wage rate also decreases people's desire to work. With fewer hours worked, total labor income declines by a greater percentage than does the wage rate (an average of 2.7% over the period). These are the net equilibrium effects on labor in the aggregate, and include the potential positive benefits of increased labor demand in sectors providing pollution control equipment and technologies.

In the sensitivity case, the projected potential impacts of a 60 ppb ozone on labor income are substantial, particularly in the later years. Labor income declines by about 0.7% to 3.3% throughout the period, resulting in job-equivalent losses that average about 4.3 million job-equivalents (compared to 2.9 million average annual job-equivalent losses in the basic 60 ppb case).

The effects of the 60 ppb ozone standard with assumed limits on natural gas production lead to an average potential U.S. welfare loss over the entire modeling horizon of 1.12%, expressed as a percentage change relative to the baseline, over the time period of our study.

Figure 27: Potential Impacts of a 60 ppb Ozone Standard on Labor (Sensitivity Case)

	Avg.	2017	2020	2023	2026	2029	2032	2035	2038
Baseline Job-Equivalents (millions)	155.7	145.2	148.4	150.3	153.5	157.2	160.6	163.7	167.0
Sensitivity Case									
Real Wage Rate (% Change from Baseline)	-2.0%	-0.9%	-2.1%	-1.9%	-2.2%	-2.3%	-2.3%	-2.2%	-2.1%
Change in Labor Income (% Change from Baseline)	-2.7%	-0.7%	-2.3%	-2.7%	-3.1%	-3.3%	-3.3%	-3.3%	-3.1%
Job-Equivalents (Change from Baseline, millions)	-4.3	-1.1	-3.4	-4.1	-4.8	-5.1	-5.3	-5.4	-5.2

Note: Average is the simple average over 2017-2040. Total job-equivalents equals total labor income change divided by the average annual income per job. This does not represent a projection of numbers of workers that may need to change jobs and/or be unemployed, as some or all of it could be spread across workers who remain employed.

Source: NERA calculations as explained in text

2. Potential Impacts on U.S. Energy System

Figure 28 shows the potential impacts on coal and natural gas production due to the 60 ppb ozone standard with assumed limits on natural gas production. The significant declines in coal production reflect the reductions in coal-fired generation. Natural gas production is restricted by assumption in the sensitivity case.

Figure 28: Potential Impacts of a 60 ppb Ozone Standard on Fossil Fuel Production (Sensitivity Case)

	2017	2020	2023	2026	2029	2032	2035	2038
Steam Coal (Quadrillion Btu)								
Baseline	17.0	17.0	18.0	18.6	18.9	19.1	19.4	19.4
Sensitivity Case	15.3	14.0	8.3	5.9	6.0	6.0	6.0	6.0
Change	-1.7	-3.0	-9.7	-12.7	-12.9	-13.1	-13.4	-13.4
Natural Gas (Quadrillion Btu)								
Baseline	26.7	29.4	31.3	32.7	33.6	34.6	35.7	36.7
Sensitivity Case	26.8	28.9	28.9	28.9	28.9	28.9	28.9	28.9
Change	0.2	-0.5	-2.4	-3.8	-4.6	-5.7	-6.8	-7.8

Source: NERA calculations as explained in text

Figure 29 shows the potential impacts on the prices of fossil fuels. Due to assumed limits on the production of natural gas in the sensitivity case, Henry Hub natural gas prices would increase by an average of 66% over the period from 2017 through 2040 (compared to about 10% in the 60 ppb case, shown in Figure 16). Delivered natural gas prices to residential and industrial customers potentially would increase on average by 32% and 52%, respectively, over the same time period. Note that part of the increase in delivered natural gas prices reflects the increase in pipeline transportation costs due to control costs for reductions in NO_X emissions in the pipeline system that would be recovered through tariff rates.

Figure 29: Potential Impacts of a 60 ppb Ozone Standard on Fossil Fuel Commodity Prices (Sensitivity Case)

	Avg.	**2017**	**2020**	**2023**	**2026**	**2029**	**2032**	**2035**	**2038**
Baseline Prices ($/MMBtu for natural gas and $/gallon for gasoline)									
Henry Hub Natural Gas	$6.02	$4.42	$4.87	$5.25	$5.70	$6.18	$6.68	$7.29	$7.76
Natural Gas Delivered (Residential)	$13.77	$12.25	$12.56	$12.96	$13.46	$14.00	$14.51	$14.99	$15.43
Natural Gas Delivered (Industrial)	$8.43	$6.80	$7.15	$7.58	$8.11	$8.67	$9.21	$9.73	$10.19
Gasoline	$3.56	$3.19	$3.25	$3.40	$3.50	$3.59	$3.70	$3.86	$4.00
Sensitivity Case ($/MMBtu for natural gas and $/gallon for gasoline)									
Henry Hub Natural Gas	$9.97	$4.45	$4.36	$9.10	$12.09	$12.30	$12.72	$13.25	$13.78
Natural Gas Delivered (Residential)	$18.16	$12.62	$12.38	$17.03	$20.09	$20.50	$20.99	$21.24	$21.54
Natural Gas Delivered (Industrial)	$12.79	$7.21	$7.03	$11.73	$14.83	$15.24	$15.75	$16.03	$16.34
Gasoline	$3.60	$3.21	$3.26	$3.45	$3.56	$3.65	$3.76	$3.91	$4.05
Sensitivity Case (% Increase from Baseline)									
Henry Hub Natural Gas	66%	0.8%	-10%	73%	112%	99%	90%	82%	78%
Natural Gas Delivered (Residential)	32%	3.0%	-1.4%	31%	49%	46%	45%	42%	40%
Natural Gas Delivered (Industrial)	52%	6.0%	-1.6%	55%	83%	76%	71%	65%	60%
Gasoline	1.3%	0.7%	0.3%	1.4%	1.8%	1.7%	1.7%	1.4%	1.2%

Note: Average is the simple average over 2017-2040.
Source: NERA calculations as explained in text

Figure 30 shows the residential and industrial sector delivered electricity prices in the baseline and under the potential impacts of the 60 ppb ozone standard with assumed limits on natural gas production. In the baseline, both residential and industrial electricity prices are projected to increase primarily due to increasing fuel prices over time. The 60 ppb ozone standard with limits on natural gas production is projected to lead to a potential increase in average delivered residential electricity price of 15% over the period from 2017 through 2040. Average delivered industrial electricity prices are projected to increase by 23% over the same period.

Figure 30: Potential Impacts of a 60 ppb Ozone Standard on Delivered Electricity Prices (¢/kWh)

	Avg.	2017	2020	2023	2026	2029	2032	2035	2038
Baseline Prices (¢/kWh)									
Residential	14.5¢	12.9¢	13.3¢	14.0¢	14.4¢	14.8¢	15.3¢	15.6¢	15.4¢
Industrial	9.4¢	7.8¢	8.1¢	8.9¢	9.3¢	9.8¢	10.3¢	10.7¢	10.5¢
Sensitivity Case (¢/kWh)									
Residential	16.6¢	13.3¢	13.9¢	16.1¢	17.4¢	17.6¢	18.0¢	18.5¢	18.4¢
Industrial	11.6¢	8.2¢	8.7¢	11.1¢	12.4¢	12.7¢	13.1¢	13.6¢	13.5¢
Sensitivity Case (% Increase from Baseline)									
Residential	15%	3.0%	4.7%	15%	21%	19%	18%	18%	19%
Industrial	23%	5.2%	8.0%	25%	33%	29%	27%	27%	29%

Note: Average is the simple average over 2017-2040.
Source: NERA calculations as explained in text

Figure 31 shows projected potential physical impacts on the electricity sector in terms of coal electricity unit retirements and overall electricity demand in the sensitivity case. Projected potential retirements of coal-fired power plants to reduce NO_X emissions in certain nonattainment states would lead to cost increases from the need to use more expensive sources of electricity. This would result in substantial potential reductions in electricity demand. The average potential reduction is 9.8% over the period from 2017 through 2040.

Figure 31: Potential Impacts of a 60 ppb Ozone Standard on Electricity Sector (Sensitivity Case)

	2017	2020	2023	2026	2029	2032	2035	2038
Baseline								
Coal-Fired Capacity (GW)	262	259	257	257	257	257	257	257
Electricity Demand (TWh)	4,150	4,250	4,370	4,480	4,580	4,650	4,750	4,850
Sensitivity Case								
Coal-Fired Capacity (GW)(*)	226	218	153	132	129	125	120	114
Electricity Demand (TWh)	4,060	4,080	3,940	3,900	4,010	4,090	4,170	4,230
Sensitivity Case (Change from Baseline)								
Coal-Fired Capacity (GW)	-37	-41	-104	-125	-128	-132	-137	-143
Electricity Demand (%)	-2.1%	-3.9%	-9.9%	-13%	-12%	-12%	-12%	-13%

Source: NERA calculations as explained in text
(*)In the sensitivity case, due to the high natural gas prices it becomes cost-effective to build new coal-fired generators with carbon capture and sequestration starting in 2032. These new builds are not reflected in the numbers, which are only reflective of the current coal-fired fleet of generators.

3. Potential Impacts on U.S. Sectors

Figure 32 shows the estimated potential changes in sectoral output for the ten sectors in the sensitivity case. The potential reduction in coal output is largely the result of the scrappage of coal-fired power plants in some nonattainment areas. Unlike in the 60 ppb case without natural gas production limitations, the retirement of coal-fired generators does not lead to a large scale increase in natural gas output, because that output is limited due to assumed constraints on new wells development (due to potential permit and offset requirements in nonattainment areas). While agriculture and commercial transportation have the largest potential percentage reductions in non-energy output, the largest absolute reductions over the period from 2017 through 2040 are in the commercial/services and manufacturing sectors. The constraint placed on natural gas production in the sensitivity case would cause additional potential harm to employment, household consumption, and GDP.

Figure 32: Potential Impacts of a 60 ppb Ozone Standard on Sectoral Output (Percentage Changes from Baseline) (Sensitivity Case)

	Avg.	2017	2020	2023	2026	2029	2032	2035	2038
Non-Energy Sectors									
Agriculture	-2.7%	0.4%	-2.2%	-2.4%	-3.0%	-3.5%	-3.7%	-3.6%	-3.3%
Commercial/ Services	-1.2%	-0.4%	-1.1%	-1.1%	-1.3%	-1.4%	-1.5%	-1.4%	-1.4%
Manufacturing	-1.3%	2.0%	-0.6%	-1.3%	-1.7%	-2.0%	-2.3%	-2.4%	-2.2%
Commercial Transportation	-2.4%	-0.9%	-2.4%	-2.2%	-2.6%	-2.8%	-2.8%	-2.7%	-2.5%
Commercial Trucking	-1.5%	-0.1%	-1.5%	-1.5%	-1.7%	-1.9%	-2.0%	-2.0%	-1.9%
Energy Sectors									
Coal	-52%	-10%	-18%	-55%	-66%	-66%	-67%	-67%	-68%
Natural Gas	-11%	0.6%	-1.8%	-7.6%	-11%	-13%	-16%	-18%	-20%
Refining	-2.3%	-0.6%	-1.6%	-2.2%	-2.5%	-2.9%	-3.2%	-2.8%	-2.5%
Crude Oil	0.2%	0.7%	0.3%	0.5%	0.5%	0.1%	-0.1%	-0.2%	-0.1%
Electricity	-9.7%	-2.1%	-3.9%	-10%	-13%	-12.4%	-11.9%	-12%	-13%

Note: Average is the simple average over 2017-2040.
Source: NERA calculations as explained in text

E. Major Uncertainties

We have referred to our results as potential costs and economic impacts as an indication of the major uncertainties involved in developing the estimates. Indeed, as discussed in the next chapter, one of the two major conclusions of the study relates to the need for EPA to develop additional information to reduce these uncertainties as part of its upcoming RIA.

The major uncertainties and data limitations can be summarized in various categories as follows.

- *Baseline future ozone concentrations*. Future ozone concentrations depend upon the nature and location of precursor emissions (as well as on future meteorological conditions). Projections for precursor emissions are inherently uncertain, since they depend on the uncertain future condition of the overall economy as well as on the future circumstances for specific emitting sectors.

- *Identification of nonattainment regions*. The regions in nonattainment of a particular ozone standard depend upon future ozone concentrations as well on the presence of monitoring sites to provide the basis for a non-attainment determination. The number of monitoring sites may increase in the future, with the result that more nonattainment regions may be designated than estimated based on current monitor locations.

- *Emission reductions required to achieve compliance.* The emission reductions needed to achieve compliance depend upon future projected baseline emissions as well as the levels of emissions that are consistent with national compliance. Both of these building blocks are uncertain, leading to uncertainties in the amount and location of necessary emission reductions.

- *Emission controls to obtain the necessary emission reductions*. We have emphasized the limited information on emission controls that is currently available, with EPA's "known" controls representing only one-third of the reductions estimated to be needed to achieve compliance with a 60 ppb standard. We use the available information to develop estimates of the types of sources that could be controlled in order to provide indications of the sources and types of controls that would need to be adopted. But these assessments are highly uncertain.

- *Costs and effectiveness of emission controls.* We have developed an evidence-based approach to determining the likely costs of the "unknown" controls. But these estimates are highly uncertain.

- *Translation of emission control costs into annual costs by sector.* We have allocated our estimates of control costs to different types of costs (capital and O&M) and to different sectors. These allocations also are uncertain, since the mix of capital and O&M may be different than we assume as might be the sectors whose costs would increase.

Although we note that our results are uncertain for these and other reasons, we also point out that we have used the most complete set of available information and have developed an evidence-based approach to fill in for unavailable information. Indeed, we believe that EPA might use the general approach we have developed to update its estimates, although we emphasize that EPA should develop a more complete set of data that would require less extrapolation.

There are of course additional uncertainties involved in modeling the effects of the potential costs related to a 60 ppb ozone standard on the energy sector and the overall economy. The N$_{ew}$ERA model is a detailed and comprehensive macroeconomic model, but there are of course uncertainties involved in the modeling and the various inputs. The model makes assumptions, for example, about various exogenous factors (e.g., the global price of oil) and about the responsiveness of different productive activities to price changes, all of which could affect the modeling results. Sensitivity analyses are therefore an important element of a full assessment process.

IV. CONCLUSIONS

The conclusions of our study relate to potential impacts of a 60 ppb ozone standard as well as our recommendations for the forthcoming EPA RIA.

A. Potential Impacts of a 60 ppb Ozone Standard

This study has developed estimates of the potential impacts on the U.S. economy, based upon the currently-available information, if the Federal ozone NAAQS were to be set at 60 ppb. The potential impacts would be substantial.

- U.S. GDP potentially would be reduced by about $270 billion per year, or about 1.2% per year over the period from 2017 through 2040.
- The stricter ozone standard would result in a potential average annual loss in consumption per household of about $1,570 over the period 2017 through 2040.
- Labor income reductions would be equivalent to a potential annual reduction of about 2.9 million job-equivalents over the period 2017 through 2040.
- The large changes in NO_X emissions required to achieve compliance would have major potential effects on the U.S. energy sector, including potential retirements of coal-fired units and potential increases in natural gas and electricity prices.
- All sectors of the economy would be negatively affected, with some sectors potentially harmed much more than others.
- All regions of the United States would be negatively affected, with some regions potentially economically disadvantaged much more than others.
- A sensitivity case assuming limits on natural gas production shows that such production constraints could have significant potential implications for U.S. energy markets.
- If, as modeled in the sensitivity case, stricter ozone regulations restricted natural gas production, the potential economic impacts of the stricter ozone standard would be more severe.

These estimated impacts are subject to substantial uncertainties due in part to modeling uncertainties but primarily due to major data limitations. As noted below, we recommend that EPA provide updated emissions, control technology/cost and other information in order to reduce these uncertainties when it develops its RIA.

B. Recommendations for Forthcoming EPA Regulatory Impact Analysis

The large potential costs and macroeconomic impacts found in this study suggest two major recommendations for EPA's forthcoming RIA on its ozone proposal:

1. EPA should develop analyses of the overall costs and economy-wide impacts if it puts forward stricter ozone standards; and
2. EPA should provide updated information on critical parameters, including the potential barriers to crude oil and natural gas production in nonattainment areas as well as updated and expanded estimates of the emission reductions and costs required to achieve alternative ozone standards.

We have developed estimates of the potential impacts of a 60 ppb ozone standard on the U.S. economy and on U.S. households given the available information on emissions and controls, including the impacts of a sensitivity case in which we assume U.S. natural gas production is constrained after 2020 as a result of the ozone standard. It will be important for EPA to provide these types of assessments based upon its estimates of potential compliance costs and resulting impacts on the economy of more stringent ozone standards. It seems clear than a more stringent ozone standard is likely to be very costly and that these compliance costs would have adverse macroeconomic impacts.

It is important that attainment expenditures and macroeconomic impact assessments be based upon reliable information. Our analyses uncovered numerous gaps that EPA should fill as it develops its RIA in order to reduce the large uncertainties in compliance costs and resulting economic impacts. Perhaps the most important gaps are the emission reduction compliance options to achieve the extent of emissions reductions predicted to be needed for attainment, and their costs. The bulk of compliance costs to meet a 60 ppb standard in EPA's 2008-2010 analyses are based upon "unknown controls" (*i.e.*, controls that are not attributed to particular control technologies or even to particular sectors). We develop estimates of these "unknown" costs based upon the best available information and various assumptions, but it would be important for EPA to update its compliance cost information to provide a more comprehensive assessment of emission control options and compliance costs. Moreover, our sensitivity analysis assuming natural gas production constraints shows the importance of this issue for energy markets and the need for EPA to evaluate potential impacts of a tighter ozone standard on domestic energy production, including natural gas and crude oil production.

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APPENDIX A. THE N$_{EW}$ERA MODEL

A. Introduction

NERA developed the N$_{ew}$ERA model to forecast the impact of policy, regulatory, and economic factors on the energy sectors and the economy. When evaluating policies that have significant impacts on the entire economy, this model specification captures the effects as they ripple through all sectors of the economy and the associated feedback effects. The N$_{ew}$ERA model combines a macroeconomic model with all sectors of the economy with a detailed electric sector model that represents electricity production. This combination allows for a complete understanding of the economic impacts of different policies on all sectors of the economy.

The macroeconomic model incorporates all production sectors except electricity and final demand of the economy. Policy consequences are transmitted throughout the economy as sectors respond until the economy reaches equilibrium. The production and consumption functions employed in the model enable gradual substitution of inputs in response to relative price changes, thus avoiding all-or-nothing solutions.

The main benefit of the integrated framework is that the electric sector can be modeled in great detail yet through integration the model captures the interactions and feedbacks between all sectors of the economy. Electric technologies can be well represented according to engineering specifications. The integrated modeling approach also provides consistent price responses since all sectors of the economy are modeled. In addition, under this framework we are able to model electricity demand response.

The electric sector model is a detailed model of the electric and coal sectors. Each of the more than 17,000 electric generating units in the United States is represented in the model. The model minimizes costs while meeting all specified constraints, such as demand, peak demand, emissions limits, and transmission limits. The model determines investments to undertake and unit dispatch. Because the N$_{ew}$ERA model is an integrated model of the entire U.S. economy, electricity demand can respond to changes in prices and supplies. The N$_{ew}$ERA model represents the domestic and international crude oil and refined petroleum markets.

The N$_{ew}$ERA model outputs include demand and supply of all goods and services, prices of all commodities, and terms of trade effects (including changes in imports and exports). The model outputs also include gross regional product, consumption, investment, and changes in "job equivalents" based on labor wage income, as discussed below in the section on macroeconomic modeling.

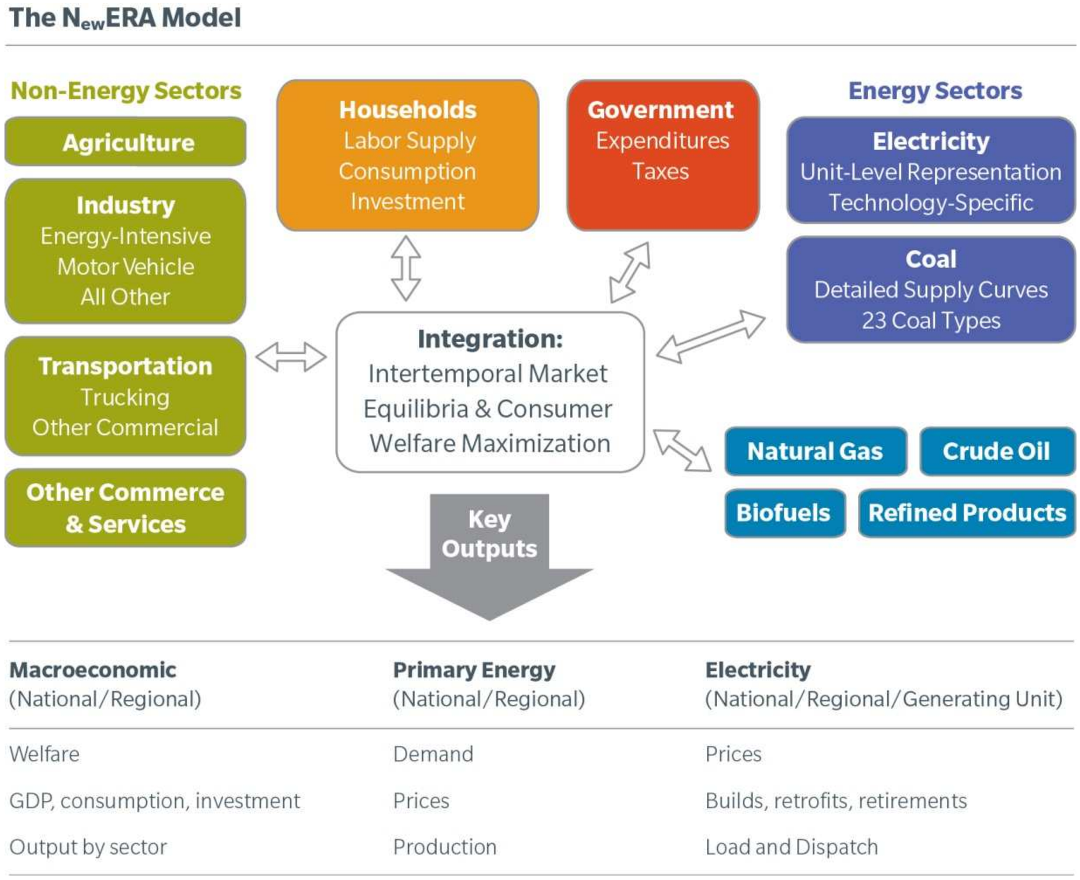
B. Overview

NERA's N$_{ew}$ERA modeling system is an integrated energy and economic model that includes a bottom-up representation of the electricity sector, including all of the unit-level details that are required to accurately evaluate changes in the electric sector. N$_{ew}$ERA integrates the electricity sector model with a macroeconomic model that includes all other sectors of the economy (except for the electricity production) using a top-down representation. The model produces integrated forecasts for future years; the modeling for this study was for the period from 2014 through 2038 with modeling inputs and results for every third year in this period. The model produces a standard set of reports that includes the following information.

- *Unit-level investments in the electric sector* – retrofits in response to environmental policies, new builds (full range of new generation technologies represented), retirements based on economics.
- *Prices* – wholesale electricity prices for each of 34 U.S. regions, capacity prices for each U.S. region, delivered electricity prices by sector for each of 11 macroeconomic regions in N$_{ew}$ERA, Henry Hub natural gas prices and delivered natural gas prices to the electric sector for each U.S. region, minemouth coal prices for 24 different types of coal, delivered coal prices by coal unit, refined oil product prices (gasoline and diesel fuel), renewable energy credit (REC) prices for each state/regional renewable portfolio standard (RPS), and emissions prices for all regional and national programs with tradable credits.
- *Macroeconomic results* – gross domestic product (and gross regional product for each macroeconomic region), welfare, changes in disposable income, and changes in labor income and real wage rates (used to estimate labor market changes in terms of an equivalent number of jobs).

Figure A-1 provides a simplified representation of the key elements of the $\mathrm{N_{ew}ERA}$ modeling system.

Figure A-1: $\mathbf{N_{ew}ERA}$ Modeling System Representation



Macroeconomic (National/Regional)	Primary Energy (National/Regional)	Electricity (National/Regional/Generating Unit)
Welfare	Demand	Prices
GDP, consumption, investment	Prices	Builds, retrofits, retirements
Output by sector	Production	Load and Dispatch

C. Electric Sector Model

The electric sector model that is part of the $\mathrm{N_{ew}ERA}$ modeling system is a bottom-up model of the electric and coal sectors. Consistent with the macroeconomic model, the electric sector model is fully dynamic and includes perfect foresight (under the assumption that future conditions are known). Thus, all decisions within the model are based on minimizing the present value of costs over the entire time horizon of the model while meeting all specified constraints, including demand, peak demand, emissions limits, transmission limits, RPS regulations, fuel availability and costs, and new build limits. The model set-up is intended to mimic (as much as is possible within a model) the approach that electric sector investors use to make decisions. In determining the least-cost method of satisfying all these constraints, the model endogenously decides:

- What investments to undertake (*e.g.*, addition of retrofits, build new capacity, repower unit, add fuel switching capacity, or retire units);

- How to operate each modeled unit (*e.g.*, when and how much to operate units, which fuels to burn) and what is the optimal generation mix; and
- How demand will respond. The model thus assesses the trade-offs between the amount of demand-side management (DSM) to undertake and the level of electricity usage.

Each unit in the model has certain actions that it can undertake. For example, all units can retire, and many can undergo retrofits. Any publicly-announced actions, such as planned retirements, planned retrofits (for existing units), or new units under construction can be specified. Coal units have more potential actions than other types of units. These include retrofits to reduce emissions of SO_2, NO_X, mercury, and CO_2.[30] The costs, timing, and necessity of retrofits may be specified as scenario inputs or left for the model to endogenously select. Coal units can also switch the type of coal that they burn (with practical unit-specific limitations). Finally, coal units may retire if none of the above actions will allow them to remain profitable, after accounting for their revenues from generation and capacity services.

Most of the coal units' actions would be in response to environmental limits that can be added to the model. These include emission caps (for SO_2, NO_X, Hg, and CO_2) that can be applied at the national, regional, state or unit level. We can also specify allowance prices for emissions, emission rates (especially for toxics such as Hg) or heat rate levels that must be met. For this analysis, we have assumed that retirements of existing coal-fired generators in some states are part of the compliance actions of those states to achieve targeted NO_X reductions.

Just as with investment decisions, the operation of each unit in a given year depends on the policies in place (*e.g.*, unit-level standards), electricity demand, and operating costs, especially energy prices. The model accounts for all these conditions in deciding when and how much to operate each unit. The model also considers system-wide operational issues such as environmental regulations, limits on the share of generation from intermittent resources, transmission limits, and operational reserve margin requirements in addition to annual reserve margin constraints.

To meet increasing electricity demand and reserve margin requirements over time, the electric sector must build new generating capacity. Future environmental regulations and forecasted energy prices influence which technologies to build and where. For example, if a national RPS policy is to take effect, some share of new generating capacity will need to come from renewable power. On the other hand, if there is a policy to address emissions, it might elicit a response to retrofit existing fossil-fired units with pollution control technology or enhance existing coal-fired units to burn different types of coals, biomass, or natural gas. Policies calling for improved heat rates may lead to capital expenditure spent on repowering existing units. All of these policies

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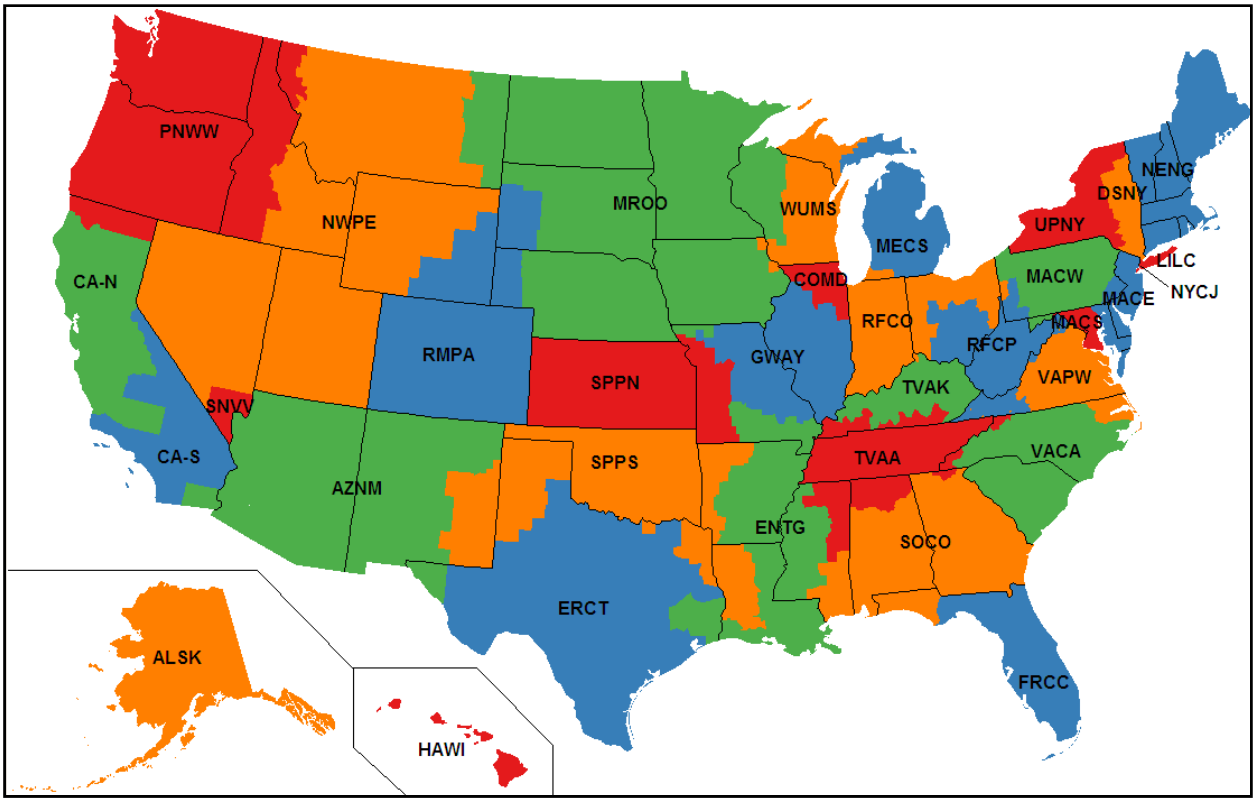
[30] As discussed in the report body, N_{ew}ERA does not incorporate EPA's recently proposed power sector CO_2 rule.

will also likely affect retirement decisions. The N$_{ew}$ERA electric sector model endogenously captures all of these different types of decisions.

The model contains 34 U.S. electricity regions (and six Canadian electricity regions). Figure A-2 shows the U.S. electricity regions.

Figure A-2: N$_{ew}$ERA Electric Sector Model – U.S. Regions



The electric sector model is fully flexible in the model horizon and the years for which it solves. When used in an integrated manner with the macroeconomic model, and to analyze long-term effects, the model has the same time steps as in the macroeconomic model (2014 through 2038, modeling every third year).

D. Macroeconomic Model

1. Overview

The N$_{ew}$ERA macroeconomic model is a forward-looking dynamic computable general equilibrium (CGE) model of the United States. The model simulates all economic interactions in the U.S. economy, including those among industry, households, and the government. Additional background information on CGE models can be found in Burfisher (2011).

The N$_{ew}$ERA CGE framework uses the standard theoretical macroeconomic structure to capture the flow of goods and factors of production within the economy. A simplified version of these interdependent macroeconomic flows is shown in Figure A-3. The model implicitly assumes “general equilibrium,” which implies that all sectors in the economy are in balance and all economic flows are endogenously accounted for within the model. In this model, households supply factors of production, including labor and capital, to firms. Firms provide households with payments for the factors of production in return. Firm output is produced from a combination of productive factors and intermediate inputs of goods and services supplied by other firms. Individual firm final output can be consumed within the United States or exported. The model also accounts for imports into the United States. In addition to consuming goods and services, households can accumulate savings, which they provide to firms for investments in new capital. Government receives taxes from both households and firms, contributes to the production of goods and services, and also purchases goods and services. Although the model assumes equilibrium, a region in the model can run deficits or surpluses in current accounts and capital accounts. In aggregate, all markets clear, meaning that the sum of regional commodities and factors of production must equal their demands, and the income of each household must equal its factor endowments plus any net transfers received.

The model uses the standard CGE framework developed by Arrow and Debreu (1954). Behavior of households is represented by a nested Constant Elasticity of Substitution (CES) utility function. The model assumes that households seek to maximize their overall welfare, or utility, across time periods. Households have utility functions that reflect trade-offs between leisure (which reduces the amount of time available for earning income) and an aggregate consumption of goods and services. Households maximize their utility over all time periods subject to an intertemporal budget constraint based on their income from supplying labor, capital, and natural resource to firms. In each time period, household income is used to consume goods and services or to fund investment. Within consumption, households substitute between energy (including electricity, coal, natural gas, and petroleum), personal transportation, and goods and services based on the relative price of these inputs. Figure A-4 illustrates the utility function of the households.

Figure A-3: Interdependent Economic Flows in N$_{ew}$ERA's Macroeconomic Model

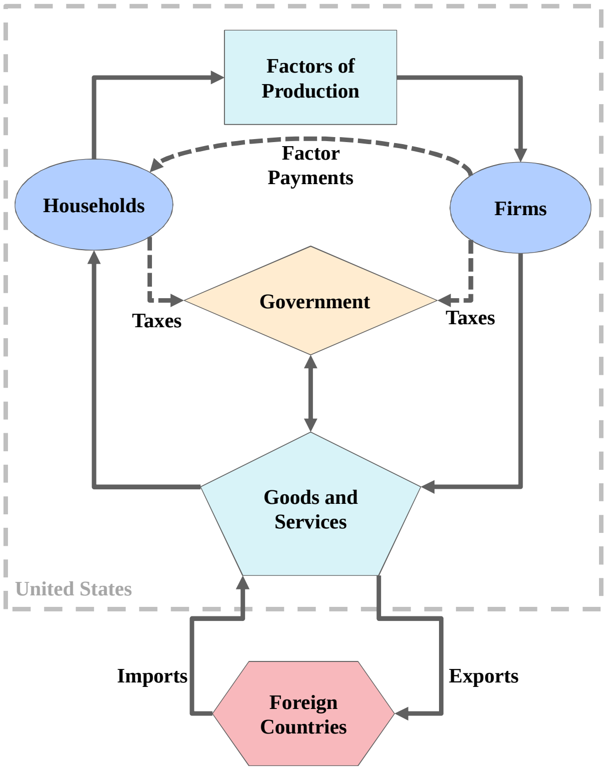
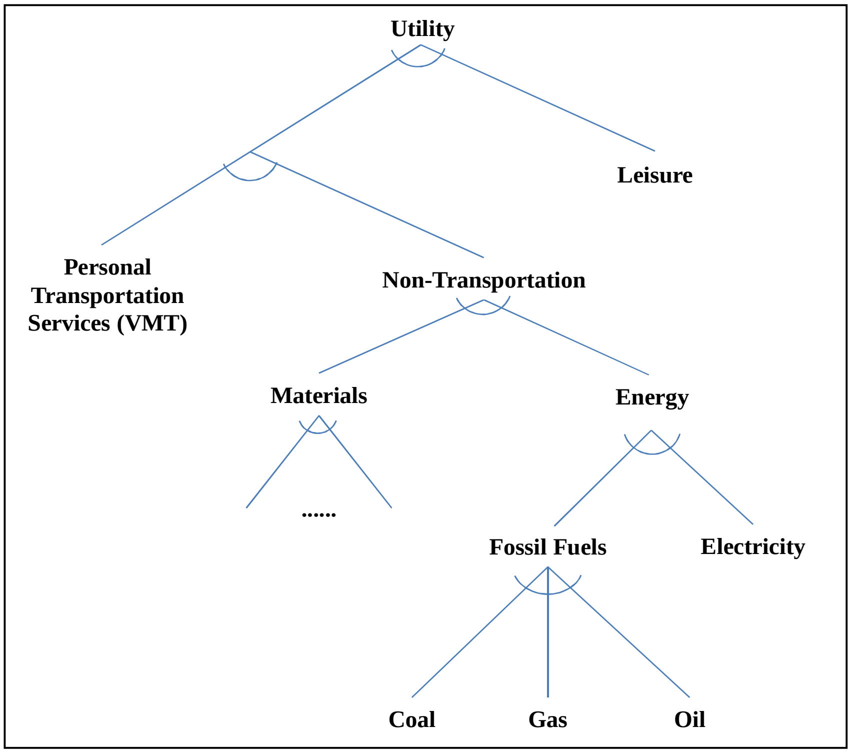


Figure A-4: Household Consumption Structure in N$_{ew}$ERA's Macroeconomic Model



On the production side, Figure A-5 shows the production structure of the commercial transportation and the trucking sector. Production structure for the rest of the industries is shown in Figure A-6. The model assumes all industries maximize profits subject to technological constraints. The inputs to production are energy (including the same four types noted above for household consumption), capital, and labor. Production also uses inputs from intermediate products (*i.e.*, materials) provided by other firms. The N$_{ew}$ERA model allows producers to change the technology and the energy source they use to manufacture goods. If, for example, petroleum prices rise, an industry can shift to a cheaper energy source. It can also choose to use more capital or labor in place of petroleum, increasing energy efficiency and maximizing profits with respect to industry constraints.

Figure A-5: Commercial Transportation and Trucking Sector Production Structure in N$_{ew}$ERA's Macroeconomic Model

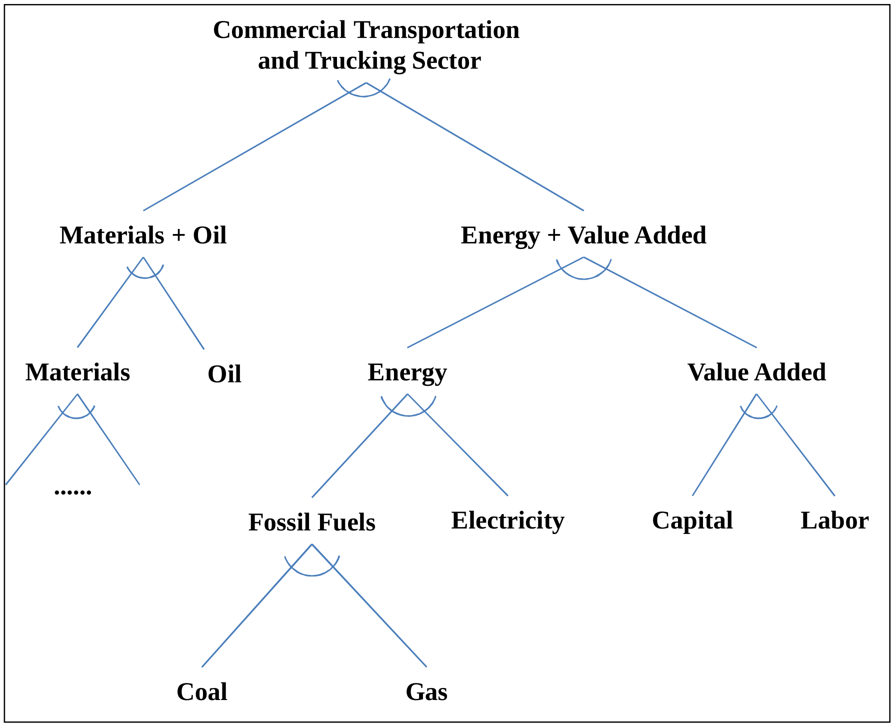
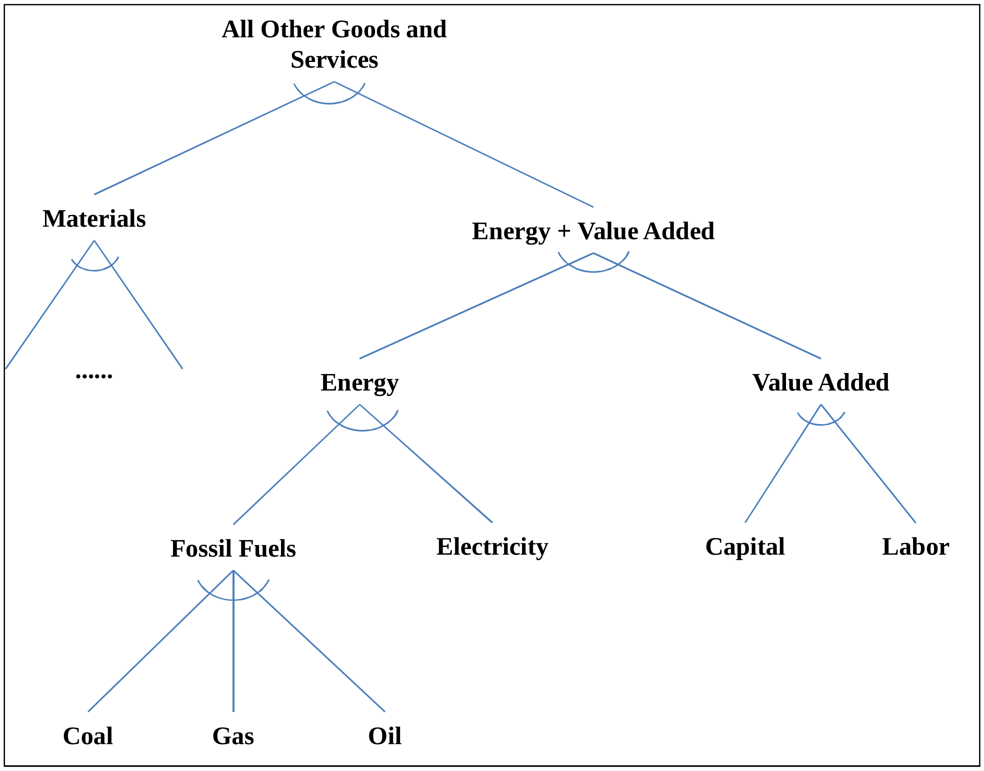


Figure A-6: Production Structure for Other Sectors in N$_{ew}$ERA's Macroeconomic Model



All goods and services, except crude oil, are treated as Armington goods, which assume the domestic and foreign goods are differentiated and thus are imperfect substitutes (Armington 1969). The level of imports depends upon the elasticity of substitution between the imported and domestic goods. The Armington elasticity among imported goods is assumed to be twice as large as the elasticity between the domestic and imported goods, characterizing the greater substitutability among imported goods.

Business investment decisions are informed by future policies and outlook. The forward-looking characteristic of the model enables businesses and consumers to determine the optimal savings and investment levels while anticipating future policies with perfect foresight.

The benchmark year economic interactions are based on the IMPLAN 2008 database, which includes regional detail on economic interactions among 440 different economic sectors. The macroeconomic and energy forecasts that are used to project the benchmark year going forward are calibrated to EIA's *Annual Energy Outlook* (*AEO*) *2014* Reference case.

2. Interactions between Compliance Costs, Capital Investment, and Household Expenditures

Regulations cause producers in the affected industries to make capital expenditures that they would not make otherwise. In addition, regulations change consumption patterns for households. To model the macroeconomic impacts of regulations, $\mathrm{N_{ew}ERA}$ accounts for interactions between compliance costs, capital investments, and household expenditures based on the following three effects.

1. *Compliance costs for producers in the regulated industries*. Producers in the regulated industries have to make capital expenditures to comply with the regulation. These expenditures increase the costs of producing goods and services in the regulated industries. The higher costs lead to higher prices for the goods and services, which in turn lead to lower demand in the regulated industries. Thus, this effect reduces economic activity.

2. *Scarcity effect due to non-optimal capital allocation*. In $\mathrm{N_{ew}ERA}$'s modeling framework, the capital expenditures for regulatory compliance are assumed to be unproductive. The capital expenditures in the regulated industries make less capital available to produce goods and services throughout the economy. In other words, the unproductive capital expenditures in the regulated industries "crowd out" productive capital investment in the broader economy. This scarcity effect increases the opportunity cost of capital in the economy, which implies higher costs of capital. This in turn lowers investment in productive capital and slows economic growth.

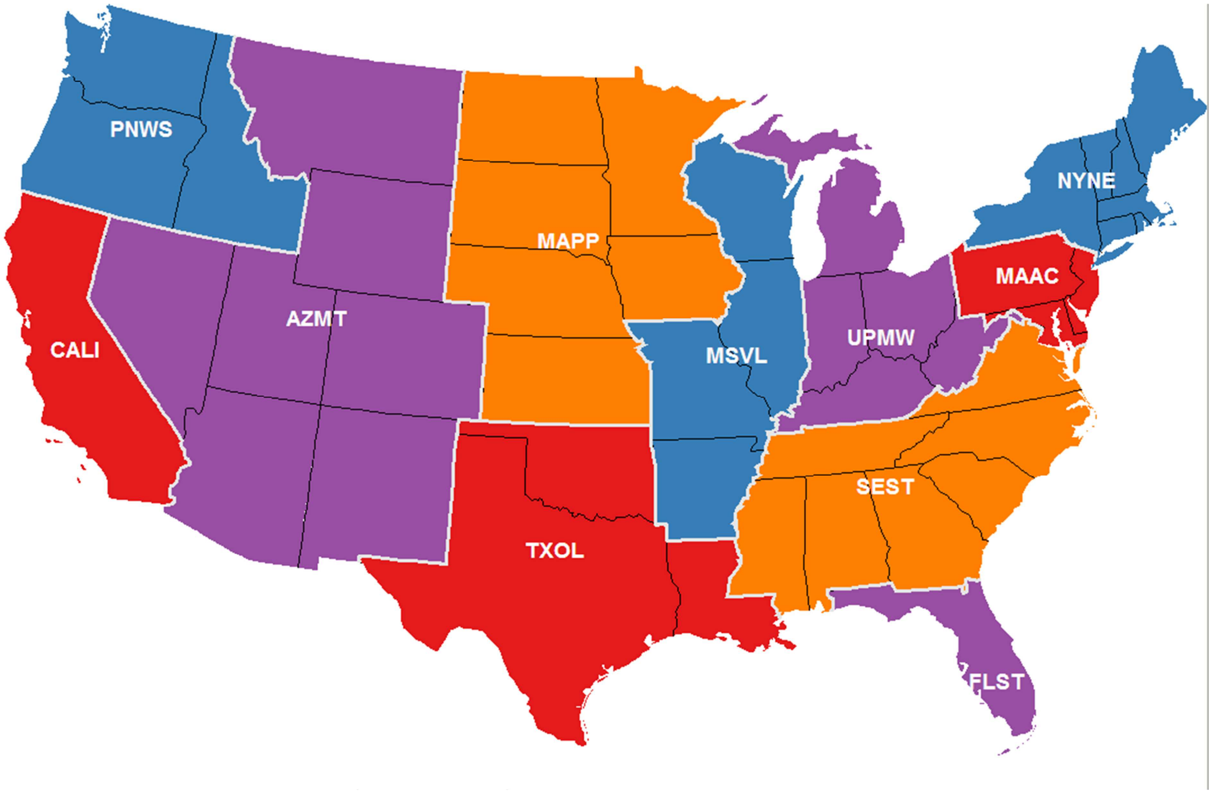
3. *Household purchases of unproductive durable goods*. Regulations also cause households to change their consumption patterns, particularly in terms of durable goods. For example, households may need to purchase new automobiles, lawn mowers, or equipment for compliance with the regulation. These additional expenditures on unproductive durable goods are non-optimal from the standpoint of households, but they represent increased demand for the manufacturing sector. Thus, these additional household purchases increase economic activity.

The net macroeconomic impacts of regulations calculated by $\mathrm{N_{ew}ERA}$ reflect the combination of these three effects.

3. Regional Aggregation

The N$_{ew}$ERA macroeconomic model includes 11 regions built up from economic data for the 50 U.S. states and the District of Columbia. The regions are shown in Figure A-7.

Figure A-7: N$_{ew}$ERA Macroeconomic Model Regions



4. Sectoral Aggregation

The N$_{ew}$ERA model includes a standard set of 10 economic sectors: five energy (coal, natural gas, crude oil, electricity, and refined petroleum products) and five non-energy sectors (services, manufacturing, agriculture, commercial transportation excluding trucking, and trucking). These sectors are aggregated up from the 440 IMPLAN sectors. The model has the flexibility to represent sectors at different levels of aggregation, when warranted, to better meet the needs of specific analyses.

5. Natural Gas and Crude Oil Markets

As with most commodity markets, there are uncertainties about how the U.S. natural gas market will evolve, and the N$_{ew}$ERA modeling system is designed explicitly to address the key factors affecting future natural gas supply and prices. To account for natural gas supply uncertainty and the subsequent effect it could have on international markets, the N$_{ew}$ERA modeling system has the ability to represent supply curves for conventional natural gas and shale gas for each region of the model. By including each type of natural gas, it is possible to incorporate expert judgments and sensitivity analyses on a variety of uncertainties, such as the extent of shale gas reserves, the cost of shale gas production, and the impacts of environmental regulations.

The $\mathrm{N_{ew}ERA}$ model represents the domestic and international crude oil and refined petroleum markets. The international markets are represented by flat supply curves with exogenously specified prices. Because crude oil is treated as a homogeneous good, the international price for crude oil sets the U.S. price for crude oil.

For this study, we calibrated natural gas and crude oil production at the state level based on information from *AEO 2014*. While *AEO 2014* does not provide state-level information, they did provide us with basin-specific production forecasts that we translated into state-level production based on historical state-level production, other publicly-available forecasts by state, and our own expertise.

6. Macroeconomic Outputs

As with other CGE models, the $\mathrm{N_{ew}ERA}$ macroeconomic model outputs include demand and supply of all goods and services, prices of all commodities, and terms of trade effects (including changes in imports and exports). The model outputs also include gross regional product, consumption, investment, cost of living or burden on consumers, and changes in "job equivalents" based on changes in labor wage income. All model outputs are calculated by time, sector, and region.

Impacts on workers are often considered an important output of policy evaluations. Impacts on workers are complicated to estimate and to explain because they can include several different impacts, including involuntary unemployment, reductions in wage rates for those who continue to work, and voluntary reductions in hours worked due to lower wage rates. No model addresses all of these potential impacts. The $\mathrm{N_{ew}ERA}$ model is a long-run equilibrium model based upon full employment, and thus its results relate to the longer-term effects on labor income and voluntary reductions in hours worked rather than involuntary unemployment impacts. It addresses long-run employment impacts, all of which are based on estimates of changes in labor income, also called the "wage bill" or "payments to labor." Labor income impacts consist of two effects: (1) changes in real wage per hour worked; and (2) changes in labor market participation (hours worked) in response to changed real wage rates. The labor income change can also be expressed on a per-household basis, which represents one of the key components of disposal income per household. (The other key components of disposable income are returns on investments or "payments to capital," and income from ownership of natural resources). The labor income change can also be stated in terms of job-equivalents, by dividing the labor income change by the annual income from the average job. A loss of one job-equivalent does not necessarily mean one less employed person—it may be manifested as a combination of fewer people working and less income per person who is working. However, this measure allows us to express employment-related impacts in terms of an equivalent number of employees earning the average prevailing wage.

For modeling the economic impacts of changes in energy prices, we assume that 50% of the wealth impacts would accrue to local residents in each energy production region (state), and the remaining 50% of wealth impacts would accrue to energy company shareholders based on national population percentages. We are not aware of any recent studies of the geographic distribution of potential energy sector gains, so we used an even division between state and national impacts given that some energy companies are in-state and some gains to national companies would accrue to local residents. A large fraction of energy production (particularly for natural gas shale developments that have become available through horizontal drilling techniques and hydraulic fracturing, or "fracking") is on private land and generates payments to local residents (payments, severance taxes, renegotiated leases, etc.). The remaining wealth impacts from changes in energy prices would affect shareholders in large publicly-traded energy companies, who are spread throughout the country.

E. Integrated N$_{ew}$ERA Model

The N$_{ew}$ERA modeling framework fully integrates the macroeconomic model and the electric sector model so that the final solution is a consistent equilibrium for both models and thus for the entire U.S. economy.

To analyze any policy scenario, the system first solves for a consistent baseline solution; it then iterates between the two models to find the equilibrium solution for the scenario of interest. For the baseline, the electric sector model is solved first under initial economic assumptions and forecasts for electricity demand and energy prices. The equilibrium solution provides the baseline electricity prices, demand, and supply by region as well as the consumption of inputs—capital, labor, energy, and materials—by the electric sector. These solution values are passed to the macroeconomic model.

Using these outputs from the electric sector model, the macroeconomic model solves the baseline while constraining the electric sector to replicate the solution from the electric sector model and imposing the same energy price forecasts as those used to solve the electric sector baseline. In addition to the energy price forecasts, the macroeconomic model's non-electric energy sectors are calibrated to the desired exogenous forecast (EIA's *AEO 2014* forecast) for energy consumption, energy production, and macroeconomic growth. The macroeconomic model solves for equilibrium prices and quantities in all markets subject to meeting these exogenous forecasts.

After solving the baseline, the integrated N$_{ew}$ERA modeling system solves for the scenario. First the electric sector model reads in the scenario definition. The electric sector model then solves for the equilibrium level of electricity demand, electricity supply, and inputs used by the electric sector (*i.e.*, capital, labor, energy, emission permits). The electric sector model passes these equilibrium solution quantities to the macroeconomic model, which solves for the equilibrium prices and quantities in all markets. The macroeconomic model then passes to the electric sector model the following (solved for equilibrium prices):

- Electricity prices by region;
- Prices of non-coal fuels used by the electric sector (*e.g.*, natural gas and oil); and
- Prices of any permits that are tradable between the non-electric and electric sectors (*e.g.*, carbon permits under a nationwide greenhouse gas cap-and-trade program).

The electric sector model then solves for the new electric sector equilibrium, taking the prices from the macroeconomic model as exogenous inputs. The models iterate—prices being sent from the macroeconomic model to the electric sector model and quantities being sent from the electric sector model to the macroeconomic model—until the prices and quantities in the two models differ by less than a fraction of a percent.

This decomposition algorithm allows the $\mathrm{N_{ew}ERA}$ model to retain the information in the detailed electricity model, while at the same time accounting for interactions with the rest of the economy. The detailed information on the electricity sector enables the model to represent regulatory policies that are imposed on the electricity sector in terms of their impacts at a unit level.

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APPENDIX B. ESTIMATES OF STATE-SPECIFIC NO_X EMISSIONS REDUCTIONS REQUIRED TO ACHIEVE 60 PPB OZONE STANDARD

This appendix provides state-specific estimates of the NO_X reductions required to achieve compliance with a 60 ppb ozone standard. The estimates are based upon EPA projected 2018 baseline emissions and estimates of the emission levels that would achieve the 60 ppb standard. The baseline NO_X emissions are based on EPA's most recent projections for the furthest year in the future (2018), supplemented by $N_{ew}ERA$ results for EGU emissions. The estimated NO_X emissions consistent with a 60 ppb ozone standard are based upon EPA's 2008-2010 ozone analyses.[31]

A. Baseline NO_X Emission Projections

1. State-Level Baseline Emissions Projections

The following table shows the baseline NO_X emission projections by state used in our analysis.[32] As shown in the table, baseline NO_X emission projections for point (non-EGU), area (non-point), onroad mobile, and nonroad mobile sources reflect EPA's most recent projections for 2018, which are based on historical emissions data for 2011 (EPA 2014a). Baseline NO_X emission projections for EGUs reflect $N_{ew}ERA$ baseline outputs for 2026. As discussed in Appendix A, $N_{ew}ERA$ incorporates a detailed database of all power plants in the United States, including their emission rates and operational characteristics. The EPA information for 2018 includes EGU emission projections, and its projections are generally similar to those from $N_{ew}ERA$; we use $N_{ew}ERA$ EGU emission projections for our analysis to maintain internal consistency with our economic impact modeling using $N_{ew}ERA$. The EGU baseline NO_X emission projections from $N_{ew}ERA$ reflect outputs for 2026 because compliance deadlines for a new ozone standard of 60 ppb would presumably be around that year for most states, as discussed in Appendix D. Note that we use EPA's projections for the furthest year in the future (2018) as estimates for emissions in the compliance year; we expect EPA to develop updated emissions information when it releases its ozone proposal.

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[31] "EPA's 2008-2010 ozone analyses" refers to information in EPA's 2008 regulatory impact analysis for the ozone NAAQS, including information on baseline future conditions and ozone standards of 84 and 75 ppb (EPA 2008); EPA's 2010 supplemental regulatory impact analysis, including information on an ozone standard of 60 ppb (EPA 2010); and data files in Docket No. EPA-HQ-OAR-2007-0225.

[32] Our analysis does not include Alaska or Hawaii, because EPA did not model air quality in these states in its 2008-2010 ozone analyses. Our analysis also excludes the District of Columbia.

Table B-1. Baseline NO$_X$ Emission Projections by State and Source Category (1000s of tons)

	EPA				N$_{ew}$ERA	NERA Baseline
	Point	Area	Onroad	Nonroad	EGU	Total
U.S. Total	**1,784**	**1,680**	**2,645**	**2,071**	**1,524**	**9,705**
Alabama	60	25	61	33	83	262
Arizona	16	7	53	37	38	152
Arkansas	33	17	38	30	20	138
California	74	66	246	160	8	553
Colorado	52	45	41	30	36	203
Connecticut	5	13	15	15	1	49
Delaware	2	2	6	8	<1	20
Florida	52	25	134	106	41	358
Georgia	51	20	110	47	17	245
Idaho	11	7	25	16	<1	58
Illinois	69	58	73	94	53	347
Indiana	65	27	67	47	114	319
Iowa	30	18	29	54	42	174
Kansas	50	69	27	54	16	217
Kentucky	32	46	49	33	84	245
Louisiana	120	97	46	122	21	407
Maine	13	11	10	9	<1	44
Maryland	16	13	42	24	15	110
Massachusetts	14	22	28	27	6	97
Michigan	58	65	84	48	65	321
Minnesota	32	34	53	53	23	195
Mississippi	39	11	33	23	20	126
Missouri	31	18	125	56	40	269
Montana	7	19	12	30	22	90
Nebraska	13	9	19	79	34	153
Nevada	9	4	26	15	9	63
New Hampshire	2	5	9	5	2	22
New Jersey	12	24	31	34	5	106
New Mexico	24	51	31	25	14	146
New York	41	75	92	69	14	291
North Carolina	38	25	101	40	39	243
North Dakota	10	17	9	34	57	127
Ohio	58	40	134	64	96	392
Oklahoma	79	97	44	32	60	312
Oregon	15	14	33	28	1	92
Pennsylvania	62	105	100	52	52	371
Rhode Island	1	6	4	3	<1	15
South Carolina	26	12	46	25	14	123
South Dakota	3	7	9	19	1	39
Tennessee	39	30	65	35	29	199
Texas	214	263	213	149	121	959
Utah	20	31	33	13	57	154
Vermont	<1	4	5	3	0	12
Virginia	38	31	68	47	22	207
Washington	24	10	85	61	7	187
West Virginia	25	53	17	15	66	176
Wisconsin	31	23	52	37	18	162
Wyoming	65	4	12	33	41	155

Note: EPA emission projections are for 2018, and N$_{ew}$ERA EGU emission projections represent 2026.
Source: NERA calculations as explained in text

2. Oil and Gas Production Projections

EPA's recent 2018 NO_X emission projections for oil and gas activity are based on oil and gas production projections from the Energy Information Administration's *Annual Energy Outlook* (*AEO*) *2013* (EPA 2014b, p. 104). As discussed in Appendix A, we calibrated future oil and gas production in N_{ew}ERA to *AEO 2014*. *AEO 2014* has a 22% higher national crude oil production projection and an 11% higher national natural gas production projection for 2019 than *AEO 2013* (EPA 2014b, p. 104). Our use of EPA emission projections for oil and gas activity based on the *AEO 2013* thus somewhat understates baseline future emissions and thus necessary emission reductions for 60 ppb.

B. NO_X Compliance Emissions

1. State-Level Compliance Emissions

We used state-specific information from EPA's 2008-2010 ozone analyses of baseline (existing standard) NO_X emission projections (baseline emissions) and NO_X reduction requirements to estimate NO_X emission levels in each state consistent with compliance with 60 ppb (compliance emissions). The necessary NO_X emission reductions for 60 ppb in each state are the difference between baseline emissions and compliance emissions.

The EPA baseline emissions projections represent 2020 and are based on historical data from 2002. Through a series of modeling exercises, EPA estimated NO_X emission reductions by sub-state area that would be needed for compliance with several alternative national ozone standards, including 60 ppb. We gathered EPA information on these reductions and aggregated baseline emissions and reduction requirements to the state level. EPA methodology was based upon noncompliance areas using its then-existing ozone monitoring information. EPA did assume that counties adjacent to nonattainment counties would need to reduce emissions to achieve compliance. But EPA did not consider the possibility of noncompliance for counties without monitors; this omission tends to reduce the extent of potential noncompliance, which would also reduce the potential costs and economic impacts of compliance with a national 60 ppb standard.

The EPA information from the 2008-2010 ozone analyses indicated that some areas of California and Texas would not comply with the 1997 ozone standard of 0.80 ppm (84 ppb based on averaging convention) under baseline conditions. The information also indicated that areas of several states would require reductions to achieve 75 ppb, which became the new ozone standard in the 2008-2010 NAAQS review.

To estimate compliance emissions in each state for past, current, and potential future ozone standards (84 ppb, 75 ppb, and 60 ppb), we subtracted any reductions required to meet each standard in EPA's analysis from 2020 baseline emissions. This calculation and the resulting compliance emissions by state are shown in Table B-2. When a state did not require any emission reductions in EPA's analysis to meet a certain standard (*e.g.*, Georgia to comply with a 75 ppb standard), we were not able to estimate state compliance emissions for that standard; in such cases, compliance emissions could be greater than or equal to 2020 baseline emissions.

Table B-2. EPA Information from 2008-2010 Ozone Analyses: Baseline NO$_X$ Emissions and Necessary NO$_X$ Emission Reductions for 84, 75, and 60 ppb (1000s tons of NO$_X$)

	2020 Baseline	Reductions from 2020 Baseline to 84ppb	84ppb Compliance Emissions	Reductions from 84ppb to 75ppb	75ppb Compliance Emissions	Reductions from 75ppb to 60ppb	60ppb Compliance Emissions
U.S. Total	**10,728**	**816**	**N/A**	**582**	**N/A**	**3,367**	**N/A**
Alabama	226	-	-	-	-	38	188
Arizona	159	-	-	-	-	50	109
Arkansas	145	-	-	-	-	34	111
California	727	576	151	45	106	49	56
Colorado	185	-	-	-	-	63	122
Connecticut	51	-	-	14	37	20	18
Delaware	36	-	-	6	30	17	13
Florida	392	-	-	-	-	63	328
Georgia	281	-	-	-	-	107	174
Idaho	70	-	-	-	-	17	53
Illinois	412	-	-	101	310	157	154
Indiana	316	-	-	69	247	122	126
Iowa	203	-	-	-	-	7	197
Kansas	240	-	-	-	-	34	205
Kentucky	219	-	-	-	-	80	139
Louisiana	517	-	-	-	-	367	151
Maine	47	-	-	-	-	16	31
Maryland	119	-	-	31	89	48	40
Massachusetts	115	-	-	-	-	50	66
Michigan	378	-	-	-	-	221	158
Minnesota	294	-	-	-	-	-	-
Mississippi	185	-	-	-	-	58	127
Missouri	283	-	-	-	-	106	178
Montana	87	-	-	-	-	-	-
Nebraska	151	-	-	-	-	4	146
Nevada	80	-	-	-	-	19	60
New Hampshire	34	-	-	-	-	2	31
New Jersey	138	-	-	31	108	57	50
New Mexico	178	-	-	-	-	69	110
New York	303	-	-	53	250	136	114
North Carolina	218	-	-	-	-	111	107
North Dakota	100	-	-	-	-	-	-
Ohio	391	-	-	-	-	238	152
Oklahoma	300	-	-	-	-	55	245
Oregon	129	-	-	-	-	12	117
Pennsylvania	348	-	-	72	276	151	125
Rhode Island	13	-	-	-	-	2	11
South Carolina	150	-	-	-	-	83	66
South Dakota	36	-	-	-	-	1	36
Tennessee	235	-	-	-	-	73	161
Texas	1,147	239	907	109	798	311	488
Utah	126	-	-	-	-	34	91
Vermont	12	-	-	-	-	-	-
Virginia	250	-	-	-	-	110	140
Washington	209	-	-	-	-	49	160
West Virginia	147	-	-	-	-	54	92
Wisconsin	213	-	-	51	161	53	109
Wyoming	133	-	-	-	-	17	116

Note: "-" denotes that all areas of the state would comply with the ozone standard under 2020 baseline conditions according to EPA information in the 2008-2010 ozone analyses.

"N/A" denotes that U.S. total NO$_X$ emissions for compliance with 84, 75, or 60 ppb are not applicable because not all states have estimated compliance emission levels for each ozone standard.

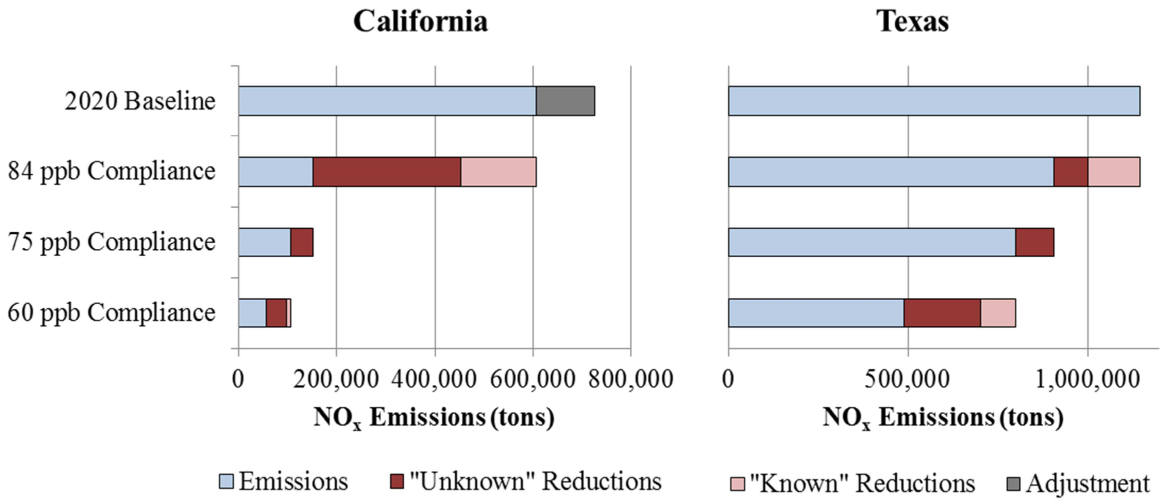
Source: EPA 2008-2010 ozone analyses and NERA calculations as explained in text

2. Texas and California Compliance Emissions

According to EPA's 2008-2010 ozone analyses, the Los Angeles-South Coast and San Joaquin Valley areas in California and the Houston area in Texas would have baseline ozone levels above the 1997 standard of 84 ppb in the future year analyzed by EPA (2020). EPA's 2008-2010 ozone analysis data includes information on baseline future emissions and necessary future emission reductions in these areas for compliance with 84 ppb, as well as necessary future emission reductions to comply with new ozone standards, including 75 and 60 ppb. In the 2008-2010 ozone analyses, EPA assumed that the California areas, which are the only ozone non-attainment areas in the country classified as Extreme, would have a longer timeline for compliance with new ozone standards, and EPA excluded the compliance costs for the California areas from the main compliance cost analysis in its 2008-2010 analyses.

The following figure summarizes our understanding of EPA data for California and Texas from the 2008-2010 analyses on baseline future emissions and necessary emission reductions for compliance with 84, 75, and 60 ppb. The figure presents our attempt at assembling information for these two states, information that is not as clear in the EPA docket files as the information for other states (with baseline future ozone levels below 84 ppb).

Figure B-1. Estimating Compliance Emissions in California and Texas



Note: EPA modeled the Los Angeles-South Coast and San Joaquin Valley regions in 2030 (as opposed to 2020, the analysis year for other states). EPA included 120,000 tons of NO$_X$ emission reductions to account for inventory changes between 2020 and 2030 attributable to recent locomotive-marine regulations (EPA 2008, p. 7b-2); we treat these reductions as a baseline adjustment.
Nearly all of the "known" reductions specifically for 60 ppb compliance occur outside of the extrapolation areas with severe non-attainment problems (*i.e.*, in areas projected to comply with 75 ppb but not with 60 ppb).

Source: NERA calculations as explained in text

C. Required NO_X Emission Reductions

Our analysis assumes that the compliance emissions for different standards implied by EPA's 2008-2010 ozone analyses would remain constant throughout the future. Using our updated baseline emissions described above, we estimated necessary NO_X emission reductions for different ozone standards as the difference between updated baseline emission projections and compliance emissions for the different standards. These required emission reduction estimates for standards of 80 ppm (84 ppb based on averaging convention), 75 ppb, and 60 ppb in each state are summarized in Table B-3.

In several cases, EPA projected in its 2008-2010 ozone analyses that a state would be compliant with a 75 ppb or 60 ppb standard, but the state's updated baseline emission projection for 2018 used in our analysis (based on 2011 data) is higher than the 2020 baseline emission projection used in EPA's 2008-2010 analysis (based on 2002 data). We were unable to infer compliance emissions levels for these states and standards from EPA's analysis (since EPA did not require any reductions from baseline emissions), so we reviewed recent historical NO_X emissions and ozone concentrations to judge whether these states were still likely to be in compliance even with the higher baseline emissions in the updated projection used in our analysis. In each of these cases except the current standard of 75 ppb in Colorado, we judged that states estimated to be in attainment in EPA's 2008-2010 analyses would still be in attainment even with higher baseline NO_X emissions. Colorado had at least one ozone monitor exceeding 75 ppb in all recent years, so we assumed it would need to return to its projected baseline emissions level in EPA's 2008-2010 ozone analyses in order to be in attainment for 75 ppb.

Table B-3. 2018 Baseline Emission Projections and Reduction Requirements for Ozone Standards (1000s tons of NO_X)

	Updated Baseline Emission Projections	Compliance Emissions			Reductions Required (from Updated Baseline Emissions)		
		84ppb	75ppb	60ppb	84ppb	75ppb	60ppb
U.S. Total	**9,705**	**N/A**	**N/A**	**N/A**	**454**	**904**	**3,866**
Alabama	262	-	-	188	-	-	75
Arizona	152	-	-	109	-	-	43
Arkansas	138	-	-	111	-	-	27
California	553	151	106	56	403	448	497
Colorado	203	-	-	122	-	18	81
Connecticut	49	-	37	18	-	11	31
Delaware	20	-	30	13	-	-	7
Florida	358	-	-	328	-	-	30
Georgia	245	-	-	174	-	-	70
Idaho	58	-	-	53	-	-	5
Illinois	347	-	310	154	-	37	194
Indiana	319	-	247	126	-	72	193
Iowa	174	-	-	197	-	-	-
Kansas	217	-	-	205	-	-	11
Kentucky	245	-	-	139	-	-	106
Louisiana	407	-	-	151	-	-	256
Maine	44	-	-	31	-	-	13
Maryland	110	-	89	40	-	21	70
Massachusetts	97	-	-	66	-	-	31
Michigan	321	-	-	158	-	-	163
Minnesota	195	-	-	-	-	-	-
Mississippi	126	-	-	127	-	-	-
Missouri	269	-	-	178	-	-	91
Montana	90	-	-	-	-	-	-
Nebraska	153	-	-	146	-	-	7
Nevada	63	-	-	60	-	-	2
New Hampshire	22	-	-	31	-	-	-
New Jersey	106	-	108	50	-	-	56
New Mexico	146	-	-	110	-	-	37
New York	291	-	250	114	-	41	177
North Carolina	243	-	-	107	-	-	136
North Dakota	127	-	-	-	-	-	-
Ohio	392	-	-	152	-	-	240
Oklahoma	312	-	-	245	-	-	67
Oregon	92	-	-	117	-	-	-
Pennsylvania	371	-	276	125	-	94	246
Rhode Island	15	-	-	11	-	-	4
South Carolina	123	-	-	66	-	-	57
South Dakota	39	-	-	36	-	-	3
Tennessee	199	-	-	161	-	-	37
Texas	959	907	798	488	51	160	471
Utah	154	-	-	91	-	-	63
Vermont	12	-	-	-	-	-	-
Virginia	207	-	-	140	-	-	67
Washington	187	-	-	160	-	-	27
West Virginia	176	-	-	92	-	-	84
Wisconsin	162	-	161	109	-	<1	53
Wyoming	155	-	-	116	-	-	39

Source: NERA calculations as explained in text

Note: “-”denotes that all areas of the state would comply with the ozone standard under future baseline conditions according to EPA information in the 2008-2010 ozone analyses and updated emission projections.

“N/A” denotes that U.S. total NO_X emissions for compliance with 84, 75, or 60 ppb are not applicable because not all states have estimated compliance emission levels for each ozone standard.

D. References to the Appendix

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U.S. Environmental Protection Agency (EPA). 2014a. "2018 Emission Projections by State and Source Sector." ftp://ftp.epa.gov/EmisInventory/2011v6/v1platform/reports/2018_emissions/2018ed_v6_11f_state_sector_totals.xlsx.

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APPENDIX C. ESTIMATES OF STATE-SPECIFIC COMPLIANCE COSTS TO ACHIEVE A 60 PPB OZONE STANDARD

This appendix provides state-specific information on estimated compliance costs for an ozone standard of 60 ppb. As discussed in the report body, we used EPA information on "known" control measures from its 2008-2010 ozone analyses. For states where the "known" control measures would be insufficient to achieve the full necessary NO_X emission reductions for 60 ppb, we supplemented the EPA information with estimates related to coal power plant scrappage and other potential additional control measures as well as with other assumptions to generate a marginal cost curve, i.e., a relationship between marginal cost per ton and the number of tons reduced.

As shown in Appendix B, some states require emission reductions to comply with existing ozone standards of 84 ppb and 75 ppb. We estimate the future compliance costs and economic impacts of *all* ozone NAAQS requirements, including costs attributable to these existing ozone standards.

All cost values in these appendices are shown in 2013 dollars. Compliance costs were developed in 2006 dollars using information from EPA's 2008-2010 analyses, converted to N_{ew}ERA model inputs in 2010 dollars using the U.S. Bureau of Economic Analysis GDP Implicit Price Deflator, and further adjusted to 2013 dollars using the *AEO 2013* GDP Chain-type Price Index.[33]

A. State-Specific Information on "Known" Control Measures

1. EPA Information on "Known" NO_X Controls

In its 2008-2010 ozone analyses, EPA presented state-specific information on "known" NO_X controls from five categories of emission sources: EGUs, non-EGU point sources, area sources, onroad mobile, and nonroad mobile. We developed a comprehensive database of the EPA's information on "known" controls from its 2008-2010 ozone analyses. We removed controls with negative annualized costs or negative NO_X reductions (which are inconsistent with typical emission control analysis) and controls with annualized costs per ton of emission reductions greater than $100,000 (which were also excluded by EPA). We also substituted EGU controls developed using N_{ew}ERA for the EGU controls developed in EPA's analysis (discussed later in this appendix). We then calculated the total annualized costs for "known" control measures in each state, accounting for the possibility of some states not requiring all (or even any) of the "known" control measures from the 2008-2010 ozone analyses based on our calculations of compliance emissions in Appendix B.

Table C-1 provides a national summary of EPA "known" NO_X controls that would be needed for compliance with a new ozone standard of 60 ppb (after removal of controls with negative

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[33] The *AEO 2013* price index is available starting in 2010.

reductions, controls with negative costs, and EGU controls). The table shows the specific types of technologies and measures for each emission source category. EPA describes each of these technologies and measures in its 2008 RIA (EPA 2008, Chapter 3 and Appendix 3a). The table also shows the "known" control emission reductions as a percentage of 2018 baseline NO_X emissions for each emission source category (based on the values above in Table B-1). "Known" controls reduce nearly half of baseline NO_X emissions from point sources, but the percentages are much lower for area, onroad mobile, and nonroad mobile sources.

Table C-1. National Summary of EPA "Known" NO_X Controls (tons of reduction)

Point (Non-EGU)	**825,400**
Selective catalytic reduction (SCR) without low-NOx burner (LNB)	466,800
Low-emission combustion (for internal combustion engines)	82,000
Selective catalytic reduction (SCR) and low-NOx burner (LNB)	80,800
Non-selective catalytic reduction (NSCR)	70,300
Selective non-catalytic reduction (SNCR)	61,400
OXY-firing (for glass manufacturers)	33,800
Low-NOx burner (LNB) without selective catalytic reduction (SCR)	20,700
Biosolid injection (for cement kilns)	8,200
Other	1,300
Area	**27,800**
Low-NOx water and space heaters (for commercial buildings)	14,000
Low-NOx burner (LNB)	12,800
Switch to low-sulfur fuel (for residential buildings)	1,000
Onroad Mobile	**256,100**
Retrofit heavy-duty diesel with selective catalytic reduction (SCR)	137,700
Continuous inspection and maintenance	27,800
Eliminate long-duration idling	10,500
Commuting programs	4,400
Low Reid Vapor Pressure	1,000
Unspecified	74,800
Nonroad Mobile	**45,000**
Retrofit heavy-duty diesel with selective catalytic reduction (SCR)	45,000
No Details (Some Omissions in EPA Data for CA and TX)	**130,100**
Total	**1,284,400**

Note: Totals may not equal sum of rows due to independent rounding.
Source: NERA calculations as explained in text

2. State-Specific “Known” NO_X Controls

State-specific information on reductions and annualized costs for “known” controls applied toward a potential standard of 60 ppb are shown in Table C-2. Note that detailed EPA control information was more difficult to assemble for California and Texas, which require controls for compliance with 84 ppb in our analysis (as described above in Appendix B). When detailed source category and cost information for “known” controls were unavailable in these states, we assumed that “known” controls had zero costs.

3. State-Specific “Known” VOC Controls

In its 2008-2010 ozone analyses, EPA includes costs for “known” control measures to reduce emissions of volatile organic compounds (VOCs), particularly from area (non-point) sources but with some additional reductions from other source categories. The NO_X emission reduction requirements that EPA calculated in the 2008-2010 ozone analyses for 60 ppb reflect implementation of VOC controls as well.

We focus on NO_X emissions and emission reductions in our analysis because EPA indicates that NO_X is the critical precursor for ozone formation in most areas of the country, particularly for a tighter new standard of 60 ppb (EPA 2010, pp. S2-3 and S2-14). We apply the VOC costs in our modeling, however, because the information on necessary NO_X emission reductions in the previous EPA analysis assumes implementation of the VOC controls (*i.e.*, necessary NO_X emission reductions in each state for 60 ppb compliance would be different without the VOC controls). Table C-3 shows the estimates of state-level VOC control costs. The VOC control costs are small compared with NO_X control costs (about $800 million in total national annualized costs).

Table C-2. “Known” NO_X Controls by Emission Source Category

	Reductions (tons NOx)					Annualized Costs (million 2013$)				
	Point	**Area**	**Onroad**	**Nonroad**	**Total**	**Point**	**Area**	**Onroad**	**Nonroad**	**Total**
U.S. Total	**825,400**	**27,800**	**256,100**	**45,000**	**1,284,400**	**$3,722**	**$76**	**$850**	**$225**	**$4,873**
Alabama	31,300	900	-	-	32,200	$87	$2	-	-	$89
Arizona	7,000	300	11,300	1,400	20,000	$13	<$1	$31	$7	$52
Arkansas	8,400	200	1,600	-	10,300	$23	<$1	$8	-	$31
California	21,700	700	55,900	10,300	161,700 *	$131	$1	$156	$53	$342
Colorado	18,800	500	11,200	900	31,400	$72	<$1	$30	$5	$107
Connecticut	2,500	300	2,100	400	5,400	$7	<$1	$5	$2	$14
Delaware	2,100	100	700	200	3,100	$7	<$1	$2	$1	$10
Florida	15,600	400	-	-	16,000	$46	<$1	-	-	$46
Georgia	16,500	1,500	18,400	1,700	38,000	$45	$3	$70	$8	$126
Idaho	2,400	100	700	-	3,200	$4	<$1	$3	-	$8
Illinois	15,600	200	8,900	3,900	28,500	$120	<$1	$36	$20	$175
Indiana	22,600	700	7,500	2,300	33,000	$93	$1	$32	$11	$138
Iowa	-	-	-	-	-	-	-	-	-	-
Kansas	11,200	-	-	-	11,200	$8	-	-	-	$8
Kentucky	14,400	400	7,500	900	23,200	$71	<$1	$27	$4	$103
Louisiana	126,300	800	3,300	800	131,200	$693	$1	$12	$4	$711
Maine	9,400	<100	1,300	200	10,900	$31	<$1	$5	$1	$37
Maryland	8,300	800	3,200	1,000	13,300	$37	$2	$8	$5	$52
Massachusetts	4,400	1,000	8,500	800	14,700	$15	$2	$23	$4	$43
Michigan	33,800	2,200	8,600	2,200	46,800	$175	$4	$36	$11	$226
Minnesota	-	-	-	-	-	-	-	-	-	-
Mississippi	-	-	-	-	-	-	-	-	-	-
Missouri	17,900	900	11,300	1,400	31,500	$65	$2	$39	$7	$113
Montana	-	-	-	-	-	-	-	-	-	-
Nebraska	3,700	300	-	-	4,100	$7	<$1	-	-	$8
Nevada	400	200	300	-	900	<$1	<$1	-	-	<$1
New Hampshire	-	-	-	-	-	-	-	-	-	-
New Jersey	4,600	1,200	4,900	1,100	11,800	$24	$2	$13	$6	$45
New Mexico	26,000	100	500	-	26,600	$85	<$1	$2	-	$87
New York	18,700	2,600	7,500	2,700	31,500	$70	$25	$25	$13	$134
North Carolina	17,100	300	12,100	1,300	30,800	$54	<$1	$45	$6	$106
North Dakota	-	-	-	-	-	-	-	-	-	-
Ohio	33,900	1,800	15,200	2,700	53,600	$178	$3	$53	$14	$249
Oklahoma	21,900	300	-	-	22,200	$112	<$1	-	-	$113
Oregon	-	-	-	-	-	-	-	-	-	-
Pennsylvania	45,000	1,700	10,900	1,600	59,300	$222	$3	$39	$8	$272
Rhode Island	800	<100	500	<100	1,500	$2	<$1	<$1	<$1	$3
South Carolina	17,300	800	6,600	500	25,300	$64	$2	$28	$3	$97
South Dakota	700	<100	-	-	700	$5	<$1	-	-	$5
Tennessee	25,500	600	2,200	-	28,400	$74	$1	$9	-	$84
Texas	167,800	2,800	13,700	3,500	244,800 *	$888	$6	$41	$17	$952
Utah	6,100	300	5,900	400	12,700	$18	<$1	$15	$2	$35
Vermont	-	-	-	-	-	-	-	-	-	-
Virginia	16,300	2,200	9,600	1,700	29,800	$42	$6	$40	$8	$96
Washington	2,000	<100	-	-	2,100	$24	<$1	-	-	$24
West Virginia	20,200	300	900	-	21,400	$82	<$1	$4	-	$86
Wisconsin	3,500	<100	3,200	800	7,500	$13	<$1	$12	$4	$29
Wyoming	3,600	<100	200	-	3,800	$15	<$1	<$1	-	$16

Source: NERA calculations as explained in text

Note: *California and Texas reduction totals include "known" controls for which we were not able to gather detailed EPA information on emission source category and cost. We assumed that these controls were zero-cost.

Table C-3. EPA VOC Controls by Emission Source Category

	Reductions (tons VOC)					Annualized Costs (million 2013$)				
	Point	**Area**	**Onroad**	**Nonroad**	**Total**	**Point**	**Area**	**Onroad**	**Nonroad**	**Total**
U.S. Total	**4,600**	**187,300**	**95,100**	**11,100**	**298,100**	**$7**	**$588**	**$173**	**$39**	**$807**
Alabama	-	-	-	-	-	-	-	-	-	-
Arizona	<100	5,800	6,400	700	13,000	<$1	$14	$16	$3	$33
Arkansas	-	-	400	-	400	-	-	$1	-	$1
California	300	27,500	<100	<100	27,900	<$1	$55	-	-	$55
Colorado	200	4,700	8,200	400	13,400	<$1	$20	$11	$1	$32
Connecticut	200	13,500	1,800	100	15,700	<$1	$56	<$1	<$1	$58
Delaware	-	-	500	<100	600	-	-	<$1	<$1	<$1
Florida	-	-	-	-	-	-	-	-	-	-
Georgia	-	-	6,800	600	7,400	-	-	$14	$2	$16
Idaho	-	-	-	-	-	-	-	-	-	-
Illinois	-	-	2,100	500	2,500	-	-	$3	-	$3
Indiana	<100	2,700	2,300	300	5,400	<$1	$8	$6	-	$14
Iowa	-	-	-	-	-	-	-	-	-	-
Kansas	-	-	-	-	-	-	-	-	-	-
Kentucky	-	-	2,900	300	3,200	-	-	$6	$1	$7
Louisiana	-	3,900	1,200	400	5,600	-	$17	$5	$2	$24
Maine	-	-	400	200	500	-	-	<$1	<$1	$1
Maryland	100	18,400	2,900	300	21,700	<$1	$68	$2	<$1	$70
Massachusetts	200	3,400	6,700	200	10,500	<$1	$8	$3	<$1	$13
Michigan	600	5,100	3,100	1,400	10,100	<$1	$12	$11	$7	$31
Minnesota	-	-	-	-	-	-	-	-	-	-
Mississippi	-	-	-	-	-	-	-	-	-	-
Missouri	800	1,400	4,600	400	7,200	$1	$3	$7	$2	$12
Montana	-	-	-	-	-	-	-	-	-	-
Nebraska	-	-	-	-	-	-	-	-	-	-
Nevada	-	-	-	-	-	-	-	-	-	-
New Hampshire	-	-	-	-	-	-	-	-	-	-
New Jersey	100	29,300	3,600	400	33,400	<$1	$117	$2	$1	$121
New Mexico	-	-	200	-	200	-	-	<$1	-	<$1
New York	500	15,000	6,200	1,000	22,600	<$1	$26	$9	$4	$39
North Carolina	-	-	4,500	500	5,000	-	-	$12	$2	$13
North Dakota	-	-	-	-	-	-	-	-	-	-
Ohio	200	16,700	8,300	1,000	26,300	<$1	$68	$20	$4	$93
Oklahoma	-	-	-	-	-	-	-	-	-	-
Oregon	-	-	-	-	-	-	-	-	-	-
Pennsylvania	400	23,000	5,600	700	29,800	<$1	$79	$13	$3	$96
Rhode Island	-	-	700	<100	700	-	-	<$1	<$1	<$1
South Carolina	-	-	2,300	300	2,600	-	-	$8	$1	$10
South Dakota	-	-	-	-	-	-	-	-	-	-
Tennessee	-	-	700	-	700	-	-	$2	-	$2
Texas	400	8,800	1,900	500	11,600	<$1	$21	-	-	$21
Utah	<100	1,000	4,300	200	5,600	<$1	$2	$4	<$1	$7
Vermont	-	-	-	-	-	-	-	-	-	-
Virginia	<100	1,600	5,700	500	7,900	<$1	$4	$11	$2	$17
Washington	-	-	-	-	-	-	-	-	-	-
West Virginia	-	-	400	-	400	-	-	$2	-	$2
Wisconsin	400	5,300	300	100	6,100	<$1	$11	<$1	-	$12
Wyoming	-	-	<100	-	<100	-	-	<$1	-	<$1

Source: NERA calculations as explained in text

B. State-Specific Information on EGU Controls

1. Development of EGU Controls in N_{ew}ERA

We used the electricity module of the N_{ew}ERA model to estimate the net changes in NO_X emissions and electricity system costs for potential EGU controls for 60 ppb compliance. In particular, in N_{ew}ERA, we did not allow coal units to operate (and emit NO_X) in states requiring emission reductions from "unknown" controls, and we developed state-specific estimates of the net NO_X reduction from EGU source categories, net costs, and costs per ton of NO_X removed.

a. Assumptions

We use the N_{ew}ERA model to estimate the potential NO_X reductions from scrapping coal-fired generation and the estimated cost per ton associated with this action. As part of the model runs we assume that there would not be any NO_X emissions from any coal-fired generation in the relevant states. We performed separate analyses for each of the 44 U.S. states that have existing coal-fired generation. We compared these results to a baseline run without coal-specific NO_X restrictions.

For each state, the coal-specific NO_X restriction was imposed in 2026 and future years. We selected 2026 for all states for purposes of consistency, even though some states would make reductions prior to 2026, and others would not make reductions until after 2026. We do not believe that changing the year would significantly change the estimated costs per ton removed. For each state with a coal-specific NO_X restriction, we took the difference between total 2026 U.S. electric sector NO_X emissions from the state-specific model run and the same emissions from the baseline run without coal-specific NO_X restrictions. This provided us with the net NO_X emission reductions (accounting for the reductions in NO_X from coal units in the state of interest, increases in NO_X emissions from natural gas-fired generation from the state of interest and surrounding states, and increases in NO_X emissions from coal-fired generation from surrounding states). This approach may understate or overstate the NO_X emission reductions because we have effectively assumed that the state of interest would be the only state to impose the NO_X restrictions on its coal-fired fleet. NO_X emission reductions would be understated if the lost generation from in-state coal generators could not be replaced by coal-fired generation from surrounding states. NO_X emission reductions would be overstated if the natural gas-fired generation in surrounding states were not available to generate more because it was already generating to replace lost coal-fired generation from within its own state as might happen if that state were to also impose a coal-specific NO_X restriction.

To calculate the increased costs resulting from the coal-specific NO_X restriction, we took the difference between total U.S. electric sector costs in the state-specific run and the baseline run without coal-specific NO_X restrictions in 2026. All capital costs were annualized for purposes of this cost comparison. These costs are mostly sourced from *AEO 2013* and *AEO 2014*, including capital and operating costs of new natural gas-fired generators and other types of generators

(*AEO 2013*), natural gas prices (*AEO 2014*), and electricity demand (*AEO 2014*). The increases in costs therefore reflect the following: changes in fuel costs resulting from operating higher cost generating units (either natural gas-fired, coal-fired, or other dispatchable resources), changes in O&M costs from the change in dispatch, and annualized costs associated with building new generating resources (if necessary). The costs are likely understated for some of the same reasons that emission reductions might be overstated; but also because if many states were to impose coal NO_X limits, then electric sector demand for natural gas would likely increase, thereby increasing natural gas prices (as shown in our main results). For this analysis of potential EGU controls, natural gas prices were assumed to be unchanged.

b. Cost per Ton of NO_X Reduced by State

Table C-4 shows the cost per ton of NO_X removed by state based upon the assumption that coal-fired generation from existing EGU sources would not occur in 2026 and beyond for the relevant states.

Oregon only has one existing coal plant, Boardman, and that plant is scheduled to retire prior to 2026, thus there are not any changes in NO_X emissions or costs. South Dakota and Georgia show increases in NO_X emissions, which happens because lower NO_X emitting coal-fired generation in those states is replaced by imports of electricity, which have higher NO_X emissions per unit of power. Finally, Connecticut shows a small decrease in costs in 2026 along with a decrease in NO_X emissions. While costs decline in 2026, costs increase over the entire model horizon, so this is just an intertemporal impact.

2. Combination of EGU Controls with EPA “Known” Controls

For states where coal power plant scrappage and replacement would cost less than $30,000 per ton, we included this measure with the EPA “known” controls in the marginal cost curve. For states where it would cost more than $30,000 per ton, we included this measure in the segment of the marginal cost curve reflecting “unknown” controls, as explained below.

C. State-Specific Information on “Unknown” Controls

1. Necessary NO_X Emission Reductions from Additional Controls

We estimated the necessary NO_X emission reductions from additional controls for each state by calculating the gap between each state’s necessary total NO_X emission reductions for 60 ppb and reductions that would be achieved from “known” controls and N_{ew}ERA EGU controls costing less than $30,000 per ton. These additional controls represent either EGU controls costing more than $30,000 per ton or “unknown” controls for which we do not have any detailed information. Table C-5 shows the calculation of reductions from additional controls for each state.

Table C-4. Summary of N$_{ew}$ERA EGU Control Modeling in 2026

	Average Cost per Ton Removed (2013$)
Alabama	$18,241
Arkansas	$10,491
Arizona	$18,411
California	$3,970
Colorado	$25,024
Connecticut	$0
Delaware	$184,330
Florida	$57,770
Georgia	N/A
Iowa	$24,593
Illinois	$68,039
Indiana	$29,061
Kansas	$84,506
Kentucky	$25,470
Louisiana	$17,671
Massachusetts	$31,329
Maryland	$15,024
Michigan	$31,528
Minnesota	$37,828
Missouri	$46,412
Mississippi	$19,888
Montana	$19,104
North Carolina	$28,351
North Dakota	$14,114
Nebraska	$28,692
New Hampshire	$20,177
New Jersey	$78,909
New Mexico	$47,929
Nevada	$2,757
New York	$10,482
Ohio	$30,612
Oklahoma	$9,741
Oregon	N/A
Pennsylvania	$43,014
South Carolina	$5,933
South Dakota	N/A
Tennessee	$47,808
Texas	$63,272
Utah	$8,536
Virginia	$7,393
Washington	$4,307
Wisconsin	$70,241
West Virginia	$119,580
Wyoming	$26,874

Note: “N/A” denotes that the state would not achieve net NO_X reductions from coal power plant scrappage. States are omitted if they do not have any coal power plants.

Source: NERA calculations as explained in text

Table C-5. Additional Reductions Required After EPA “Known” and N$_{ew}$ERA EGU Controls Costing Less than $30,000 per Ton (tons of NO$_X$)

	Updated Baseline Emission Projections	Reductions for 60ppb (from Updated Baseline)	EPA "Known" Reductions	Coal Power Plant Scrappage Reductions (<$30,000/ton)	Additional Reductions Needed
U.S. Total	**9,704,600**	**3,866,100**	**1,284,400**	**698,200**	**1,883,500**
Alabama	262,300	74,700	32,200	42,500	-
Arizona	152,300	43,200	20,000	23,100	-
Arkansas	138,300	27,300	10,300	17,000	-
California	553,400	497,300	161,700	-	335,500
Colorado	203,300	81,000	31,400	32,700	16,900
Connecticut	48,500	30,900	5,400	600	24,900
Delaware	19,700	6,800	3,100	-	3,700
Florida	358,000	29,700	16,000	-	13,700
Georgia	244,600	70,400	38,000	14,400	18,000
Idaho	57,700	4,600	3,200	-	1,400
Illinois	347,500	193,700	28,500	-	165,200
Indiana	319,100	193,300	33,000	106,200	54,100
Iowa	173,900	-	-	-	-
Kansas	216,500	11,200	11,200	-	-
Kentucky	245,000	106,200	23,200	82,000	1,000
Louisiana	406,900	256,400	131,200	11,200	113,900
Maine	43,600	12,700	10,900	-	1,800
Maryland	110,000	69,800	13,300	11,000	45,500
Massachusetts	96,900	30,900	14,700	3,900	12,400
Michigan	320,500	162,800	46,800	55,700	60,300
Minnesota	194,900	-	-	-	-
Mississippi	126,400	-	-	-	-
Missouri	268,500	90,600	31,500	-	59,200
Montana	90,400	-	-	-	-
Nebraska	153,200	6,800	4,100	2,700	-
Nevada	62,500	2,300	900	1,400	-
New Hampshire	22,200	-	-	-	-
New Jersey	106,300	56,000	11,800	-	44,200
New Mexico	146,100	36,600	26,600	-	9,900
New York	291,400	177,400	31,500	5,900	140,000
North Carolina	243,400	136,100	30,800	36,900	68,500
North Dakota	127,200	-	-	-	-
Ohio	392,300	240,000	53,600	86,600	99,800
Oklahoma	311,900	67,100	22,200	44,900	-
Oregon	91,600	-	-	-	-
Pennsylvania	370,800	245,600	59,300	-	186,200
Rhode Island	14,900	3,600	1,500	-	2,100
South Carolina	123,300	57,100	25,300	9,800	22,000
South Dakota	39,200	3,400	700	-	2,700
Tennessee	198,700	37,300	28,400	-	8,900
Texas	958,600	471,000	244,800	-	226,200
Utah	153,900	62,800	12,700	50,100	-
Vermont	12,300	-	-	-	-
Virginia	206,700	67,100	29,800	19,200	18,200
Washington	187,000	27,300	2,100	5,400	19,800
West Virginia	176,200	83,900	21,400	-	62,500
Wisconsin	161,600	52,600	7,500	-	45,000
Wyoming	155,100	38,600	3,800	34,800	-

Source: NERA calculations as explained in text

2. Estimating the Cost of Additional Controls

a. Overview of the NERA Marginal Cost Curve

As mentioned in the report body, we performed detailed analyses of residual emissions from each source category in each state assuming implementation of all the EPA "known" controls to develop the bases for updated estimates of potential additional control options and their costs. We developed illustrative extensions of each state's marginal cost curve for "unknown" controls (as needed) using as an anchor point a particular potential additional control at an estimated cost per ton and an estimated placement along the horizontal axis reflecting cumulative NO_X emission reductions up to that point. In particular, our anchor point for the segment of each state's marginal cost curve for "unknown" controls reflects scrappage of older high-emission-rate passenger cars and light duty trucks and replacement with new low-emission-rate vehicles.

To estimate the cost per ton of this anchor point, we adapted the methodology used in Knittel (2009) to estimate the cost-effectiveness of the Consumer Assistance to Recycle and Save Act (CARS or "Cash for Clunkers"). The Knittel (2009) model compares the average rebate paid for scrapping an existing vehicle and purchasing a new one through the CARS program (the cost) with an estimate of emission reductions achieved by the vehicle trade-in. We use a similar framework with different assumptions to estimate the cost per ton of reducing NO_X emissions through a vehicle scrappage program in an illustrative *future* year of 2020 (the first attainment year in our analysis). We assumed the target age of vehicles scrapped in the future program would be 13 years with an expected remaining useful life of about 45,000 miles based on the survival probabilities and average VMT by vehicle vintage shown in Knittel (2009), Table 2.[34] We assumed the rebate (the cost per vehicle) would be about $4,200 in 2009 dollars, the same as the average rebate paid through the CARS program.[35] We annualized the rebate over a remaining useful vehicle life of about 4 years at a 5% discount rate.[36]

Newer vehicles are required to meet more stringent NO_X emission standards, so NO_X emissions are reduced as older vehicles are scrapped and replaced with new vehicles. The emission rate for scrapped vehicles was estimated as the average of NO_X emission rate standards for new cars and light trucks in 2007, the relevant emission rate standards for vehicles that will be 13 years old in

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[34] Survival probabilities are from the NHTSA 2006 Vehicle Survivability and Travel Mileage Schedule. We use the average of car and light truck expected VMT remaining, weighted by the 2020 car and light truck stock projected in *AEO 2014* and conditional on survival to age 13 as in Knittel (2009).

[35] The average rebate assumed in Knittel (2009) is $4,200, and the average age of vehicles scrapped through the CARS program was 14 years (NHTSA, 2009 p. 21). We assume a program aiming to scrap vehicles averaging less than 13 years of age would require a somewhat higher average rebate; for programs targeting older vehicles, we select a rebate by multiplying the *AEO 2014* projected new light duty vehicle price for 2020 by the target vehicle's share of remaining lifetime VMT, scaled by a calibration factor to return a rebate of $4,200 for a program targeting 13-year-old vehicles (as observed in the CARS program).

[36] Annualization years were based on vehicle miles remaining (described above) and an assumed average of 12,000 miles per year from Knittel (2009).

2020.[37] The resulting emission rate for scrapped vehicles was 0.19 g/mile. Finally, we assumed new replacement vehicles would have an emission rate of 0.03 g/mile to meet EPA Tier 3 emission rate standards and calculated annual NO_X emission reductions per vehicle of 0.0022 tons. Comparing the annualized rebate cost to the annual emission reductions gave a cost per ton of about $540,000.

Using VMT by age information shown in Knittel (2009) and the 1999 age distribution of the car and light truck stock from MOVES2010 documentation (EPA 2010a), we estimate that scrapping light-duty vehicles 13 years old and older would eliminate about 50% of light-duty vehicle emissions. As explained above, the marginal cost of scrapping enough of the fleet to achieve a 50% NO_X emissions reduction from passenger cars and light duty trucks would be approximately $500,000 per ton, and we assume that this option would be undertaken at the part of each state's marginal cost curve corresponding to a 75% reduction from the baseline NO_X emission level. This calculation is based on estimates for NO_X emissions rates by age of passenger cars and light duty trucks, survival rates and VMT for vehicles, estimated rebates that would need to be paid to vehicles owners to scrap their vehicles, and the remaining useful life of a vehicle when it would be scrapped.

This anchor point, in combination with cost-per-ton information for "known" controls (including coal scrappage if less than $30,000/ton in the state), determines the slope of the "unknown" segment of each state's marginal cost curve. We estimate total annualized costs for "unknown" controls for each state using this slope and the necessary remaining tons of NO_X emission reductions after implementation of "known" controls (including coal scrappage if less than $30,000/ton in the state). Section II of the report illustrates the nature of the marginal cost curve we presume, showing the anchor points and the segment of the curve representing costs for "unknown" control measures.

The increasing marginal cost curve can be motivated by considering the steps involved in expanding a program to scrap existing passenger cars and light duty trucks. Using the same methodology described above, we estimate that a vehicle scrappage program targeting older vehicles than our example above could achieve a 10% reduction in light-duty vehicle emissions at a marginal cost of about $120,000 per ton. In contrast, newer vehicles have a longer useful life and would thus require a larger rebate to incentivize their owners to scrap and replace them with lower-emitting vehicles. Scrapping newer vehicles also reduces emissions less than scrapping older, higher-emitting vehicles, so the marginal cost of reducing vehicle emissions would thus increase as a program moves from scrapping older vehicles to scrapping a larger share of the vehicle fleet (including newer vehicles).

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[37] We estimate vehicle NO_X emission rates for each vehicle vintage by linearly interpolating between historical federal NO_X emission standards for new vehicles.

b. Implications for Other Source Categories

We believe that other source categories have a rising marginal cost curve similar to that of passenger cars and light duty trucks. We have estimates of the emissions that remain in these source categories after accounting for "known" controls and can infer an approximate minimum cost for these reductions (otherwise these reductions would have been included in "known" controls). Further, the remaining NO_X emissions from many of these other source categories reflect different vintages of equipment presumably with improving NO_X emissions rates over time as efficiencies of the equipment have improved, much like that of passenger cars and light duty trucks. Thus, we think it is reasonable that the cost of reductions in these sectors would conform to a marginal cost curve similar to the form for passenger cars and light duty trucks.

3. Reductions and Costs from Additional Controls by State

Table C-6 shows emission reductions from additional controls beyond "known" controls and EGU controls costing more than $30,000 per ton. The costs of "unknown" controls were estimated at the state level using the cost curve methodology discussed above. The final compliance costs for all EGU controls were determined endogenously in the N_{ew}ERA model and cannot be isolated from other electricity sector impacts of the ozone standards.

We allocated total estimated costs for "unknown" controls (shown in Table C-6) to the four emission source categories other than EGU: (1) point; (2) area; (3) onroad mobile; and (4) nonroad mobile. This allocation was based on the state-level emissions remaining in each source category after applying the EPA "known" controls. For example, if 30% of a state's non-EGU emissions after implementing "known" controls were in the nonroad emission source category, we placed 30% of that state's "unknown" control costs in the nonroad source category. Table C7 shows the share of "unknown" control costs allocated to each emission source category by state.

D. Total State-Specific Annualized Compliance Costs

Table C-8 summarizes our total non-EGU annualized compliance cost estimates by state, separated between "known" and "unknown" control measures. Note that annualized costs for "known" control measures include costs for VOC controls in addition to costs for NO_X controls. Final compliance costs for all EGU controls were determined endogenously in the N_{ew}ERA model and are not included in Table C-8.

Table C-6. Costs of Additional Controls by State

	Reductions from Additional Controls (tons NO_x)			Costs of Additional Controls (million 2013$)	
	Coal Power Plant Scrappage (>$30,000/ton)	**"Unknown"**	**Total**	**Coal Power Plant Scrappage (>$30,000/ton)**	**"Unknown"**
U.S. Total	**295,200**	**1,588,300**	**1,883,500**	**Modeled**	**$342,159**
Alabama	-	-	-	-	-
Arizona	-	-	-	-	-
Arkansas	-	-	-	-	-
California	-	335,500	335,500	-	$128,751
Colorado	-	16,900	16,900	-	$1,309
Connecticut	-	24,900	24,900	-	$6,112
Delaware	-	3,700	3,700	-	$395
Florida	-	13,700	13,700	-	$466
Georgia	-	18,000	18,000	-	$1,065
Idaho	-	1,400	1,400	-	$23
Illinois	48,200	117,000	165,200	-	$18,973
Indiana	-	54,100	54,100	-	$9,475
Iowa	-	-	-	-	-
Kansas	-	-	-	-	-
Kentucky	-	1,000	1,000	-	$28
Louisiana	-	113,900	113,900	-	$24,527
Maine	-	1,800	1,800	-	$81
Maryland	-	45,500	45,500	-	$10,710
Massachusetts	-	12,400	12,400	-	$1,153
Michigan	-	60,300	60,300	-	$9,012
Minnesota	-	-	-	-	-
Mississippi	-	-	-	-	-
Missouri	38,600	20,600	59,200	-	$1,132
Montana	-	-	-	-	-
Nebraska	-	-	-	-	-
Nevada	-	-	-	-	-
New Hampshire	-	-	-	-	-
New Jersey	2,600	41,600	44,200	-	$7,876
New Mexico	9,900	-	9,900	-	-
New York	-	140,000	140,000	-	$32,816
North Carolina	-	68,500	68,500	-	$12,983
North Dakota	-	-	-	-	-
Ohio	-	99,800	99,800	-	$20,485
Oklahoma	-	-	-	-	-
Oregon	-	-	-	-	-
Pennsylvania	43,800	142,500	186,200	-	$28,791
Rhode Island	-	2,100	2,100	-	$170
South Carolina	-	22,000	22,000	-	$2,778
South Dakota	-	2,700	2,700	-	$107
Tennessee	4,800	4,100	8,900	-	$116
Texas	72,000	154,200	226,200	-	$17,070
Utah	-	-	-	-	-
Vermont	-	-	-	-	-
Virginia	-	18,200	18,200	-	$1,303
Washington	-	19,800	19,800	-	$1,185
West Virginia	62,500	-	62,500	-	-
Wisconsin	12,800	32,300	45,000	-	$3,264
Wyoming	-	-	-	-	-

Note: Coal power plant scrappage compliance costs are determined in the N_{ew}ERA model.
Source: NERA calculations as explained in text

Table C-7. Cost Allocation for “Unknown” Controls to Non-EGU Source Categories

	Non-EGU "Unknown" Control Annualized Costs (million 2013$)	Share of Non-EGU Emissions Remaining After "Known" Controls			
		Point	Area	Onroad	Nonroad
U.S. Total	$342,159	14%	24%	34%	29%
Alabama	-	-	-	-	-
Arizona	-	-	-	-	-
Arkansas	-	-	-	-	-
California	$128,751	11%	14%	42%	33%
Colorado	$1,309	24%	33%	22%	21%
Connecticut	$6,112	6%	29%	31%	34%
Delaware	$395	0%	15%	36%	49%
Florida	$466	12%	8%	45%	35%
Georgia	$1,065	18%	10%	48%	24%
Idaho	$23	16%	12%	44%	29%
Illinois	$18,973	20%	22%	24%	34%
Indiana	$9,475	25%	15%	34%	26%
Iowa	-	-	-	-	-
Kansas	-	-	-	-	-
Kentucky	$28	13%	33%	30%	24%
Louisiana	$24,527	0%	37%	16%	47%
Maine	$81	12%	34%	26%	28%
Maryland	$10,710	10%	15%	47%	28%
Massachusetts	$1,153	13%	28%	25%	34%
Michigan	$9,012	12%	30%	36%	22%
Minnesota	-	-	-	-	-
Mississippi	-	-	-	-	-
Missouri	$1,132	6%	9%	57%	28%
Montana	-	-	-	-	-
Nebraska	-	-	-	-	-
Nevada	-	-	-	-	-
New Hampshire	-	-	-	-	-
New Jersey	$7,876	9%	25%	29%	37%
New Mexico	-	-	-	-	-
New York	$32,816	9%	30%	34%	27%
North Carolina	$12,983	12%	15%	51%	23%
North Dakota	-	-	-	-	-
Ohio	$20,485	10%	16%	49%	25%
Oklahoma	-	-	-	-	-
Oregon	-	-	-	-	-
Pennsylvania	$28,791	7%	40%	34%	19%
Rhode Island	$170	4%	43%	28%	26%
South Carolina	$2,778	11%	13%	47%	29%
South Dakota	$107	7%	20%	24%	49%
Tennessee	$116	10%	21%	45%	25%
Texas	$17,070	7%	40%	31%	22%
Utah	-	-	-	-	-
Vermont	-	-	-	-	-
Virginia	$1,303	14%	19%	38%	29%
Washington	$1,185	12%	5%	48%	34%
West Virginia	-	-	-	-	-
Wisconsin	$3,264	20%	17%	36%	27%
Wyoming	-	-	-	-	-

Note: “-” indicates that there were no non-EGU “unknown” control costs in the state, and therefore no need to estimate emissions remaining in each source category after “known” controls.

Source: NERA calculations as explained in text

Table C-8. Annualized Compliance Costs of a 60 ppb Standard by Control Type and State (million 2013$)

	"Known" Control Costs	"Unknown" Control Costs	Total Non-EGU Control Costs
U.S. Total	**$5,703**	**$342,159**	**$347,862**
Alabama	$89	-	$89
Arizona	$85	-	$85
Arkansas	$32	-	$32
California	$397	$128,751	$129,148
Colorado	$139	$1,309	$1,448
Connecticut	$72	$6,112	$6,184
Delaware	$10	$395	$406
Florida	$46	$466	$513
Georgia	$142	$1,065	$1,207
Idaho	$9	$23	$32
Illinois	$178	$18,973	$19,151
Indiana	$152	$9,475	$9,628
Iowa	-	-	-
Kansas	$8	-	$8
Kentucky	$111	$28	$139
Louisiana	$735	$24,527	$25,262
Maine	$39	$81	$120
Maryland	$122	$10,710	$10,833
Massachusetts	$56	$1,153	$1,209
Michigan	$256	$9,012	$9,269
Minnesota	-	-	-
Mississippi	-	-	-
Missouri	$126	$1,132	$1,258
Montana	-	-	-
Nebraska	$8	-	$8
Nevada	$23	-	$23
New Hampshire	-	-	-
New Jersey	$166	$7,876	$8,042
New Mexico	$88	-	$88
New York	$173	$32,816	$32,989
North Carolina	$119	$12,983	$13,102
North Dakota	-	-	-
Ohio	$342	$20,485	$20,827
Oklahoma	$113	-	$113
Oregon	-	-	-
Pennsylvania	$369	$28,791	$29,160
Rhode Island	$4	$170	$174
South Carolina	$106	$2,778	$2,885
South Dakota	$5	$107	$112
Tennessee	$86	$116	$202
Texas	$973	$17,070	$18,043
Utah	$42	-	$42
Vermont	-	-	-
Virginia	$113	$1,303	$1,417
Washington	$24	$1,185	$1,209
West Virginia	$88	-	$88
Wisconsin	$41	$3,264	$3,305
Wyoming	$16	-	$16

Note: “-” indicates that there were no non-EGU “unknown” control costs in the state, and therefore no need to estimate emissions remaining in each source category after “known” controls.
Source: NERA calculations as explained in text

E. EPA Compliance Cost Estimates

This section discusses issues related to EPA's estimates of total annualized costs for 60 ppb in its 2010 supplemental ozone analysis. In this section, we present the estimates, note important details regarding their calculations and scope, and summarize key differences from the cost estimates that we developed for this analysis. As the final section of this section, we also discuss implications of these issues for the forthcoming EPA ozone analysis.

1. EPA Total Cost Estimates

EPA provided information on the necessary emission reductions and costs for 60 ppb compliance in its 2010 supplemental ozone analysis (EPA 2010b). EPA performed its analysis for a single future year: 2020. Its calculations of necessary emission reductions and costs for 60 ppb reflect its projections of baseline emissions and baseline air quality in that future year.

EPA used two approaches to estimate the costs of "unknown" controls in its 2008-2010 ozone analyses, and it developed estimates using various parameters for each of the two approaches. In the "fixed" approach, EPA assumed that all "unknown" controls would have a constant cost per ton, and it developed estimates using $10,000, $15,000, and $20,000 per ton as parameters. In the "hybrid" approach, EPA assumed that "unknown" controls would begin at $15,000 per ton in each area and would gradually increase in marginal cost based on possible slope parameters. EPA developed estimates for the "hybrid" approach using 0.12, 0.24, and 0.48 as the slope parameters (EPA 2008, pp. 5-10 to 5-22; EPA 2010b, pp. S2-17 to S2-18).[38]

Table C-9 reproduces the total annualized cost estimates for 60 ppb from EPA (2010b). As shown in the table, EPA estimated that "known" controls for 60 ppb compliance in 2020 would have a total annualized cost of $4.5 billion (in 2006 dollars). The cost estimates for "unknown" controls reflect the two approaches with their middle parameters (*i.e.*, the "fixed" approach assuming $15,000 per ton and the "hybrid" approach assuming 0.24 as the slope parameter). Thus, the total cost for 60 ppb in the EPA 2010 analysis was about $52 billion for the "fixed" approach with this assumed cost per ton and about $90 billion for the "hybrid" approach with this assumed slope parameter.

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[38] NERA's approach for estimating the costs of "unknown" controls is similar to EPA's "hybrid" approach in using an upward-sloped marginal cost curve, as described in Appendix C.

Table C-9. EPA Total Annualized Cost Estimates for 60 ppb from 2010 RIA (billion 2006$)

“Known” Controls	$4.5	
“Unknown” Controls	“Fixed”: $47	“Hybrid”: $85
Total	“Fixed”: $52	“Hybrid”: $90

Note: Costs reflect compliance actions for 2020.
“Fixed” approach for costs of “unknown” controls reflects assumption of $15,000 per ton.
“Hybrid” approach for costs of “unknown” controls reflects assumption of 0.24 slope parameter.
Source: EPA (2010b), Table S2.9 (p. S2-19)

The following points should be noted regarding the EPA cost estimates from the 2010 analysis.

- *Annualized costs for 2020*. As noted above, EPA only evaluated a single future year (2020) for its previous ozone analysis. EPA did not address staggered implementation of compliance deadlines for nonattainment areas in its analysis. Its cost estimates reflect annualized costs that combine capital expenditures (converted from lump sums to annualized values) and operating expenditures (incurred on an annual basis). It did not calculate a present value based on its annualized cost estimates.

- *Ranges of cost estimates.* As noted above, EPA used various approaches and various parameters to estimate the costs of “unknown” controls for 60 ppb compliance. Its main table of results (reproduced above) uses the middle parameters for the two approaches. Results using other parameters are shown in Docket File 399 (EPA 2010c). This file shows that for the “fixed” approach, “unknown” controls would cost $32 billion (in 2006 dollars) using $10,000 per ton and $63 billion using $20,000 per ton. It also shows that for the “hybrid” approach, “unknown” controls would cost $66 billion using 0.12 as the slope parameter and $123 billion using 0.48 as the slope parameter.

- *Exclusion of Southern and Central California.* EPA did not include ozone compliance costs for Southern and Central California in its main cost estimates, because these areas would have extra time (beyond 2020) to improve their air quality (EPA 2008, pp. 4-3, 5-10, and 7b-1 to 7b-14; EPA 2010b, p. S2-19).

- *Error in “Hybrid” Approach Calculations.* The spreadsheet that EPA used to calculate the costs for “unknown” controls with the “hybrid” approach contains an error. Information for Cleveland, Mississippi was erroneously applied to Cleveland, Ohio, leading to incorrect cost estimates for both areas. As a result of this error, cost estimates for 60 ppb based on the “hybrid” approach were too high by about $8 billion (in 2006 dollars) using the low slope parameter of 0.12, by about $15 billion using the middle slope parameter of 0.24, and by about $30 billion using the high slope parameter of 0.48. While EPA was made aware of these errors, it was instructed to terminate the ozone reconsideration in September 2011 (OMB 2011), and as a result corrected cost estimates were never issued.

2. Differences from NERA Cost Estimates

The EPA total cost estimates that are summarized above differ from cost estimates in this study because NERA has undertaken an improved, more evidence-based approach for developing reasoned estimates of the costs for the two-thirds of the controls that EPA treated as “unknown” in its prior analysis. EPA made estimates of the cost per ton for those two-thirds of the overall controls without any reference to or assessment of the actual types of controls that would logically have to be undertaken to eliminate those additional tons. Our assessment, having used available information to estimate the range of costs per ton that would be associated with those remaining types of emissions sources, indicates that EPA’s earlier extrapolation assumptions were probably too low. There are a number of other reasons why NERA’s cost estimates differ from those in the earlier EPA RIA:

- *Annualized vs. annual costs and present values*. As discussed earlier in this appendix, NERA used annualized cost information for “known” controls from the EPA 2008-2010 ozone analysis and supplemented it with modeling of coal-fired generation unit scrappage and other potential additional controls to estimate the costs of “unknown” controls, which we also calculated on an annualized basis. As discussed in Appendix D, the costs for each state were divided between capital and operating expenditures and were entered into various years in $\mathrm{N_{ew}}$ERA based on potential state designations and compliance deadlines. The report body also shows the estimated costs as a present value. Thus, the NERA cost information accounts for staggered implementation of the ozone standard across states and includes a present value, in contrast to the EPA analysis.

- *2020 vs. staggered implementation*. As discussed above, EPA used baseline emissions and air quality projections for 2020 to estimate necessary emission reductions and associated costs for 60 ppb compliance in that year. NERA incorporated staggered implementation of the ozone standard into the modeling by specifying potential designations and compliance deadlines for each state and developing cost estimates by year based on those designations.

- *Exclusion vs. inclusion of Southern and Central California.* In contrast to the EPA analysis, NERA included all parts of the country (with available information) in the cost estimates and economic impact modeling. As with other areas, NERA specified a potential ozone nonattainment designation and compliance deadline for California for each relevant level (84, 75, and 60 ppb). Our analyses related to California are described in Appendices B, C, and D.

- *All sectors vs. separate modeling of electricity sector costs*. The EPA cost estimates reflect emission reductions in all sectors, including the electricity sector. In contrast, NERA used the electricity sector module of the $\mathrm{N_{ew}}$ERA modeling system to analyze emission reductions in that sector, and compliance costs for the electricity sector are not included in NERA’s cost estimates.

- *2006 vs. 2013 dollars*. EPA presented its cost estimates in the 2008-2010 ozone analyses in 2006 dollars. NERA presents costs in 2013 dollars.

For these reasons, the EPA and NERA cost estimates cannot be compared on an "apples-to-apples" basis.

3. Implications for Forthcoming EPA Analysis

This discussion of EPA's total cost estimates from its 2010 analysis and differences with NERA's analyses has several implications for EPA's forthcoming ozone analysis.

- *Staggered implementation*. Analysis for a single future year has limited usefulness when different areas of the country would have different compliance timelines (and may also still need to comply with previously promulgated standards, such as the 1997 ozone standard of 84 ppb and the 2008 ozone standard of 75 ppb). EPA should incorporate staggered implementation into its forthcoming ozone analysis for a more realistic treatment of timing issues. In addition, expanding the analysis beyond a "snapshot" year (*e.g.*, 2020) would allow EPA to include Southern and Central California in its compliance cost estimates.

- *Identification of additional controls and cost estimation for any "unknown" controls*. In EPA's 2010 analysis of 60 ppb, "known" controls achieved less than one-half of the necessary total emission reductions in many areas of the country, and the total costs for "unknown" controls were much larger than the total costs for "known" controls, using either the "fixed" or "hybrid" approach for "unknown" control cost estimation and using any of the parameters. Moreover, EPA's cost estimates for "unknown" controls vary widely, from about $32 billion (in 2006 dollars) using the "fixed" approach and low parameter of $10,000 per ton to about $123 billion using the "hybrid" approach and high slope parameter of 0.48 (or about $93 billion after correcting the calculation error). To reduce the reliance on "unknown" controls for this regulation and reduce the uncertainty regarding its costs, EPA should dedicate more resources to identifying additional potential control measures and developing more precise estimates of the cost of any remaining "unknown" controls.

F. References to the Appendix

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APPENDIX D. ESTIMATES OF STATE-SPECIFIC COMPLIANCE COST INPUTS TO N_{EW}ERA TO ACHIEVE A 60 PPB OZONE STANDARD

A. Allocation of Costs to N_{ew}ERA Sectors

As described in Appendix C, we developed state-level compliance costs by control type ("known," coal scrappage, and "unknown") and by emission source category (point, area, onroad, nonroad, and EGU).[39] In order to model the economic impacts of these compliance costs, we then divided costs in each emission source category among economic sectors used in the N_{ew}ERA model. This section describes those sector allocations.

In general, the same methodology was used to allocate "known" and "unknown" control costs to N_{ew}ERA sectors. Table D-1 and Table D-2 show respectively the resulting national-level shares of "known" and "unknown" control costs by source category and N_{ew}ERA sector.[40] The national sector composition of each source category is different in the two tables; this primarily reflects state-level differences in the source categories of "unknown" control costs and state-specific sector allocations.

Table D-3 shows the resulting state-level annualized cost inputs by N_{ew}ERA sector based on both "known" and "unknown" controls. These costs reflect the many different types of controls that could be required for the various emission sources within each N_{ew}ERA sector to achieve a new ozone NAAQS of 60 ppb. For example:

- Services. Businesses in the services sector could be required to install lower-emitting equipment for space heating, air conditioning and water heaters. Service sector businesses also operate substantial numbers of transportation vehicles, and the older portions of those fleets face the need for early scrappage, which accounts for a fair share of the total costs. Similarly, but a smaller part of the total cost, service sector businesses use landscaping equipment that would also need to be replaced with lower-emitting versions.

- Commercial transportation except trucking. This category includes locomotives, airplanes, river and ocean-going vessels in port, and off-road commercial equipment (bulldozers, dump trucks, etc.). A small fraction of the cost in this category comes from retrofitting NO_X reduction equipment onto existing engines. The larger part of the costs comes from assumed replacement of current equipment with lower-emitting versions,

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[39] EPA's 2008-2010 analyses provide the emission source category of each "known" control. As discussed in Appendix C, we divided "unknown" control costs among source categories using state-level emissions remaining after applying any "known" controls in each state. Coal scrappage is in the EGU emission source category.

[40] Sector allocations were developed at the state level and therefore vary by state.

including electrification of locomotives and auxiliary ship engines (for use while at dock).

- Household transportation. This sector primarily reflects personal on-road vehicles (both cars and light duty trucks and vans). Among the “known” controls modeled by EPA are a number of behavioral or operational changes, such as enhanced inspection and maintenance requirements and carpooling programs. Beyond those relatively modest “known” costs come a substantial share of “unknown” control costs based primarily on early scrappage of the oldest personal vehicles. Households would also face costs for early scrappage of their non-road mobile equipment such as lawnmowers, snowmobiles, and ATVs.

- Manufacturing. As shown in Table D-1, a large fraction of the total costs for “known” controls represent measures for manufacturing sector sources, such as retrofitting boilers, steam generators, and other large stationary facilities with SCR, low-NO_X burners, and other emission-reduction equipment. In addition, cost inputs for this sector also reflect “unknown” controls that are likely a mix of retrofits on some of the smallest manufacturing sector point sources and retirements of some of the oldest combustion equipment rather than retrofitting it (the latter occurring to the extent that it has a lower cost-per-ton than the incremental retrofit on a relatively small source).

- Trucking. Costs to the trucking sector include retrofits of SCR onto heavy-duty trucks and operational changes such as anti-idling programs and electrification of truck stops. Nevertheless, a substantial share of the total costs is assumed to also involve early scrappage of the oldest, highest-emitting of the fleet of commercial trucks.

- Other. This category includes all other types of controls, each of which has a smaller total cost than any of the above categories. An important cost element in this column is retrofitting compressors along natural gas and oil pipelines with SCR (or possibly electrification at compressor locations where it may be more cost-effective), which we have estimated will cost pipeline companies about $22.5 billion (annualized). Controls for this sector also include replacing household space heaters, water heaters, and air conditions with lower-emitting (or non-emitting) versions, replacing agricultural equipment with lower-emitting (or non-emitting) versions, *etc*.

Costs to reduce electricity generation emissions by forcing coal-fired generating units to stop operating are also an important cost component in our analysis. These costs do not appear in Table D-3 because they were endogenously estimated by N_{ew}ERA, given a modeling constraint to eliminate generation from certain coal-fired units in certain states (*i.e.*, where those controls were a cost-effective part of a state’s necessary NO_X tonnage reductions.) They account for approximately 8% of the total regulatory impact on GDP.

Table D-1. Cost Allocation for "Known" Controls to Source Categories and N$_{ew}$ERA Sectors: National Summary

EPA Source Category	Share of "Known" Control Costs	N$_{ew}$ERA Sector	Share of EPA Source Category Costs
EGU	-	Modeled	
Point (Non-EGU)	65%	Manufacturing	48%
		Refined Products	29%
		Services	17%
		Natural Gas	3%
		Crude Oil	3%
		Other	<1%
Area	12%	Services	75%
		Household Durable Goods	25%
Onroad Mobile	18%	Household Transportation	38%
		Trucking	31%
		Services	31%
Nonroad Mobile	5%	Commercial Trans (exc Trucking)	43%
		Manufacturing	25%
		Agriculture	13%
		Household Durable Goods	10%
		Services	9%

Note: State cost allocations reflect state-specific information and differ from national summary.
Source: NERA calculations as explained in text

Table D-2. Cost Allocation for “Unknown” Controls to Source Categories and N_{ew}ERA Sectors: National Summary

EPA Source Category	Share of "Unknown" Control Costs	N_{ew}ERA Sector	Share of EPA Source Category Costs
EGU	-	Modeled	
Point (Non-EGU)	10%	Services	56%
		Manufacturing	38%
		Crude Oil	2%
		Refined Products	2%
		Natural Gas	1%
		Coal	1%
		Other	<1%
Area	22%	Services	53%
		Natural Gas Pipelines	26%
		Household Durable Goods	18%
		Oil Pipelines	3%
Onroad Mobile	37%	Household Transportation	38%
		Trucking	31%
		Services	31%
Nonroad Mobile	30%	Commercial Trans (exc Trucking)	48%
		Manufacturing	24%
		Agriculture	12%
		Services	8%
		Household Durable Goods	8%

Note: State cost allocations reflect state-specific information and differ from national summary.
Source: NERA calculations as explained in text

Table D-3. Annualized Cost Inputs by State and N$_{ew}$ERA Sector for “Known” and “Unknown” Controls (millions of 2013$)

	Services	Commercial Trans (exc Trucking)	Household Transportation	Manufacturing	Trucking	Other	Total
U.S. Total	$109,994	$49,343	$48,275	$39,917	$39,776	$60,556	$347,862
Alabama	$29	-	-	$52	-	$8	$89
Arizona	$36	$5	$18	$7	$15	$5	$85
Arkansas	$12	-	$3	$14	$3	<$1	$32
California	$43,258	$19,403	$18,172	$16,165	$17,815	$14,336	$129,148
Colorado	$338	$115	$141	$140	$91	$622	$1,448
Connecticut	$2,334	$940	$1,137	$649	$372	$751	$6,184
Delaware	$94	$124	$67	$33	$38	$50	$406
Florida	$144	$61	$98	$104	$55	$52	$513
Georgia	$352	$109	$254	$246	$172	$73	$1,207
Idaho	$10	$3	$6	$6	$4	$3	$32
Illinois	$7,076	$2,810	$1,684	$2,367	$1,459	$3,754	$19,151
Indiana	$2,404	$910	$1,222	$2,419	$1,037	$1,635	$9,628
Iowa	-	-	-	-	-	-	-
Kansas	$7	-	-	<$1	-	<$1	$8
Kentucky	$35	$6	$14	$36	$14	$33	$139
Louisiana	$4,166	$9,921	$1,386	$794	$1,323	$7,673	$25,262
Maine	$36	$11	$10	$40	$8	$15	$120
Maryland	$3,841	$1,136	$2,091	$1,296	$1,479	$989	$10,833
Massachusetts	$524	$181	$141	$129	$88	$145	$1,209
Michigan	$2,664	$550	$1,482	$1,066	$922	$2,586	$9,269
Minnesota	-	-	-	-	-	-	-
Mississippi	-	-	-	-	-	-	-
Missouri	$435	$160	$125	$127	$286	$124	$1,258
Montana	-	-	-	-	-	-	-
Nebraska	$4	-	-	$4	-	<$1	$8
Nevada	$13	<$1	$3	<$1	$3	$3	$23
New Hampshire	-	-	-	-	-	-	-
New Jersey	$3,296	$1,238	$1,081	$907	$611	$909	$8,042
New Mexico	$37	-	<$1	$13	$1	$36	$88
New York	$14,435	$3,391	$4,028	$3,000	$3,654	$4,481	$32,989
North Carolina	$3,772	$779	$3,713	$2,156	$1,492	$1,191	$13,102
North Dakota	-	-	-	-	-	-	-
Ohio	$6,618	$2,276	$4,054	$2,598	$3,012	$2,269	$20,827
Oklahoma	$17	<$1	-	$39	-	$57	$113
Oregon	-	-	-	-	-	-	-
Pennsylvania	$7,794	$2,376	$4,371	$2,487	$2,779	$9,353	$29,160
Rhode Island	$79	$15	$25	$16	$12	$28	$174
South Carolina	$920	$340	$456	$469	$440	$259	$2,885
South Dakota	$28	$10	$10	$11	$7	$45	$112
Tennessee	$72	$12	$21	$56	$20	$20	$202
Texas	$3,350	$1,741	$1,577	$1,401	$1,846	$8,127	$18,043
Utah	$14	$1	$8	$6	$6	$8	$42
Vermont	-	-	-	-	-	-	-
Virginia	$377	$209	$212	$231	$167	$221	$1,417
Washington	$285	$259	$245	$131	$162	$127	$1,209
West Virginia	$69	-	$2	$13	$2	$2	$88
Wisconsin	$1,015	$248	$417	$692	$381	$552	$3,305
Wyoming	$4	-	<$1	<$1	<$1	$11	$16

Note: Table includes annualized costs of “known” and “unknown” controls except for compliance costs associated with control measures in the electric power sector (scrappage of coal-fired power plants), which are modeled in N$_{ew}$ERA. Estimates are based on annualized costs of “known” controls provided in EPA’s 2008-2010 analyses and NERA state marginal cost curves (developed in annualized dollars per ton). See Figure D-3 and surrounding text for additional assumptions regarding annualization of compliance costs.

Source: NERA calculations as explained in text

The following sections describe the development of state-level sector shares for costs in each emission source category.

1. Point (Non-EGU)

Point (non-EGU) control costs were allocated to N_{ew}ERA sectors using three-digit North American Industry Classification System (NAICS) codes. For “known” controls we used costs reported by the EPA in their 2008-2010 ozone docket files for each control. We estimated the NAICS composition of “unknown” point control costs using EPA’s 2018 projected state-level emissions remaining in each NAICS industry after applying any “known” point controls.

In most cases, the NAICS codes corresponded to a single N_{ew}ERA sector. Several codes, however, were divided among multiple N_{ew}ERA sectors to better reflect the composition of economic activity in the N_{ew}ERA macroeconomic model. This mapping of NAICS codes into N_{ew}ERA sectors is summarized in Table D-4. A few “known” controls did not include industry codes in the EPA data;[41] we placed costs for these controls in the services sector.

Controls in NAICS industry 211, Oil and Gas Extraction, were divided between the N_{ew}ERA natural gas and crude oil sectors using state-level shares of 2014 crude oil and natural gas production; for example, if a state produced natural gas but no crude oil in 2014, all of that state’s Oil and Gas Extraction control costs were allocated to the natural gas sector in N_{ew}ERA. All other relationships between NAICS industry codes and N_{ew}ERA sectors were constant across states.

1. Non-Point (Area)

Costs for EPA “known” area source controls were split between the services sector (75%) and household durable goods (25%) in every state, as shown above in Table D-1. These splits roughly reflect the shares of “known” commercial/industrial area source controls and residential water and space heater controls shown in EPA’s 2008 RIA (pp. 3a-4 to 3a-11).

Costs for “unknown” area controls were first divided between crude oil and natural gas pipeline controls and other area controls. In each state, the share of EPA projected baseline area source emissions attributable to oil and gas pipelines was used to approximate the share of state area source costs attributable to pipeline controls. Pipeline control costs were then split between the natural gas (90%) and crude oil sectors (10%), which affect delivered natural gas and oil prices in the N_{ew}ERA model. The remaining non-pipeline “unknown” area control costs were split between the services sector (75%) and household durable goods (25%).

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[41] These represented less than 1% of annualized costs from “known” point source controls.

Table D-4. NAICS Codes Corresponding to N$_{ew}$ERA Sectors

NewERA Sector	NewERA Code	NAICS (1997)	NAICS Description	Share of NAICS
Agriculture	AGR	11 (111-115)	Agriculture, Forestry, Fishing and Hunting	
Natural Gas	GAS	211	Oil and Gas Extraction	Varies by state
Crude Oil	CRU	211	Oil and Gas Extraction	Varies by state
Coal	COL	212	Mining (except Oil and Gas)	30%
Refined Products	OIL	324	Petroleum and Coal Products Mfg	
Energy-Intensive Sectors	EIS	322	Paper Mfg	
		325	Chemical Mfg	
		327	Nonmetallic Mineral Product Mfg	80%
		331	Primary Metal Mfg	
Motor Vehicles	M_V	336	Transportation Equipment Mfg	50%
Other Manufacturing	MAN	212	Mining (except Oil and Gas)	70%
		213	Support Activities for Mining	
		23 (233-235)	Construction	
		327	Nonmetallic Mineral Product Mfg	20%
		336	Transportation Equipment Mfg	50%
		Other 31-33	Other Manufacturing	
Trucking	TRK	484-485	Truck, Transit, and Ground Passenger Trans	
Other Commercial Trans	TRN	481-483	Air, Rail, and Water Transportation	
Other Commerce & Services	SRV	22 (221)	Utilities	
		486	Pipeline Transportation	
		Other >33		

Source: NERA calculations as explained in text

2. Onroad

Onroad control costs for both “known” and “unknown” controls were allocated to N$_{ew}$ERA sectors using projected baseline onroad NO_X emissions in each state. The share of baseline onroad emissions attributable to passenger cars and light-duty trucks was used to approximate the share of state onroad control costs affecting household transportation in N$_{ew}$ERA. The remaining onroad control costs in each state were divided evenly between the trucking sector and the services sector.

3. Nonroad

Nonroad control costs for both “known” and “unknown” controls were similarly allocated to sectors using projected baseline nonroad NO_X emissions in each state. The share of baseline nonroad emissions attributable to marine and railroad sources was used to approximate the share of state nonroad control costs in the non-trucking commercial transportation sector. Remaining nonroad control costs were split between N$_{ew}$ERA sectors using industry shares of baseline projected emissions related to off-road equipment; these industries corresponded to non-trucking commercial transportation, agriculture, services, manufacturing, and durable goods consumption in the N$_{ew}$ERA model.

4. Electricity Generating Units (EGUs)

EGU controls applied in EPA's 2008-2010 ozone analyses (based on IPM modeling) were not included in our compliance cost modeling. Instead, as discussed in Appendix C, we estimated the NO_X emission reductions and approximate electricity sector costs associated with coal power plant scrappage in each state within the N$_{ew}$ERA model. Whenever these coal scrappage controls are adopted by states to comply with a 60 ppb standard, the final sector-specific costs were determined endogenously in N$_{ew}$ERA.

B. Allocation of Costs to N$_{ew}$ERA Modeling Years

As discussed in the report body, the version of N$_{ew}$ERA used in this analysis models every third year between 2014 and 2038. This section describes the timing of compliance costs as N$_{ew}$ERA inputs based on estimated deadlines for ozone NAAQS attainment as well as the division of annualized costs into capital costs (incurred before compliance deadlines) and operating and maintenance (O&M) costs (incurred from the compliance deadlines onward).

1. Classifications and Attainment Timing

The ozone NAAQS have a staggered implementation. Areas in non-attainment of a standard are given classifications ranging from Marginal to Extreme based on recent ozone monitoring data. Each classification is associated with an attainment year such that areas with more severe classifications (higher ozone design values) are given additional time to come into attainment.

As discussed in Appendix B, several states would have nonattainment areas for the 1997 ozone standard of 84 ppb and the 2008 (current) standard of 75 ppb under future baseline conditions. We used existing EPA information to set the compliance deadlines for these two standards for our modeling. For 60 ppb compliance deadlines, we developed illustrative estimates of potential ozone design values for relevant states (those requiring reductions for 60 ppb according to the analysis in Appendix B) for 2016, the likely most recent data that will be available to EPA when it would be making its nonattainment designations for 60 ppb in 2017, as discussed below.

a. 1997 Standard of 84 ppb

Classifications and attainment years for the 1997 ozone standard of 84 ppb are still relevant for California and Texas; areas in these states were projected to be in nonattainment of 84 ppb in 2020 based on EPA's 2008-2010 analyses (and areas in these states have been above 84 ppb in ozone readings from recent years, as discussed in Section I of the report body). EPA assumed that California would have more time than other states to come into attainment with a new standard and estimated California reduction requirements and costs in 2030 (EPA 2008, p. 4-3).

We assumed 84 ppb attainment in 2030 for California and 2019 for Texas based on the attainment year for the Houston area (EPA 2013a).

b. 2008 Standard of 75 ppb

We developed state-level classifications for the current ozone standard of 75 ppb using EPA county-level classifications in EPA (2012 and 2013b). We use the most extreme classification of any county in a state to determine the classification and attainment year for the entire state. Attainment years for the different classifications are summarized in Table D-5.

Table D-5. Classifications and Attainment Years for the Current 75 ppb Standard

Classification	Attainment Year	States	
Compliant	N/A	22	AL, FL, ID, IA, KS, ME, MI, MN, MT, NE, NV, NH, NM, ND, OK, OR, RI, SD, UT, VT, WA, WV
Marginal	2016	23	AZ, AR, CO, CT, DE, GA, IL, IN, KY, LA, MA, MS, MO, NJ, NY, NC, OH, PA, SC, TN, VA, WI, WY
Moderate	2019	2	MD, TX
Serious	2022	0	
Severe-15	2028	0	
Severe-17	2030	0	
Extreme	2033	1	CA

Note: Attainment years represent the first year after a state comes into attainment. For example, EPA's attainment date for Marginal areas is December 31, 2015 (EPA 2012) and the NERA attainment year for Marginal states is 2016.

Source: EPA (2012) and NERA calculations as explained in text

c. Potential Standard of 60 ppb

For states requiring emission reductions for attainment with a 60 ppb standard based on our analysis of baseline and compliance emissions, we developed potential classifications using EPA's methodology for previous NAAQS and recent information on ozone concentrations and NO_X emissions.[42]

Our classifications are based on projected 2016 ozone design values as a percentage of the 60 ppb standard. Final classifications for a potential standard of 60 ppb would probably be determined by EPA in 2017. We assume that these classifications would be based upon three-

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[42] Recent ozone monitoring data suggests that we may be understating the geographic scope of nonattainment under a potential 60 ppb standard. Several states projected to comply with a 60 ppb standard in our emissions analysis would be classified as nonattainment using recent ozone monitoring data and our classification methodology.

year averages of 4th-highest 8-hour ozone concentration monitor readings, so the relevant years of ozone concentrations would be 2014 through 2016.

We estimated these future ozone concentration averages (and percentage exceedances) by projecting county-level ozone readings in each state. We estimated background ozone by state ranging from 40 (in the eastern U.S.) to 55 (in the southwestern U.S.).[43] We then calculated NO_X emissions in future years by assuming a fixed growth rate from 2011 historical emissions to EPA's 2018 projected emissions, and we found for each state the percentage change in NO_X emissions from 2013 to the average for the 2014 through 2016 period. Finally, we applied this percentage change in the NO_X emissions to 2013 ozone monitor readings after netting out our estimate of the background ozone in the state.[44] These resulting adjusted ozone readings for 2014 through 2016 were the primary basis for our ozone classification of states.

EPA used percentage exceedance of the ozone standard to determine classifications for the 1997 and 2008 ozone standards (EPA 2012). We applied the same percentage exceedance cutoffs to classify states requiring emission reductions for 60 ppb. The high end of the ozone range for a classification of Marginal is 15% above 60 ppb, Moderate is 33.33% above, Serious is 50% above, Severe-15 is 58.33% above, Severe-17 is 133.33% above, and Extreme is everything higher. In the resulting classifications, 34 states are Marginal or Moderate, and Texas and Michigan are classified as Serious. California was "bumped up" to Extreme so that its classification for 60 ppb would not be lower than its classification for 75 ppb. Classifications for 60 ppb are shown in Table D-6.

We based the attainment year for each 60 ppb classification on expectations about rule timing and EPA's 2012 announcement regarding attainment timing for the current 75 ppb standard. The potential attainment years for 60 ppb classifications used in our analysis are summarized in Figure D-2.

We used the state classifications and attainment years for each standard as the basis for the assumed staggered implementation schedule in this analysis.

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[43] These estimates are based on EPA (2014), Figure 7, p. 2A-28.

[44] For example, if the 2013 ozone reading was 70 ppb, the background was estimated to be 50 ppb, and the change in NO_X emissions between 2011 and 2018 was -20%, then we applied the -20% change to an ozone reading of 20 (70 less 50), which would be -4, and then added that back to the original ozone reading of 70 to arrive at an estimated 2014 through 2016 ozone reading of 66 ppb.

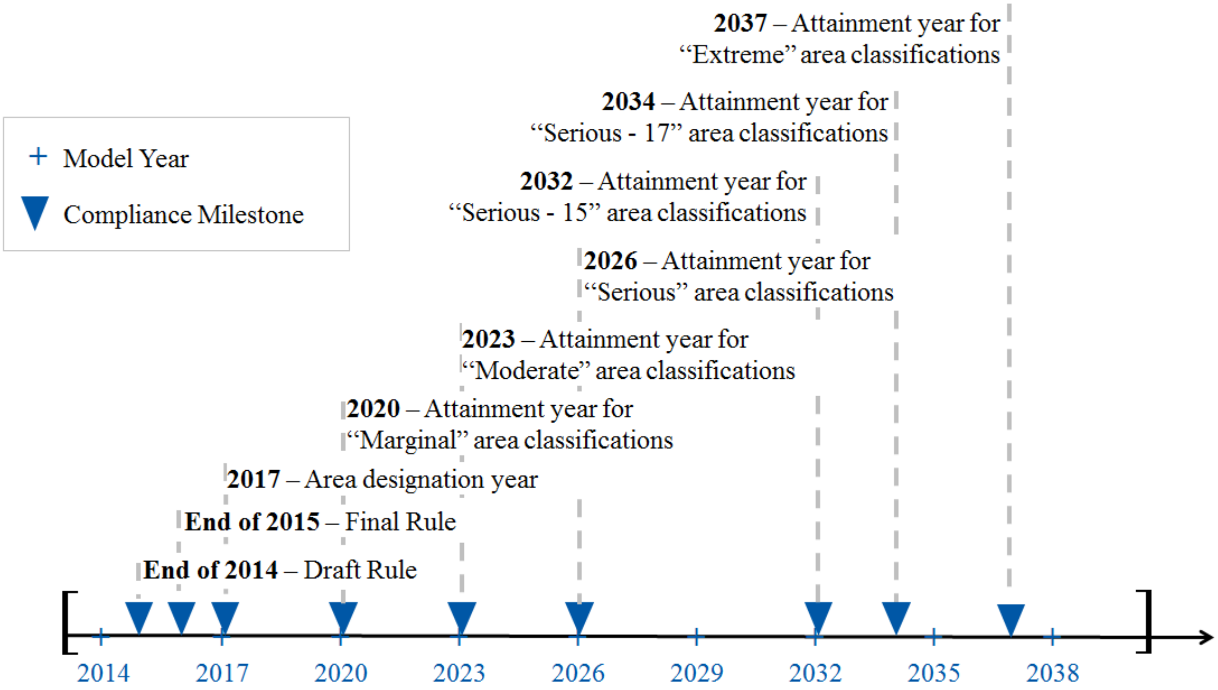
Table D-6. Classifications and Attainment Years for a Potential Standard of 60 ppb

Classification	Attainment Year	States	
Compliant	N/A	8	IA, MN, MS, MT, NH, ND, OR, VT
Marginal	2020	5	FL, NE, SC, SD, WA
Moderate	2023	32	AL, AZ, AR, CO, CT, DE, GA, ID, IL, IN, KS, KY, LA, ME, MD, MA, MO, NV, NJ, NM, NY, NC, OH, OK, PA, RI, TN, UT, VA, WV, WI, WY
Serious	2026	2	MI, TX
Severe-15	2032	0	
Severe-17	2034	0	
Extreme	2037	1	CA

Note: WA was classified as in attainment using our classification methodology but required controls based on our emissions analysis, so it was "bumped up" to a Marginal classification for cost timing purposes. CA was "bumped up" to an Extreme classification because it was Extreme for 75 ppb.

Source: NERA calculations as explained in text.

Figure D-2. Attainment Years for 60 ppb Classifications



Source: NERA calculations as explained in text

Note: The attainment years displayed in the figure represent the first year after a state comes into attainment.

2. Nature of Expenditures

a. Capital and O&M

The compliance cost estimates based on our state NO_X control marginal cost curves are annualized costs. We assumed 50% of annualized compliance costs are capital and 50% are operating and maintenance (O&M). The actual split will differ with the type of control; but controls generally require an up-front investment such as equipment retrofit/replacement and annual expenses to operate equipment or staff an ongoing program. We estimated the present value (*i.e.*, lump sum) of the capital portion of annualized compliance costs using 7% discount rate and 20-year capitalization period. The discount rate reflects EPA practice (EPA 2008, pp. 5-5 and 5-6), and the capitalization period reflects part of the range of equipment life for air emission controls used in EPA analyses (Pechan 2006). The capitalization period is an uncertain parameter in this analysis, and we would encourage EPA to provide detail on capitalization periods in its forthcoming ozone RIA.

b. Incremental Costs

Compliance costs were separated into incremental costs to achieve different ozone standards (84 ppb from baseline, 75 ppb incremental to 84 ppb, and 60 ppb incremental to 75 ppb). Costs attributable to each standard were then distributed over time according to state classifications and attainment years for the standards as described below.

c. VOC Costs

As discussed in Appendix C, EPA's 2008-2010 ozone analyses included the use of some VOC controls. These "known" VOC controls represent less than 1% of total compliance costs and we assume (following EPA) that NO_X is the limiting factor in ozone formation (EPA 2010, p. S2-3); however the ozone impact of NO_X reductions in EPA's analysis was incremental to these VOC controls, so we include them in our total compliance costs when reasonable for consistency. If we estimate that a state incurs any NO_X control costs to comply with the existing standard of 75 ppb, we include any EPA-modeled VOC control costs for that state using the same timing assumptions as other compliance costs attributable to the 75 ppb standard. If we estimate that a state is already compliant with a 75 ppb standard but requires reductions and costs to attain a 60 ppb standard, we apply VOC control costs in that state according the timing assumptions for the 60 ppb standard. Timing assumptions for the different ozone standards are described below.

3. Cost Timing

a. Distribution of Capital Costs

The present value of capital costs for each state and standard was distributed in an increasing fashion over the years leading up to attainment under the assumption that capital costs would be incurred before the compliance deadline for each state. We assumed capital costs would be incurred up to nine years prior to attainment.[45] Costs attributable to the potential standard of 60 ppb were incurred no earlier than 2017 (allowing time for EPA to develop state designations).

We divided capital costs so that they would be small shares of the total present value in early years and large shares of the total present value in the years immediately prior to attainment of a standard. Specifically, we counted the number of years over which capital would be distributed for a certain state and standard; for example, capital costs for Moderate states to comply with a 60 ppb standard (incremental to 75 ppb) were distributed over six years from 2017 through 2022 (the year prior to attainment). We then calculated the sum of the numbers up to the compliance year (*e.g.*, 1 + 2 + 3 + 4 + 5 + 6 = 21), and assigned shares of costs to each year based on its number relative to the sum (1/21 = 5% for 2017, 2/21 = 10% for 2018, *etc.*).

Figure D-3 provides an example of our capital cost distribution methodology using an area classified as Moderate for 60 ppb with $1 billion of annualized capital costs beginning in the attainment year (2023). In this example, we calculate the present value of the 20-year stream of annualized capital costs one year before attainment (in this case 2022) using a 7% discount rate. This present value ($10.6 billion) is shown in the second graph. Finally, we spread the present value over the years leading up to attainment, following the method discussed above.

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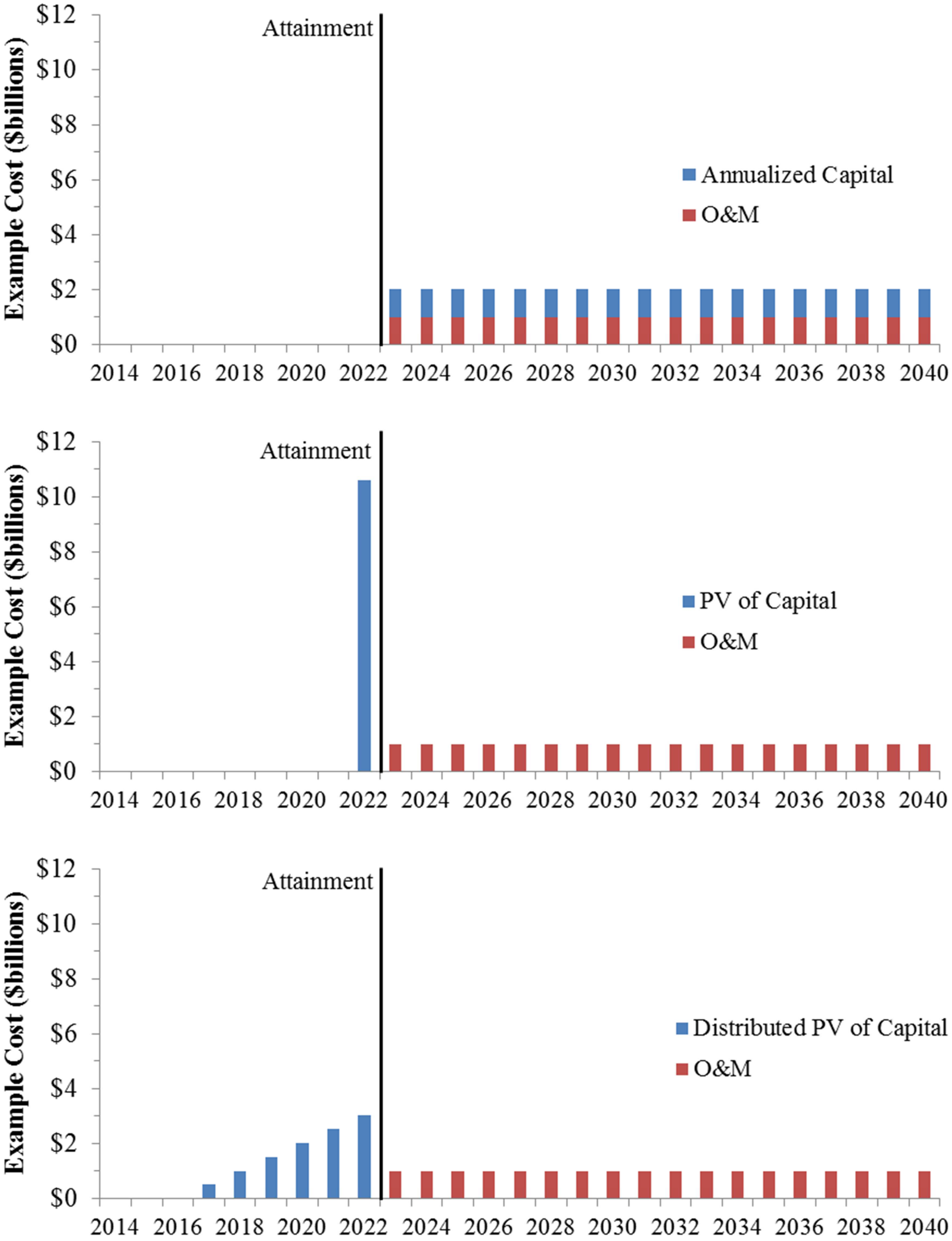
[45] In one case, the 84 ppb standard in California, we spread capital costs over more than nine years (the entire period from 2014 to the assumed attainment year of 2030).

Figure D-3. Illustration of Capital Cost Distribution Methodology

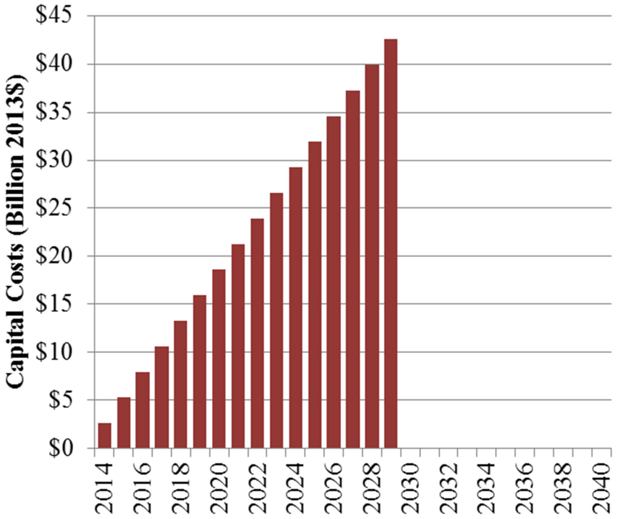


Note:	Example based on a state classified as Moderate for 60 ppb, implying an attainment year of 2023 and no capital costs incurred prior to 2017.
Source:	Illustrative example

Note that capital costs for different standards may overlap depending on specific state classifications and attainment years. For example, California was designated as Extreme under the 84 ppb standard with an attainment year of 2030; we also designate California as Extreme under a 75 ppb standard with an attainment year of 2033 and Extreme under a 60 ppb standard with an attainment year of 2037. California will incur capital costs for 84 ppb from 2014 through 2030, it will incur capital costs for 75 ppb from 2024 through 2032 (the nine years prior to attainment), and it will incur capital costs for 60 ppb from 2028 through 2036 (again, the nine years prior to attainment).

The distributions of nationwide capital costs for each incremental ozone standard are summarized in Figure D-4 through Figure D-6.

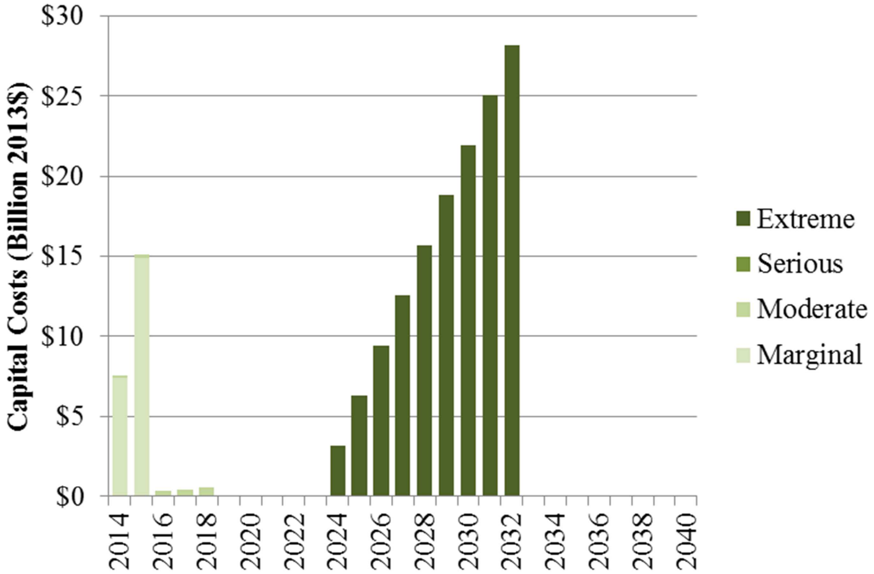
Figure D-4. Capital Costs by Year to Attain 84 ppb



Note: All costs to attain 84 ppb in our analysis are in California. Texas also requires reductions to attain 84 ppb, but due to difficulty assembling detailed EPA information on “known” controls in Texas we conservatively assume zero costs for Texas to attain 84 ppb (as noted in Appendix C).

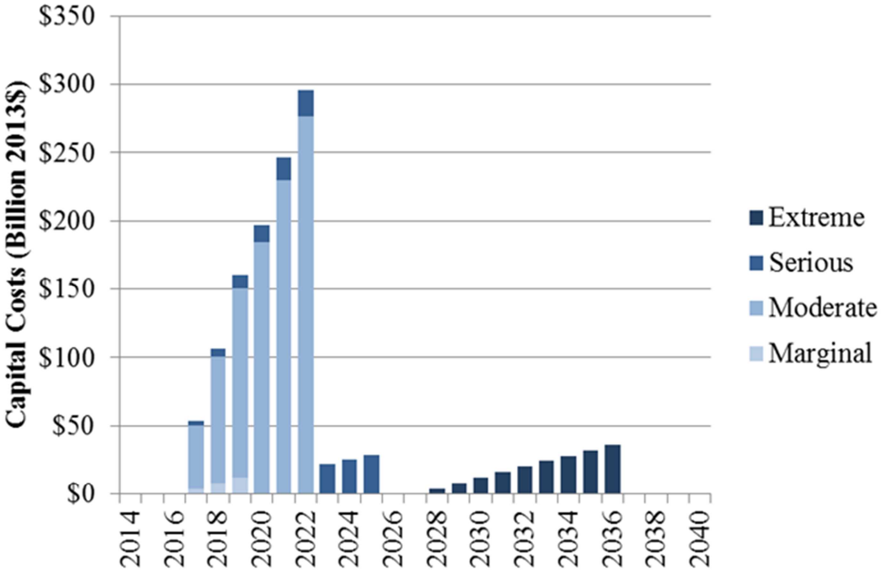
Source: NERA calculations as explained in text.

Figure D-5. Nationwide Capital Costs by Year to Attain 75 ppb (Incremental to 84 ppb)



Source: NERA calculations as explained in text.

Figure D-6. Nationwide Capital Costs by Year to Attain 60 ppb (Incremental to 75 ppb)



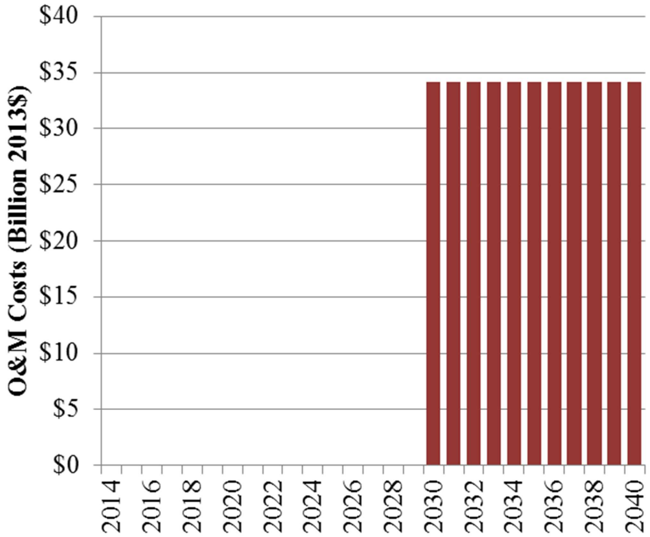
Source: NERA calculations as explained in text

b. Distribution of O&M Costs

We assume that the O&M portion of total annualized compliance costs under each standard are incurred in every year from the relevant state attainment year to the end of the model period.

The distributions of nationwide O&M costs for each incremental ozone standard are summarized in Figure D-7 through Figure D-9.

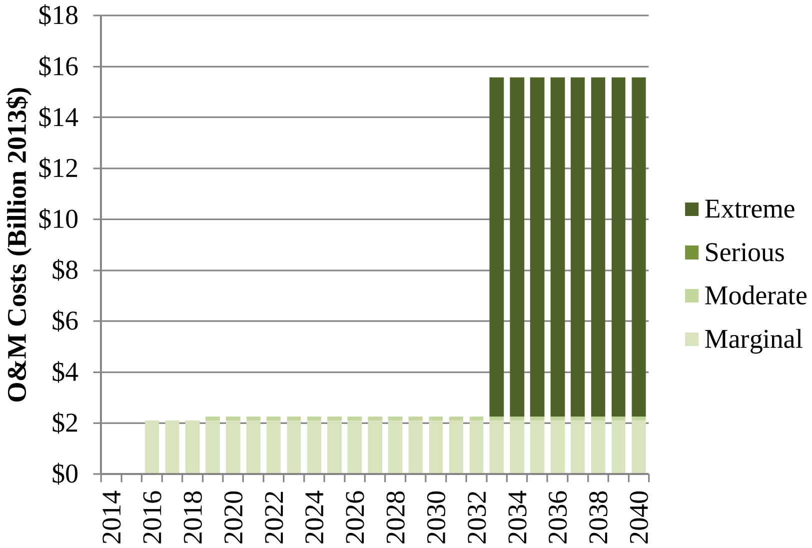
Figure D-7. O&M Costs by Year to Attain 84 ppb



Note: All costs to attain 84 ppb in our analysis are in California. Texas also requires reductions to attain 84 ppb, but due to difficulty assembling detailed EPA information on "known" controls in Texas we conservatively assume zero costs for Texas to attain 84 ppb (as noted in Appendix C).

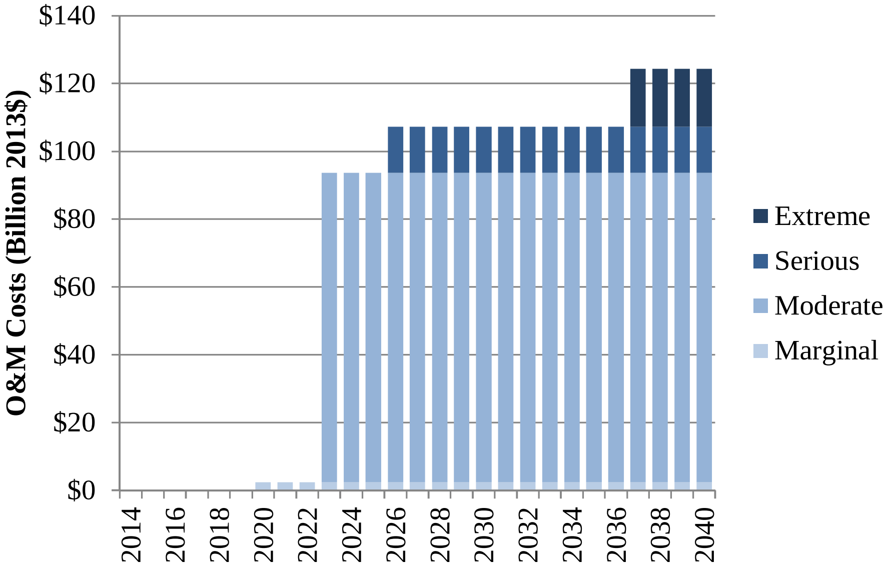
Source: NERA calculations as explained in text.

Figure D-8. Nationwide O&M Costs by Year to Attain 75 ppb (Incremental to 84 ppb)



Source: NERA calculations as explained in text.

Figure D-9. Nationwide O&M Costs by Year to Attain 60 ppb (Incremental to 75 ppb)



Source: NERA calculations as explained in text.

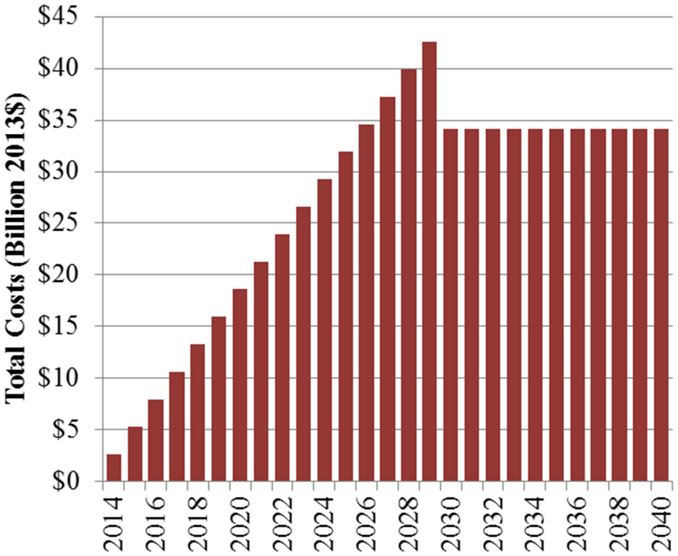
c. Total Costs by Year

The distributions of *nationwide* total costs (capital and O&M) for each incremental ozone standard are summarized in Figure D-10 through Figure D-13.

d. Total Costs by N$_{ew}$ERA Model Year

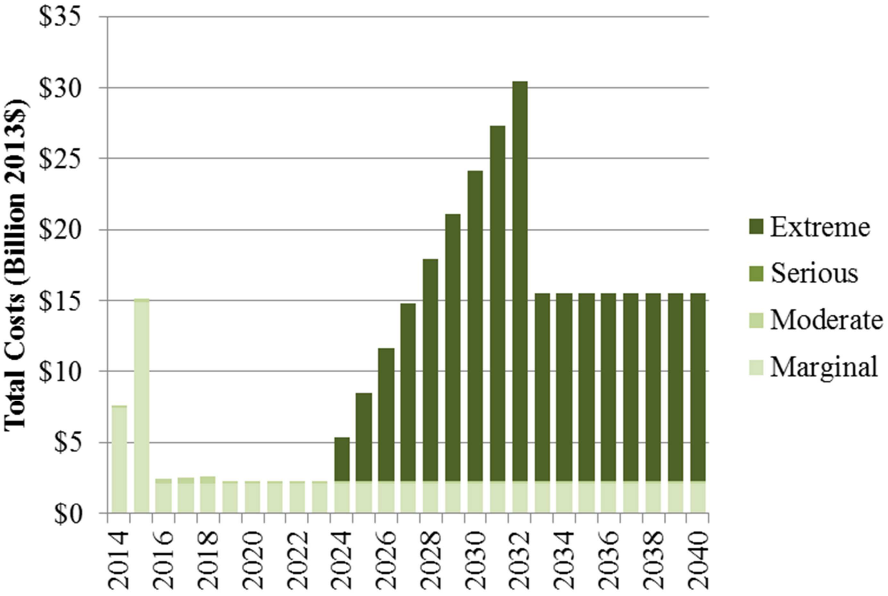
The N$_{ew}$ERA model used for this analysis operates in three-year increments beginning in 2014; model year 2014 represents 2014 through2016, model year 2017 represents 2017 through2019, and so on. For each model year, we took averages of annual compliance cost estimates for the corresponding three-year increment to create N$_{ew}$ERA input costs. Figure D-14 provides a national summary of those state-level N$_{ew}$ERA input costs.

Figure D-10. Total Costs by Year to Attain 84 ppb



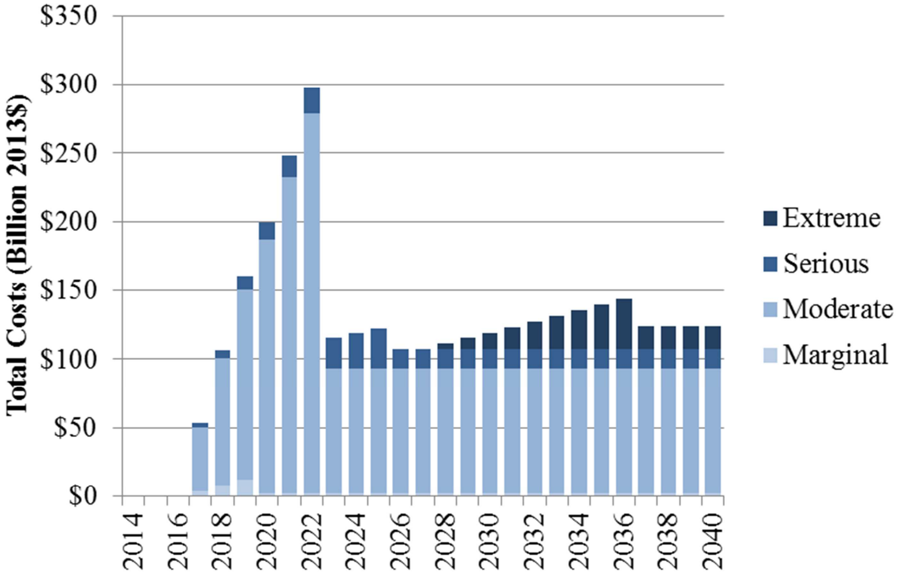
Note:	All costs to attain 84 ppb in our analysis are in California. Texas also requires reductions to attain 84 ppb, but due to difficulty assembling detailed EPA information on “known” controls in Texas we conservatively assume zero costs for Texas to attain 84 ppb (as noted in Appendix C).
Source:	NERA calculations as explained in text.

Figure D-11. Nationwide Total Costs by Year to Attain 75 ppb (Incremental to 84 ppb)



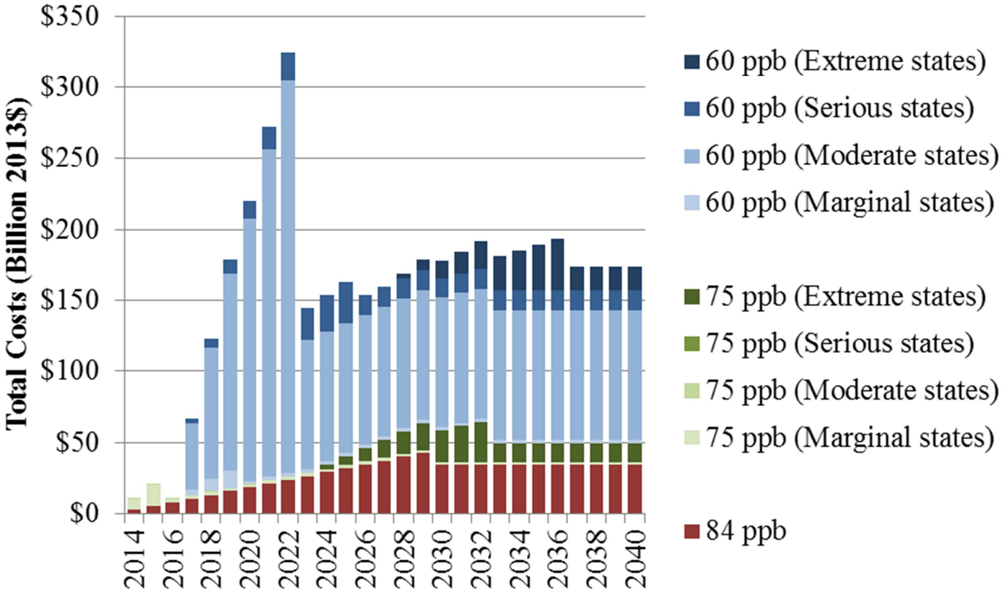
Source: NERA calculations as explained in text.

Figure D-12. Nationwide Total Costs by Year to Attain 60 ppb (Incremental to 75 ppb)



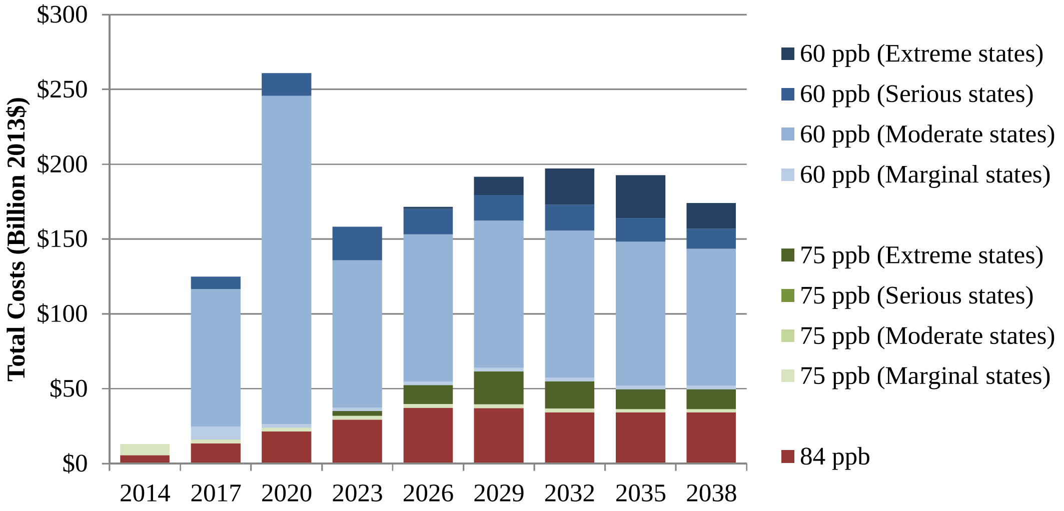
Source: NERA calculations as explained in text.

Figure D-13. Nationwide Total Costs by Year and Standard



Source: NERA calculations as explained in text.

Figure D-14. Nationwide Total Costs by N_{ew}ERA Model Year and Standard



Source: NERA calculations as explained in text.

C. References to the Appendix

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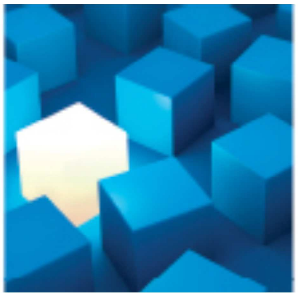

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