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for

The Benefits and Costs of the Clean Air Act: 1990 to 2020 (Preliminary Draft Report, April 2010)

[Note: these pages substitute for pages in the April 2010 draft document to replace highlighted placeholder text.]

impact of Tier 1 NO_x tailpipe standards as well as the impact of Tier 2 standards, which went into effect in 2004.

Figure 2-2 shows increasing VOC emissions reductions from 2000 to 2020, with contributions from all source categories, with the exception of EGUs. The figure also shows a marked increase in on-road and nonroad emissions reductions between 2000 and 2010, reflecting both the delayed impact of Tier 1 VOC standards and the effect of low-sulfur gasoline regulations. Additionally, about half of the rules affecting nonroad sources came into effect between 2000 and 2010, explaining the increase in emissions reductions during that time. Area sources also show large emissions reductions across all three target years, driven primarily by regulations controlling evaporative emissions from solvents, though residential fireplace and woodstove emissions are also projected to decline as obsolete woodstoves are replaced with low-emitting models required by the CAAA.

In Figure 2-3, SO_2 emissions reductions increase by more than 60 percent between 2000 and 2010, with a smaller increase between 2010 and 2020. Most reductions in SO_2 emissions in all three target years come from EGUs, with smaller contributions from non-EGU point sources and area sources as well. As with reductions in NO_x emissions, the CAIR and the Title IV cap and trade program are partly responsible for SO_2 reductions from EGUs, along with the revised $PM_{2.5}$ NAAQS.

Figure 2-4 presents reductions in $PM_{2.5}$ emissions for the three target years, with a steady increase in reductions from 2000 through 2020, as $PM_{2.5}$ NAAQS requirements ramp up. Reductions in primary fine particulate emissions are expected to come from area sources, nonroad and onroad vehicles, and EGUs. Reductions from area sources are driven largely by the replacement of obsolete residential fireplaces and wood stoves, as well as local controls on construction sites for PM NAAQS compliance. As noted above, we set $PM_{2.5}$ emissions at non-EGU industrial point sources in the *without-CAAA* scenario to be equal to emissions in the *with-CAAA* scenario, so we do not estimate that there will be any significant direct $PM_{2.5}$ emissions reductions from that source category.

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TABLE 2-5. EMISSION TOTALS AND REDUCTIONS BY POLLUTANT – ALL SECTORS (THOUSAND TONS PER YEAR)

POLLUTANT	1990	2000			2010			2020		
		WITHOUT-CAAA	*WITH-CAAA*	REDUCTION	*WITHOUT-CAAA*	*WITH-CAAA*	REDUCTION	*WITHOUT-CAAA*	*WITH-CAAA*	REDUCTION
VOC	25,790	24,477	17,798	*6,679*	26,742	14,117	*12,626*	31,288	13,704	*17,584*
NO_x	25,917	26,688	20,837	*5,851*	28,517	13,640	*14,877*	31,740	10,092	*21,647*
CO	154,513	127,093	107,691	*19,403*	134,151	86,705	*47,447*	155,970	84,637	*71,332*
SO_2	23,143	25,129	15,319	*9,810*	26,831	10,347	*16,484*	27,912	8,272	*19,640*
PM_{10}	25,454	26,418	21,143	*5,275*	26,405	20,413	*5,992*	28,280	20,577	*7,702*
$PM_{2.5}$,[1]	5,527 ~~7,519~~	5,822 ~~8,022~~	5,489	*333* ~~*2,533*~~	5,924 ~~8,190~~	5,241	*682* ~~*2,949*~~	6,368 ~~8,903~~	5,297	*1,072* ~~*3,607*~~
NH_3	3,656	4,136	3,983	*153*	4,405	4,224	*181*	4,787	4,587	*200*

[1] $PM_{2.5}$ without-CAAA emissions were adjusted from previously reported values by reducing emissions from non-EGU industrial point sources and area sources.

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FIGURE 2-3. SO_2 REDUCTIONS ASSOCIATED WITH CAAA COMPLIANCE BY SOURCE CATEGORY

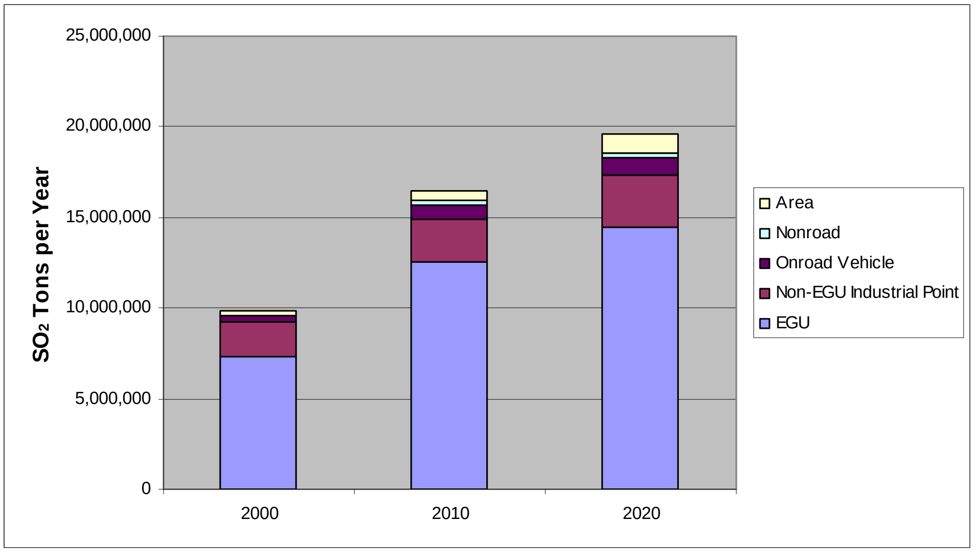
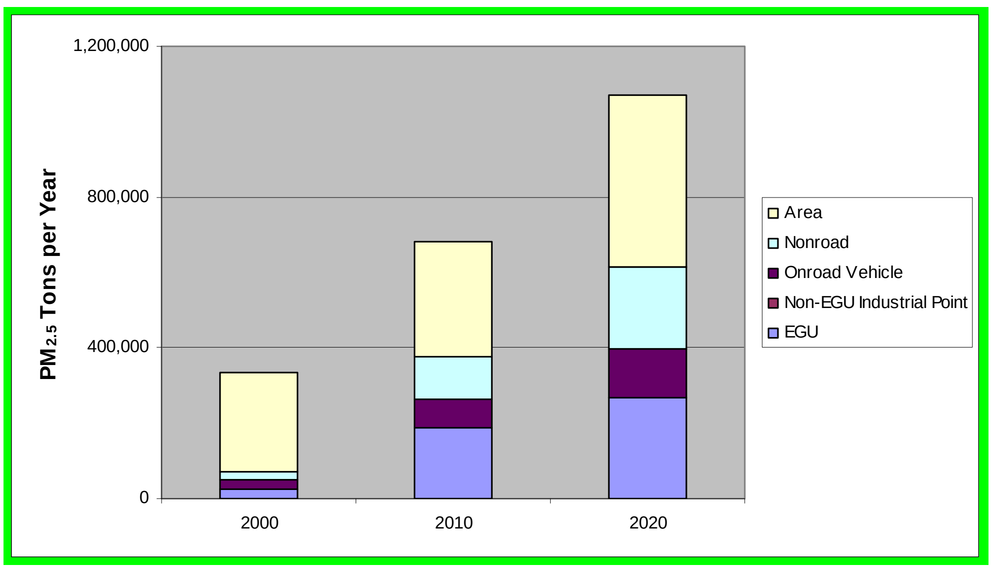


FIGURE 2-4. PRIMARY $PM_{2.5}$ REDUCTIONS ASSOCIATED WITH CAAA COMPLIANCE BY SOURCE CATEGORY



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COMPARISON OF EMISSIONS ESTIMATES WITH THE FIRST PROSPECTIVE ANALYSIS

DIFFERENCES IN METHODOLOGY

In comparison with the First Prospective 812 Analysis, the Second Prospective includes a number of refinements and improvements in emissions estimation methods, as well as a different set of regulatory assumptions.

1. *Updated Emissions and Economic Activity Data*: Because the Second Prospective analysis was developed ten years after the First Prospective, it incorporates additional information that was not available when the First Prospective was developed. This information includes *with-CAAA* emissions estimates for the historical year 2000 as well as additional historical trend data used to project economic activity from 1990 to 2000.

2. *Additional Regulatory Requirements*: The Second Prospective Analysis accounts for several major CAA regulations that were not yet promulgated in 1996, when decisions were made about which regulations to include in the First Prospective. These regulations include, but are not limited to, the Clean Air Interstate Rule (CAIR); the Clean Air Visibility Rule (CAVR); Tier II vehicle rules and heavy-duty diesel vehicle rules, and the local controls required for the revised 8-hour ozone and $PM_{2.5}$ NAAQS. Because of this difference, the Second Prospective Analysis models greater emissions reductions in 2000 and 2010 than were predicted in the First Prospective, as we discuss in the following section.

3. *Integrated Economic Modeling Approach*: In the First Prospective Analysis, we relied on a number of modeling tools to project future emissions, including projections of economic activity and population growth from the Bureau of Economic Analysis, and vehicle miles traveled from EPA's MOBILE fuel consumption model. By using fully-integrated economic growth, energy demand, and fuel price projections from DOE's AEO 2005, we were able to achieve a greater degree of internal consistency in the Second Prospective Analysis.

DIFFERENCES IN EMISSIONS RESULTS

Figures 2-5 and 2-6 show estimates from the First and Second Prospective Analyses of cumulative criteria pollutant emissions and emissions reductions for 2000 and 2010, the two years that were modeled in both analyses. The figures present emissions data for the four pollutants presented in Figures 2-1 through 2-4: VOC, NO_x, SO_2, and primary $PM_{2.5}$. As Figure 2-5 shows, the Second Prospective Analysis estimates slightly higher 2000 emissions in the *without-CAAA* scenario, and slightly lower emissions in the *with-CAAA* scenario. VOC and primary $PM_{2.5}$ emissions estimates are approximately the same in both analyses, but the Second Prospective estimates reductions in combined emissions of NO_x and SO_2 of about three million tons more than in the First Prospective. As noted above, most of the difference in SO_2 emissions reductions is attributable to SO_2 controls from CAIR, but there are also substantial additional reductions attributable to reduced

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fuel sulfur content regulations. The difference in NO_x emissions reductions is due primarily to differences in the onroad and nonroad engine and EGU rules included in the Second Prospective, but also to corrections made in the Second Prospective to more accurately characterize the impact of the NO_x SIP Call provisions for electric generating units.

In Figure 2-6, the difference between emissions estimates in the First and Second Prospective Analyses is much more noticeable. Although the *without-CAAA* scenario emissions estimates for VOC, NOx, and SO_2 are virtually identical for the two analyses, estimates of *with-CAAA* emissions of these pollutants are all substantially lower in the Second Prospective Analysis than in the First Prospective, yielding a difference in cumulative emissions reductions of about 15 million tons. As discussed above, the Second Prospective estimates much larger emissions reductions primarily because it accounts for a number of major control programs that were not yet in place when the last analysis was published.

FIGURE 2-5. FIRST AND SECOND PROSPECTIVE 2000 EMISSIONS AND EMISSIONS REDUCTIONS (EXCLUDING CO AND PM_{10})

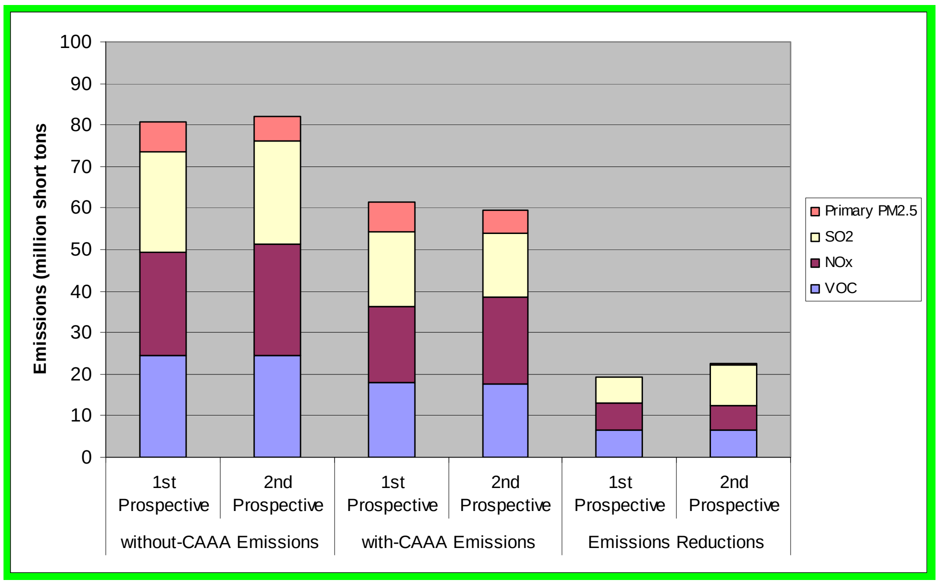

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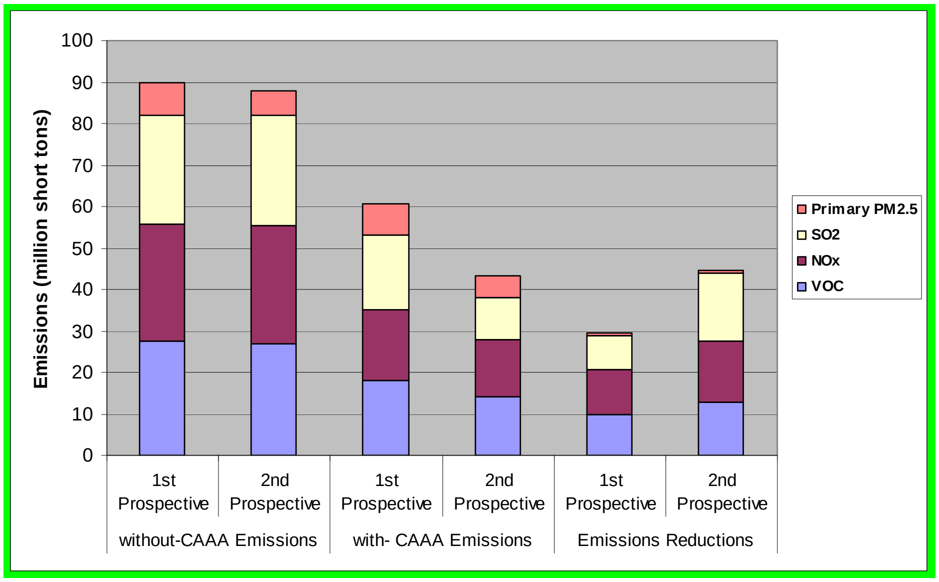
FIGURE 2-6. FIRST AND SECOND PROSPECTIVE 2010 EMISSIONS AND EMISSIONS REDUCTIONS (EXCLUDING CO AND PM_{10})



UNCERTAINTY IN EMISSIONS ESTIMATES

Table 2-6 lists several sources of uncertainty associated with generating the emissions estimates discussed in this chapter, as well as the expected direction of bias introduced by each uncertainty (if known), and the relative significance of each uncertainty in the overall 812 benefits analysis. These uncertainty sources are organized by the three factors that drive our results: identifying base-year emissions, forecasting growth in emissions-related activity, and modeling emissions controls in future years.

UNCERTAINTIES RELATED TO BASE-YEAR EMISSIONS

We estimated emissions from onroad motor vehicles, nonroad engines, and area sources at the county level, since these source categories are generally not tied to a specific location. Accordingly, our estimates of the spatial location of these emissions are less precise than for EGUs and industrial point sources. This uncertainty affects our ability to model changes in air quality associated with emissions reductions attributed to the CAAA. However, we expect that this uncertainty has a minor impact on the overall net benefit projections of the analysis.

UNCERTAINTIES RELATED TO GROWTH FACTORS

When projecting future growth in economic activity, even the most thorough projection model must tolerate a high amount of uncertainty. The factors we used to model growth in this analysis reflect uncertainty both in the economic activity forecasted and in how this activity translates into emissions of criteria pollutants. For example, because the AEO 2005 economic growth projection predates the recent economic downtown, it is

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possible that we overestimate emissions in both the *with-CAAA* and *without-CAAA* scenarios. However, because we use the same growth factors to project emissions under the *with-CAAA* and *without-CAAA* scenarios, this source of uncertainty probably has a minor effect on our overall net benefits estimates. In addition, we considered projecting emissions under high-growth and low-growth AEO projection scenarios, but we did not find sufficient variation in our conclusions to justify such an analysis. For these reasons, we do not believe this is a significant factor in our results.

Similarly, our projected emissions from on-road motor vehicles are based on vehicle fleet compositions included in the MOBILE6.2 model. Any change in fuel prices that might cause a shift away from low-fuel-efficiency vehicles could cause us to overestimate emissions from this sector. However, we expect that the impact of this uncertainty on our estimate of net benefits is minor.

UNCERTAINTIES RELATED TO EMISSIONS CONTROL MODELING

When modeling the *with-CAAA* scenario, we incorporated the effects of rules promulgated through September 2005. Accordingly, we did not fully account for rules promulgated since that time, such as the revised NAAQS for lead, and we modeled reductions from rules that have since been vacated, like the Clean Air Mercury Rule (CAMR) and the Clean Air Interstate Rule (CAIR), though CAIR has since been remanded. We estimated that CAMR would have only a modest impact on the pollutants we examined in this analysis, since mercury controls do not have large co-control benefits with other pollutants. However, our analysis projects that CAIR would have a large impact on NO_x and SO_2 emissions at EGUs in 2010 and 2020. Ultimately, a new rule will be promulgated to replace CAIR, and the emissions reductions, compliance costs, and locations of emissions reductions could all be different from what we modeled in this analysis. As a result, it is unclear whether our analysis overestimates or underestimates the net benefits of CAAA provisions on EGU emissions.

Estimates of emissions of volatile organic compounds are also a source of uncertainty because VOCs can be emitted through fuel combustion—like SO_2 and NO_x—as well as evaporation of volatile materials. Because evaporation rates depend largely on temperature, our estimates of future VOC emissions are influenced by the inherent difficulty of predicting future temperatures. The analysis uses projections of average daily minimum and maximum temperatures in order to predict average VOC emissions, but the resulting estimates do not adequately capture the variability of such emissions. The likely significance of this uncertainty, in terms of its impact on the overall net benefits estimated in this analysis, is probably minor.

Our future-year control assumptions are also a source of uncertainty. The flexibility allowed by the CAAA in achieving air quality standard target emission levels allows for emissions control schemes that may differ significantly from the controls modeled in this analysis. This is particularly true in the case of reductions needed for NAAQS compliance for which we have not identified a specific sector target. This analysis treats mortality applies a five percent discount rate to the lagged estimates over the periods 2000 to 2020, 2010 to 2030 and 2020 to 2040. We discount over the period between the initial PM exposure change (2000, 2010, or 2020) and the timing of the resulting change in incidence.

HEALTH EFFECTS MODELING RESULTS

This section presents a summary of the differences in health effects resulting from improvements in air quality between the *with-CAAA* and the *without-CAAA* scenarios. Table 5-5 summarizes the CAAA-related avoided health effects in 2020 for each health endpoint included in the analysis and the associated monetary benefits. The mean estimate is presented as the primary central estimate, the 5th percentile observation is presented as the primary low estimate and the 95th percentile is presented as the primary high estimate.[42] In general, because the differences in air quality between the *with-* and *without-CAAA* scenarios are expected to increase from 1990 to 2020 and because population is also expected to increase during that time, the health benefits attributable to the CAAA are expected to increase consistently from 1990 to 2020. More detailed results can be found in *Human Health and Welfare Benefits Estimates for the Clean Air Act Second Section 812 Prospective Analysis*, April 2010.

AVOIDED PREMATURE MORTALITY ESTIMATES

Our analysis indicates that the benefit of avoided premature mortality risk reduction dominates the overall net benefit estimate. This is, in part, due to the high monetary value assigned to the avoidance of premature mortality relative to the unit value of other health endpoints. As described in detail in this chapter, there are also significant reductions in other short-term and chronic health effects and a substantial number of health benefits that we could not quantify or monetize.

As shown in Table 5-5, our primary central estimate implies that PM and ozone reductions due to the CAAA in 2020 will result in 230,000 avoided deaths, with a primary low and primary high bound on this estimate of 45,000 and 490,000 avoided deaths, respectively. These avoided deaths are valued at $1.8 trillion (2006$), with primary low and primary high bounds on this estimate of $170 billion to $5.5 trillion.

[Placeholder: We will add life years lost and life expectancy results from the population simulation modeling both in the text and in Table 5-6 to the next draft of the report.]

[42] The distribution of incidence results represent the uncertainty associated with the coefficient of the C-R function for each health endpoint. The distribution around the monetized benefits estimate reflects both uncertainty in the incidence as well as uncertainty associated with the valuation estimate.

[Continued on 5-20a – April 29 revised]

TABLE 5-5. CAAA-RELATED AVOIDED INCIDENCE OF HEALTH EFFECTS AND ASSOCIATED MONETARY VALUATION IN 2020

		INCIDENCE			VALUATION		
ENDPOINT	POLLUTANT	5TH %ILE	MEAN	95TH %ILE	5TH %ILE	MEAN	95TH %ILE
Mortality							
Mortality[1]	PM, Ozone	45,000	230,000	490,000	$170,000	$1,800,000	$5,500,000
Morbidity							
Chronic Bronchitis	PM	12,000	75,000	130,000	$3,100	$36,000	$130,000
Non-fatal Myocardial Infarction	PM	80,000	200,000	300,000	$6,200	$21,000	$48,000
Hospital Admissions, Respiratory	PM, Ozone	24,000	66,000	110,000	$320	$1,100	$1,800
Hospital Admissions, Cardiovascular	PM	52,000	69,000	84,000	$1,400	$2,000	$2,600
Emergency Room Visits, Respiratory	PM, Ozone	64,000	120,000	180,000	$22	$44	$69
Acute Bronchitis	PM	-7,000	180,000	340,000	-$4	$94	$220
Lower Respiratory Symptoms	PM	1,200,000	2,300,000	3,300,000	$18	$42	$76
Upper Respiratory Symptoms	PM	620,000	2,000,000	3,300,000	$17	$60	$130
Asthma Exacerbation	PM	270,000	2,400,000	6,700,000	$15	$130	$390
Minor Restricted Activity Days	PM, Ozone	91,000,000	110,000,000	140,000,000	$3,800	$6,700	$10,000
Work Loss Days	PM	15,000,000	17,000,000	19,000,000	$2,300	$2,700	$3,000
School Loss Days	Ozone	2,200,000	5,400,000	8,600,000	$190	$480	$770
Outdoor Worker Productivity	Ozone	N/A	N/A	N/A	$170	$170	$170

Notes:
[1] Includes adult and infant mortality for PM and all ages for ozone.
All incidence and valuation results are rounded to two significant figures.

[Continued on 5-21 – April 29 revised]

NON-FATAL HEALTH IMPACTS

We report non-fatal health effects estimates in a similar manner to estimates of premature mortality – as a range of estimates for each quantified health endpoint, with the range dependent on the quantified uncertainties in the underlying C-R functions. The range of results for 2020 is characterized in Table 5-5 with 5th percentile, mean, and 95th percentile estimates which correspond to the primary low, central, and high estimates. All estimates are expressed as new cases avoided in 2020, with the following exceptions. Hospital admissions reflect admissions for a range of respiratory and cardiovascular diseases and these results, along with emergency room visits for respiratory disease, do not necessarily represent the avoidance of new cases of disease (i.e., air pollution may simply exacerbate an existing condition, resulting in an emergency room visit or hospital admission). Further, each admission is only counted once, regardless of the length of stay in the hospital. Minor restricted activity days, school loss days, and work loss days are expressed in terms of person-days. For instance, one "case" of a school loss day represents one person out of school for one day.

AVOIDED HEALTH EFFECTS OF AIR TOXICS

The prior discussion focuses on the effects of the 1990 CAAA on particulate matter and ozone health effects, but the Amendments also address the control of air toxics or hazardous air pollutants (HAPs). HAPs are pollutants regulated under Title III of the CAAA that can cause adverse effects to human health and ecological resources. The Amendments establish a list of HAPs to be regulated, require EPA to establish air toxic emissions standards based on Maximum Achievable Control Technology (MACT) standards, and include a provision that requires EPA to establish more stringent air toxics standards if MACT controls do not sufficiently protect the public health against residual risks. Control of air toxics is expected to result both from these changes and from incidental control due to changes in criteria pollutant programs, such as controls on volatile organic compounds (VOCs) necessary to achieve the NAAQS for ambient tropospheric ozone.

Both the Retrospective analysis and the First Prospective analysis omitted a quantitative estimation of the benefits of reduced concentrations of air toxics, citing gaps in the toxicological database, difficulty in designing population-based epidemiological studies with sufficient power to detect health effects, limited ambient and personal exposure monitoring data, limited data to estimate exposures in some critical microenvironments, and insufficient economic research to support valuation of the types of health impacts often associated with exposure to individual air toxics. Based on a recommendation by the SAB Council, EPA developed a case study of the benefits of CAAA controls on

[Continued on 5-22]

DIFFERENCES IN HEALTH EFFECTS MODELING RESULTS

The health effects estimates for the second prospective are much larger than the estimates EPA developed for the first prospective. The 2020 estimates are new to the second prospective, but the comparable mean estimate of health benefits in 2000 and 2010 for the first prospective were $71 billion in 2000 and $110 billion in 2010, in 1990$[49] - if updated to 2006$, these estimates would be $110 billion in 2000 and $170 billion in 2010. The second prospective results are larger by roughly a factor of 10. There are four key reasons we have identified for the increase in benefits:

1. ***Scenario differences*:** The *with-CAAA* scenario, especially for the 2010 target year, includes new rules with substantial additional pollutant reductions that were not included in the comparable first prospective scenario, such as the Clean Air Interstate Rule (CAIR).

2. ***Improved air quality models*:** The first prospective relied on the Regional Acid Deposition Model/Regional Particulate Model (RADM/RPM) for PM and deposition estimates in the eastern U.S., the Regulatory Modeling System for Aerosols and Acid Deposition (REMSAD) for PM estimates in the western U.S., and the Urban Airshed Model (versions V and IV) at various regional and urban scales to generate ozone estimates. The second prospective relies on the integrated CMAQ modeling tool, which reflects substantial improvements in air quality modeling, provides more comprehensive spatial coverage, and achieves improved model performance.

3. ***Better, more comprehensive exposure estimates*:** The first prospective relied on first generation exposure extrapolation tools to generate monitor-adjusted exposure estimates away from monitors. Since then, the monitor network, availability of speciated data, and the performance of speciated exposure estimation tools have improved substantially.

4. ***Updated dose-response estimates***: Since 1999, some concentration response functions have been updated, most notably the PM-premature mortality C/R function, whose central estimate of the mortality impact of fine PM has nearly doubled. In addition, health effects research has addressed endpoints that were not covered in the first prospective, including premature mortality associated with ozone exposure.

Although the Agency has not yet conducted a rigorous quantitative analysis to assess the impact of these methodology and data improvements, the impact of most of these factors is to increase the estimates of benefits.

[49] See The Benefits and Costs of the Clean Air Act 1990 to 2010, USEPA Office of Air and Radiation and Office of Policy, EPA-410-R-99-001, November 1999.

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UNCERTAINTY IN HEALTH BENEFITS ESTIMATES

A number of important assumptions and uncertainties in the health benefits analysis may influence the estimate of monetary benefits presented in this study. In this section of the chapter, we first discuss several quantitative sensitivity analyses undertaken to characterize the impact of key assumptions on the ultimate health benefits estimates. We then conclude with a qualitative discussion of the impact of both quantified and unquantified sources of uncertainty.

QUANTITATIVE SENSITIVITY TESTS

We performed three quantitative sensitivity tests to estimate the impact of alternate assumptions on our overall benefits estimates due to avoided premature mortality, the largest contributor to our overall health benefits estimates. The three focal areas for sensitivity analysis were: (1) the C-R function estimate; (2) the PM/mortality cessation lag structure; and (3) the mortality valuation estimate (including both the VSL and the discount rate). These are influential assumptions in our analysis and those for which plausible alternative quantitative estimates are available. Table 5-8 below provides the results of these sensitivity analyses.

Concentration-Response Function

Our monetized estimate of the benefits of reducing premature mortality from CAAA-related pollution reductions is based on a single primary estimate C-R function for each of the criteria pollutants included in our analysis, $PM_{2.5}$ and ozone. This selection is associated with uncertainty related to potential across-study variation. That is, different published studies of the same pollutant/health effect relationship often do not report identical findings; in some instances, the differences are substantial. These differences can arise from differences in factors such as study design, random sampling for subject populations, or modeling choices, such as inclusion of potential confounders.

In order to estimate the effect of across-study variation on our CAAA-related mortality benefits from reductions in $PM_{2.5}$ and ozone, we performed a sensitivity analysis on the C-R functions selected. For $PM_{2.5}$, our primary estimate is based on a Weibull distribution of C-R coefficients with a mean of 1.06 percent decrease in annual all-cause mortality per 1 $\mu g/m^3$ and an interquartile range bracketed by the Pope et al. (2002) ACS estimate (0.55 percent) on the low end and the Six Cities Laden et al. (2006) extended follow-up estimate (1.5 percent) at the high end. We conducted a sensitivity analysis by first substituting the primary C-R distribution with alternative C-R functions, one based

[Continued on 5-29 – April 29 revised]

on the Pope et al. (2002) ACS study, one based on the Laden et al. (2006) Six Cities cohort study as well as the C-R distributions provided by each of the 12 experts included in the PM/mortality expert elicitation study.

For ozone, our primary estimate consists of a pooled estimate of six studies, three based on the NMMAPS database (Schwartz, 2005; Bell et al., 2004; Huang et al., 2005) and three meta-analyses (Ito et al., 2005; Levy et al., 2005; Bell et al., 2005). We conducted a sensitivity analysis by substitute this primary C-R function with the C-R functions reported in each of the six individual studies.

As shown in Table 5-8, substituting alternate PM C-R functions results in total mortality benefits estimates that range from between 81 percent lower up to 78 percent higher than the primary estimate. Substituting alternative ozone C-R function does not affect the total mortality benefits estimate, since ozone does not contribute significantly to this estimate. However, the C-R function selection does affect the ozone mortality estimates, ranging from 63 percent lower up to 66 percent higher than the primary estimate for ozone mortality incidence.

PM/Mortality Cessation Lag

The timing of the cessation lag between PM exposure and mortality remains uncertain. Our primary monetized estimate of PM/mortality benefits assumes a 20-year distributed lag (30 percent of the mortality reductions occur in the first year, 50 percent occur equally in years two through five, and the remaining 20 percent occur equally in years six through 20). We tested the sensitivity of this assumption by calculating monetized mortality benefits based on alternative cessation lag structures. We selected two alternative lag structures – a 5-year distributed lag (which was employed in the First Prospective) and a smooth function (which assumes an exponential decay model and is based on an analysis by Roosli et al., 2005; see Chapter 6 of *Uncertainty Analyses to Support the Second Section 812 Benefit-Cost Analysis of the Clean Air Act* for further details). We also calculated benefits assuming no cessation lag. Application of alternative cessation lag structures had a smaller impact on the benefits estimates than the C-R function, resulting in benefits estimates that range from 22 percent lower up to 16 percent higher than the primary estimate.

Mortality Valuation

We apply a VSL value to reductions in premature mortality based on a Weibull distribution of 26 study estimates. The literature on VSL is extensive, and studies have measured VSL using different methodological approaches (e.g., revealed versus stated preference) on a variety of study populations (e.g., workers versus a general population sample) in a variety of different risk contexts (e.g., fatal workplace accidents versus mortality risk from disease). In addition, several meta-analyses of the literature have been conducted in an attempt to synthesize the literature. As a result, there are many options for alternative VSL estimates. We selected several alternative VSL estimates derived from the literature for sensitivity testing, including two estimates from a meta-analysis by Viscusi and Aldy (2003), an estimate used in past EPA regulatory analyses in

[Continued on 5-30 – April 29 revised]

the form of a normal distribution, and an estimate from a wage-risk study by Viscusi (2004). VSL did not affect the benefits results to the same degree as the C-R function, with alternative monetized benefits ranging from 21 percent lower to approximately equivalent to our primary estimate.

Our primary monetized benefits estimate of avoided premature mortality also assumes a discount rate of five percent. We tested the sensitivity of our primary results by substituting alternative discount rates of three and seven percent.[50] This assumption has a small effect on the benefits estimates; applying a discount rate of seven percent results in benefits that are 6 percent lower than the default and applying a three percent discount rate results in a benefits estimate 6 percent higher than the default.

TABLE 5-8. RESULTS OF QUANTITATIVE SENSITIVITY TESTS

FACTOR	STRATEGY FOR SENSITIVITY ANALYSIS	RANGE OF PERCENT CHANGES FROM MEAN PRIMARY MORTALITY BENEFITS ESTIMATE[1]
PM C-R Function	Alternative C-R functions - two from empirical literature (Pope et al., 2002 and Laden et al., 2006) and 12 subjective estimates from the expert elicitation study	-81% to 78%, Based on most extreme estimates from PM EE study. Rest of alternatives range from -41% to 40%.
Ozone C-R Function	Alternative C-R functions - three from NMMAPS-based studies and three meta-analyses	0% for total mortality benefits. -63% to 66% For ozone-related mortality.
PM/Mortality Cessation Lag	Alternative lag structures - one step function and one smooth function (based on an exponential decay function)	-22% to 16%
VSL	Alternative VSL estimates	-21% to 0%
Discount Rate	Alternative discount rates	-6% to 6%

[1] All values in the table represent the percent change from the mean primary estimate. Percent change estimates to not vary by target year.

[50] Alternative discount rates of three and seven percent are recommended in U.S. Environmental Protection Agency (2000). *Guidelines for Preparing Economic Analyses*, EPA 240-R-00-003, September.

[Continued on 5-31]

for each endpoint-pollutant combination and to characterize the uncertainty surrounding each estimate.[77]

The ecological and welfare results are not currently amenable to the same type of uncertainty analysis. The modeling procedures for estimating the effects of sulfur and nitrogen deposition in acidifying lakes, the effects of ozone in reducing timber and agricultural production, and the effects of particulate matter on visibility are all subject to uncertainty, but they require substantial resources simply to develop single point estimates. We describe key uncertainties in these estimation procedures qualitatively in Chapter 6, with some limited sensitivity analyses also presented to characterize the effect of key assumptions. The sources of uncertainty in these estimates, however, cannot as easily be disaggregated among physical effects modeling and valuation components, and they have not been assessed with the BenMAP model used for health benefits uncertainty analysis. As a result, we cannot reliably develop an aggregate estimate of the uncertainty in the sum of health and welfare benefits estimates.

ANNUAL BENEFITS ESTIMATES

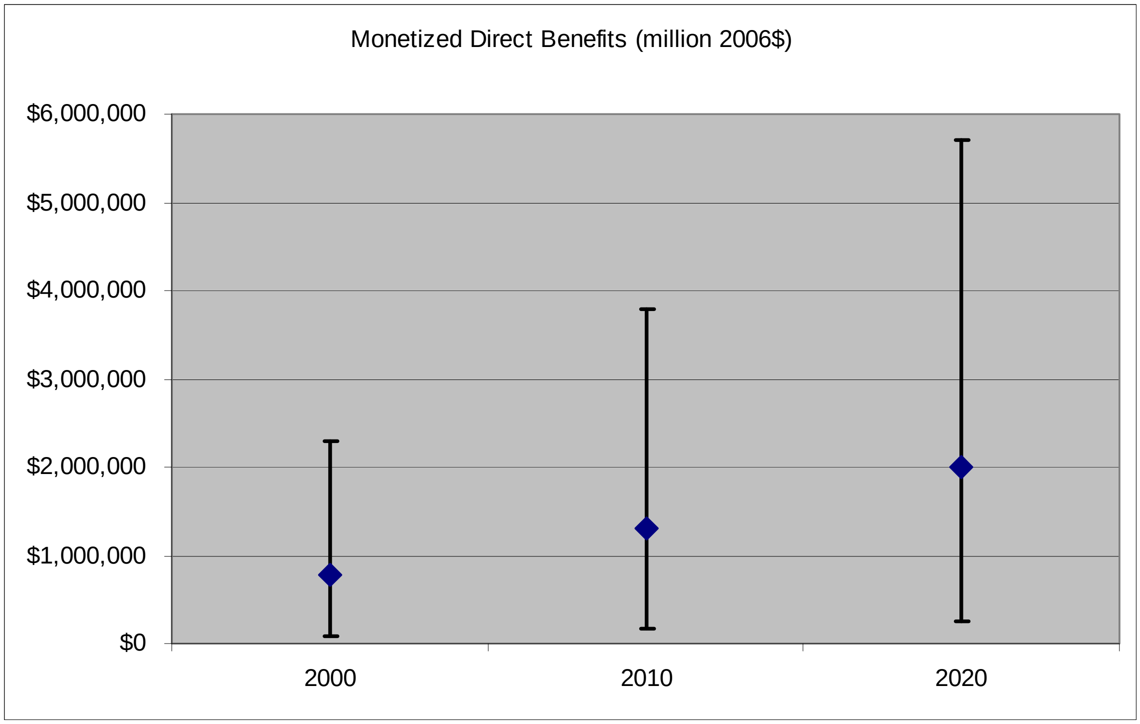
We present the results of our aggregation of primary annual health benefits estimates for the CAAA in Figure 7-1 below. The figure provides a characterization of both the primary central estimate and the range of values generated by the aggregation procedure described above, for each of the three target years of the analysis (2000, 2010, and 2020). The Primary High estimate corresponds to the 95th percentile value from the health benefits aggregation, and the Primary Low estimate corresponds to the 5th percentile value. The total benefits estimates are substantial; for example, the Primary Central estimate in 2020 is $2.0 trillion.

Table 7-1 shows the detailed breakdown of benefits estimates for 2000, 2010, and 2020. As shown in the table, $1.7 trillion of the $2.0 trillion total benefit estimate in 2020, or 85 percent, is attributable to reductions in premature mortality associated with reductions in ambient particulate matter. . The remaining benefits are roughly equally divided among three broad categories of benefits: avoided premature mortality associated with ozone exposure; avoided morbidity, the largest component of which is avoided acute myocardial infarctions and avoided chronic bronchitis; and avoided ecological and other welfare effects, the largest component of which is improved visibility. Note that, because of the

[77] The statistical aggregation technique applied is commonly referred to as Monte Carlo analysis. The technique involves many re-calculations of results, using different combinations of input parameters each time. For each calculation, values from each input parameter's statistical distribution are selected at random to ensure that the calculation does not always result in extreme values, or rely solely on low end or solely on high end input parameters. The aggregate distribution more accurately reflects a reasonable likelihood of the joint occurrence of multiple input parameters.

[Continued on 7-3a – April 29 revised]

FIGURE 7-1. ANNUAL HEALTH BENEFITS IN 2000 , 2010 AND 2020



[Continued on 7-4 – April 29 revised]

aggregation procedure used, and because we round all intermediate results to two significant digits for presentation purposes, the columns of Table 7-1 may not sum to the total estimate presented in the last row.

TABLE 7-1. SUMMARY OF MEAN PRIMARY BENEFITS RESULTS

BENEFIT CATEGORY	MONETIZED BENEFITS (MILLION 2006$) BY TARGET YEAR			NOTES
	2000	2010	2020	
Health Effects				
PM Mortality PM Morbidity Ozone Mortality Ozone Morbidity	$710,000 $27,000 $10,000 $420	$1,200,000 $46,000 $33,000 $1,300	$1,700,000 $68,000 $55,000 $2,100	- PM mortality estimates based on Weibull distribution derived from Pope et. al (2002) and Laden et al., 2006. - Ozone mortality estimates based on pooled function
Subtotal Health Effects	$750,000	$1,300,000	$1,900,000	
Visibility				
Recreational Residential	$4,100 ~~$4,600~~ $13,000 ~~$14,000~~	$9,000 ~~$10,000~~ $27,000 ~~$30,000~~	$18,000 ~~$20,000~~ $49,000 ~~$54,000~~	Recreational visibility only includes benefits in the regions analyzed in Chestnut and Rowe, 1990 (i.e., California, the Southwest, and the Southeast).
Subtotal Visibility	$17,000 ~~$19,000~~	$36,000 ~~$40,000~~	$67,000 ~~$74,000~~	
Agricultural and Forest Productivity	[Not available for this draft]			
Materials Damage	$58	$93	$110	
Ecological	$6.9	$7.5	$8.2	Reduced lake acidification benefits to recreational fishing assuming effect threshold of 50 microequivalents per liter.
Total: all categories	$770,000	$1,300,000	$2,000,000	
Note: See Chapters 5 and 6 of this report for detailed results summaries. Values presented are means from results reported as distributions. Estimates presented with two significant figures.				

[Continued on 7-5 – April 29 revised]

As shown in Table 7-2, there is considerable uncertainty in the estimates of health benefits. As described above, the health benefit uncertainty analysis is based on underlying statistical uncertainties in the concentration-response and valuation coefficients. The low estimates are approximately an order of magnitude less than the central estimate; the high estimate is three times the central estimate. Uncertainty analyses for non-health benefits were not developed, but as they constitute only about five percent of the central estimate, their contribution to the overall uncertainty in benefits estimates is likely to be proportionally small.

TABLE 7-2. DISTRIBUTION OF PRIMARY BENEFITS RESULTS FOR 2020

BENEFIT CATEGORY	PRIMARY MONETIZED BENEFITS (MILLION 2006$)			NOTES
	LOW	CENTRAL	HIGH	
Health Effects				
PM Mortality PM Morbidity Ozone Mortality Ozone Morbidity	$170,000 $17,000 $3,200 $780	$1,700,000 $68,000 $55,000 $2,100	$5,300,000 $190,000 $170,000 $3,600	Low and high are 5th and 95th percentile estimates from health benefits uncertainty analysis
Subtotal Health Effects	$190,000	$1,900,000	$5,700,000	
Visibility				
Recreational Residential		$18,000 ~~$20,000~~ $49,000 ~~$54,000~~		Only central estimates were developed for visibility
Subtotal Visibility	Not estimated	$67,000 ~~$74,000~~	Not Estimated	
Agricultural and Forest Productivity	[Not available for this draft]			
Materials Damage		$110		Only central estimates were developed
Ecological		$8.2		Reduced lake acidification benefits to recreational fishing assuming effect threshold of 50 microequivalents per liter.
Total: all categories	$190,000	$2,000,000	$5,700,000	
Note: See Chapters 5 and 6 of this report for detailed results summaries. Estimates presented with two significant figures.				

[Continued on 7-5a – April 29 revised]

AGGREGATE MONETIZED BENEFITS

As discussed earlier in this chapter, we interpolate benefit estimates between target years and then aggregate the resulting annual estimates across the entire 1990 to 2020 period of the study to yield a present discounted value of total aggregate benefits for the period. In this section we present the results of the aggregation.

In Table 7-3 we present the mean estimate from the aggregation procedure, along with the Primary Low (i.e., 5th percentile of the distribution) and Primary High (i.e., 95th percentile of the distribution) estimates, for all provisions we assessed. Aggregating the stream of monetized benefits across years involved discounting the stream of monetized benefits estimated for each year to the 1990 present value (using a five percent discount rate).

[Continued on 7-6 – April 29 revised]

TABLE 7-3. PRESENT VALUE OF MONETIZED BENEFITS OF THE CAAA

	PRESENT VALUE (MILLIONS 2006$, DISCOUNTED TO 1990 AT 5 PERCENT)		
	PRIMARY LOW	PRIMARY CENTRAL	PRIMARY HIGH
All Provisions, 1990 to 2020	$1,400,000	$12,000,000	$35,000,000

COMPARISON OF BENEFITS AND COSTS

Table 7-4 presents summary quantitative results for the prospective assessment, with costs disaggregated by emissions source category and benefits disaggregated by type. We present annual, Primary Central estimate results for each of the three target years of the analysis, with all dollar figures expressed as inflation-adjusted 2006 dollars. The final columns provide net present value estimates for costs and benefits from 1990 to 2020, discounted to 1990 at five percent. The results indicate that the Primary Central estimate of benefits clearly exceeds the costs of the CAAA, for each of the target years and for the cumulative estimates of present value over the 1990 to 2020 period.

[Continued on 7-7 – April 29 revised]

TABLE 7-4. SUMMARY OF QUANTIFIED PRIMARY CENTRAL ESTIMATE BENEFIT AND COSTS (ESTIMATES IN MILLION 2006$)

COST OR BENEFIT CATEGORY	ANNUAL ESTIMATES			PRESENT VALUE
	2000	2010	2020	
Costs:				
Electric Utilities	$1,400 ~~$1,100~~	$6,600 ~~$5,600~~	$10,000 ~~$8,800~~	$49,000
Industrial Point Sources	$3,100 ~~$2,600~~	$5,200 ~~$4,400~~	$5,100 ~~$4,300~~	$43,000
Onroad Vehicles and Fuels	$14,000 ~~$12,000~~	$26,000 ~~$22,000~~	$28,000 ~~$24,000~~	$220,000
Nonroad Engines and Fuels	$300 ~~$250~~	$360 ~~$300~~	$1,200 ~~$970~~	$4,500
Area Sources	$660 ~~$560~~	$690 ~~$580~~	$770 ~~$640~~	$7,600
Local Controls	$0	$14,000 ~~$12,000~~	$20,000 ~~$17,000~~	$53,000
Total Costs	$20,000 ~~$17,000~~	$53,000 ~~$45,000~~	$65,000 ~~$55,000~~	$380,000
Monetized Benefits:				
Avoided Mortality	$720,000	$1,200,000	$1,800,000	$11,000,000
Avoided Morbidity	$27,000	$47,000	$70,000	$410,000
Ecological and Welfare Effects	$17,000	$36,000	$67,000	$300,000
Total Benefits	$770,000	$1,300,000	$2,000,000	$12,000,000

As the table indicates, a very high percentage of the benefits is attributable to reduced premature mortality associated with reductions in ambient particulate matter and ozone. The CAAA achieves ambient PM reductions through a wide range of provisions controlling emissions of both gaseous precursors of PM that form particles in the atmosphere (sulfur dioxide and nitrogen oxides as well as, to a lesser extent, organic constituents) and directly emitted PM (i.e., dust particles). Because the effects of these constituents on ambient PM are nonlinear, and because some precursor pollutants interact with each other in ways which influence the total concentration of particulates in the atmosphere, separating the effects of individual pollutants on the change in ambient PM would require many iterations of our air quality modeling system. Even with such a tool, the interactive effects of pollutants are complex – as a result the marginal impact of any particular pollutant is dependent on the levels of other pollutants as well.

[Continued on 7-8 – April 29 revised]

Table 7-5 provides the results of our comparison of primary benefits estimates to primary cost estimates. In the top half of the table we show both annual and present value estimates. The cost estimates presented in the table reflect estimates presented in Chapter 3. The monetized benefits indicate both the Primary Central estimate (the mean) from our statistical aggregation procedure and the Primary Low and Primary High estimates (5th and 95th percentile values, respectively). In the bottom half of the table we present two alternative methods for comparing benefits to costs. "Net benefits" reflect estimates of monetized benefits less costs. The table also notes the benefit/cost ratios implied by the benefit ranges.

TABLE 7-5. SUMMARY COMPARISON OF BENEFITS AND COSTS (ESTIMATES IN MILLION 2006$)

	ANNUAL ESTIMATES			PRESENT VALUE ESTIMATE
	2000	2010	2020	1990-2020
Monetized Direct Costs:				
Low [a]				
Central	$20,000~~$17,000~~	$53,000~~$45,000~~	$65,000~~$55,000~~	$380,000
High [a]				
Monetized Direct Benefits:				
Low[b]	$90,000	$160,000	$250,000	$1,400,000
Central	$770,000	$1,300,000	$2,000,000	$12,000,000
High[b]	$2,300,000	$3,800,000	$5,700,000	$35,000,000
Net Benefits:				
Low	$70,000	$110,000	$190,000	$1,400,000
Central	$750,000	$1,200,000	$1,900,000	$12,000,000
High	$2,300,000	$3,700,000	$5,600,000	$35,000,000
Benefit/Cost Ratio:				
Low[c]	5/1	3/1	4/1	4/1
Central	39/1	25/1	31/1	32/1
High[c]	115/1	72/1	88/1	92/1

[a] The cost estimates for this analysis are based on assumptions about future changes in factors such as consumption patterns, input costs, and technological innovation. We recognize that these assumptions introduce significant uncertainty into the cost results; however the degree of uncertainty or bias associated with many of the key factors cannot be reliably quantified. Thus, we are unable to present specific low and high cost estimates.

[b] Low and high benefits estimates based on primary results and correspond to 5th and 95th percentile results from statistical uncertainty analysis, incorporating uncertainties in physical effects and valuation steps of benefits analysis. Other significant sources of uncertainty not reflected include the value of unquantified or unmonetized benefits that are not captured in the primary estimates and uncertainties in emissions and air quality modeling.

[c] The low benefit/cost ratio reflects the ratio of the low benefits estimate to the central costs estimate, while the high ratio reflects the ratio of the high benefits estimate to the central costs estimate. Because we were unable to reliably quantify the uncertainty in cost estimates, we present the low estimate as "less than X," and the high estimate as "more than Y"", where X and Y are the low and high benefit/cost ratios, respectively.

[Continued on 7-9 – April 29 revised]

The conclusion we draw from Table 7-5 is that, given the particular data, models and assumptions we believe are most appropriate at this time, our analysis indicates that the benefits of the CAAA substantially exceed its costs. Furthermore, the results of the uncertainty analysis imply that it is extremely unlikely that the monetized benefits of the CAAA over the 1990 to 2020 period could be less than its costs. The central benefits estimate exceeds costs by a factor of more than 30 to one, whether we are looking at annual or present value measures, and the high estimate exceeds costs by roughly 90 to one. In general, these results suggest that costs for criteria pollutant programs grow more quickly than benefits at the beginning of the CAAA compliance period, from 2000 to 2010, but that benefits grow more quickly at the end of the period, from 2010 to 2020. This is consistent with the general statement that investments in clean air tend to involve upfront costs and benefits that accrue over time, but as the present value estimates in Table 7-5 show, the total value of benefits far exceeds the costs – by our measures, therefore, the programs associated with the 1990 Clean Air Act Amendments have been, and will likely continue to be, a very good investment.

The results also suggest that, because benefits remain uncertain, there is a small probability that the estimated costs for the CAAA exceed the estimated benefits. . As indicated in the table, the low estimate of net benefits for the year 2020 is positive (i.e., benefits exceed costs) and of significant magnitude - $70 billion. Our uncertainty modeling indicates the likelihood that the cost estimates will exceed the benefits estimates is much less than five percent.

MAJOR SOURCES OF UNCERTAINTY

[This section reserved for this draft.]