Chapter 6: Cost Analysis Approach and Results

Synopsis

This chapter describes our illustrative analysis of the engineering costs and monitoring costs associated with attaining the final and alternative standards for the National Ambient Air Quality Standard (NAAQS) for SO_2. We present our analysis of these costs in four separate sections. Section 6.1 presents the cost estimates. Sections 6.2 and 6.3 summarize the illustrative economic and energy impacts of these standards, respectively, while Section 6.4 outlines the main limitations of the analysis. As mentioned previously, the analysis is presented here for the final standard of 75 ppb, and two alternative standards: 50 ppb and 100 ppb in the year 2020.

Section 6.1 breaks out discussion of cost estimates into five subsections. The first subsection summarizes the data and methods that we employed to estimate the costs associated with the control strategies outlined in Chapter 4. The second subsection presents county level estimates of the costs of identified controls associated with the regulatory alternatives examined in this RIA. Following this discussion, the third subsection describes the approach used to estimate the extrapolated costs of unspecified emission reductions that may be needed to comply with the final and alternative standards. The fourth subsection provides a brief discussion of the monitoring costs associated with the final NAAQS. The fifth subsection provides the estimated total costs of the regulatory alternatives examined. This section concludes with a discussion of technological innovation and how that affects regulatory cost estimates.

This analysis does not estimate the projected attainment status of areas of the country other than those counties currently served by one of the approximately 349 monitors with complete data in the current network. It is important to note that the final rule will require a monitoring network wholly comprised of monitors sited at locations of expected maximum hourly concentrations. Only about one third of the existing SO_2 network may be source-oriented and/or in the locations of maximum concentration required by the final rule because the current network is focused on population areas and community-wide ambient levels of SO_2. Actual monitored levels using the new monitoring network may be higher than levels measured using the existing network. We recognize that once a network of monitors located at maximum-concentration is put in place, more areas could find themselves exceeding the new SO_2 NAAQS. However for this RIA analysis, we lack sufficient data to predict which counties might exceed the new NAAQS after implementation of the new monitoring network. Therefore we lack a credible analytic path to estimating costs and benefits for such a future scenario.

In addition, this chapter presents cost estimates associated with both identified control measures and unspecified emission reductions needed to reach attainment. Identified control measures include known measures for known sources that may be implemented to attain the alternative standard, whereas the achievement of unspecified emission reductions requires implementation of hypothetical additional measures in areas that would not attain the selected standard following the implementation of identified controls to known sources.

Note that the universe of sources achieving unspecified emission reductions beyond identified controls is not completely understood; therefore we are not able to identify known control devices, work practices, or other control measures to achieve these reductions. We calculated extrapolated costs for unspecified emission reductions using a fixed cost per ton approach. The analysis presents hypothetical costs of attaining the SO_2 NAAQS, subject to States' abilities to find emission reductions whose costs are finite, although likely to be higher than those of the identified control measures we believe to exist. Section 6.1 below describes in more detail our approaches for estimating both the costs of identified controls and the extrapolated costs of unspecified emission reductions needed beyond identified controls.

As is discussed throughout this RIA, the technologies and control strategies selected for this analysis are illustrative of one approach that nonattainment areas may employ to comply with the revised SO_2 standard. Potential control programs may be designed and implemented in a number of ways, and EPA anticipates that State and Local governments will consider those programs that are best suited for local conditions. As such, the costs described in this chapter generally cover the annualized costs of purchasing, installing, and operating the referenced technologies. We also present monitoring costs. Because we are uncertain of the specific actions that State Agencies will take to design State Implementation Plans to meet the revised standard, we do not estimate the costs that government agencies may incur to implement these control strategies.

6.1 Engineering Cost Estimates

6.1.1 Data and Methods: Identified Control Costs

Consistent with the emissions control strategy analysis presented in Chapter 4, our analysis of the costs associated with the final SO_2 NAAQS focuses SO_2 emission controls for EGU sources first, then nonEGU point sources, and then area sources.

6.1.1.1 EGU Sources

We used equations for wet FGD scrubber controls used in the Integrated Planning Model (IPM) to estimate the control cost for SO_2 reductions from EGUs. Equations are available for estimating capital and annual costs, and these equations are dependent on unit capacity and capacity factor (fraction of hours in a year that an EGU operates). Annual costs for control measures applied in IPM include those for fixed and variable operating and maintenance (O&M) items and annualized capital costs calculated using a capital recovery factor and are specifically applicable to EGUs.

6.1.1.2 NonEGU Point and Area Sources

After designing the hypothetical control strategy using the methodology discussed in Chapter 4, EPA used the Control Strategy Tool (CoST) and AirControlNET to estimate engineering control costs for nonEGU and Area sources. CoST calculates engineering costs using three different methods: (1) by multiplying an average annualized cost per ton estimate against the total tons of a pollutant reduced to derive a total cost estimate; (2) by calculating cost using an equation that incorporates key plant information; or (3) by using both cost per ton and cost equations. Most control cost information within CoST has been developed based on the cost per ton approach. This is because estimating engineering costs using an equation requires more data, and parameters used in other non-cost per ton methods may not be readily available or broadly representative across sources within the emissions inventory. The costing equations used in CoST require either plant capacity or stack flow to determine annual, capital and/or operating and maintenance (O&M) costs. Capital costs are converted to annual costs using the capital recovery factor (CRF)[1]. Where possible, cost calculations are used to calculate total annual control cost (TACC) which is a function of the capital (CC) and O&M costs. The capital recovery factor incorporates the interest rate and equipment life (in years) of the control equipment. Operating costs are calculated as a function of annual O&M and other variable costs. The resulting TACC equation is TACC = (CRF * CC) + O&M.

Engineering costs will differ based upon quantity of emissions reduced, plant capacity, or stack flow which can vary by emissions inventory year. Engineering costs will also differ in a nominal sense by the year the costs are calculated for (i.e., 1999$ versus 2006$).[2] For capital

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[1] For more information on this cost methodology and the role of AirControlNET in control strategy analysis, see Section 6 of the 2006 PM RIA, AirControlNET 4.1 Control Measures Documentation (Pechan, 2006b), or the EPA Air Pollution Control Cost Manual, Section 1, Chapter 2, found at http://www.epa.gov/ttn/catc/products.html#cccinfo.

[2] The engineering costs will not be any different in a real (inflation-adjusted) sense if calculated in 2006 versus 1999 dollars if properly escalated. For this analysis, all costs are reported in real 2006 dollars.

investment, we do not assume early capital investment in order to attain standards by 2020. For 2020, our estimate of annualized costs represents a “snapshot” of the annualized costs, which include annualized capital and O&M costs, for those controls included in our identified control strategy analysis. Our engineering cost analysis uses the equivalent uniform annual costs (EUAC) method, in which annualized costs are calculated based on the equipment life for the control measure along with the interest rate by use of the CRF as mentioned previously in this chapter. Annualized costs are estimated as equal for each year the control is expected to operate. Hence, our annualized costs for nonEGU point and area sources estimated for 2020 are the same whether the control measure is installed in 2019 or in 2010. We make no presumption of additional capital investment in years beyond 2020. The EUAC method is discussed in detail in the EPA Air Pollution Control Cost Manual[3]. Applied controls and their respective engineering costs are provided in the SO_2 NAAQS docket.

6.1.2 Identified Control Strategy Analysis Engineering Costs

In this section, we provide engineering cost estimates of the control strategies identified in Chapter 4 that include control measures applied to nonEGU sources, area sources, and EGUs. Engineering costs generally refer to the expense of capital equipment installation, the site preparation costs for the application, and annual operating and maintenance costs.

The total annualized cost of control in each geographic area of our analysis for the hypothetical control scenario is provided in Table 6.1. These numbers reflect the engineering costs across all sectors. Estimates are annualized at a discount rate of 7%.

Table 6.1 summarizes these costs in total and by sector nationwide. As indicated in the table, the estimated annualized costs of these controls under the 75 ppb final standard in 2020 are $960 million per year (2006$). For the other 2 alternative standards examined, in 2020 the annualized costs range from $470 million to $2,600 million. Consistent with Chapter 4's summary of the air quality impacts associated with identified controls, the cost estimates in Table 6.1 reflect partial attainment with the alternative standard being examined in this RIA. Consistent with the identified control strategy analysis emission reductions presented in Chapter 4, a majority of the costs are from controls applied to EGU sources, but a relatively large share of costs is borne by nonEGU point sources.

The costs of the EGU strategy reflect application of controls (described in Chapter 4) where needed to obtain as much reductions as possible to attain each alternative standard.

[3] http://epa.gov/ttn/catc/products.html#cccinfo

Table 6.2 presents the identified control costs in 2020 by county for each alternative standard. These costs are shown for a 7 percent discount rate.

Table 6.1: Annual Control Costs of Identified Controls in 2020 in Total and by Sector (Millions of 2006$) [a, b]

	50 ppb	75 ppb	100 ppb
Total Costs for Identified Controls[c, d]	$ 2,600	$ 960	$ 470
EGUs	$ 1,700	$ 700	$ 300
nonEGUs	$ 900	$ 260	$ 170
Area Sources	$ 40	$ 0.55	$ 0.24

[a] All estimates rounded to two significant figures. As such, totals will not sum down columns.
[b] All estimates provided reflect the engineering cost of the identified control strategy analysis, incremental to a 2020 baseline.
[c] Total annualized costs were calculated using a 7% discount rate
[d]These values represent partial attainment costs for the identified control strategy analysis. There were locations not able to attain the alternative standard being analyzed with identified controls only.

Table 6.2: Identified Controls – Total Annual Cost by County in 2020 (Millions of 2006$)[a,b,c,d]

state	county	50 ppb	75 ppb	100 ppb
Arizona	Gila Co	$8.8	$8.8	$8.8
Colorado	Denver Co	$39.0		
Connecticut	New Haven Co	$8.2		
Florida	Duval Co	$24.0		
Florida	Hillsborough Co	$3.2		
Georgia	Chatham Co	$42.0	$12.0	
Idaho	Bannock Co	$0.6		
Illinois	Cook Co	$16.0		
Illinois	Madison Co	$65.0	$31.0	
Illinois	St Clair Co			
Illinois	Sangamon Co	$60.0	$30.0	
Illinois	Tazewell Co	$120.0	$27.0	
Indiana	Floyd Co	$0.14		
Indiana	Fountain Co	$19.0		
Indiana	Jasper Co			
Indiana	Lake Co	$210.0	$49.0	
Indiana	Morgan Co	$10.0		
Indiana	Porter Co			
Indiana	Wayne Co	$47.0	$47.0	$35.0
Iowa	Linn Co	$26.0	$18.0	
Iowa	Muscatine Co	$89.0	$65.0	$31.0
Kentucky	Jefferson Co	$85.0		
Kentucky	Livingston Co	$11.0		
Louisiana	East Baton Rouge Par	$29.0		

state	county	50 ppb	75 ppb	100 ppb
Missouri	Greene Co	$16.0		
Missouri	Jackson Co	$59.0	$26.0	
Missouri	Jefferson Co	$310.0	$280.0	$280.0
Montana	Yellowstone Co	$12.0		
Nebraska	Douglas Co	$17.0	$17.0	
New Hampshire	Merrimack Co	$19.0		
New York	Erie Co	$38.0	$14.0	
New York	Monroe Co	$7.5		
New York	Suffolk Co	$50.0	$21.0	
North Carolina	New Hanover Co	$19.0		
Ohio	Clark Co	$19.0		
Ohio	Jefferson Co	$18.0		
Ohio	Lake Co	$110.0	$47.0	
Ohio	Summit Co	$76.0	$19.0	$3.0
Oklahoma	Kay Co	$28.0		
Oklahoma	Muskogee Co	$78.0	$51.0	$25.0
Oklahoma	Tulsa Co	$24.0		
Pennsylvania	Allegheny Co	$160.0		
Pennsylvania	Blair Co	$38.0		
Pennsylvania	Northampton Co	$61.0	$28.0	
Pennsylvania	Warren Co	$29.0	$29.0	$29.0
South Carolina	Lexington Co	$22.0		
Tennessee	Blount Co	$36.0		
Tennessee	Bradley Co	$39.0	$2.9	
Tennessee	Montgomery Co	$38.0	$38.0	$38.0
Tennessee	Shelby Co	$16.0		
Tennessee	Sullivan Co	$110.0	$47.0	
Texas	Harris Co	$66.0		
Texas	Jefferson Co	$61.0	$28.0	
West Virginia	Hancock Co	$30.0		
Wisconsin	Brown Co	$40.0		
Wisconsin	Oneida Co	$22.0	$22.0	$22.0

[a] All estimates rounded to two significant figures. As such, totals will not sum down columns.
[b] All estimates provided reflect the engineering cost of the identified control strategy analysis, incremental to a 2020 baseline.
[c] Total annualized costs were calculated using a 7% discount rate.
[d]These values represent partial attainment costs for the identified control strategy analysis. There were locations not able to attain the alternative standard being analyzed with identified controls only.

6.1.3 Extrapolated Costs

Prior to presenting the methodology for estimating costs for unspecified emission reductions, it is important to provide information from EPA's Science Advisory Board (SAB) Council Advisory on the issue of estimating costs of unidentified control measures.[4]

> *812 Council Advisory, Direct Cost Report, Unidentified Measures (charge question 2.a):*
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> *"The Project Team has been unable to identify measures that yield sufficient emission reductions to comply with the National Ambient Air Quality Standards (NAAQS) and relies on unidentified pollution control measures to make up the difference. Emission reductions attributed to unidentified measures appear to account for a large share of emission reductions required for a few large metropolitan areas but a relatively small share of emission reductions in other locations and nationwide.*
>
> *"The Council agrees with the Project Team that there is little credibility and hence limited value to assigning costs to these unidentified measures. It suggests taking great care in reporting cost estimates in cases where unidentified measures account for a significant share of emission reductions. At a minimum, the components of the total cost associated with identified and unidentified measures should be clearly distinguished. In some cases, it may be preferable to not quantify the costs of unidentified measures and to simply report the quantity and share of emissions reductions attributed to these measures.*
>
> *"When assigning costs to unidentified measures, the Council suggests that a simple, transparent method that is sensitive to the degree of uncertainty about these costs is best. Of the three approaches outlined, assuming a fixed cost/ton appears to be the*

[4] U.S. Environmental Protection Agency, Advisory Council on Clean Air Compliance Analysis (COUNCIL), *Council Advisory on OAR's Direct Cost Report and Uncertainty Analysis Plan*, Washington, DC. June 8, 2007.

simplest and most straightforward. Uncertainty might be represented using alternative fixed costs per ton of emissions avoided."

EPA has considered this advice and the requirements of E.O. 12866 and OMB circular A-4, which provides guidance on the estimation of benefits and costs of regulations.

As indicated above the identified control costs do not result in attainment of the selected or alternative standards in four areas. In these areas, unspecified emission reductions needed beyond identified controls will likely be necessary to reach attainment.

Taking into consideration the above SAB advice, we estimated the costs of unspecified future emission reductions using a fixed (annualized) cost per ton approach. In previous analyses we have estimated the extrapolated costs using other marginal cost based approaches in addition to the fixed cost per ton approach. We examine the data available for each analysis and determine on a case by case basis the appropriate extrapolation technique. Due to the limited number of control measures applied in this analysis across all sectors, we concluded that it would not be credible to establish a marginal cost-based approach or a representative value for the costs of further SO_2 emission reductions. We also recognize that the emissions from EGUs are the largest for these areas. In addition, there is also limited information on SO_2 controls applied to non-EGUs beyond the scope of this analysis, especially for small sources. For these reasons, we have relied upon a simple fixed cost approach utilized for that analysis to represent the fixed cost of unspecified emission reductions for this analysis. The primary estimate presented is $15,000 (2006$), with sensitivities of $10,000/ton and $20,000/ton. Use of $15,000/ton as a fixed cost estimate is commensurate with the cost of nonEGU SO_2 control measures as applied in the $PM_{2.5}$ RIA three years ago. This fixed costs is also much higher than reported costs for SO_2 controls such as wet FGD scrubbers for industrial boilers are reported to be up to at least $5,200/ton (2006$).[5] Also, this estimate is considerably greater than the current and futures prices for SO_2 emissions allowances traded for compliance with the CAIR program.[6] Finally, as

[5] Applicability and Feasibility of NOx, SO_2, and PM Emissions Control Technologies for Industrial, Commercial, and Institutional (ICI) Boilers. NESCAUM, November 2008. Available on the Internet at http://www.nescaum.org/documents/ici-boilers-20081118-final.pdf/.

[6] The Evolving SO2 Allowance Market: Title IV, CAIR, and Beyond. Palmer, Karen, Resources for the Future and Evans, David, US EPA/OPEI, July 13, 2009. Available on the Internet at http://www.rff.org/Publications/WPC/Pages/090713-Evolving-SO2-Allowance-Market.aspx.

mentioned above, the use of a fixed cost per ton of $15,000/ton is consistent with what an advisory committee to the Section 812 second prospective analysis on the Clean Air Act Amendments suggested in June 2007 for estimating the costs of reductions from unidentified controls.

The estimation of costs for emission reductions needed to reach attainment many years in the future is inherently difficult. We expect that additional control measures that we were not able to identify may be developed by 2020. As described later in this chapter, our experience with Clean Air Act implementation shows that technological advances and development of innovative strategies can make possible cost effective emissions reductions that are unforeseen today, and can reduce costs of some emerging technologies over time. But we cannot precisely predict the amount of technology advance in the future. The relationship of the cost of additional future controls to the cost of control options available today is not at all clear. Available, currently known control measures increase in costs per ton beyond the range of what has ever been implemented and because they are not currently required can not serve as an accurate representation of expected costs of implementation. Such measures would still not provide the needed additional control for full attainment in the analysis year 2020. History has shown that when faced with potentially costly controls requirements, firms could adapt by changing their production process or innovate to develop more cost effective ways of meeting control requirements. We recognize that a single fixed cost of control of $15,000 per ton of emissions reductions does not account for the significant emissions cuts that are necessary in some areas and so its use provides an estimate that is likely to differ from actual future costs. Yet, the limited emission controls dataset applied for the identified control strategy analysis significantly limits our ability to estimate full attainment costs using more sophisticated methods.

In the economics literature there are a variety of theoretical ways to estimate the cost of more stringent emissions reductions than can be achieved by known technologies. One method would be to estimate the cost of reducing all remaining tons by simply extrapolating the cost curve using data on cost and effectiveness of all known controls. This method can imply the last ton of reductions costs an amount which is thousands of times higher than the fixed cost presumed above (i.e., $15,000 per ton). This result is highly unlikely given the uncertainty surrounding the assumptions implicit in this estimate (e.g. projecting 10 years into the future, not including factors for technological innovation and improvements, not including societal and economy wide changes from dealing with climate change). Such a result does not necessarily mean that such costs will be incurred, because of uncertainties about future control technology, economic activity and the possibility of deferment of full attainment dates. Another variant on this approach is to develop a method which simulates technological change by causing shifts in the cost curve over time to reflect that innovation can reduce costs of control.

In addition, it is theoretically possible to consider the cost of a geographic area changing to a different type of economic structure over time (e.g. moving from a one type of manufacturing to another or from manufacturing to a more service oriented economy) as another way to predict the cost of meeting a tighter standard. This would be a challenging, data intensive exercise that would be very area specific. Nationwide estimates would have to be built from an area by area basis. In some areas, mobile sources may be a significant source of emissions; some areas are experimenting with congestion pricing as a means of restructuring how people and goods travel to reduce emissions.

In the absence of more robust methods for estimating these costs, EPA is following the SAB advice to keep the approach simple and transparent. If commentors have different assumptions about the cost of attainment, it is easy for them to calculate the cost of attaining a tighter standard using the fixed cost formula. EPA is going to continue to work on most robust methods of developing these estimates. EPA will continue to improve methods of estimating the costs of full attainment when health-based standards require emissions cuts greater than can be achieved by all known engineering controls. Over the course of the next several months EPA, in partnership with OMB and interested federal agencies will be investigating different ways of estimating these extrapolated full attainment costs, including consideration of ways of incorporating technological change and other factors. In addition, EPA is looking into developing approaches to characterize different future states of the world. These scenarios (similar to the goal of the IPCC scenarios for the outcome of climate change, for example) would allow us to consider a range of possibilities. Many criteria pollutant emissions result from combustion processes used to make energy, transport goods and people and other industrial operations. Our alternative futures could represent different types of power generation that could become more prevalent under different circumstances. For example, in one scenario solar or wind power would prevail leading to reductions in the burning of coal for power generation. In contrast, in another scenario coal use remains consistent with current usage but is subject to more emissions reductions. Another could presume significant inroads for electric vehicles. EPA will be considering this approach as another method for projecting a range of possibilities for the cost of attaining a tighter standard. This research will include a review of how best to characterize the likely adoption by 2020 (or similar target years) of new technologies (e.g., solar, wind and others unrelated to fossil fuel combustion, as well as more fuel-efficient vehicles), that are expected to have the ancillary benefit of facilitating compliance with new standards for criteria air pollutants. It will also include consideration of control measures that depend on behavioral change (such as congestion pricing) rather than simply the adoption of engineering controls.

The approach outlined above represents a significant amount of theoretical and applied analysis and the development of new methodologies for doing this analysis. Data supporting our cost approach is in the SO2 NAAQS RIA docket and we welcome ideas from the public on suggestions for analytical methods to estimate these future costs and plans to hopefully utilize portions of it in the proposed PM2.5 NAAQS RIA to be released with the rest of the material accompanying the standard.

Table 6.3 presents the extrapolated costs for each alternative standard analyzed. See Chapter 4 for a complete discussion of the air quality projections for these counties.

Table 6.3: Extrapolated Costs Estimated for the Alternative Standards (Millions of 2006$) [a, b]

	50 ppb	75 ppb	100 ppb
Total Extrapolated Costs ($10,000/ton):	$ 1,200	$ 330	$ 180
Total Extrapolated Costs ($15,000/ton):	**$ 1,800**	**$ 500**	**$ 260**
Total Extrapolated Costs ($20,000/ton):	$ 2,400	$ 670	$ 350

[a] All estimates rounded to two significant figures. As such, totals will not sum down columns.
[b] Estimates of extrapolated costs are assumed using a 7% discount rate. Given the fixed cost per ton approach used here, 3% discount rate estimates could not be calculated.

6.1.4 Monitoring Costs

The final amendments would revise the technical requirements for SO_2 monitoring sites; require the siting and operation of additional SO_2 ambient air monitors, and the reporting of the collected ambient monitoring data to EPA's Air Quality System (AQS). We have estimated the burden based on the monitoring requirements of this rule. Details of the burden estimate are contained in the information collection request (ICR) accompanying the final rule.[7] The ICR estimates annualized costs of a new monitoring network at approximately $15 million per year (2006 dollars).

6.1.5 Summary of Cost Estimates

Table 6.4 provides a summary of total costs to achieve the alternative standards in the year 2020, and this summary includes the sensitivity estimates. As mentioned previously, we use $15,000/ton as our primary estimate of the extrapolated costs on a per ton reduction basis, and $10,000/ton and $20,000/ton are used as sensitivities. Using that estimate, we find that the total annualized costs for the 75 ppb final standard in 2020 are $1.0 billion (2006$) using seven percent as the discount rate and applying the primary estimate of the extrapolated costs, and the costs for the other alternative standards range from $0.5 billion to $2.6 billion (2006$). The portion of these costs accounted for by identified controls ranges from 59 percent for the 50 ppb standard to 64 percent for the 100 ppb standard. Hence, the portion of these costs accounted for by extrapolated controls ranges from 41 percent for the 50 ppb standard to 36 percent for the 100 ppb standard.

Finally, Table 6.5 present the annual cost/ton for the identified controls by sector as applied for the alternative standards in 2020. For each alternative standard, the annual cost/ton for reductions from the non-EGU sector is the most expensive. For the 75 ppb final standard, reductions from non-EGUs occur at $2,400/ton while the annual cost/ton for EGU sector is $2,700/ton. All of these estimates are for reductions in 2020 in 2006 dollars and using a seven percent discount rate.

The significant difference between the costs of identified controls alone and the cost of achieving attainment (i.e. including both identified controls and emission reductions beyond identified controls) in this and other areas reflects the limited information available to EPA on

[7] ICR 2358.01, May 2009.

the control measures that sources may implement. Although AirControlNET contains information on a large number of different point source controls, we would expect that State and local air quality managers would have access to additional information on the controls available to the most significant sources.

Table 6.4: Total Annual Costs for Alternative Standards (Millions of 2006$)[a, b]

		50 ppb	75 ppb	100 ppb
Identified Control Costs		$ 2,600	$ 960	$ 470
Monitoring Costs		$2.1	$2.1	$2.1
Extrapolated Costs	Fixed Cost ($10,000/ton)	$ 1,200	$ 330	$ 180
	[d]Fixed Cost ($15,000/ton)	**$ 1,800**	**$ 500**	**$ 260**
	Fixed Cost ($20,000/ton)	$ 2,400	$ 670	$ 350
Total Costs	Fixed Cost ($10,000/ton)	$ 3,800	$ 1,300	$ 650
	[d]Fixed Cost ($15,000/ton)	**$ 4,400**	**$ 1,500**	**$ 730**
	Fixed Cost ($20,000/ton)	$ 5,000	$ 1,600	$ 820

[a] All estimates rounded to two significant figures. As such, totals will not sum down columns.
[b] All estimates provided reflect the engineering cost of the identified control strategy analysis, incremental to a 2020.
[c] Values reflect a 7% discount rate.
[d] Our primary estimate of extrapolated costs is, as mentioned earlier in this RIA, based on a fixed annual cost of $15,000/ton. This estimate of extrapolated costs is incorporated into our estimate of total costs for the alternative standards.

Table 6.5: Annual Cost per Ton of Identified Controls applied for the Alternative Standards by Emissions Sector (2006$) [a, b]

Emissions Sector	50 ppb	75 ppb	100 ppb
NonEGU	$ 2,400	$ 2,700	$ 2,800
Area	$ 2,500	$ 2,200	$ 2,100
EGU	$ 2,700	$ 2,700	$ 2,800

[a] All estimates rounded to two significant figures. As such, totals will not sum down columns.
[b] All estimates provided reflect the engineering cost of the identified control strategy analysis, incremental to a 2020 baseline.

6.1.6 Technology Innovation and Regulatory Cost Estimates

There are many examples in which technological innovation and "learning by doing" have made it possible to achieve greater emissions reductions than had been feasible earlier, or have reduced the costs of emission control in relation to original estimates. Studies[8] have suggested that costs of some EPA programs have been less than originally estimated due in part to inadequate inability to predict and account for future technological innovation in regulatory impact analyses.

Constantly increasing marginal costs are likely to induce the type of innovation that would result in lower costs than estimated early in this chapter. Breakthrough technologies in control equipment could by 2020 result in a rightward shift in the marginal cost curve for such equipment (Figure 6.1)[9] as well as perhaps a decrease in its slope, reducing marginal costs per unit of abatement, and thus deviate from the assumption of a static marginal cost curve. In addition, elevated abatement costs may result in significant increases in the cost of production and would likely induce production efficiencies, in particular those related to energy inputs, which would lower emissions from the production side.

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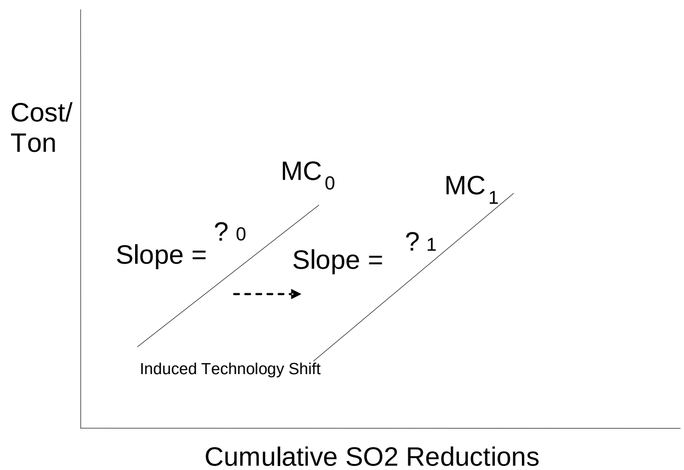
[8] Harrington et al. (2000) and previous studies cited by Harrington.
Harrington, W., R.D. Morgenstern, and P. Nelson. 2000. "On the Accuracy of Regulatory Cost Estimates." *Journal of Policy Analysis and Management* 19(2):297-322.
[9] Figure 6.1 shows a linear marginal abatement cost curve. It is possible that the shape of the marginal abatement cost curve is non-linear.

Figure 6.1: Technological Innovation Reflected by Marginal Cost Shift



6.1.6.1 Examples of Technological Advances in Pollution Control

There are numerous examples of low-emission technologies developed and/or commercialized over the past 15 or 20 years, such as:

- Selective catalytic reduction (SCR) and ultra-low NOx burners for NOx emissions
- Scrubbers which achieve 95% and even greater SO2 control on boilers
- Sophisticated new valve seals and leak detection equipment for refineries and chemical plans
- Low or zero VOC paints, consumer products and cleaning processes
- Chlorofluorocarbon (*CFC)* free air conditioners, refrigerators, and solvents
- Water and powder-based coatings to replace petroleum-based formulations
- Vehicles far cleaner than believed possible in the late 1980s due to improvements in evaporative controls, catalyst design and fuel control systems for light-duty vehicles; and treatment devices and retrofit technologies for heavy-duty engines

- Idle-reduction technologies for engines, including truck stop electrification efforts
- Market penetration of gas-electric hybrid vehicles, and clean fuels
- The development of retrofit technology to reduce emissions from in-use vehicles and non-road equipment

These technologies were not commercially available two decades ago, and some were not even in existence. Yet today, all of these technologies are on the market, and many are widely employed. Several are key components of major pollution control programs and most of the examples are discussed further below.

What is known as "learning by doing" or "learning curve impacts", which is a concept distinct from technological innovation, has also made it possible to achieve greater emissions reductions than had been feasible earlier, or have reduced the costs of emission control in relation to original estimates. Learning curve impacts can be defined generally as the extent to which variable costs (of production and/or pollution control) decline as firms gain experience with a specific technology. Such impacts have been identified to occur in a number of studies conducted for various production processes. Impacts such as these would manifest themselves as a lowering of expected costs for operation of technologies in the future below what they may have been.

The magnitude of learning curve impacts on pollution control costs has been estimated for a variety of sectors as part of the cost analyses done for the Draft Direct Cost Report for the second EPA Section 812 Prospective Analysis of the Clean Air Act Amendments of 1990.[10] In that report, learning curve adjustments were included for those sectors and technologies for which learning curve data was available. A typical learning curve adjustment example is to reduce either capital or O&M costs by a certain percentage given a doubling of output from that sector or for that technology. In other words, capital or O&M costs will be reduced by some percentage for every doubling of output for the given sector or technology.

T.P. Wright, in 1936, was the first to characterize the relationship between increased productivity and cumulative production. He analyzed man-hours required to assemble successive airplane bodies. He suggested the relationship is a log linear function, since he observed a constant linear reduction in man-hours every time the total number of airplanes assembled was doubled. The relationship he devised between number assembled and assembly

[10] E.H. Pechan and Associates and Industrial Economics, Direct Cost Estimates for the Clean Air Act Second Section 812 Prospective Analysis: Draft Report, prepared for U.S. EPA, Office of Air and Radiation, February 2007. Available at http://www.epa.gov/oar/sect812/mar07/direct_cost_draft.pdf.

time is called Wright's Equation (Gumerman and Marnay, 2004)[11]. This equation, shown below, has been shown to be widely applicable in manufacturing:

$$\text{Wright's Equation: } C_N = C_o * N^b,$$

Where:

N	=	cumulative production
C_N	=	cost to produce N^{th} unit of capacity
C_o	=	cost to produce the first unit
B	=	learning parameter = ln (1-LR)/ln(2), where
LR	=	learning by doing rate, or cost reduction per doubling of capacity or output.

The percentage adjustments to costs can range from 5 to 20 percent, depending on the sector and technology. Learning curve adjustments were prepared in a memo by IEc supplied to US EPA and applied for the mobile source sector (both onroad and nonroad) and for application of various EGU control technologies within the Draft Direct Cost Report.[12] Advice received from the SAB Advisory Council on Clean Air Compliance Analysis in June 2007 indicated an interest in expanding the treatment of learning curves to those portions of the cost analysis for which no learning curve impact data are currently available. Examples of these sectors are non-EGU point sources and area sources. The memo by IEc outlined various approaches by which learning curve impacts can be addressed for those sectors. The recommended learning curve impact adjustment for virtually every sector considered in the Draft Direct Cost Report is a 10% reduction in O&M costs for two doubling of cumulative output, with proxies such as cumulative fuel sales or cumulative emission reductions being used when output data was unavailable.

For this RIA, we do not have the necessary data for cumulative output, fuel sales, or emission reductions for all sectors included in our analysis in order to properly generate control costs that reflect learning curve impacts. Clearly, the effect of including these impacts would be to lower our estimates of costs for our control strategies in 2020, but we are not able to include such an analysis in this RIA.

[11] Gumerman, Etan and Marnay, Chris. Learning and Cost Reductions for Generating Technologies in the National Energy Modeling System (NEMS), Ernest Orlando Lawrence Berkeley National Laboratory, University of California at Berkeley, Berkeley, CA. January 2004, LBNL-52559.

[12] Industrial Economics, Inc. Proposed Approach for Expanding the Treatment of Learning Curve Impacts for the Second Section 812 Prospective Analysis: Memorandum, prepared for U.S. EPA, Office of Air and Radiation, August 13, 2007.

6.1.6.2 Influence on Regulatory Cost Estimates

Studies indicate that it is not uncommon for pre-regulatory cost estimates to be higher than later estimates, in part because of inability to predict technological advances. Over longer time horizons the opportunity for technical advances is greater.

- *Multi-rule study:* Harrington et al. of Resources for the Future[13] conducted an analysis of the predicted and actual costs of 28 federal and state rules, including 21 issued by EPA and the Occupational Safety and Health Administration (OSHA), and found a tendency for predicted costs to overstate actual implementation costs. Costs were considered accurate if they fell within the analysis error bounds or if they fall within 25 percent (greater or less than) the predicted amount. They found that predicted total costs were overestimated for 14 of the 28 rules, while total costs were underestimated for only three rules. Differences can result because of quantity differences (e.g., overestimate of pollution reductions) or differences in per-unit costs (e.g., cost per unit of pollution reduction). Per-unit costs of regulations were overestimated in 14 cases, while they were underestimated in six cases. In the case of EPA rules, the agency overestimated per-unit costs for five regulations, underestimated them for four regulations (three of these were relatively small pesticide rules), and accurately estimated them for four. Based on examination of eight economic incentive rules, "for those rules that employed economic incentive mechanisms, overestimation of per-unit costs seems to be the norm," the study said. It is worth noting here, that the controls applied for this NAAQS do not use an economic incentive mechanism. In addition, Harrington also states that overestimation of total costs can be due to error in the quantity of emission reductions achieved, which would also cause the benefits to be overestimated.

Based on the case study results and existing literature, the authors identified technological innovation as one of five explanations of why predicted and actual regulatory cost estimates differ: "Most regulatory cost estimates ignore the possibility of technological innovation … Technical change is, after all, notoriously difficult to forecast … In numerous case studies actual compliance costs are lower than predicted because of unanticipated use of new technology."

It should be noted that many (though not all) of the EPA rules examined by Harrington had compliance dates of several years, which allowed a limited period for technical innovation.

[13] Harrington, W., R.D. Morgenstern, and P. Nelson. 2000. "On the Accuracy of Regulatory Cost Estimates." *Journal of Policy Analysis and Management* 19(2):297-322.

- *Acid Rain SO2 Trading Program*: Recent cost estimates of the Acid Rain SO2 trading program by Resources for the Future (RFF) and MIT have been as much as 83 percent lower than originally projected by EPA.[14] As noted in the RIA for the Clean Air Interstate Rule, the ex ante numbers in 1989 were an overestimate in part because of the limitation of economic modeling to predict technological improvement of pollution controls and other compliance options such as fuel switching. The fuel switching from high-sulfur to low-sulfur coal was spurred by a reduction in rail transportation costs due to deregulation of rail rates during the 1990's Harrington et al. report that scrubbing turned out to be more efficient (95% removal vs. 80-85% removal) and more reliable (95% vs. 85% reliability) than expected, and that unanticipated opportunities arose to blend low and high sulfur coal in older boilers up to a 40/60 mixture, compared with the 5/95 mixture originally estimated.

Phase 2 Cost Estimates	
Ex ante estimates	\$2.7 to \$6.2 billion[a]
Ex post estimates	\$1.0 to \$1.4 billion

[a] 2010 Phase II cost estimate in 1995\$.

- *EPA Fuel Control Rules:* A 2002 study by EPA's Office of Transportation and Air Quality[15] examined EPA vehicle and fuels rules and found a general pattern that "all ex ante estimates tended to exceed actual price impacts, with the EPA estimates exceeding actual prices by the smallest amount." The paper notes that cost is not the same as price, but suggests that a comparison nonetheless can be instructive.[16] An example focusing on fuel rules is provided in Table 6.6:

[14] Carlson, Curtis, Dallas R. Burtraw, Maureen, Cropper, and Karen L. Palmer. 2000. "Sulfur Dioxide Control by Electric Utilities: What Are the Gains from Trade?" *Journal of Political Economy* 108(#6):1292-1326.
Ellerman, Denny. January 2003. Ex Post Evaluation of Tradable Permits: The U.S. SO2 Cap-and-Trade Program. Massachusetts Institute of Technology Center for Energy and Environmental Policy Research.

[15] Anderson, J.F., and Sherwood, T., 2002. "Comparison of EPA and Other Estimates of Mobile Source Rule Costs to Actual Price Changes," Office of Transportation and Air Quality, U.S. Environmental Protection Agency. Technical Paper published by the Society of Automotive Engineers. SAE 2002-01-1980.

[16] The paper notes: "Cost is not the same as price. This simple statement reflects the fact that a lot happens between a producer's determination of manufacturing cost and its decisions about what the market will bear in terms of price change."

Table 6.6: Comparison of Inflation-Adjusted Estimated Costs and Actual Price Changes for EPA Fuel Control Rules[a]

	Inflation-adjusted Cost Estimates (c/gal)				Actual Price Changes (c/gal)
	EPA	DOE	API	Other	
Gasoline					
Phase 2 RVP Control (7.8 RVP—Summer) (1995$)	1.1	1.8		0.5	
Reformulated Gasoline Phase 1 (1997$)	3.1-5.1	3.4-4.1	8.2-14.0	7.4 (CRA)	2.2
Reformulated Gasoline Phase 2 (Summer) (2000$)	4.6-6.8	7.6-10.2	10.8-19.4	12	7.2 (5.1, when corrected to 5yr MTBE price)
30 ppm sulfur gasoline (Tier 2)	1.7-1.9	2.9-3.4	2.6	5.7 (NPRA), 3.1 (AIAM)	N/A
Diesel					
500 ppm sulfur highway diesel fuel (1997$)	1.9-2.4		3.3 (NPRA)	2.2	
15 ppm sulfur highway diesel fuel	4.5	4.2-6.0	6.2	4.2-6.1 (NPRA)	N/A

[a] Anderson, J.F., and Sherwood, T., 2002. "Comparison of EPA and Other Estimates of Mobile Source Rule Costs to Actual Price Changes," Office of Transportation and Air Quality, U.S. Environmental Protection Agency. Technical Paper published by the Society of Automotive Engineers. SAE 2002-01-1980.

- Chlorofluorocarbon (*CFC) Phase-Out:* EPA used a combination of regulatory, market based (i.e., a cap-and-trade system among manufacturers), and voluntary approaches to phase out the most harmful ozone depleting substances. This was done more efficiently than either EPA or industry originally anticipated. The phaseout for Class I substances was implemented 4-6 years faster, included 13 more chemicals, and cost 30 percent less than was predicted at the time the 1990 Clean Air Act Amendments were enacted.[17]

The Harrington study states, "When the original cost analysis was performed for the CFC phase-out it was not anticipated that the hydrofluorocarbon HFC-134a could be substituted for CFC-12 in refrigeration. However, as Hammit[18] notes, 'since 1991 most new U.S. automobile air conditioners have contained HFC-134a (a compound for which no commercial production technology was available in 1986) instead of CFC-12" (p.13). He cites a similar story for HCFRC-141b and 142b, which are currently substituting for CFC-11 in important foam-blowing applications."

[17] Holmstead, Jeffrey, 2002. "Testimony of Jeffrey Holmstead, Assistant Administrator, Office of Air and Radiation, U.S. Environmental Protection Agency, Before the Subcommittee on Energy and air Quality of the committee on Energy and Commerce, U.S. House of Representatives, May 1, 2002, p. 10.
[18] Hammit, J.K. (2000). "Are the costs of proposed environmental regulations overestimated? Evidence from the CFC phaseout." *Environmental and Resource Economics*, 16(#3): 281-302.

Additional examples of decreasing costs of emissions controls include: SCR catalyst costs decreasing from \$11k-\$14k/m^3 in 1998 to \$3.5k-\$5k/m^3 in 2004, and improved low NOx burners reduced emissions by 50% from 1993-2003 while the associated capital cost dropped from \$25-\$38/kW to \$15/kW[19]. Also, FGD scrubber capital costs have been estimated to have decreased by more than 50 percent from 1976 to 2005, and the operating and maintenance (O&M) costs decreased by more than 50% from 1982 to 2005. Many process improvements contributed to lowering the capital costs, especially improved understanding and control of process chemistry, improved materials of construction, simplified absorber designs, and other factors that improved reliability.[20]

We cannot estimate the precise interplay between EPA regulation and technology improvement, but it is clear that a *priori* cost estimation often results in overestimation of costs because changes in technology (whatever the cause) make less costly control possible.

6.2 Economic Impacts

The assessment of economic impacts in Table 6.7 was conducted based on those source categories which are assumed in this analysis to become controlled. The impacts presented here are a comparison of the control costs to the revenues for industries affected by control strategies applied for the 75 ppb final standard. Control costs are allocated to specific source categories by North American Industry Classification System (NAICS) code.

[19] ICF Consulting. October 2005. The Clean Air Act Amendment: Spurring Innovation and Growth While Cleaning the Air. Washington, DC. Available at http://www.icfi.com/Markets/Environment/doc_files/caaa-success.pdf.

[20] Yeh, Sonia and Rubin, Edward. February 2007. "Incorporating Technological Learning in the Coal Utility Environmental Cost (CUECost) Model: Estimating the Future Cost Trends of SO_2, NOx, and Mercury Control Technologies." Prepared for ARCADIS Geraghty and Miller, Research Triangle Park, NC 27711. Available at http://steps.ucdavis.edu/People/slyeh/syeh-resources/Drft%20Fnl%20Rpt%20Lrng%20for%20CUECost_v3.pdf.

Table 6.7: Identified Cost/Revenue Ratios by Affected Industry for Illustrative Control Strategy for the Final SO2 Standard (75 ppb) in 2020 (Millions of 2006$)[a, b, c]

NAICS Code	Industry Description	3% Discount Rate[d]	7% Discount Rate	Industry Revenue in 2007[e]	Cost/Revenue Ratio
2211	Electric Power Generation, Transmission and Distribution	699	699	440,000	0.16%
311	Food Manufacturing	55	19.9	589,000	<0.01%
312	Beverage and Tobacco Product Manufacturing	1.3	7.0	128,000	<0.01%
322	Paper Manufacturing	$143	$31.2	$170,000	< 0.01%
324	Petroleum and Coal Products Manufacturing	$245	$39.5	$590,000	< 0.01%
325	Chemical Manufacturing	$12.8	$12.8	$720,000	< 0.01%
326	Plastics and Rubber Products Manufacturing	6.2	6.2	211,000	<0.01%
327	Nonmetallic Mineral Product Manufacturing	266	43.5	128,000	<0.01%
331	Primary Metal Manufacturing	$	$43.6	$250,000	< 0.01%
332	Fabricated metal product manufacturing	0.4	0.4	344,000	< 0.01%
333	Machinery manufacturing	3.0	3.0	19,700	< 0.01%
336	Transportation equipment manufacturing	2.9	0.8	737,000	< 0.01%
611	Educational services	137	51.9	47,000	0.13%

[a] All estimates rounded to two significant figures. As such, totals will not sum down columns.
[b] All estimates provided reflect the engineering cost of the identified control strategy analysis, incremental to a 2020 baseline.
[c] NAICS codes were unavailable for area source controls. These controls account for less than 2% of the total identified control strategy costs.
[d] Total annualized costs were calculated using a 3% discount rate for controls which had a capital component and where equipment life values were available. For the identified control strategy, data for calculating annualized costs at a 3% discount was available for point sources. Therefore, the total annualized identified control cost value presented in this referenced cell is an aggregation of engineering costs at 3% and 7% discount rate.
[e] Source: U.S. Census Bureau 2007 Economic Census. Industry-level data on revenues can be found at http://factfinder.census.gov/servlet/IBQTable?_bm=y&-fds_name=EC0700A1&-_skip=0&-ds_name=EC0700A1&-_lang=en.
[f] No data on budget or revenues for this NAICS code is included in the 2007 Economic Census.

6.3 Energy Impacts

This section summarizes the energy consumption impacts associated with control strategies applied for the final SO_2 NAAQS of 75 ppb. The SO_2 NAAQS revisions do not constitute a “significant energy action” as defined in Executive Order 13211; this information merely represents impacts of the illustrative control strategy applied in the RIA. The rule does not prescribe specific control strategies by which these ambient standards will be met. Such strategies will be developed by States on a case-by-case basis, and EPA cannot predict whether the control options selected by States will include regulations on energy suppliers, distributors, or users. Thus, EPA concludes that this rule is not likely to have any adverse energy effects as defined in Executive Order 13211.

For this RIA, implementation of the control measures needed for attainment with the alternative standards will likely lead to increased energy consumption among SO_2 emitting facilities. In addition, because the energy consumption and impacts on various energy markets associated with emission reductions beyond identified controls is uncertain, we only consider the energy impacts associated with identified controls.

With respect to energy supply and prices, the analysis in Table 6.7 suggests that at the electric power industry level, the annualized costs associated with the illustrative control strategy for the final standard (75 ppb) represent only about 0.16 percent of its revenues in 2020. In addition, for the other industries affected under the 75 ppb standard, no other industry has annualized costs of more than 0.13 percent of its revenues. As a result we can conclude that impacts to supply and electricity price are small

6.4 Limitations and Uncertainties Associated with Engineering Cost Estimates

- EPA bases its estimates of emissions control costs on the best available information from engineering studies of air pollution controls and has developed a reliable modeling framework for analyzing the cost, emissions changes, and other impacts of regulatory controls. The annualized cost estimates of the private compliance costs are meant to show the increase in production (engineering) costs to the various affected sectors in our control strategy analyses. To estimate these annualized costs, EPA uses conventional and widely-accepted approaches that are commonplace for estimating engineering costs in annual terms. However, our engineering cost analysis is subject to uncertainties and limitations.

- One of these limitations is that we do not have sufficient information for all of our known control measures to calculate cost estimates that vary with an interest rate. We are able to calculate annualized costs at an interest rate other than 7% (e.g., 3% interest rate) where there is sufficient information—available capital cost data, and equipment life—to annualize the costs for individual control measures. For the vast majority of nonEGU point source control measures, we do have sufficient capital cost and equipment life data for individual control measures to prepare annualized capital costs using the standard capital recovery factor. Hence, we are able to provide annualized cost estimates at different interest rates for the point source control measures.

- For area source control measures, the engineering cost information is available only in annualized cost/ton terms. We have extremely limited capital cost and equipment life data for area source control measures. We know that these annualized cost/ton estimates reflect an interest rate of 7% because these estimates are typically products of technical memos and reports prepared as part of rules issued by EPA over the last 10 years or so, and the costs estimated in these reports have followed the policy provided in OMB Circular A-4 that recommends the use of 7% as the interest rate for annualizing regulatory costs. Capital cost information for these area source controls, however, is often limited since these measures are often not the traditional add-on controls where the capital cost is well known and convenient to estimate. The limited availability of useful capital cost data for such control measures has led to our use of annualized cost/ton estimates to represent the engineering costs of these controls in our cost tools and hence in this RIA.

- There are some unquantified costs that are not adequately captured in this illustrative analysis. These costs include the costs of federal and State administration of control programs, which we believe are less than the alternative of States developing approvable SIPs, securing EPA approval of those SIPs, and Federal/State enforcement. The analysis also did not consider transactional costs and/or effects on labor supply in the illustrative analysis.