Benefits and Costs of the Clean Air Act 1990 - 2020: Revised Analytical Plan For EPA's Second Prospective Analysis

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CHAPTER 1 - PROJECT GOALS AND ANALYTIC SEQUENCE

Purpose and Goals of the Study

Section 812 of the Clean Air Act of 1990 requires EPA to perform periodic, comprehensive analyses of the total costs and total benefits of programs implemented pursuant to the Clean Air Act (CAA). The first analysis required under the Clean Air Act is a retrospective analysis, which EPA completed in October 1997. Section 812 also requires completion of a prospective cost-benefit analysis every two years. EPA completed the first of these prospective studies in November 1999.

This document represents the second step in EPA's development of a second prospective analysis of the Clean Air Act and Amendments of 1990: the development of a revised analytic plan and schedule for completing the study. In completing the second prospective, EPA is attempting to follow a process in which we seek a thorough review of our plans for conducting the study early in the process, incorporate review comments in a final analytic plan that incorporates the results of the review, complete the analytic steps in an expedited fashion consistent with the final plan, and then seek final review of the report and its results. EPA completed the first step in this process in July of 2001, when the SAB Council met to review a June 2001 draft analytical plan document. This final analytic plan document reflects significant revisions from the draft plan in response to: (1) SAB Council review comments finalized and delivered to EPA in September 2001; (2) the evolution of regulatory analytic practice at EPA over the last two years, including the establishment by OMB of Data Quality Guidelines for US Government reports; and (3) recommendations made to EPA by a special National Academy of Sciences (NAS) panel on the conduct of benefits analysis for air pollution. The NAS report in particular is the motivation for a major increased emphasis on the development of methods for characterizing uncertainty in benefit estimates developed for this report.

EPA continues to have four major goals for the second prospective:

1. ***Support CAA reauthorization and related legislative efforts.*** To achieve this goal, EPA has designed an analytic process that will provide a comprehensive accounting of CAA programs. To further this goal, EPA had originally proposed a Title-by-Title disaggregation of benefit and cost information. In response to SAB comments and discussion on this topic, we now plan to conduct disaggregation by major emitting source category (e.g., utility, non-utility industrial point source, mobile source), considering all applicable regulations regardless of Title. In addition, EPA still plans to assess costs and benefits of a limited set of additional measures that go beyond the current CAA provisions, although the nature of those additional measures has changed since the June 2001 draft plan. We hope these two sets of results will provide insight on the most cost-effective directions for potential future legislative efforts.

2. ***Capture interaction effects between program elements not reflected in RIAs and other analyses focused on individual programs or CAA provisions.*** To achieve this goal, EPA intends to provide estimates of overall program benefits and costs on an integrated basis, using scenarios that reflect the expected implementation pathway for all major provisions of the CAA.

3. ***Improve analytical methodologies for current and future 812 assessments as well as other OAR and EPA benefit-cost analyses***. As outlined in this document, EPA intends to continue to develop and refine benefit-cost analysis methods and data, and to define approaches for treatment of controversial assumptions, with a particular focus on resolving issues identified as major uncertainties in the first prospective analysis, in the NAS report, and in recent regulatory rulemakings.

4. ***Provide a basis for identifying program and research priorities.*** To support this goal, EPA's proposed analytic approach is designed to provide an ongoing "learning laboratory" for clean air benefit-cost analytical methods. This will be achieved by providing program benefit information on an ambient pollutant-specific basis as well as cost and benefit information on a major source category basis, and by providing an accounting and analysis of key uncertainties in both benefit and cost estimates in as comprehensive a manner as feasible.

General Analytic Framework and Analytic Sequence

EPA intends to use the same general analytic framework used in the first prospective, with one major refinement: costs and benefits will be generated and separately compared for each major emitting source category as well as for the CAAA as a whole. The overall analysis will compare the estimated health, welfare, ecological and economic benefits of the 1990 Clean Air Act Amendment programs to the costs of these programs. Similar to previous reports in this series, the primary analysis will adopt a damage function approach reliant on calculation of the change in incidences of adverse effects implied by changes in ambient concentrations of air pollutants. The analysis relies on our construction and comparison of two distinct scenarios: a "Pre-CAAA" and a "Post-CAAA" scenario. The Pre-CAAA scenario will essentially freeze federal and related state and local air pollution controls at the levels of stringency and effectiveness which prevailed in 1990. The Post-CAAA scenario will assume that all federal, state, and local rules promulgated pursuant to, or in support of, the 1990 CAAA were implemented. This analysis then will estimate the differences between the economic and environmental outcomes associated with these two scenarios, for target years that occur at ten-year intervals over a period of 30 years (1990 through 2020).

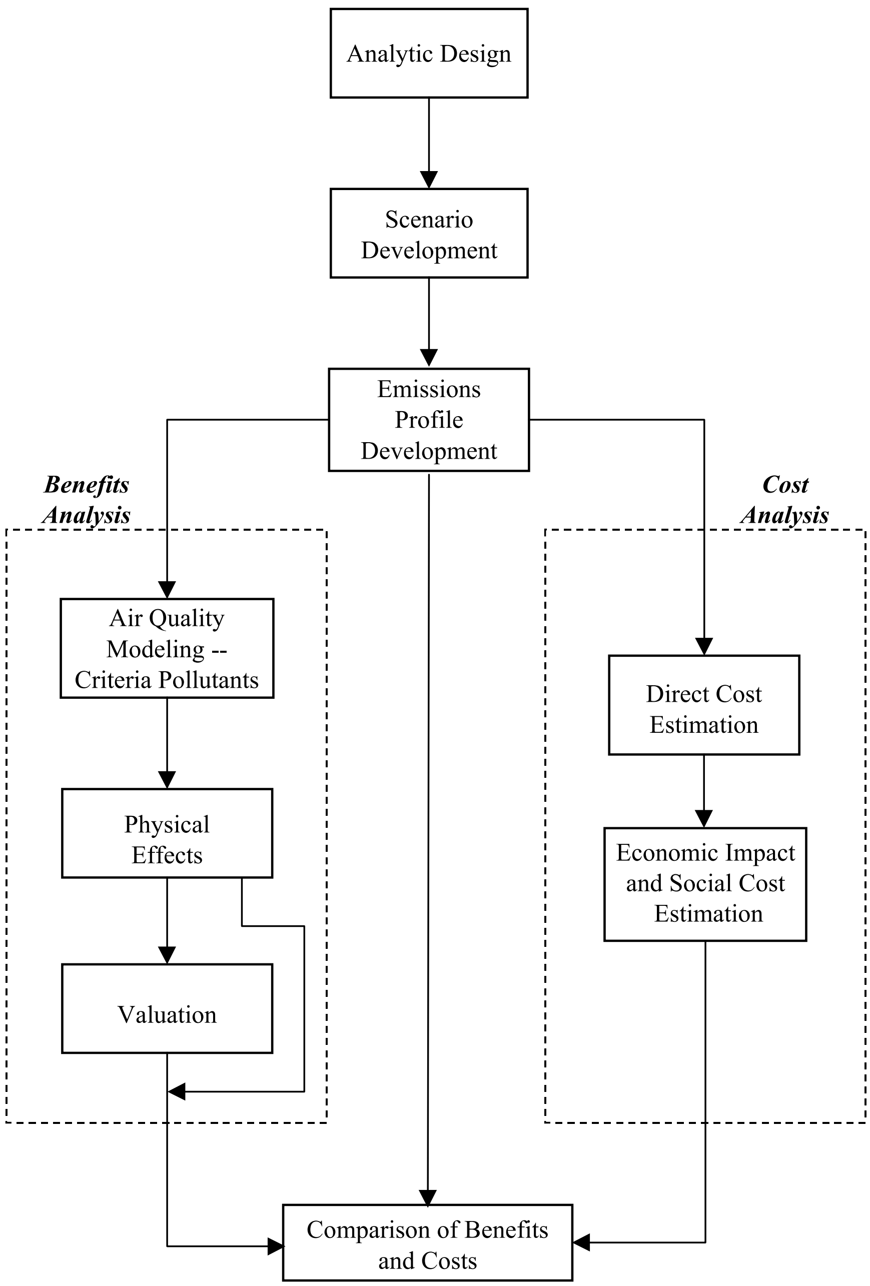
In a major refinement of previous approaches, however, benefits estimates for individual source categories will be developed based on selective "turning off" of the impact of the provisions that affect all sources in each category. For example, to estimate the individual benefits attributable to regulation of electric utilities, we will construct a scenario that uses the Pre-CAAA construction for this category of emissions, and the Post-CAAA construction for all other sources affected by the Act. The results of this scenario will then be compared to the results of the full Pre-CAAA scenario to arrive at the incremental benefit and cost estimates for regulation of emissions from electric utilities. We provide a more detailed description of the construction of these scenarios in Chapter 2 of this document.

The analytic sequence for the primary analysis will be similar to that used in the first prospective, and is illustrated in Figure 1-1 below. The approach first requires the development of a consistent set of scenarios and emissions estimates (the methods for these steps are described in detail in Chapters 2 and 3, respectively). The emissions results will then be used to generate cost and benefit estimates on separate tracks. To estimate benefits, emissions estimates for each scenario will be used as inputs to air quality models, which will provide estimates of the changes in atmospheric concentrations of CAAA-regulated criteria pollutants. The air quality modeling estimates will then be used to estimate health and environmental outcomes, and those outcomes will be valued using economic analysis. To estimate direct costs, we will use three basic approaches, depending on the requirements of a specific provision. If compliance with a provision requires the implementation of a particular control technology, for example, Title III Maximum Achievable Control Technology rules, our approach will involve estimating the costs to install and maintain that technology at a level that achieves the desired emissions reduction. If compliance allows for trading of emissions permits, as under Title IV, then the emissions and cost estimation processes will be more integrated. In concept, a least-cost scenario for the universe of facilities who may trade will be developed, and then emissions outcomes will be determined based on individual facility decisions to adopt control technologies or purchase emissions credits from other facilities that amass credits. Finally, in some cases compliance actions and their costs are dictated by the difference between the sum total of mandated emissions reductions and the need to achieve ambient standard compliance at the local level. In those cases, for example, Reasonable Further Progress requirements, we will estimate the "shortfall" in emissions reductions that needs to be made up by additional measures, and then estimate the incremental costs to implement those additional measures.

The results of the cost and benefit analyses will then be aggregated, compared, and interpreted. The comparison will yield an estimate of net benefits, which in this second prospective will include estimates for all provisions of the Act, the incremental costs and benefits attributable to each major emitting source category individually, and costs and benefits of provisions beyond the current CAA.

The assessment will incorporate the results of uncertainty analysis to assess the degree of certainty EPA holds in the key target variable(s) and the resulting net benefit estimates. As mentioned above, the uncertainty analysis plan represents a major refinement in the analytical plan relative to the June 2001 draft reviewed by the SAB Council in July 2001. This part of the plan is discussed in detail in Chapter 9.

Figure 1-1
Proposed Analytic Sequence for
Second Prospective Analysis



In some cases, the comparisons of costs and benefits may necessarily be based on non-monetary evaluations of the benefits of the provisions. For example, the current state-of-the-art does not support the development of comprehensive monetary estimates of the benefits of air toxics control. We had originally proposed to consider the benefits of Title III in terms of the quantitative emissions reductions of specific air toxics that will result from Title III implementation. In response to SAB comments on the June 2001 draft plan, we developed a detailed analytical plan for a case study of the benefits of air toxics control, focusing on a single pollutant (benzene) in a limited geographical area (the Houston, TX metropolitan area). Our plan is described in detail in Appendix E of this document.

Within the scope of each of these individual analytic steps, we propose to implement a number of methodological refinements from the first prospective, and in a few cases refinements from the June 2001 draft second prospective plan, as follows:

- ***Scenario Development***: We propose to construct the Post-CAAA scenario to include several important regulatory initiatives finalized since the November 1999 publication of the first prospective, including: revisions to the Particulate Matter and Ozone National Ambient Air Quality Standards; Tier II tailpipe standards in place through 2020; Heavy Duty Diesel engine and fuel sulfur standards in place through 2020; the recently proposed Non-Road Diesel tailpipe standards; and several recent MACT rules. See Chapter 2 for more details.

- ***Emissions Estimation:*** Emissions estimates will be refined to reflect recent data on the effectiveness of mobile source requirements. In addition, since the June 2001 draft plan we have revised our base emissions inventory to take advantage of the recently released 1999 National Emissions Inventory, and we now plan to employ a revised set of projection factors for future emissions using the EGAS system. See Chapter 3 for more details.

- ***Cost Estimation:*** We propose to estimate a more complete set of indirect costs of provisions; conduct regional and/or national assessments of economic impacts of compliance costs on output, employment, and prices; and provide an estimate of the uncertainty in individual and aggregate cost estimates. As part of the final plan, we also include more complete documentation of models we plan to use, and we refined our plans for the use of national-level CGE for social cost estimation. See Chapter 4 for more details.

- ***Air Quality Modeling:*** We plan to rely on a single, national scale model to estimate ambient concentrations of particulate matter (the REMSAD model). As part of the final plan, we outline in greater detail the justification for using the model, based on the model selection protocol the SAB Council recommended, include information on model performance as part of the plan itself (see Appendix B), and describe our revised ozone modeling strategy. For ozone modeling, we now plan to use CAMx. See Chapter 5 for more details.

- ***Health and Environmental Effects:*** Estimates of health effects will incorporate the latest Health Effects Institute (HEI) results on the link between premature mortality and exposure to ambient particulate matter, as well as other updates to the health estimation process EPA relied on in the recent Nonroad Diesel standards. In addition, in this final version we provide expanded documentation of our approach for analysis of stratospheric ozone protection provisions (see Appendix D), and as outlined above we include a plan for an air toxics benefits case study (see Appendix E). See Chapter 6 for more details.

- ***Ecological Effects:*** In the final plan we have significantly expanded both the goals and documentation of analyses to characterize ecological effects, in response to SAB comments. We plan a case study of ecological and economic quantification of the effects of nitrogen deposition at a watershed-level geographic scope, and also describe in more detail than in the June 2001 draft our plan for updating the qualitative characterization of ecological effects. See Chapter 7 for more details.

- ***Benefits Valuation:*** For the final plan, we further revised and updated our strategy for estimating the monetary value of avoided premature mortality, based on a new meta-analytic approach. We also plan to make use of the previously proposed procedure for accounting for changes in income over time. See Chapter 8 and Appendix H for more details.

- ***Uncertainty Analysis:*** As a result of the recommendations of the NAS report, we provide a substantially refined plan for uncertainty analysis. The plan for uncertainty analysis continues to evolve in concert with the evolving plan for addressing uncertainty for the final version of the Nonroad Diesel rule (due to be complete in late 2003). In addition, we plan to conduct a series of influence and, to the extent possible, uncertainty analyses on certain steps of the analytic chain that will not be addressed in the Nonroad Diesel rule, including the emissions, costs, and air quality modeling steps. See Chapter 9 for more details.

- ***Comparison of Benefits and Costs:*** As stated above the major refinement in our comparison of benefits and costs will be the proposed disaggregation of cost and benefit estimates by major emitting source category. See Chapter 10 for more details.

- ***Schedule:*** EPA intends to complete the second prospective analysis in a shorter period of time than was required for the first prospective, but the additional work required to complete the substantially refined uncertainty analysis, as well as analysis of additional scenarios, suggests that the study will take longer to complete than we originally outlined in July 2001. See Chapter 11 for more details.

The remainder of this analytical plan describes in detail our proposed approach. The approach outlined here reflects application of largely off-the-shelf methods for critical path elements of the analysis, based in most cases on methods applied in recent EPA rulemakings. The major exception is the uncertainty analysis, which requires the development of new tools and data, some likely acquired by expert elicitation, that are specific to this analysis. Many refinements to our proposed approach are possible, but the large number of potential options for extending the analysis requires careful consideration of the relative value of each option. To this end, we present a summary of potential refinements in Table 11-3, at the end of Chapter 11, for the purpose of soliciting SAB advice on the relative utility of different options.

CHAPTER 2 - SCENARIO DEVELOPMENT

The detailed description of the pre-CAAA and post-CAAA scenarios is the initial step in our analytic design. The goal of this step is to define reasonable backward- and forward-looking projections of air pollution control requirements as currently implemented and as they would be in the absence of the CAAA. The differences in the costs, emissions, impacts, and benefits realized under these two scenarios represent the primary results of the analysis. This chapter provides a brief summary of our proposed scenario development process.

Scenario Development in the First Prospective

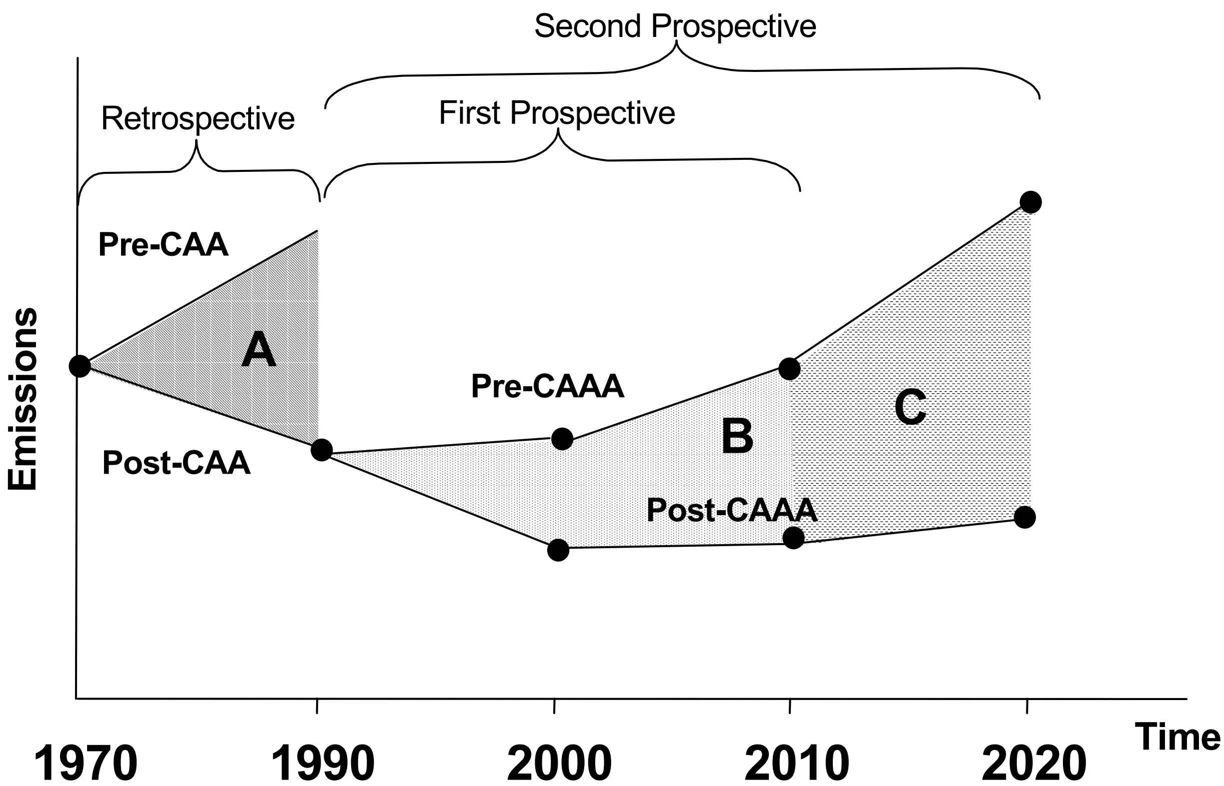
The first prospective examined two distinct scenarios: a pre-CAAA and a post-CAAA scenario. The pre-CAAA scenario freezes Federal, State, and local air pollution controls at 1990 levels. The post-CAAA scenario includes all Federal, State, and local rules enacted in response to the 1990 CAAA. The first prospective also assumed that population size and geographic distribution would change as predicted by the Bureau of Economic Analysis (BEA) in both the pre-CAAA and post-CAAA scenarios.

Based on these assumptions, EPA projected emissions by source category for the pre-CAAA and post-CAAA scenarios in the first prospective. Exhibit 2-1 illustrates how emissions under the pre-CAAA and post-CAAA scenarios differed in the first prospective. In the pre-CAAA scenario, emissions began to increase in 1990 and continued to increase through 2010, after having decreased between 1970 and 1990 as a result of the Clean Air Act. Under the post-CAAA scenario, emissions continued to fall between 1990 and 2000 before leveling off between 2000 and 2010. The difference in emissions under these two scenarios is illustrated by Area B in Exhibit 2-1. Similarly, area A in Exhibit 2-1 shows the emissions reductions attributable to the Clean Air Act between 1970 and 1990.

We focused the first prospective analysis on those rules that affect six major pollutants: volatile organic compounds (VOCs), nitrogen oxides (NO_x), sulfur dioxide (SO_2), carbon monoxide (CO), particulate matter with an aerodynamic diameter of 10 microns or less (PM_{10}), and fine particulate matter ($PM_{2.5}$).[1] For each of these pollutants we projected 1990 emissions to the years 2000 and 2010 under the two basic scenarios.

[1] We also estimated ammonia (NH_3) emissions. NH_3 influences the formation of secondary PM (PM formed as a result of atmospheric chemical processes). We used NH_3 emissions estimates as an input during the air quality modeling phase of the prospective analysis when estimating future-year ambient PM concentrations. However, we did not examine the human health and environmental effects of exposure to NH_3. In addition to NH_3, we also estimated mercury (Hg) emissions. We qualitatively evaluated the effects of Hg emissions on ecological systems, but we did not examine the impact of Hg on human health. We did not estimate the effect of the CAAA on lead (Pb) emissions. By 1990 most major airborne Pb emission sources were already controlled and the CAAA has minimal additional impact on Pb emissions.

Exhibit 2-1: Schematic of Section 812 Scenarios and Emissions over Time



EPA projected emissions in the first prospective by adjusting 1990 base year emissions to reflect projected economic activity levels in 2000 and 2010, and applying future year control assumptions. The resulting estimates depended largely upon three factors: how the base year inventory was selected, what indicators were used to forecast growth, and what specific regulatory programs were incorporated in the pre- and post-CAAA scenarios. These three factors are addressed in Exhibits 2-2 through 2-4. Exhibit 2-2 highlights the approach EPA used to establish the base year inventory. The indicators the Agency relied on to forecast growth and predict future activity levels, along with the analytical approach EPA used to project emissions, are shown in Exhibit 2-3. The pre- and post-CAAA regulatory scenarios are summarized in Exhibit 2-4.

EPA included in the first prospective's post-CAAA scenario:

- Title I VOC and NO_x reasonably available control technology (RACT) and reasonable further progress (RFP) requirements for ozone nonattainment areas (NAAs);

- Title II motor vehicle and nonroad engine/vehicle provisions;
- Title III 2- and 4-year maximum achievable control technology (MACT) standards;
- Title IV SO_2 and NO_x emissions programs for utilities;
- Title V permitting system for primary sources of air pollution; and
- Title VI emissions limits for chemicals that deplete stratospheric ozone.

This scenario also assumed the implementation of a region-wide NO_x cap and trade system for the entire OTAG domain and a similarly designed trading program for the Ozone Transport Region (OTR) that was consistent with Phase II of the Ozone Transport Commission (OTC) NO_x Memorandum of Understanding (MOU). For motor vehicles, emissions reductions associated with a 49-State low emission vehicle (LEV) program were also included in the post-CAAA scenario. A more detailed outline of the controls included in both the pre- and post-CAAA scenarios is provided in Exhibit 2-4.

Refinements in Scenario Development for the Second Prospective Analysis

The second prospective analysis will revise projected emissions estimates in a number of ways. First, we will include an additional projection year, 2020, for a total of three projection year comparisons. Inclusion of this additional projection year enables EPA to estimate emissions reductions attributable to the Amendments over a 30-year period, as illustrated by Area C in Exhibit 2-1. Second, we are re-evaluating the three factors which drive future projections — base year inventory selection, indicators used to forecast growth, and specific included regulatory programs — and all are expected to change to some degree. Third, we will examine the impacts of the CAAA on different source categories by setting controls for individual source categories to pre-CAAA levels and comparing the outcome to that of the post-CAAA scenario.

First, we propose to revise 1990 emissions estimates. EPA continually updates and refines estimates of historical emissions for sources where emissions are estimated, to reflect refinements in emissions estimation methods. As a result, EPA has published revised 1990 emissions estimates, updated from those we used in the first prospective. We propose to use the updated estimates to characterize base-year, 1990, emissions. These estimates will also be used as the basis for projections by source category of the pre-CAAA scenarios for target years 2000, 2010, and 2020.

Exhibit 2-2

Base Year Inventory - Summary of Approach in First Prospective

Sector	Analysis Approach/Data Sources
Industrial Point Sources	1985 National Acid Precipitation Assessment Program (NAPAP) emissions inventory grown to 1990 based on historical Bureau of Economic Analysis (BEA) earnings data. PM_{10} emissions based on total suspended particulate (TSP) emissions and particle-size multipliers.
Utilities	1990 utility emission estimates from the 1990 NPI.
Nonroad	Nonroad Engines/Vehicles (VOC, NO_x, CO, PM_{10}): 1991 Office of Mobile Sources (OMS) Nonroad Inventory. Nonroad Engines/Vehicles (SO_2) and Aircraft, Commercial Marine Vessels, Railroads: 1985 NAPAP grown to 1990 based on historical BEA earnings data.
Motor Vehicles	Federal Highway Administration (FHWA) travel data, MOBIL5a/PART5 emission factors.
Area Sources	1985 NAPAP inventory grown to 1990 based on historical BEA earnings data and State Energy Data Systems (SEDS) fuel use data; emission factor changes for selected categories.

Exhibit 2-3

Analysis Approach by Major Sector in the First Prospective

Sector	Growth Forecast	Analysis Approach
Industrial Point	1995 BEA Gross State Product (GSP) Projections by State/Industry.	**VOC, NO_x** — Emission Reduction and Cost Analysis Model (ERCAM): applies BEA growth projection to base year emissions and applies future year controls as selected by the user. **PM_{10}, SO_2, CO** — While no formal model exists, the same basic approach applied in ERCAM was used for these pollutants.
Utilities	Projections of heat input by unit based on National Electric Reliability Council (NERC) data, price and demand forecasts, and technology assumptions.	**SO_2, NO_x** — Integrated Planning Model (IPM). **VOC, PM_{10}, CO** — Base year emissions rates or AP-42 emission factors applied to IPM projected heat input by unit.
Nonroad	1995 BEA GSP and Population Projections by State/Industry.	**VOC, NO_x** — ERCAM. **PM_{10}, SO_2, CO** — ERCAM approach (no formal model).
Motor Vehicles	MOBILE Fuel Consumption Model (FCM) National Vehicle Miles Traveled (VMT) Projection Scaled to Metropolitan/REST-of-State Areas by Population.	**NO_x, VOC, CO** — ERCAM: applies MOBIL5a emission factors to projected VMT by month and county/vehicle type/roadway classification. **PM_{10}, SO_2** — PART5 emission factors applied to projected VMT.
Area	1995 BEA GSP and Population Projections by State/Industry, and USDA Agricultural Projections.	**VOC, NO_x** — ERCAM. **PM_{10}, SO_2, CO** — ERCAM approach (no formal model).

Exhibit 2-4

Projection Scenario Summary by Major Sector in the First Prospective

Sector	Pre-CAAA	Post-CAAA*
Industrial Point	RACT held at 1990 levels.	**NO_x**: RACT for all NAAs (except NO_x waivers), 0.15 pounds per million British thermal unit (lbs/MMBtu) OTAG-wide cap on fuel combustors of 250 MMBtu per hour or above, OTAG Level 2 NO_x controls across OTAG States. **VOC**: RACT for all NAAs, New control technique guidelines (CTGs), 2- and 4- year MACT standards (VOC). **Ozone**: Rate-of-Progress (3 percent per year) requirements (further reductions in VOC).
Utilities	250 ton prevention of Significant Deterioration (PSD) and New Source Performance Standards (NSPS) held at 1990 levels. RACT and New Source Review (NSR) held at 1990 levels.	**NO_x**: RACT and NSR for all non-waived (NO_x waiver) NAAs, Title IV Phase I and Phase II emission limits for all boiler types, Phase II of the Ozone Transport Commission (OTC) NO_x memorandum of understanding 0.15 lbs/MMBtu OTAG-wide seasonal NO_x cap with banking/trading, 250 ton PSD and NSPS. **SO_x**: Title IV SO_2 emission allowance program.
Nonroad	Controls (engine standards) held at 1990 levels.	**NO_x**: Federal Phase I and II compression ignition (CI) engine standards, Federal Phase I and II spark ignition (SI) engine standards, Federal locomotive standards, Federal commercial marine vessel standards, Federal recreational marine vessel standards. **PM**: Federal Phase I and II compression ignition (CI) engine standards Federal locomotive standards (NO_x, PM). **CO**: Federal Phase I and II spark ignition (SI) engine standards **VOC**: Federal Phase I and II spark ignition (SI) engine standards Federal recreational marine vessel standards.

Exhibit 2-4

Projection Scenario Summary by Major Sector in the First Prospective

Sector	Pre-CAAA	Post-CAAA*
Motor Vehicles	Federal Motor Vehicle Control Program (FMVCP) — engine standards set prior to 1990. Phase 1 Reid vapor pressure (RVP) limits. I/M programs in place by 1990.	**NO_x**: Tier 1 tailpipe standards (Title II) 49-State LEV program (Title I), I/M programs for ozone and CO NAAs (Title I) Federal reformulated gasoline for ozone NAAs (Title I) California LEV (California only) (Title I) California reformulated gasoline (California only) (Title I) **VOC**: Tier 1 tailpipe standards (Title II) 49-State LEV program (Title I) Phase 2 RVP limits (Title II) I/M programs for ozone and CO NAAs (Title I) Federal reformulated gasoline for ozone NAAs (Title I) California LEV (California only) (Title I) California reformulated gasoline (California only) (Title I) **CO**: 49-State LEV program (Title I) I/M programs for ozone and CO NAAs (Title I) Federal reformulated gasoline for ozone NAAs (Title I) California LEV (California only) (Title I) California reformulated gasoline (California only) (Title I) Oxygenated fuel in CO NAAs (Title I) (CO). **SO_x**: Diesel fuel sulfur content limits (Title II) (SO_2, PM). **PM**: Diesel fuel sulfur content limits (Title II)
Area	Controls held at 1990 levels.	**NO_x**: RACT requirements. **VOC**: RACT Requirements New CTGs (VOC). 2- and 4- year MACT standards (VOC). Ozone Rate-of-Progress (3 percent per year) requirements Onboard vapor recovery (vehicle refueling) Stage II vapor recovery systems, **PM**: PM NAA controls

*Also includes all Pre-CAAA measures.

In addition, we plan to revise the base year inventory used to develop post-CAAA projections to 2000, 2010, and 2020 to reflect the new data available as a result of the 1999 National Emissions Inventory (NEI). This revised base year has been used by most recent EPA regulatory analyses, including the nonroad diesel analyses. We discuss our reasons for this decision in detail in Chapter 3.

Our indicators for forecasting growth also include some significant revisions, which reflect the availability of new models and data sets (for more information, see Chapter 3). Significant changes include:

- EPA's Economic Growth Analysis System (EGAS) was updated in 2001, and we plan to use EGAS instead of Bureau of Economic Analysis (BEA) gross state product (GSP) projections as the primary driver for stationary source emissions growth projections. GSP is used as a measure of general economic growth for non-EGU emissions because it serves as a value added variable, which EPA prefers to earnings and employment projections because it is a measure of economic growth that may more closely track emissions.

- EPA's MOBILE model has been updated, and we intend to use this updated version to predict highway vehicle emissions.

- EPA has issued a draft NONROAD model to project nonroad engine and vehicle emissions.

- A few area sources will have revised projections to reflect EPA's work on recent OAR rules.

Utility point source emissions will still be measured using EPA's Integrated Planning Model (IPM). Census population data will be used for 1990 and 2000 population estimates, and Census projections will be used for 2010 and 2020. Exhibit 2-5 provides a summary of our proposed approach for growth projections.

Our final refinement is a disaggregated analysis of the following source categories: industrial point sources, utilities, area sources, motor vehicles, and nonroad mobile sources. This analysis will require five additional scenarios. All five source categories will be included in these scenarios, but for each scenario regulation for one source category will be set to pre-CAAA levels while the remaining source categories stay at post-CAAA control levels. For example, one scenario will assume that emissions controls for industrial point sources remain at their pre-CAAA levels while the other four source categories operate at post-CAAA levels. This analysis will allow EPA to examine the relative contributions to total CAAA quantified benefits from each of the major emitting sectors.

Exhibit 2-5

DATA NEEDS AND PROPOSED APPROACH FOR GROWTH PROJECTIONS IN THE SECOND PROSPECTIVE

	Population	Economic Growth
Data Needs	Population statistics and projections for the period 1990 to 2020, by age and location. For the benefits analysis, data are needed at the census tract level.	EPA Guidelines for projecting emissions into the future recommend the use of economic variables which forecast (in order of preference) product output; value added; earnings; and employment.
Proposed Source	U.S. Census data for 1990-2000 and Census projections for 2000-2010 and 2010-2020.	Projections derived from EPA's EGAS model, which is based on Wharton Economic Forecasting, Regional Economic Modeling, and BEA estimates.[a]
Additional Information	1995 BEA projections based on 1990 Census data are an alternative. These estimates factor in regional economic impacts.	BEA growth projections for Gross State Product (GSP), a value-added variable, provide an alternative. EPA's Heavy Duty Diesel Vehicle Rule RIA utilized the BEA GSP variable.
National Level Summary of Data	Implied Annual Growth Rates: 1990-2000, 1.24%; 2000-2010, 0.86%; 2010-2020- 0.81%	Implied Annual Growth Rates: 1996-2001, 2.9%; 2001-2012, 2.3%

a. EPA may adjust EGAS 4.0 projections or update the data included in EGAS. Chapter 2 describes these potential adjustments in detail. The growth rates presented here are EGAS 4.0 projections.

Regulations and rules will also change in the second prospective to reflect the addition of new rules and provisions in place as of spring 2003. The new inclusions are:

- The revisions to the ozone and PM NAAQS will be reflected in the post-CAAA scenario (and excluded from the pre-CAAA scenario). The NAAQS for fine PM were updated in July of 1997 after EPA conducted a review of the standards that were in place at the time. Although the goal of the revision was to reduce ambient levels of fine particulate matter, the revised standards also targeted pollutants such as NO_x and SO_x, which form fine PM in the atmosphere. With these new measures in place, emissions of several pollutants must decline further than originally estimated in the first prospective for generators to comply with the Clean Air Act Amendments. Cost and benefit results will therefore reflect the impacts of these major changes. Information on the emissions reductions necessary to comply with the revised PM NAAQS is provided in Chapter 3, which presents EPA's approach to emissions estimation for the second prospective.

- Recent rules limiting mobile source emissions will be included in the post-CAAA scenario, including the Tier II tailpipe standards, gasoline sulfur limitations, heavy-duty diesel tailpipe standards, diesel fuel sulfur limitations, and the nonroad diesel rule.

- The NO_x State Implementation Plan (SIP) Call will be incorporated in its final form instead of the Ozone Transport Commission NO_x Memorandum of Understanding, which was the best projection for a future NO_x cap and trade program available during the design of the first prospective. The final rule affects sources in 22 States (a variant that affected 37 states was used in the first prospective). Controls will also be applied to all non-electrical generating units (EGUs) NO_x sources; these controls were only applied to cement kilns and internal combustion engines in the first prospective.

- The post-CAAA scenario will include additional Title III Maximum Achievable Control Technology (MACT) rules, including as broad a range as possible of the 7-year and 10-year MACT rules that were not reflected in the first prospective. Criteria pollutant emissions reductions associated with these rules, which include directly emitted PM, SO_x, NO_x, and VOCs, will be incorporated in the subsequent modeling steps, and individual air toxic species emissions reductions will be tallied and aggregated for comparison to costs in the results aggregation step.

Exhibit 2-6 lists several of the air pollution control measures that will be incorporated into the second 812 prospective analysis. Column 1 lists major emissions source categories; column 2 lists pollution control measures in place under the pre-CAAA scenario, and column 3 provides information on measures in effect under the post-CAAA scenario. Most of the items in the post-CAAA column are the same as in the first prospective. However, in the second prospective, EPA will incorporate the regulatory changes described above.

Supplemental Scenarios

The supplemental scenarios that were proposed for analysis during the first prospective are listed below:

- **Scenario 1** – Utility sulfur dioxide (SO_2) and oxides of nitrogen (NO_x) reductions. This scenario leads to a 47 percent reduction in SO_2 beyond the post-1990 case, and also achieves some utility NO_x reductions. In the ozone/PM/regional haze National Ambient Air Quality Standards (NAAQS) RIA schematic, this case was known as the *national PM strategy*. It simulates a program with a goal of achieving a 50 percent reduction in utility SO_2 emissions beyond what is currently required by Title IV of the CAAA. Many of these provisions have recently or are currently being analyzed by EPA as part of EPA's evaluation of legislative proposals to tighten utlility emissions requirements.

Exhibit 2-6

Projection Scenario Summary by Major Sector in the Second Prospective

Sector	Pre-CAAA	Post-CAAA*	
Industrial Point	RACT held at 1990 levels	**NO_x**:	RACT for all NAAs (except NO_x waivers), NO_x measures included in ozone SIPs and SIP Call post-2000.
		VOC/HAP:	RACT for all NAAs, VOC measures included in ozone SIPs, 2-, 4-, 7-, and 10-year MACT standards, New control technique guidelines (CTGs).
		Ozone:	Rate-of-Progress (3 percent per year) requirements (further reductions in VOC).
Utility	RACT and New Source Review (NSR) held at 1990 levels. 250 ton Prevention of Significant Deterioration (PSD) and New Source Performance Standards (NSPS) held at 1990 levels.	**NO_x**:	RACT and NSR for all non-waived (NO_x waiver) NAAs, SIP Call post -2000, Phase II of the Ozone Transport Commission (OTC) NO_x memorandum of understanding, Title IV Phase I and Phase II limits for all boiler types, 250 ton PSD and NSPS, Mercury MACT (pending 2003 proposal), Additional measures to meet PM and ozone NAAQS.
		SO_x:	Title IV emission allowance program, Mercury MACT (pending 2003 proposal), Additional measures to meet revised PM NAAQS.
Non-road	Controls (engine standards) held at 1990 levels.	**NO_x**:	Federal Phase I and II compression ignition (CI) and spark ignition (SI) engine standards, Federal locomotive standards, Federal commercial marine vessel standards, Federal recreational marine vessel standards, NO_x measures included in ozone SIPs, Nonroad Diesel Rule.
		VOC/HAP:	Federal Phase I and II spark ignition (SI) engine standards, Federal recreational marine vessel standards. VOC measures included in ozone SIPs.
		CO:	Federal Phase I and II spark ignition (SI) engine standards. Category 3 marine diesel engines - proposed standards.
		PM:	Federal Phase I and II compression ignition (CI) engine standards, Federal Phase I and II spark ignition (SI) engine standards, Federal locomotive standards, Nonroad Diesel Rule.

Exhibit 2-6

Projection Scenario Summary by Major Sector in the Second Prospective

Motor Vehicles	Federal Motor Vehicle Control Program (FMVCP) % engine standards set prior to 1990. Phase 1 Reid vapor pressure (RVP) limits. I/M programs in place by 1990.	**NO_x**:	Tier 1 tailpipe standards (Title II), Tier 2 tailpipe standards, 49-State LEV program (Title I), I/M programs for ozone and CO NAAs (Title I), Federal reformulated gasoline for ozone NAAs (Title I), California LEV (California only) (Title I), California reformulated gasoline (California only) (Title I), NO_x measures included in ozone SIPs, HDDV standards, Additional measures to meet PM and ozone NAAQS.
		VOC/HAP:	Tier 1 tailpipe standards (Title II), Tier 2 tailpipe standards, 49-State LEV program (Title I), I/M programs for ozone and CO NAAs (Title I), Phase 2 RVP limits (Title II), Federal reformulated gasoline for ozone NAAs (Title I), California LEV (California only) (Title I), California reformulated gasoline (California only) (Title I), VOC measures included in ozone SIPs, HDDV standards, Additional measures to meet PM and ozone NAAQS.
		CO:	49-State LEV program (Title I), I/M programs for CO NAAs (Title I), Tier 2 tailpipe standards, California LEV (California only) (Title I), California reformulated gasoline (California only) (Title I), Oxygenated fuel in CO NAAs (Title I), HDDV standards.
		PM:	Diesel fuel sulfur content limits (Title II) (1993).
		SO_x:	Diesel fuel sulfur content limits (Title II) (1993), HDDV standards and associated diesel fuel sulfur content limits, Gasoline fuel sulfur limits, Tier 2 tailpipe standards, Additional measures to meet new PM NAAQS.
Area	Controls held at 1990 levels	**NO_x**:	RACT requirements, NO_x measures included in ozone SIPs, Additional measures to meet PM and ozone NAAQS.
		VOC/HAP:	RACT requirements, New CTGs, 2-, 4-, 7-, and 10-year MACT Standards, Onboard vapor recovery (vehicle refueling), Stage II vapor recovery systems, Additional measures to meet PM and ozone NAAQS.
		PM:	$PM_{2.5}$ and PM_{10} NAA controls, VOC measures included in ozone SIPs.
		Ozone:	Rate-of-Progress (3% per year) requirements (further reductions in VOC), Model rules in OTC States.

NOTE: *Also includes all Pre-CAAA measures.

- **Scenario 2** – On-highway vehicle NO_x and volatile organic compound (VOC) reductions. The specific control programs would include: (a) Tier 2 tailpipe standards applied nationwide,[2] (b) expansion of Federal reformulated gasoline to the entire Ozone Transport Assessment Group (OTAG) region, and (c) application of high enhanced inspection and maintenance (I/M) in metropolitan statistical areas and consolidated metropolitan statistical areas with 1990 population greater than 500,000.

- **Scenario 3** – This would include a combination of SO_2, NO_x, and VOC emission reductions from Scenarios 1 and 2.

In addition, EPA had previously planned to include alternative energy scenarios in its analysis of supplemental scenarios. In order to perform all of the disaggregated analyses necessary to meet the core objectives of the Section 812 study, however, EPA will need to exclude the analysis of alternative energy scenarios from the second prospective. EPA hopes to address alternative energy scenarios in future efforts.

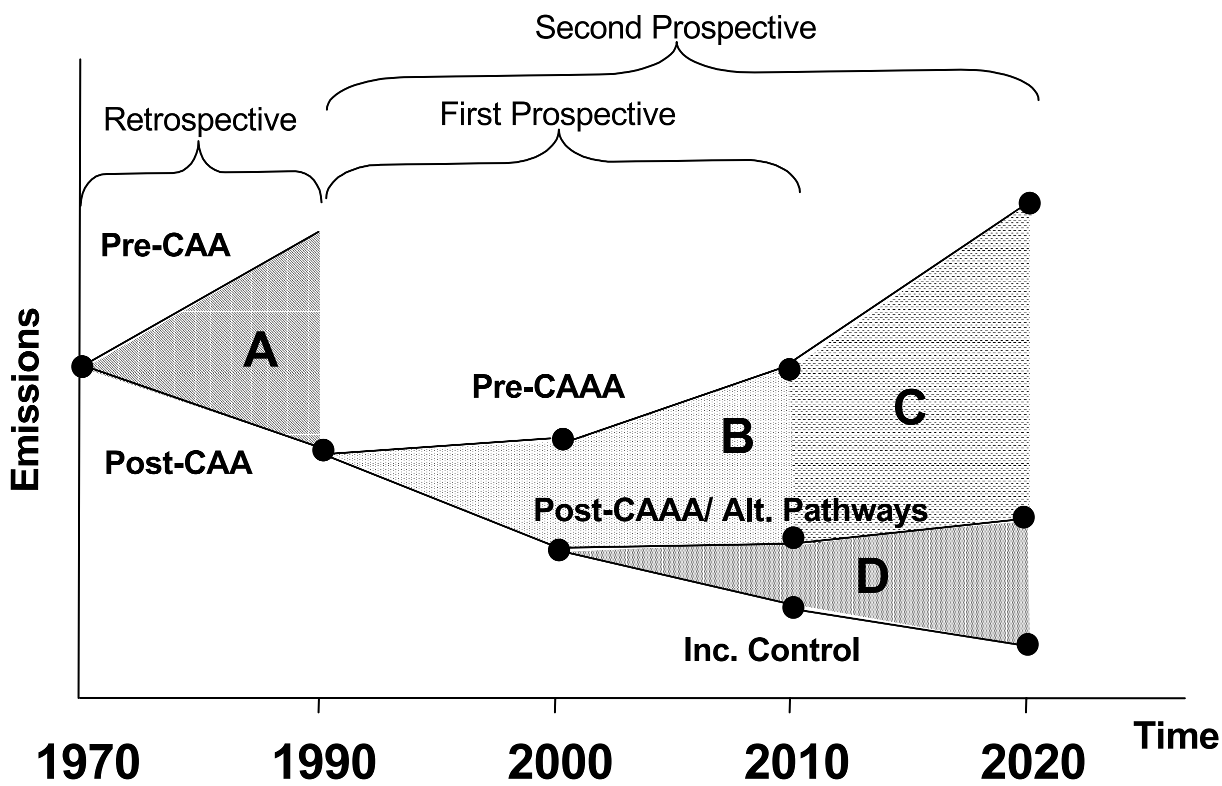
For the second prospective, EPA intends to analyze two types of supplemental scenarios: alternative pathway scenarios and increased control scenarios. For the alternative pathway analyses, EPA plans to assess the costs and benefits of different programatic pathways to core CAAA compliance. *These pathways represent a redistribution of emissions reductions across source categories*. As Exhibit 2-7 illustrates, alternative pathway emissions are intended to be comparable to post-CAAA emissions. Such an analysis will allow EPA to evaluate the relative efficiency of different strategies for complying with the CAAA. EPA also proposes to examine the costs and benefits of standards more stringent than those required by the CAAA. Area D in Exhibit 2-7 illustrates how an increased control scenario builds incrementally on the post-CAAA scenario. This analysis will provide insight into the potential implications of tightening CAAA requirements across source categories and pollutants.

EPA proposes the analysis of five alternative pathways. The first two pathways emphasize emissions reductions at utilities, with compensatory easing of reduction requirements from selected non-utility sources, resulting in overall progress toward NAAQS attainment comparable to that achieved by the core control scenario. The third pathway reflects a shift in NAAQS compliance strategies toward highway vehicles, and the last two pathways combine elements of the first three. The pathways are as follows:

- **Pathway 1:** This pathway would reflect the electric generating unit cap and trade proposals included in the Clear Skies Initiative. These proposals include emissions caps of 3 million

[2] The Tier 2 tailpipe standards applied nationwide will now be applied in the post-CAAA baseline scenario, and will affect 2010 and 2020 emissions.

Exhibit 2-7: Comprehensive Schematic of Section 812 Scenarios and Emissions over Time



tons, 1.7 million tons, and 15 tons for SO_2, NO_x, and mercury respectively for the year 2018.[3] With this pathway's emphasis on emissions caps and allowance trading, other control methods included in the post-CAAA scenario would be eased since they would not be necessary for core CAAA compliance.

- **Pathway 2:** The second pathway would target the closure or modernization of coal-fired power plants as a means of complying with the Amendments, potentially by terminating New Source Review grandfathering for old emissions sources. This scenario is intended to reflect recent recommendations from the National Academy of Public Administration.[4] With the decline in emissions from coal-fired power plants, other post-CAAA controls not necessary for core CAAA compliance would be excluded from this pathway.

- **Pathway 3:** The third alternative pathway tightens NO_x and VOC emissions restrictions on motor vehicles while loosening CAAA standards for other source categories. The specific

[3] Additional information on the Clear Skies Initiative can be found on the EPA website: http://www.epa.gov/air/clearskies/basic.html#emissions.

[4] National Academy of Public Administration. April 2003. *A Breath of Fresh Air: Reviving the New Source Review Program*. This report is available on the web at http://www.napawash.org/Pubs/Fresh%20Air%20Summary.pdf.

control programs would include: (a) expansion of Federal reformulated gasoline to the entire Ozone Transport Assessment Group (OTAG) region, and (b) application of high enhanced inspection and maintenance (I/M) in metropolitan statistical areas and consolidated metropolitan statistical areas with 2000 population greater than 500,000. We are also exploring options to reflect additional measures beyond expanded reformulated gasoline and enhanced I/M programs as part of this scenario.

- **Pathway 4:** This pathway combines pathways 1 and 3 and eases other controls so that emissions remain at post-CAAA levels.

- **Pathway 5:** This pathway combines pathways 2 and 3 and eases other controls so that emissions remain at post-CAAA levels.

Ideally, EPA's alternative pathways analysis would hold air quality constant to ensure that benefits remain constant across different pathways of compliance. Given increased emissions reductions for one source category, the ideal analysis would calculate the degree to which CAAA restrictions on other source categories would be eased in order to achieve air quality consistent with primary post-CAAA air quality. Based on the difference between primary and alternative emissions reductions, EPA could then estimate changes in compliance costs for each source category.

Unfortunately, EPA will not be able to follow this methodology for its assessment of alternative pathways in the second prospective. Estimating the changes in emissions reductions necessary to hold air quality constant would require feedback capabilities too cumbersome for available air quality models. Given an increased emphasis on emissions reductions for one source category, EPA would need to run several iterations of an air quality model to calculate the degree to which emission reductions from other sources could be eased while maintaining constant overall air quality. Although EPA could program an air quality model to perform such an analysis, model run time would be prohibitively long.

Given the infeasibility of holding air quality constant, EPA plans to hold emissions constant in its analysis of alternative pathway scenarios, although some slight variation in emission reductions between scenarios may prevail given the noncontinuousness of emission control options. For the pathways emphasizing tighter controls on utilities, the decline in emissions from utilities will be approximately equal to the increase in emissions from other sources. Similarly, for the pathways targeting motor vehicle emissions reductions, the extra decline in motor vehicle emissions will roughly equal the increase in emissions from other sources. EPA recognizes that air quality, and therefore benefits, might change if emissions are simply redistributed among source categories. However, given the computational limitations of air quality modeling, emissions is the best variable around which to anchor an alternative pathway analysis since it is only one step removed from air quality in the 812 analytic sequence.

The second prospective will also consider increased control scenarios under which the Clean Air Act is made even more stringent by varying degrees, starting in the year 2000. Under these scenarios, emissions from all major source categories will continue to decline after 2000, instead of leveling off. EPA is still in the process of precisely defining the increased control scenarios.

CHAPTER 3 - EMISSION ESTIMATION

This chapter provides a brief overview of our approach to developing emissions inventories for the second prospective for each of the scenarios described in Chapter 2 of this document. Many elements of the approach outlined here directly or indirectly reference information presented in Chapter 2.

Approach in First Prospective

We focused the first prospective analysis on those rules that affect six major pollutants: volatile organic compounds (VOCs), nitrogen oxides (NO_x), sulfur dioxide (SO_2), carbon monoxide (CO), particulate matter with an aerodynamic diameter of 10 microns or less (PM_{10}), and fine particulate matter ($PM_{2.5}$).[1] For each of these pollutants we projected 1990 emissions to the years 2000 and 2010 under the two basic scenarios.

We projected emissions for five major source categories: industrial point sources, utilities, nonroad engines/vehicles, motor vehicles, and area sources (see Exhibit 3-1).[2] The basic method we applied involves estimating emissions in the 1990 base-year, adjusting the base-year emissions to reflect projected growth in the level of pollution-generating activity by 2000 and 2010 in the absence of additional CAAA requirements, and modifying these projections to reflect future-year CAAA control assumptions.

Exhibit 3-1
MAJOR EMISSIONS SOURCE CATEGORIES

Source Category	Examples
Industrial Point Sources	boilers, cement kilns, process heaters, turbines
Utilities	electricity producing utilities
Nonroad Engines/Vehicles	aircraft, construction equipment, lawn and garden equipment, locomotives, marine engines
Motor Vehicles	buses, cars, trucks (sources that usually operate on roads and highways)
Area Sources	agricultural tilling, dry cleaners, open burning, wildfires

[1] Emissions estimates for ozone depleting substances were developed separately. Our planned approach for the ODS analysis is described in Appendix B to this report.

[2] We estimated utility and industrial point source emissions at the plant/facility level. We estimated nonroad engine/vehicle, motor vehicle, and area source emissions at the county level.

We constructed the base-year inventory using 1990 emissions levels. Emissions levels from Version 3 of the National Particulates Inventory (NPI) served as the baseline for all of the air pollutants examined in this analysis, with the exception of particulate matter. The NPI consisted of emissions data compiled primarily by the National Acid Precipitation Assessment Program (NAPAP), EPA's Office of Transportation and Air Quality (OTAQ), and the Federal Highway Administration (FHWA). For both $PM_{2.5}$ and PM_{10}, however, we updated NPI estimates, accounting for changes in the methodology used to calculate fugitive dust emissions. Adoption of this new technique, also used to develop EPA's National Emission Trend (NET) $PM_{2.5}$ and PM_{10} inventory, led to lower estimates of fugitive dust emissions and therefore of overall primary PM.[3]

After establishing the base-year inventory, we projected emissions to the years 2000 and 2010, adjusting for influences expected to cause future emissions to deviate from 1990 levels. With the exception of utility sources, our analysis relied on the Emissions Reduction and Cost Analysis Model (ERCAM), which accounted for the effects of pollution-generating activity and the stringency and success of regulations designed to protect air quality. In this analysis, we viewed changes in economic growth as an important indicator of future activity levels and, thus, future emissions. We used 1995 Bureau of Economic Analysis (BEA) Gross State Product (GSP) projections to forecast the growth of emissions from industrial point sources. Estimates of future nonroad and area source emissions were based on BEA GSP projections, as well as BEA population projections.[4] We used BEA population growth as an indicator of the increase in nonroad emissions from recreational marine vessels, recreational vehicles, and lawn/garden equipment as well as an indicator of the increase in area source solvent emissions (e.g., VOC emissions from dry cleaners). Our estimates of future motor vehicle emissions were based primarily on the projected increase in vehicle miles traveled (VMT), as estimated by EPA's MOBILE fuel consumption model.

Revisions to Approach for Second Prospective

For the second prospective, we plan to revise the 1990 emission estimates to reflect updates to the historical 1990 emissions inventories for the on-road vehicle, off-road engines/vehicles, and some stationary (non-point) area source categories. Criteria pollutant emission projections will be revised to reflect use of the 1999 National Emissions Inventory (NEI) Version 3.0 as the new base year. In March of 2003, EPA released draft Version 3.0 of the NEI, but EPA has made several major improvements to Version 3.0 since release of the draft in March. EPA therefore plans to use the most updated rendering of Version 3.0, which includes these changes. Emission estimates for

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[3]Primary PM consists of directly emitted particles such as wood smoke and road dust. Secondary PM forms in the atmosphere as a result of atmospheric chemical reactions.

[4]The growth forecast for area source agricultural tilling was based on projections of acres planted, not BEA GSP and population projections.

2000, 2010, and 2020 will be based on adjustments or replacements to the 1999 inventory, not 1990 as in the first prospective analysis.

We also plan to conduct an analysis of disaggregated, sector-specific emissions for the second prospective. To disaggregate emissions, the project team plans to isolate the pre- versus post-CAAA emission changes for each primary sector – electric generating units (EGUs), non-EGU point sources, on-road vehicles, off-road engines/vehicles, and stationary (non-point) area sources. This analysis will provide estimates of the net effect of all CAAA provisions on each individual sector. For non-EGU stationary sources, the proposed approach to estimating future year emissions by source category is to identify the most stringent post-1990 emissions control requirement (binding constraint) in each geographic area. Therefore, if a source category's VOC emissions are affected by both a VOC RACT requirement and a more stringent NESHAP, the NESHAP associated emission reduction is used to estimate projection year emissions.

The regulatory scenarios that define the emissions projections included in the second prospective are both complex and numerous. To highlight the differences between scenarios, EPA will provide Title-specific schematics making explicit the assumptions underlying each scenario. These schematics will illustrate how each Title of the Clean Air Act affects different pollutants under each scenario.

The SAB Council and Subcommittees made a number of comments about the emissions inventories that were prepared for the first prospective:

1. Estimates of speciated PM emissions should be provided, including elemental carbon, organic carbon, and crustal material.

2. Improved emission inventories and an integrated air quality modeling system, such as CMAQ/Models-3, should be used to support future prospective studies.

3. Hazardous air pollutants (HAPs) should be included in future prospective studies.

4. EPA should evaluate whether it underestimated particulate matter (PM) emissions from diesels and non-road engines/vehicles. EPA should also identify any changes in emission estimation methods since the first prospective.

5. There may be different, more robust techniques for forecasting economic trends for future prospective studies.

In addition, although it was not specifically proposed by the SAB, we plan to include updated base and future year emission estimates for Canada and base year emission estimates for the northern states of Mexico to support the dispersion modeling analyses. Further details on Canadian and Mexican emissions are presented later in this chapter.

The SAB review of the draft analytical plan for EPA's second prospective analysis provided some additional comments related to the emissions analysis:

1. Disaggregation by broad sectors of the economy is more appropriate and defensible than Title-by-Title disaggregation. We recommend aggregation into sectors relevant to air pollution. For the sectoral analysis to inform regulations more effectively, the Council recommends that key regulations be analyzed individually, rather than in groups.

2. The Council recommends that the second prospective analysis also provide a component that evaluates, for overlapping years (e.g., 2000 and 2010), how updates of assumptions, data, and models affect the results for costs and benefits.

3. For whatever scenarios EPA may choose to implement, the Council suggests that the Agency make explicit the assumptions underlying the scenarios. To help put these scenarios in perspective for Congress and other interested parties, the Council recommends that for each scenario EPA present a clear and succinct schematic of the different Titles, and how each Title affects emissions of all of the key chemicals under that scenario.

4. Mobile Sources. The AQMS believes it is very important that the model MOBILE6 be used to estimate VOC and NO_x emissions from on-road mobile sources.

5. Uncertainties, Consistency and Evaluation. Comparisons of modeled and observed trends is possible to a certain extent and should be conducted. These comparisons can help identify problems with the emission estimates and with the modeling approaches. In addition, ongoing regional studies should either be consistent with the 812 analysis, or any differences should be carefully documented and addressed.

6. The Council recommends that EPA, for the most part, decline to disaggregate net benefits by region, or by group of regulations.

The remainder of this chapter provides information on how we plan to refine our analytical approaches to address these comments.

Emissions Inventory Design

Design of the second 812 prospective study emissions analysis continued pursuant to the SAB review of the first draft blueprint with an EPA planning workshop in May 2002. The primary purpose of this workshop was to develop a plan for the 812 study emissions inventories that would respond to the SAB recommendations, and ensure the best available emissions data and models would be applied. The workshop generated several specific recommendations for the 812 Project Team. The two key elements of advice from the OAQPS and OTAQ emissions inventory managers were:

(1) The second prospective should use the 1999 NEI Version 2.0 as a base. Version 3.0 of this emission database is already available. Therefore, the project team expects to use Version 3.0 because it will be the most complete and up-to-date 1999 NEI file at the time the analytic work on the second prospective is initiated.

(2) Use of available emission data, along with new MOBILE6 and NONROAD2002 model simulations, would be the best approach for estimating 1990 emissions. The potential inconsistency of this data set with the first prospective is less of an issue now because other aspects of the scenario are changing (and an updated method will also allow us to see how the 1990 estimates have changed as reporting and modeling methods have been updated).

An overview of EPA's approach to emissions inventory development for the second 812 prospective analysis, therefore, begins with Exhibits 3-2 and 3-3, which summarize the overall organization and set of methodologies for sector-specific emissions inventory development. Specifically, Exhibit 3-2 summarizes the primary and secondary emissions projections methods for the five primary sectors that are included as anthropogenic emission sources in this analysis. These sectors, slightly refined in terminology from the first prospective, are: electricity generating units (EGUs), non-EGU point sources, highway vehicles, nonroad engines, and other area sources. The change in terminology from "utilities" to "electric generating units (EGU)"is intended to make it clear that generating stations owned independently of regulated public utilities are included in "EGU."

Exhibit 3-3 shows the relationship between the 1990 and 1999 emission estimates, as well as how to estimate year 2000 and future year emissions. The emission projections will begin with 1999 as the starting point and will be designed to account for the expected State or Federal Implementation Plans to meet the ozone and PM NAAQS. Previously, discretionary measures were selected for ozone nonattainment areas that had rate-of-progress requirements. For the second prospective, the ozone nonattainment analysis will begin with the post-1999 measures states have committed to in their ozone SIPs. We plan to use results from a recent work assignment sponsored by EPA-OAQPS to determine expected VOC and NO_x emission control measures by nonattainment area. The associated emission reductions will then be accounted for in the post-CAAA emission forecasts to 2010 and 2020.

As discussed above, the 1999 EPA National Emission Inventory (NEI) will be the primary emissions database used to estimate year 2000, 2010, and 2020 criteria pollutant emissions. The 1999 NEI contains estimates of PM_{10} and $PM_{2.5}$ emissions. To calculate elemental carbon and organic carbon, the project teams for recent rulemaking analyses have developed a database of fractional aerosol coefficients (FACs) for primary $PM_{2.5}$ organic carbon, primary $PM_{2.5}$ elemental carbon, primary $PM_{2.5}$ sulfate, primary $PM_{2.5}$ nitrate, and primary $PM_{2.5}$ crustal/other material. The primary PM FAC are defined as the fraction of organic carbonaceous material, elemental carbon, etc. contained in primary $PM_{2.5}$. The database is developed so that the FACs can be applied directly to estimate organic carbon and elemental carbon emissions from emission inventories that contain primary PM_{10} and $PM_{2.5}$ emission estimates.

The raw data used to calculate these coefficients were obtained from source profiles extracted from EPA's SPECIATE database. The SPECIATE data were supplemented with literature values to estimate mass fractions for Source Classification Codes (SCCs) where missing, zero, or unrealistic values were observed. Most of these literature values were taken from size fractionated source profiles developed by the Desert Research Institute for use in receptor modeling. A few additional missing fractions were assigned based on estimates of the ratio of $PM_{2.5}$ to PM_{10} and known organic carbon and elemental carbon values for other similar categories with data. A work assignment is in progress now to update these FACs to reflect speciaton profile data contained in the more recent scientific literature. These updated FACs will be used if they are available at the start of the analysis.

Once the FACs are applied to the PM_{10} and $PM_{2.5}$ emission estimates for each analysis year to estimate elemental carbon and organic carbon emissions, each source category is identified as being either (1) a crustal fugitive dust source, (2) a crustal industrial source, or (3) a non-crustal source. Crustal fugitive dust sources include windblown dust, agricultural tilling, and paved and unpaved road reintrained dust. Crustal industrial sources are those in the ferrous and non-ferrous metals and mineral products industries.

EGUs

The first prospective analysis used the Integrated Planning Model (IPM) to prepare EGU emission estimates for 2000 and 2010. IPM has also been used more recently by EPA to provide 2020 emission estimates. Because IPM performs its computations for model plants, another processing step is needed to convert the model plant information to grid-based unit-level data files. For example, for the Clear Skies Initiative (CSI) benefits analysis performed in 2002, EPA generated projection year unit-level output files from IPM for 2010 and 2020. These files include estimates of heat input, SO_2 and NO_x emissions, and unit characteristics such as prime mover, primary fuel, bottom type, firing type, and emission control unit(s) type. EPA supplemented the IPM output with estimates of VOC, carbon monoxide (CO), PM_{10}, $PM_{2.5}$, and ammonia emissions, as well as other data elements needed for modeling.[5]

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[5] Note that electricity demand growth factors employed in recent IPM runs will be re-visited to ensure consistency with the growth factors planned for application to non-EGU sources.

Exhibit 3-2
Planned Emissions Estimation Procedures for Second Prospective

Sector	Primary Projection Method	Alternatives	
Point Sources			
EGU	Use IPM output.	Develop alternate projection methods based on SIP Call NO_x analysis.	Use the EGU emission projection methods and costing that was/is being used for the SAMI analysis.
Non-EGU	Update point source control factors to reflect a 1999 base year and new control initiatives. Update most influential growth factors from BEA to EGAS 4.0.		
Area Sources			
Highway Vehicle	Use MOBILE6 for all highway vehicle emission factor estimates.		Investigate alternative VMT projections to the EPA estimates used in recent regulatory analyses.
Nonroad Engines/Vehicles, excluding below	Draft EPA NONROAD2002 model for the categories included in this model (revised draft expected to be released in Spring 2003).		
• Aircraft	Federal Aviation Administration (FAA) landing and take-off operation (LTO) forecasts		
• Commercial Marine Vessels	Department of Energy (DOE) fuel consumption projections[1] with impact of Federal marine standards		
• Locomotives	DOE fuel consumption projections[1] with impact of Federal locomotive standards		

Sector	Primary Projection Method	Alternatives	
Other Area Sources	Use area source control factors from the EPA HDD study for the post-CAAA case with updates to reflect a 1999 base year and new control initiatives. Use EGAS version 4.0 for estimating population and economic growth		

[1]Regionalized using EGAS 4.0 sector output projections.

Exhibit 3-3
Section 812 Projection Scenario Summary by Major Sector

Sectors	**1990**	**1999**	**2000**	**2010**	**2020**
EGU	Use 1990 estimates from First Prospective	NEI Version 3.0	CEM-based	IPM	IPM
Non-EGU Point	Use 1990 estimates from First Prospective	NEI Version 3.0	1 year projection from 1999 NEI	EGAS 4.0 growth and impact of non-EGU point source controls	EGAS 4.0 growth and impact of non-EGU point source controls
Stationary Area	Same as above except for a few categories revised to be consistent with 1999	NEI Version 3.0	1 year projection from 1999 NEI	EGAS 4.0 growth and impact of area source controls	EGAS 4.0 growth and impact of area source controls
On-Road	MOBILE6	NEI Version 3.0 MOBILE6	MOBILE6	MOBILE6	MOBILE6
Nonroad[1]	NONROAD2002	NEI Version 3.0 NONROAD2002	NONROAD2002	NONROAD2002	NONROAD2002
Scenarios	None		1. Pre-	1. Pre-	1. Pre-
			2. Post-	2. Post-	2. Post-
			3. Compare 1st prospective post- with actual 2000	3. Supplemental scenarios	3. Supplemental scenarios

[1]Includes all nonroad engines and vehicles except for aircraft, locomotives, and commercial marine vessels (see Exhibit 3-2 for summary of methods for these categories).

As an alternative to IPM, EPA considered using the same emission estimation methods that were used in the NO_x State Implementation Plan (SIP) Call to estimate emissions for the SIP Call affected states. The SIP Call emission projections used 1995 and 1996 emissions and generation for affected EGU units to establish baseline conditions, and then developed a state-level growth factor for each state that provides an estimate of 2007 generation when multiplied by 1995/1996 generation. Then, 2007 emissions were calculated by multiplying the NO_x emission limit of 0.15 pounds per million British thermal units by the estimated 2007 generation. For non-SIP Call states, generation in 2007 (and beyond) can be estimated using existing emission rates, and estimates of future generation that are consistent with data sources used for the SIP Call states.

A second EGU alternative we have considered is to extend the methods that were recently used for the Southern Appalachian Mountains Initiative (SAMI) to estimate emissions and costs of various strategies in the Southeast United States. SAMI analysis years are 2010 and 2040. These analytic methods were developed with extensive input from SAMI stakeholders, including several electric utility industry representatives. Emission projection methods have been designed to produce modeling input files.

The SAMI inventories were developed from the SAMI EGU workgroup recommendations. Coal-fired boilers were grouped by size and age to apply future year capacity factors. For other unit types, including oil or gas fired boilers and combustion turbines, base year 1990 emissions were extrapolated to 2010 or 2040 using default growth factors that were developed from U.S. Department of Energy (DOE) generation projections by North American Electric Reliability Council (NERC) region and fuel type. Planned future units that were identified in DOE's Form 860 were added in the two projection years. New generic units met additional generation demand that was not supplied by existing and planned units. Based on the consensus of stakeholder utility companies in the Southeastern United States, SAMI assumed a mix of fuel types/prime movers for each megawatt of generic capacity added. This included three types: pulverized coal boilers, integrated gasification combined cycle (IGCC) units, and natural gas fired combined cycle (NGCC) units; the stakeholders anticipate that these unit types will each create new generic capacity at a ratio of 20, 40, and 40 percent, respectively.

In addition, the SAMI EGU analysis assumes that units, except those larger than 350 megawatts (MW), are retired after 65 years of service. Coal-fired units greater than 350 MW were assumed to be repowered, rather than retired after 65 years. A capacity factor of 0.77 is applied to repowered units.

We currently plan to use IPM in order to be generally consistent with earlier EPA work, to be consistent with the outcome of recent interagency consultations on certain input estimates such as future natural gas prices, to facilitate application in the 812 study of emissions inventories and relevant results files already generated for other recent analyses, and to ensure consistency of target year selection and other critical design elements between the EGU and other sectors in the 812 analysis. In addition, IPM provides a thorough and comprehensive analysis of emissions that currently cannot be matched by other models without significant additional development. Descriptive information on the version of IPM that was used by EPA in 2002 to analyze the proposed Clear Skies legislation is available at **www.epa.gov/airmarkets/epa-ipm/index.html.** Updates have been made in 2003, but documentation for these is not yet available.

Non-EGU Stationary Sources

The 2007 and 2020 non-EGU stationary source emission projections that were performed for the HDD rulemaking[6] were based on the 1996 National Emission Trends version 3.12. Applying Bureau of Economic Analysis (BEA) growth factors, these projections reflected control measures required by the CAAA. Such control measures included estimates of the benefits of the 7 and 10 year maximum achievable control technology (MACT) standards, the NO_x SIP Call requirements for 22 states plus DC, and various national rules. For two more recent analytical projects, the 2002 analysis of the proposed Clear Skies legislation and the analysis for the recently proposed rule addressing Tier 4 requirements for nonroad diesel engines, this 2020 projection was again used, and estimates for 2010 were created by linear interpolation between these 2007 and 2020 inventories.

Modifications to the emission projection methods for the second prospective analysis include incorporation of the newest 1999 NEI to reflect recent state submittals of data on point sources, area sources, on-road vehicles, and nonroad engines/vehicles; inclusion of recent Ozone Transport Commission (OTC) state actions and modifications to the NO_x point source files to better identify sources affected by the SIP Call; and potential revisions to the population and economic growth factors that are used in the emission projections.

Emission projections performed for point sources in the first prospective (and in other EPA regulatory analyses) have applied growth and control factors in a way that effectively assumes that, in the absence of new rules affecting emissions of existing sources, future year emission rates are consistent with existing emission rates. This assumption allows for an accurate assessment of the path of future emissions as long as the existing plant stock has the capacity to increase utilization to meet future production needs. For industries that operate at or near current capacity, increased demand must be met either by constructing new units at existing plant sites, or by constructing new greenfield plants. In either case, the new units will be subject to new source review, under which new source emissions rates must meet BACT/LAER levels.

An alternative to the previous growth in-place method is to include both growth and retirement rates in the analysis, and to assume that retired sources are replaced with new sources that meet BACT/LAER requirements. Operationally, this can be accomplished by adopting the

[6] U.S. EPA, OAQPS, (2000c)."Procedures for Developing Base Year and Future Year Mass and Modeling Inventories for the Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel (HDD) Rulemaking," EPA-450-R-00-020k. October

algorithms that were developed for the Grand Canyon Visibility Transport Commission Integrated Assessment System (IAS), and adapted by Pechan for the Western Regional Air Partnership (WRAP) Emission Forecasts to 2018 study that was recently completed. Using this method will produce results that are more consistent with those of the WRAP.

The retirement approach works best when the operational age of the major pollution emitting equipment is known, and the model can simulate the retirement of each piece of equipment at the end of its expected lifetime. While some studies of Best Available Retrofit Technology (BART) applications have developed estimates of start-up dates, such data are not universally available outside the utility sector. Therefore, for most units, retirement rates would be applied to retire a portion of the capacity that is replaced by new source emission rate-emitting capacity each year. Another alternative would be to assume that all existing plants began operating in 1999 (or some other recent year) and retire in 30 to 60 years according to source type. For a 2020 time horizon, this would effectively mean no retirements.

The practical difference between the previous and alternative emission forecasting methods is that the approach including both growth and retirement factors will produce a lower future year emissions forecast than with previous methods.

There are many EPA and other air quality agency programs that affect non-EGU stationary source emissions including, but not limited to, new source performance standards, State Implementation Plan (SIP) control measures, new source review, and national emission standards for hazardous air pollutants (NESHAPs). We will utilize internal databases as the starting point for estimating the impact of these programs on post-CAAA emissions. Among the databases that we have in-house is ControlNET, which is a relational database system in which control technologies are linked to sources within emission inventories to calculate emission reductions (and costs) of alternative control strategies. We also have databases containing the emission controls used in past EPA projection efforts including the previous Section 812 analysis and the analysis of the Heavy Duty Diesel Vehicle emission regulations, both of which included projections for all emission categories, including non-EGU stationary sources. These studies include control factor files for non-EGU stationary sources because emission projections are needed for all sectors for inclusion in air quality modeling analyses.

We will update any of the information in these databases to account for any revisions that have occurred (e.g., proposed emission standards that have now been promulgated), and supplement them with control information for new regulatory programs. For example, we will compile control information for new Maximum Achievable Control Technology (MACT) standards because the existing databases do not contain comprehensive information for the 7- and 10-year MACT standards. This effort will include a review of information and contacts with EPA staff to obtain criteria pollutant emission reduction estimates for all MACT standards, which typically focus on estimating hazardous air pollutant (HAP) emission reductions.

Estimating Future Emissions - Non-EGU Generating Activity

The previous Section 812 analysis used state-level economic projections prepared by the Bureau of Economic Analysis (BEA) to estimate growth in non-EGU stationary source emissions activity. The BEA growth factors are now dated since the most recent set of projections was released in 1995. As a response to this concern, EPA developed an updated Economic Growth Analysis System (EGAS) model. EGAS is a software tool that produces state and sub-state emission growth factors for use in projecting emission inventories. As with previous versions of the model, most of the growth factors for non-EGU stationary source categories in EGAS Version 4.0 are based on economic sector output projections from economic models developed by Regional Economic Models, Inc. (REMI). These models estimate regional economic activity based on each region's cost competitiveness relative to the nation. For fuel combustion sectors, EGAS Version 4.0 utilizes regional projections of fuel consumption prepared by the Department of Energy's Energy Information Administration (EIA). EGAS Version 4.0 utilizes the EIA's *Annual Energy Outlook 1999* projections. For the second prospective, we will replace the EGAS 4.0 EIA-based growth factors with growth factors based on EIA forecasts from the latest version of *Annual Energy Outlook*. The development of EGAS growth factors is described in more detail in the publicly distributed EGAS documentation.[7]

The current version of EGAS relies on REMI models that are also somewhat dated. For example, the EGAS 4.0 REMI regional models, which utilize historical data through 1996, are driven by a REMI national forecast based on 1997 Bureau of Labor Statistics (BLS) projections. This creates two potential sources of error in using the existing EGAS model for the Section 812 analysis. First, EGAS utilizes forecast rather than actual economic data for the 1997-2001 period. To the extent that these forecasts are not consistent with actual growth, EGAS estimates will be biased. Second, the forecasts that drive post-2001 growth will be based on somewhat outdated views of the structure and future prospects of the national economy. The implications of these concerns are addressed below.

REMI Forecast Accuracy

Forecasts of the sector output values that drive much of the non-EGU sector emissions growth in EGAS will be strongly and positively correlated with overall levels of national economic activity as measured by real gross domestic product (GDP). To get a general assessment of the level of error in the EGAS projections for the 1997-2001 period, we compared REMI's 1997-2001 GDP forecasts with actual GDP growth in the period. This comparison suggests that the REMI projections for the period under-predicted actual growth in GDP. As shown in Exhibit 3-4, total

[7] A complete description of the development and use of EGAS growth factors is included in, E.H. Pechan & Associates, Inc., (2001), "Economic Growth Analysis System:Version 4.0, Reference Manual, Final Draft," January 26, also available in PDF format at: http:/www.epa.gov/ttnchie1/emch/projection/egas40/ref_man_4.pdf.

GDP growth in the U.S. was 19.5 percent for the 1997-2001 period, compared with the REMI-BLS forecast of 15.3 percent.

Exhibit 3-4. REMI Forecast GDP Growth Versus Actual GDP Growth, 1996-2001

	Overall Growth	Annualized Growth Rate
REMI-BLS (97)	15.3%	2.9%
Actual	19.5%	3.6%

A second source of potential error arises if forecasters have substantially changed their views about levels of likely future economic growth. Specifically, more recent forecasts will reflect information about long-term prospects for the economy that were not available in 1997 and thus are not reflected in the national projections that underlie the EGAS model. Estimates of the size of this potential error are presented in Exhibit 3-5, where REMI-BLS (97) growth forecasts for the 2001-2012 period are compared to the BEA's projections, as well as recent projections from the major economic forecasters, including the Congressional Budget Office (CBO), the Office of Management and Budget (OMB), the BLS (2001), and the "Blue Chip" indicator based on forecasts from 50 leading public, private, and academic economists.

Exhibit 3-5. Comparison of REMI GDP Forecast with Alternative Forecasts, 2001-2012

	Most Recent Projections				Older Projections	
Period	CBO	OMB	BLS (2001)	Blue Chip	BEA	REMI-BLS (97)
2001-2012	39%	39%	44%	40%	21%	29%

The data in Exhibit 3-5 are significant for three reasons. First, they indicate that the BEA projections forecast growth in overall economic activity at approximately one-half the level predicted by the most recent projections. Second, they suggest that there is a strong consensus among major forecasters regarding likely growth in the US economy over the next decade, with each of the four forecasts predicting cumulative growth of between 39 and 44 percent between 2001 and 2012. Moreover, the forecast that differs most from the others--the BLS (2001) forecast--was developed before the 9/11 events, timing that might account for its somewhat more optimistic projection of growth. Together, though, the data in Exhibit 3-5 suggest that OMB, CBO, BLS, or any other well-known forecast will provide similar estimates of national economic growth for the next decade.

A third and more significant implication of Exhibit 3-5 is that the REMI-BLS (97) projections included in EGAS are significantly lower than any of the recent forecasts. While recent CBO, BLS, OMB, and the Blue Chip forecasts all project approximately 40 percent cumulative growth for the 2001 to 2012 period, REMI-BLS (97) forecasts approximately 30 percent growth.

As a result of this difference, REMI-BLS (97) estimates of cumulative GDP growth are also lower over the entire available period (1996-2012) as Exhibit 3-6 indicates.

Exhibit 3-6. Comparison of REMI GDP with Alternative Estimates, 1996-2012

Period	CBO	OMB	BLS (2001)	Blue Chip	REMI
1996-2012	66%	66%	72%	67%	49%

This difference is fairly large relative to the uncertainty inherent in long-term projections. A review of past BLS GDP forecasts indicate that its "moderate" and "low" and "high" growth forecasts will generate ten year cumulative growth differences of 30 to 45 percent. Therefore, although the difference associated with the REMI-BLS (97) forecast is within this range, it is relatively close to the outer bounds that BLS has used in developing past GDP projections.

The difference between the REMI BLS (97) and more recent forecasts of economic activity can be traced to a fundamental change in forecasters' views about the long-term prospects for the American economy. Differences between BLS's 1997 forecasts and its most recent (2001) forecast of GDP growth reflect this change. In its November 1997 forecast, BLS projected that real GDP would grow by 2.1 percent in the 1996-2006 period, an estimate that implied slower growth than that of the previous decade (1986-1996), when real GDP had increased by an average of 2.3 percent per year. In its November 2001 forecast, however, BLS projected GDP growth of 3.4 percent for the 2000-2010 period, an increase over the previous decade's (1990-2000) actual growth of 3.2 percent annually. Thus, between 1997 and 2001, BLS adjusted its expectations for the next decade's growth from 2.1 to 3.4 percent.

Options for Estimating Emissions Growth in Section 812 Analysis

We do not plan on using the BEA projections for this analysis because they are lower than all of the other alternative forecasts, and are less geographically detailed, more dated, and less source category-specific than the available EGAS forecasts. Based on the available data sources and the results of the comparisons described above, we have identified the following optional approaches for projecting non-EGU sector emissions growth:

- Utilize EGAS Version 4.0 growth factors;
- Utilize EGAS Version 4.0 growth factors after adjusting each growth factor upward by the difference between each analysis year’s CBO/OMB GDP forecast and the REMI-BLS (97) GDP forecast;

- Procure and use updated National and Regional REMI models and updated EIA energy projections to develop a new EGAS reflecting current forecast assumptions; and

- Use existing EGAS Version 4.0 growth factors for most source categories, but review and improve the growth factors for the *major emitting source categories* as identified in the 1999 NEI.

Each of these options is briefly described in the following subsection. The 812 Project Team is still considering these options, but expects to choose a methodology shortly after the June 11-13 SAB review meeting. Therefore EPA is interested in any advice the SAB wishes to convey regarding the technical merits of each of these alternative approaches.

Approach #1

The simplest approach would be to utilize the emission growth factors developed by EGAS Version 4.0. Although the existing national GDP growth estimates can be viewed as representing a current BLS low growth scenario, it is important to note that the use of economic output projections may tend to overstate actual emissions activity changes. As noted in EPA's emission projections guidance, emission activity changes are best estimated using forecast changes in product output. Less preferred methods rely on economic forecasts, such as value added or employment. The use of REMI economic output (sales) projections for most non-EGU emission sources assumes that any growth in the sales of products sold is proportional to growth in emissions activity. This approach cannot capture the decline in emissions per unit of output that characterizes many industrial sectors. For some EGAS source categories, EGAS includes bridge equations that link changes in sales with changes in emissions activity levels. In each case, the historical data indicate that emissions activity grows more slowly than economic output. As a result, for at least some of the sectors without bridge equations, EGAS is likely to overestimate emissions growth. Therefore, if EGAS economic projections are lower than actual economic growth, then this would offset some of the over-estimation bias of the model.

Approach #2

An alternative approach would be to use the EGAS 4.0 growth factors after adjusting each growth factor upward by the difference between each analysis year's REMI-BLS (2001) GDP forecast and the REMI-BLS (97) GDP forecast. The purpose of this option is to ensure that emissions growth projections reflect the most recent set of official government economic growth rate assumptions. This approach is consistent with the geographic structure of the regional models embedded in EGAS, which partition national growth based on the relative economic characteristics of regions, e.g., relative wage rates. In addition to potentially exacerbating the emissions per unit of output issue described previously, there are at least two other concerns with this approach: (1) it is not clear if sectoral output growth rates move in lock-step with overall national growth rates; and

(2) the approach does not address any structural changes that might underlie the new national GDP projections. One advantage of this approach is that it provides national-scale consistency with the data used as a basis for income adjustment on the benefits side.

Approach #3

Another alternative would be to procure an updated set of REMI national and regional economic forecast models. These updated models would be used along with the existing EGAS framework to develop new EGAS-based growth factors. This approach would capture the most recent structural features of the national and sub-national economies, but would entail significant additional resource and time requirements, including a possible delay of several months in the initiation of non-EGU emissions inventories, a critical path task for the overall analysis. In addition, this option would potentially exacerbate the emissions per unit of output issue described above.

Approach #4

A final alternative is to use the existing EGAS Version 4.0 growth factors for most source categories, but review and refine the estimates for the largest-emitting source categories. This "ad hoc" approach would focus resources on the most significant pollutant sources and would entail one of two sub-approaches, depending on data availability, as described below. The first sub-approach would entail research into the availability of actual emissions activity projections from other information sources (e.g., use of the most up-to-date EIA fuel consumption projections). Because most of these sources are expected to report only national-level forecasts, it would be important to regionalize the projections. This step would be accomplished by applying ratios to the national forecast data. These ratios, which would be developed using EGAS growth factors for a surrogate indicator of emissions activity, would represent the growth in each EGAS region relative to national growth. It is important to capture differential growth by region because the location of emissions activity growth may significantly affect the level of control applied to that growth. For example, total manufacturing employment in the U.S. declined by 3.0 percent in the 1990s. This national average, however, masks significant differences in urban and rural employment patterns: while manufacturing employment declined by 4.6 percent in urban areas, it actually grew by 2.8 percent in rural areas. Therefore, use of national projections data would likely lead to an overestimation of emissions-generating activity in urban/non-attainment areas and an underestimation of activity in rural/attainment areas.

The second sub-approach would be implemented for the largest-emitting sources for which actual emissions activity projections are not available. For these sources, we would perform additional regression analyses to reflect the relationship between historical emissions activity changes and historical economic activity changes, and then apply the coefficients from these analyses to EGAS growth factors. Before applying these coefficients to the growth factors, we would first adjust the Version 4.0 growth factors upward to reflect the difference between the REMI-BLS (97) projected GDP growth rates and the most recent OMB/CBO projected GDP growth rates.

Planned Approach

Unless additional resources are available to update all of the underlying economic models and data in EGAS, the current plan is to compile emissions activity growth factors using the final "ad hoc" approach described above. By targeting efforts on the non-EGU stationary source categories of greatest importance, we will ensure that project resources are used most efficiently to improve the validity of the resulting emission projections.

Highway Vehicle Emissions

The MOBILE6 emission factor model will be used to compute onroad emission factors in the second prospective. The term MOBILE6 encompasses the MOBILE6.0, MOBILE6.1, and MOBILE6.2 models. The MOBILE6.1 and MOBILE6.2 models do not supercede MOBILE6.0, but add to the capabilities present in MOBILE6.0. With the MOBILE6 models, users can calculate onroad emission factors for hydrocarbons (including VOC), NO_x, CO, SO_2, ammonia, particulate matter, hazardous air pollutants (HAPs), and carbon dioxide. Tailpipe exhaust emission factors are included for all of these pollutants, with evaporative emission factor components also included for hydrocarbons and brake wear and tire wear particulate matter components. MOBILE6 includes 28 gasoline and diesel-fueled vehicle types, including passenger cars, light-duty trucks, heavy-duty trucks, buses, and motorcycles. In addition, emission factors can be estimated for natural gas-fueled or electric vehicles. The emission factor data for six HAPs are built into MOBILE6.2. Emission factors for additional HAPs can be calculated in MOBILE6.2 with user-supplied basic emission factor data. In Version 3.0 of the NEI, EPA developed the inputs to calculate 35 HAPs. This includes the fuel parameters needed by MOBILE6.2 to model the 6 HAPs included in MOBILE6.2 (benzene, MTBE, 1,3-butadiene, formaldehyde, acetaldehyde, and acrolein).

Issues Associated with NEI Version 3.0

EPA's estimates of 1990 and 2000 VMT for all states are based on state and urban area VMT estimates by roadway type from the Federal Highway Administration. For 2010 and 2020 VMT estimates, though, EPA uses an alternative source for some states. The 1999 onroad NEI Version 3.0 includes state-provided vehicle miles traveled (VMT) estimates for a select group states.[8] The 2010 and 2020 VMT estimates for these states will be projected from the1999 NEI VMT. For all other states, VMT for 2010 and 2020 will be projected from the Federal Highway Administration's1999 VMT estimates.

Since the 2010 and 2020 VMT estimates for some states will be based on a different source than the 1990 and 2000 estimates, there will be a disconnect between the 1990 and 2000 VMT estimates and the 2010 and 2020 VMT estimates for these states. Consistency issues arising from this disconnect include the possibility that one set of inventories estimates positive VMT for a particular road type in a given county while another set of inventories estimates zero VMT for that particular road type/county pairing. In addition, the use of different data sources for the same area may generate inconsistent trends in VMT (e.g., VMT may decrease from 1999 to 2000 for a specific county due to the differences in data sources rather than the actual trends in the county). Consistency should not be an issue for those states for which 1990, 2000, 2010, and 2020 VMT are all estimated from the same source (i.e., Federal Highway Administration data).

To evaluate the potential significance of using more than one data source for some states, we plan to compare our primary VMT estimates with alternative estimates for selected states generated by the following method:

1) Develop growth factors for each "county / vehicle type / roadway type" combination using the FHWA-based approach, including a retrospective growth factor from 1990 to 1999,

2) Apply these growth factors to state- supplied 1999 VMT to derive 1990 base year plus 2010 and 2020 VMT,

3) Combine these reestimated 1990, 2010, and 2020 VMT estimates with the 2000 and 2010 estimates already derived using 1999 state-supplied VMT.

The significance of any differences between our primary and alternative VMT estimates will be evaluated, and EPA will consider whether adjustments to the primary VMT estimates are

[8] Generally, state-level VMT estimates are close to what EPA would otherwise estimate from state and urban area VMT estimates by roadway type from the Federal Highway Administration, allocated to vehicle types according to MOBILE6 estimates. EPA's estimated distribution among counties, roadway types, and vehicle types, however, may differ from state-level estimates.

appropriate, considering the significance of these differences and any available information pertaining to the comparative validity and reliability of the relevant state-supplied VMT estimates (e.g., whether the relevant state-supplied VMT estimates provide the same accounting for shifts in fleet composition already captured in the primary, FHWA-based VMT estimates, such as the widespread shift toward sport utility vehicles).

In addition to providing VMT for the 1999 NEI, California used its own emissions model, EMFAC, to provide its own estimates of 1999 emissions of VOC, NO_x, CO, SO_2, PM_{10}, and $PM_{2.5}$. Both the emissions and VMT data were provided by county and by vehicle type.[9] No distributions were made to individual roadway types. For modeling needs, however, California emissions and VMT will need to be allocated to road categories within each county. We plan to use the overall allocation of VMT to roadway types in the rest of the nation for this purpose, if California cannot provide a better approach. In addition, because these emissions were calculated using California's EMFAC model, the emission factors for California may be significantly different than with those in MOBILE6. EPA is presently unable to apply EMFAC to generate consistent 1990, 2000, 2010, and 2020 emission factors. Possible approaches to improve consistency across years include:

1) Use MOBILE6 emission factors for all years except 1999. This has the advantage of being the simplest approach, but the disadvantage of being the least reflective of California emission factors, particularly in 1990 and 2000.
2) Obtain EMFAC-based emissions for as many years of data as possible from California. This approach would be the most consistent, but requires input from California.
3) Calculate 1990, 2000, 2010, and 2020 emissions for California off of the 1999 starting point using emission factor ratios based on MOBILE6. This should provide a reasonable estimate, preferable to using EMFAC for one year and MOBILE6 for the others.

The 812 Project Team has carefully considered these approaches, and plans to pursue the third option, basing 1990, 2000, 2010, and 2020 estimates of California emissions off of the 1999 EMFAC estimate.

[9] In total, there are 8 vehicle types.

VMT Projections

We plan to use VMT projections developed for the Heavy-Duty Diesel (HDD) Vehicle Rulemaking analysis, which have also been used in the 2002 analysis of the proposed Clear Skies legislation and the recent proposal for Tier 4 controls for nonroad diesel engines. For this analysis, VMT was projected from a 1996 baseline using growth factors by vehicle type and geographic area supplied by EPA's Office of Transportation Air Quality. This analysis included projections to 2020. These projections will be adjusted through interpolation to apply to a 1999 base year. The VMT for 1990 and 2000 was discussed above.

Scheduling

The 812 Project Team has already developed both 1990 and 2000 onroad criteria pollutant emissions inventories using MOBILE6 and the latest VMT estimates. The Project Team does not expect the estimates used for the Section 812 Prospective analysis to differ from these estimates except as needed to deal with the consistency issues discussed above. A pre-CAAA 2000 inventory still needs to be developed.

Non-road Vehicle and Engine Emissions

The nonroad sector is comprised of vehicle engines that are not operated on the nation's roadways, and include such diverse source categories as construction forklifts, aircraft engines, and jet skis. The EPA's NONROAD model provides a tool for estimating base year and future year criteria pollutant emissions for all nonroad source categories except aircraft, locomotives, and commercial marine vessels. The following section describes our planned approach for using the NONROAD model in this effort.

Distribution generation, or micropower units, have been recently recognized as a potentially important, and growing, air pollution source. The NONROAD model does include emission estimates for about 450,000 diesel-fired generators in the nation. They are classified as light commercial engines, and include engines of 600 horsepower or less. The number of generators was estimated from engine manufacturer sales surveys conducted by Power Systems Research.

NONROAD Model Source Categories

We plan to use EPA's NONROAD2002 model to estimate 1990, 2000, 2010, and 2020 emissions for the second prospective analysis. This significantly revised version of NONROAD has just been released in connection with the proposed Tier 4 standards for nonroad diesel engines. The model uses an emission estimation methodology that accounts for equipment population by horsepower and the associated activity level (load factors and hours of use). The model eliminates the need to explicitly use the 1999 inventory as a *base* year for preparing 1990 or forecasted nonroad inventories. This model provides emission estimates with the implementation of most Federal EPA emission standards that have been enacted in response to the 1990 CAAA. External adjustments are available to take account of one suite of standards that are not internal to this version of NONROAD. Because the NONROAD2002 model does not provide a way to run a pre-CAAA scenario, it will be necessary to review the emission factors that NONROAD2002 uses to estimate pre- versus post-control emission rates, and run the model with revised emission factor input files. This task will be performed with the assistance of EPA's OTAQ staff because the model does not offer the option of removing nonroad emission control programs.

In addition, the model uses national growth rates for each source category. For nearly every nonroad sector, NONROAD2002 model growth rates are based on the 1989-1996 change in national nonroad equipment populations. When forecasting over long periods, these forecasts may lead to understated projections in high growth areas and overstated projections in low/no growth areas. We plan to adjust for these regional differences by creating separate state-specific equipment population input files, and county geographic allocation files (GAFs) where needed, for each forecast year.

The current NONROAD2002 model allocates equipment populations from the nation to counties for each forecast year using GAFs based on data for a single historical year (county-level equipment populations are then summed up to the state level and are reflected in state-specific equipment population input files). These GAFs are based on a surrogate indicator for the emissions activity associated with each nonroad source category. The draft NONROAD2002 model, for example, uses the 1997 value of construction activity to allocate construction equipment for all years in the model. We plan to select variables from EGAS Version 4.0 to use as a surrogate indicator for future changes in the equipment population and GAFs and create future year input files by applying EGAS growth factors for each relevant surrogate indicator to the base year input files in the model. In cases where the EGAS growth rates are the same for all areas in a State, only the state-level equipment population input file will need to be revised.

In addition, we plan to review the NONROAD2002 model growth indicators for possible replacement indicators that more closely relate to changes in emissions activity. For example, we plan to replace the use of Bureau of Economic Analysis (BEA) economic data for the oil field equipment sector with the historical/projected number of barrels of oil produced. Historical oil production is available by state from the Department of Energy (DOE) and the DOE develops forecasts of oil production activity by oil production region. We plan to replace the BEA oil field equipment sector data with the DOE production data.

It is important to note that because OTAQ continues to make refinements to the NONROAD model, we will closely coordinate with the OTAQ NONROAD model team to ensure that the latest model is used in this effort and to ensure their review of the changes that we plan to make to the model.

Aircraft

There are several aircraft emission subcategories of interest in this study: commercial aircraft, air taxi, general aviation, and military aircraft.

Commercial and Military

For commercial and military aircraft, we plan to reflect post-1999 changes in aircraft emissions activity using historical and forecast Landing and Takeoff (LTO) data available from the Federal Aviation Administration (FAA). EPA recognizes, however, that this methodology may lead to underestimation of baseline emissions from military aircraft, given the lack of extensive, publicly available records for military aircraft.

We must also consider the effect of changes in fleet technology mix due to the progressive phase in of cleaner aircraft engines. In 1981, the International Civil Aviation Organization (ICAO) published recommended commercial aircraft engine standards for all three pollutants (HC, CO, and NO_x) for turbofan and turbojet engines manufactured after 1986. Although the ICAO's HC standard has been in effect in the U.S. since 1984, the ICAO's 1981 CO and NO_x standards were not adopted at the same time. In 1993 ICAO issued an amendment reducing the ICAO's 1981 NO_x standard by 20 percent for engines newly certified after 1996 and newly manufactured after 2000. In 1997, EPA adopted the ICAO's 1993 NO_x and 1981 CO aircraft engine emission standards, with the new ICAO NO_x standard taking effect in 1996 for newly certified engines and 2000 for newly manufactured engines.

The aircraft engine regulations are not attributable to the CAAA so there is no need to distinguish pre-CAAA emissions from post-CAAA emissions. We will estimate the emissions impact of the commercial aircraft engine regulations to the extent that OTAQ is able to estimate the following for each analysis year: the HC emission reduction associated with the 1984 standards, the NO_x and CO emission reductions associated with the 1997 standards, and the percentage of total emissions affected by each standard. Previous contacts with OTAQ staff indicated that this information was not available, while concluding that the reductions associated with the standards would be small.

Air Taxi and General Aviation

These two subcategories of emissions are calculated by multiplying LTO estimates by emission factors. Because the ICAO standards apply only to commercial aircraft engines, we do not plan to model any emission factor changes to these subcategories over the analysis period. As with commercial and military aircraft, changes in air taxi and general aviation activity will be based on historical FAA and forecast LTO data.

Locomotives

Locomotive emissions are estimated for Version 3.0 of the NEI by applying emission factors to national fuel consumption estimates. National locomotive fuel consumption estimates are based on Department of Energy fuel usage statistics, with an adjustment to account for engine types not included in those statistics. National emissions are then allocated to counties based on county shares of national ton-miles of operation, determined by overlaying track maps (with ton-miles) onto county boundaries. EPA considers this to be a significant improvement in estimating county-level emissions compared to previous methods. Future fuel use for estimating future national emissions can be estimated from the same DOE fuel statistics. Because fuel consumption forecasts are only available on a national basis, regional fuel consumption growth will be estimated using ratios of regional to national railroad sector output as projected by EGAS Version 4.0.

Emission factors must reflect the fact that the EPA has adopted three separate sets of locomotive emission standards, with the applicability of the standards dependent on the date that the locomotive is first manufactured. The first set of standards (Tier 0) apply to locomotives and locomotive engines originally manufactured from 1973 through 2001. The second set of standards (Tier 1) apply to locomotives and locomotive engines originally manufactured from 2002 through 2004. The final set of standards (Tier 2) apply to locomotives and locomotive engines originally manufactured in 2005 and later. The EPA has developed year-specific fleet average emission factors for locomotives to estimate the post-CAAA emission reductions expected from these standards. Locomotive emissions will be calculated using these emission factors with the estimates of locomotive fuel consumption as described above.

Commercial Marine Vessels

Version 3.0 of the 1999 NEI incorporates an improved method for estimating historical emissions from these vessels. These vessels were essentially uncontrolled in 1999, but EPA promulgated emission standards for Category 1 and Category 2 commercial marine diesel engine vessels in 1999, which will reduce emission factors in future years. Category 1 includes engines greater than 37 kilowatts (kW) but with a per-cylinder displacement of 5 liters/cylinder or less; category 2 includes engines greater than 37 kW with a displacement of 5 to 30 liters/cylinder. The EPA also recently promulgated emission standards for the remaining largest commercial marine diesel engine (Category 3) vessels. We plan to use the emissions control assumptions used by EPA in preparing regulatory impact analyses for these standards to model the post-CAAA scenario for the affected source categories. We will project emission activity changes in the marine vessel source categories using historical/projected fuel consumption estimates developed by the Department of

Energy (DOE). We will consider EGAS Version 4.0 or other data sources to regionalize national DOE fuel consumption estimates.

Stationary Area Sources (Non-point)

Stationary area sources are those sources that emit pollutants to the air, but are not accounted for in the 1999 NEI point source file. Area source emissions from highway vehicles and nonroad engines/vehicles are accounted for separately, so stationary area source emissions include the many solvent utilization VOC sources, small fuel combustors (NO_x and SO_2), gasoline marketing, several types of biomass burning, household waste burning, as well as many fugitive dust PM sources.

The 1999 NEI area source file will be used as the primary source of criteria pollutant emissions for use in the emission projections. As noted in Exhibit 3-3, the 1990 stationary area source emission estimates will be the same as the estimates used in the first prospective, with a few exceptions. At the aforementioned May 2002 emissions inventory planning workshop, there was a consensus view among the emissions inventory experts that there are a few stationary area source categories whose emission estimation methods have changed dramatically since the 1990 estimates for the first prospective were developed, and that the 1990 estimates for these source categories should be re-calculated. Stationary area source categories that are candidates for re-estimation using revised methods are listed below:

1. Agricultural tilling
2. Residential wood
3. Prescribed burning
4. Wildfires
5. Construction activity
6. Resuspended road dust
7. Open burning of household waste, yard waste, and land clearing debris

This is not an exhaustive list of stationary area sources whose methods have been recently improved. The categories on the list represent those stationary area sources with the most significant criteria pollutant emissions. Ammonia-emitting source categories with significant emission changes are not listed above. Since we plan to use the 1990 emissions database for new air quality modeling simulations, we also plan to update the 1990 ammonia inventory to ensure its consistency with 1999 estimates. EPA plans to apply methods that were developed to estimate ammonia emissions for the 1999 NEI to estimate 1990 emissions using 1990 activity level estimates.

Stationary area source control factor files will be developed using the HDD rulemaking files (which were developed for application to a 1996 base year emission inventory) with updates to account for new Federal/State regulations that affect 1999 emissions – differentiated from those likely to influence emissions post-1999. National VOC rules implemented between 1996 and 1999 include those affecting consumer products and architectural coatings.

EGAS 4.0 will be the primary data source for the growth factors to be used in the 2010 and 2020 emission projections. For the first prospective, there were a number of source categories where alternatives to the BEA earnings projections were used as a better indicator of activity growth. One example is the analysis performed for agricultural tilling, where trends in agricultural tilling practices were found to be a much better indicator of future changes in agricultural tilling activity than projections of earnings in the agricultural industry. Therefore, alternatives to EGAS will be identified and evaluated by source category in instances where EGAS-based growth factors do not represent a good surrogate for emissions generating activity growth.

Canadian and Mexican Emissions

EPA-Office of Air Quality Planning and Standards has received and is processing a 1995 emission inventory for Canada from Environment Canada. Environment Canada is expected to deliver model-ready point, area, and mobile source emissions databases for projection years of 2010 and 2020 by June 1, 2003. SMOKE (the emissions pre-processor for Models-3) processing of these projection year data sets is expected to be completed by June 15, 2003, so they should be available for use in this 812 effort.

Four sets of Mexican emission estimates are available or in development. One set of Mexican emission estimates is that being used in the ongoing WRAP-sponsored visibility modeling efforts. For large point sources, there are 19 Mexican sources included, with coordinates used to place these emissions in the appropriate grid cells of the REMSAD air quality model planned for use in this analysis. Mexican area source emission estimates in this set include area, on-road mobile, road dust, and low-level point source emissions for four Northwest Mexico states. Second, a more inclusive set of estimates has been developed for an ongoing study of visibility in the the Big Bend area of the Rio Grande, the "BRAVO" study. Third, by this summer, a base year emission inventory is expected to be available for the six Northern states of Mexico that border the United States, as the first installment of a new National Emissions Inventory for Mexico. This inventory may be missing some source categories. The sponsors of this inventory may recommend against its immediate use, pending review by external parties. Finally, base year emission estimates for the remainder of Mexico, and any missing categories for the six northern states, are scheduled for completion in the summer of 2004.

Quality Assurance/Data Evaluation

Efforts sponsored by regional planning agencies are examining emission projection and cost issues similar to those in the second prospective. To the extent that their results are available on a timely basis, these studies will be used for the geographic areas that they cover as a quality assurance/data validation step. In the first prospective, the emissions projections to 2000 and 2010 from the Grand Canyon Visibility Transport Commission study were used as a point of comparison with the first prospective projections for the same years. Under the auspices of the WRAP, the same states and other western states have been sponsoring efforts to update their emission projections, and to revise their base year (1996 and 1998) emission estimates. WRAP efforts to date have focused on point sources and SO_2 emissions. We are aware of two WRAP-sponsored efforts–one to augment the Integrated Assessment System (IAS) model to improve emission and cost projections for some non-EGU source categories, and the other to update 1996 and 1998 SO_2 emission estimates for non-EGU sources, and to develop a revised emission projection to 2018. Recent comparison of the WRAP SO_2 emissions estimates indicate that national EPA databases and models may over-estimate point source SO_2 emissions in the west. This is true for both base and future year emissions. A second potential comparison point for emission projections and cost estimates are the results of the SAMI project. SAMI emission projection years are 2010 and 2040. A variety of emission management scenarios have been included in the emission projections performed for SAMI.

For mobile sources, there have been many research studies performed in the past 10 years to check the accuracy of EPA and Air Resources Board mobile source emission factor models. Some of these efforts are acknowledged in the 2000 National Research Council (NRC) Report "Modeling Mobile-Source Emissions." Techniques for validating/evaluating these mobile source emission factor models include tunnel studies, remote sensing, roadside inspection programs, ambient air quality monitoring and modeling, chemical mass balance, and fuel-based approaches to estimating emissions. The NRC report was issued when MOBILE5 was the EPA mobile source emission factor model. Since then, MOBILE6 has been released. Therefore, mobile source emissions evaluations to be included in the second prospective will focus on work performed in the past two years to evaluate MOBILE6. This will include the work jointly sponsored by EPA and the Coordinating Research Council to validate MOBILE6.

Comparison of Year 2000 First Prospective and National Emissions Inventory Emissions

One of the quality control checks recommended by the SAB was a comparison of the 2000 emission estimates from the first prospective analysis with estimates of actual 2000 year emissions. This analysis has now been completed. This comparison reviewed the accuracy of the first prospective assessment's emissions activity growth assumptions for the purpose of refining the growth assumptions for the second prospective analysis. The CAAA do not specifically mandate emission control requirements for the source categories that were included in this comparative analysis. The analysis, therefore, does not address the accuracy of the first prospective analysis in modeling CAAA emission control impacts.

We developed a comparison of year 2000 non-mobile area source emission estimates projected in the first prospective analysis, with estimates of year 2000 emissions developed for EPA's National Emissions Inventory (NEI). Because the NEI reflects actual emissions for the year

2000, the analysis compares the NEI emissions with the first prospective's post-CAAA emissions scenario. The source categories analyzed include all area sources except highway vehicles and nonroad engines/vehicles. The comparisons were performed for non-mobile area source categories because the Version 3.0 NEI emission estimates were not available for other source categories at the time that this analysis was performed. Because EPA has not prepared year 2000 estimates for many area source categories, we projected estimates for these categories from Version 3.0 of the 1999 NEI. These projections were prepared using growth factors from EGAS Version 4.0 (Pechan, 2001) and control factors developed for use with the NEI.

Exhibit 3-7 compares the 1990 and 2000 area source emissions from the first prospective with 2000 NEI area source estimates. This Exhibit indicates that, for most pollutants, actual emissions in 2000 were lower than projected in the first prospective. The two exceptions, however, were VOC and CO emissions, which were approximately 12 percent and 53 percent higher than anticipated, respectively. Because the emission growth indicators do not vary by pollutant, this Exhibit demonstrates that factors other than emission activity growth can account for significant emission level changes. As discussed later, one of the main explanations for these differences is the impact of emission estimation methodology changes between the first prospective and the NEI.

As mentioned above, the SAB also requested that EPA evaluate whether it underestimated particulate matter (PM) emissions from diesels and non-road engines/vehicles in the first prospective. In response to this request, EPA plans to perform a disaggregated analysis, comparing diesel and non-road engine PM emissions estimates with actual PM emissions from these sources in 2000.

Exhibit 3-7
Comparison of First Prospective and NEI Area Source Emission Estimates
(in 1000s of tons)

Pollutant	First Prospective 1990	First Prospective 2000	NEI 2000	% Difference[1]
VOC	10,346	7,993	9,054	11.7
NO_X	2,189	2,619	2,036	-22.3
SO_2	1,042	1,294	1,203	-7.0
PM_{10}	26,389	26,141	20,208	-22.7
$PM_{2.5}$	5,809	5,932	5,568	-6.1
NH_3	3,726	4,776	4,530	-5.2
CO	11,605	12,945	19,837	53.2

[1] (NEI-First Prospective)/First Prospective * 100

Assessing Differences in First Prospective and NEI Emissions Estimates

We undertook a detailed source category level comparison to identify area source categories that contribute most to the differences between the first prospective and the NEI year 2000 inventories. The results of this analysis are presented in Exhibit 3-8, which displays source classification codes (SCCs) that account for the largest percentage discrepancies between the two inventories. For some pollutants, such as VOC, large differences between source category inventories tend to offset one other. After identifying the source categories with the largest differences between the two inventories, we conducted further investigations into the reasons for these discrepancies. These reasons fall into one four general categories:

- The NEI Year 2000 estimates were developed using different EPA methodologies than were used in preparing the first prospective 1990 estimates. The Residential Wood Combustion source categories represent examples of source categories for which a new EPA emission estimation methodology was implemented in the NEI. The *NOTES* column in Exhibit 3-8 identifies source categories for which NEI estimates are based on new emission estimation methodologies.

- The incorporation of state and local agency emissions data into the 1999 NEI. When State or Local agencies supply emissions data to the NEI, EPA replaces its estimates with the estimates supplied by these agencies. Information about potential differences between EPA standard methods and those used by state/local agencies to generate their inventory submissions is unavailable.

- Use of different SCCs in the two inventories for reporting emissions for the same processes. Because EPA periodically updates its SCC list, emissions that were reported in one SCC in the first prospective may be reported in a different SCC or set of SCCs in the NEI.

- The inherent uncertainty associated with forecasting emission activity levels. In some cases, there is no good way to forecast emissions activity levels because these levels are based on a natural activity (e.g., forest wildfires). Wildfires are a particularly important source of emissions for several pollutants, and, therefore, will be discussed in detail in the next section.

It should be noted that we plan to utilize different growth indicators in the second prospective for many of the Exhibit 3-8 source categories (see the Planned Growth Indicator column in this Exhibit). For example, fuel combustion estimates in the first prospective were based on population and gross state product forecasts. In the second prospective, we plan to base fuel combustion projections on DOE energy consumption forecasts. (This is also the approach that was adopted for Version 4.0 of the EGAS model.) Exhibit 3-8 identifies the planned second prospective growth indicator for each source category.

Exhibit 3-8. Area Source Categories with Significant 2000 Year NEI-First Prospective Emission Discrepancies

SCC	SCC DESCRIPTION	NEI EMISSIONS - FIRST PROSPECTIVE EMISSIONS	% DIFF	FIRST PROSPECTIVE GROWTH INDICATOR[1]	PLANNED SECOND PROSPECTIVE GROWTH INDICATOR[2]	NOTES
		VOC				
2810001000	Miscellaneous Area Sources Other Combustion Forest Wildfires Total	830,905	33.9%	Zero growth	Historical average	NEI based on new method
2104008051	Stationary Source Fuel Combustion Residential Wood Non-catalytic Woodstoves: Conventional	(564,922)	-21.5%	Population	Residential "renewables" energy consumption	NEI based on new method
2501050120	Storage and Transport Petroleum and Petroleum Product Storage Bulk Stations/Terminals: Loss Gasoline	(534,731)	-20.4%	Trucking and Warehousing (SIC 42)	Gasoline and oil expenditures	
2104008001	Stationary Source Fuel Combustion Residential Wood Fireplaces: General	506,588	20.7%	Population	Residential "renewables" energy consumption	NEI based on new method
		NOx				
2102006000	Stationary Source Fuel Combustion Industrial Natural Gas Total: Boilers and IC Engines	(896,669)	-80.2%	Total manufacturing	Industrial natural gas consumption	
2810001000	*Miscellaneous Area Sources Other Combustion Forest Wildfires Total*	*133,311*	*29.7%*			
2104002000	Stationary Source Fuel Combustion Residential Bituminous/Subbituminous Coal Total: All Combustor Types	97,059	21.6%	Population	Residential coal consumption	
2104004000	Stationary Source Fuel Combustion Residential Distillate Oil Total: All Combustor Types	76,372	17.0%	Population	Residential distillate oil consumption	
2104006000	Stationary Source Fuel Combustion Residential Natural Gas Total: All Combustor Types	63,067	14.1%	Population	Residential natural gas consumption	
		CO				
2104008051	*Stationary Source Fuel Combustion Residential Wood Non-catalytic Woodstoves: Conventional*	*(4,196,057)*	*-79.9%*			
2810001000	*Miscellaneous Area Sources Other Combustion Forest Wildfires Total*	*5,637,658*	*71.1%*			
2810015000	Miscellaneous Area Sources Other Combustion Prescribed Burning for Forest Management Total	818,041	10.3%	Private lands - no growth; Public lands- projections by Federal land managers	Based on National Fire Plan Implementation by DOI and Forest Service	NEI based on new method
		SO2				
2102002000	Stationary Source Fuel Combustion Industrial Bituminous/Subbituminous Coal Total: All Combustion Types	(134,190)	-46.7%	Total manufacturing	Industrial steam coal consumption	
2103004000	Stationary Source Fuel Combustion Commercial/Institutional Distillate Oil Total: All Boilers & IC Engines	58,345	31.5%	Government and government enterprises	Commercial distillate oil consumption	

SCC	SCC DESCRIPTION	NEI EMISSIONS - FIRST PROSPECTIVE EMISSIONS	% DIFF	FIRST PROSPECTIVE GROWTH INDICATOR[1]	PLANNED SECOND PROSPECTIVE GROWTH INDICATOR[2]	NOTES
2102008000	Stationary Source Fuel Combustion Industrial Wood Total: All Boiler Types	57,106	30.9%	Total manufacturing	Industrial "renewables" energy consumption	
2102005000	Stationary Source Fuel Combustion Industrial Residual Oil Total: All Boiler Types	(58,894)	-20.5%	Total manufacturing	Industrial residual oil consumption	
2102004000	Stationary Source Fuel Combustion Industrial Distillate Oil Total: All Boiler Types	30,887	16.7%	Total manufacturing	Industrial distillate oil consumption	
2103005000	Stationary Source Fuel Combustion Commercial/Institutional Residual Oil Total: All Boilers & IC Engines	(43,354)	-15.1%	Government and government enterprises	Commercial residual oil consumption	
PM_{10}						
2296000000	Mobile Sources Unpaved Roads All Unpaved Roads Total: Fugitives	(2,652,109)	-69.9%	Extrapolated from historic trend in unpaved road mileage	Extrapolated from historical data on unpaved roads	
2325000000	Industrial Processes Mining and Quarrying: SIC 14 All Processes Total	720,033	44.2%	Total manufacturing	Non-metallic mineral, except fuel (SIC 14)	NEI based on new method
2810001000	*Miscellaneous Area Sources Other Combustion Forest Wildfires Total*	*522,660*	*32.1%*			
2801000003	Miscellaneous Area Sources Agriculture Production - Crops Tilling	(425,188)	-11.2%	Farm activity	USDA acres tilled projections	NEI based on new method
$PM_{2.5}$						
2810001000	*Miscellaneous Area Sources Other Combustion Forest Wildfires Total*	*473,516*	*51.4%*			
2296000000	*Mobile Sources Unpaved Roads All Unpaved Roads Total: Fugitives*	*(397,725)*	*-38.1%*			
2104008051	*Stationary Source Fuel Combustion Residential Wood Non-catalytic Woodstoves: Conventional*	*(394,905)*	*-37.8%*			
2325000000	*Industrial Processes Mining and Quarrying: SIC 14 All Processes Total*	*143,924*	*15.6%*			
2103008000	Stationary Source Fuel Combustion Commercial/Institutional Wood Total: All Boiler Types	81,714	8.9%	Government & government enterprises	Commercial "renewables" energy consumption	
NH3						
2805020000	Miscellaneous Area Sources Agriculture Production-Livestock Cattle and Calves Composite Total	(580,980)	-79.9%	Farm	USDA animal projections	
2805030000	Miscellaneous Area Sources Agriculture Production-Livestock Poultry and Chickens Composite Total	304,509	57.8%	Farm	USDA animal projections	See note in text concerning SCC changes.
2801700004	Miscellaneous Area Sources Agriculture Production-Crops Fertilizer Application Urea	118,599	22.5%	Farm	USDA animal projections	

Notes: categories in italics were listed previously under a different pollutant.
[1] For growth indicators identified as economic sectors, indicator is based on BEA gross state product for sector.
[2] For growth indicators identified as economic sectors, planned indicator is based on EGAS 4.0 sector output.

The remainder of this section describes efforts to analyze particular Exhibit 3-8 source categories to determine whether the growth projection methods for these categories should be revised for the second prospective.

Because of the large discrepancy between the first prospective and NEI year 2000 PM_{10} emissions, we reviewed the emission projection methodologies for the following source categories: unpaved roads, wildfires, and agricultural tilling. Prescribed fires were also included in this review because the level of wildfire activity is thought to correlate inversely with the level of prescribed burning activity in the long-run. A summary of the findings of these reviews is provided in the following section along with a summary of our planned projection methods for the second prospective. A detailed discussion of the analyses conducted for these categories is available in a separate document (Pechan, 2002).

Analysis of Key PM_{10} Emission Sources

Unpaved Roads

In the first prospective, PM_{10} emissions from unpaved roads were projected to decline from 12.4 million tons in 1990 to 10 million tons in 2000. This drop was largely attributable to a projected decline in unpaved roads VMT. The NEI year 2000 inventory, however, indicates that unpaved roads PM_{10} emissions were only 7.3 million tons. As shown in Exhibit 3-9, the use of actual rather than projected VMT does not explain the discrepancy between the NEI and first prospective estimates. In fact, the data indicate that the first prospective VMT projections *under-predicted* actual unpaved roads VMT by more than 10 percent.

Exhibit 3-9. Unpaved Road VMT Estimates Used in First Prospective and NEI Inventory Development

First Prospective (Section 812)		NEI
1990 VMT	2000 VMT	2000 VMT
41,049	36,244	41,445

Three factors account for the lower PM_{10} emission estimates in the NEI compared with the first prospective forecast estimates:

- The PM_{10} unpaved road emission factor was reduced in the NEI by approximately 25 percent;
- The NEI replaces EPA-developed estimates with state/local agency estimates that may rely on different emission estimation methodologies; and

- The NEI used actual rather than historical average precipitation data.

Projecting Unpaved Road Emissions Activity in the Second Prospective

New unpaved road VMT data indicate that the VMT projection equations underestimate recent activity on unpaved roads. To improve predictive capability, we plan to develop new unpaved VMT equations based on the most recent data available. While the original equations were derived from 1984-1996 data, the new equations will be based on an analysis of data through 2002. The use of post-1996 data and a re-examination of the functional forms of the previous projection equations should result in more accurate estimates of future unpaved road VMT. We do not plan to make any changes to the use of historical average precipitation in forecasting unpaved road emissions because there is no way to accurately predict precipitation in future years.

Wildfires and Prescribed Fires

The first prospective assumed no change in PM_{10} emissions from wildfires between 1990 and 2000. The NEI year 2000 inventory, however, indicates that wildfire PM_{10} emissions doubled between 1990 and 2000. Acres burned in wildfires were higher in 2000 than any other year over the 1960-2000 period (NIFC, 2002). As indicated in Exhibit 3-10, the acreage burned in 2000 was about twice the annual average of any of the previous four decades.

Exhibit 3-10. Historical Wildfire Activity Data

Year(s)	Acres Burned
Average 1960-1969	4,571,754
Average 1970-1979	3,194,421
Average 1980-1989	4,235,983
Average 1990-1999	3,786,411
2000	8,422,237

Even so, 1990-2000 wildfire emissions growth (200 percent) was much higher than predicted by the change in national activity levels (54 percent).

Part of the PM_{10} emissions discrepancy may be explained in part by a change in the geographic distribution of wildfire activity between 1990 and 2000. A key variable in calculating PM_{10} emissions from wildfires is the fuel loading per acre burned. Fuel loadings differ considerably across different types of vegetation, and therefore across different regions of the country. Therefore, changes in the regional distribution of wildfire activity can greatly impact wildfire emission levels. Moreover, between 1990 and 2000 EPA changed the method used to estimate fuel loading for the NEI, changing from a few large regions each with an average fuel loading to a larger number of smaller regions with different loadings.

<u>Projecting Prescribed Fire and Wildfire Emissions Activity in the Second Prospective</u>

For wildfires, activity growth will be based on recent average historical levels of activity. We specifically plan to use the average acres burned over the 1990-2002 period to represent levels in both 2010 and 2020. The use of this time-frame will capture recent changes in wildfire patterns, particularly the trend towards "larger" fires, and will result in setting post-2000 wildfire activity at 52 percent of the 2000 NEI levels.

For prescribed burning, it is important to acknowledge that the National Fire Plan and associated policies are likely to lead to an increase in acres burned, at least for the next decade. This will be in addition to the 35 percent increase in prescribed fires that took place between 2000 and 2001. One knowledgeable source estimates that prescribed burning on federal lands will increase by 20 percent between 2001 and 2011 (Hartzell, 2002). When combined with the growth in the 2000-2001 period, we plan to assume a 60 percent increase in prescribed burning activity over the 2000-2010 period.

Agricultural Tilling

When compared to the 2000 NEI estimates, the first prospective overestimated PM_{10} emissions by approximately 11 percent. There are two reasons why the first prospective projections overstated 2000 year agricultural tilling emissions: (1) the first prospective overestimated planting activity (based on USDA planting projections), and (2) the first prospective slightly underestimated conservation tillage rates (based on Conservation Technology Information Center tillage forecasts).

Exhibit 3-11 identifies the number of conventional and conservation tillings by crop type, along with the relationship between the NEI and the first prospective crop acreage estimates. As shown in Exhibit 3-11, USDA projections were as much as 12.4 percent too low for some crops and as much as 10.9 percent too high for others. The first prospective assumed a conservation tillage rate of 36 percent of planted acres in 2000 (the actual figure was 37 percent). Therefore, the major factor leading to the first prospective and NEI PM_{10} emissions discrepancy is the difference between the first prospective and NEI crop-specific acreage estimates.

Exhibit 3-11. Number of Tillings and Effect of Conservation by Crop Type

		# of Tillings	
Crop	**2000 NEI Acres Tilled as % of First Prospective Estimates**	**Conservation Use**	**Conventional Use**
Corn	97.0	2	6
Spring Wheat	87.6	1	4
Soybeans	109.3	1	6
Rice	100.0	5	5
Cotton	110.9	5	8
Sorghum	87.6	1	6

Projecting Agricultural Tilling Emissions Activity in the Second Prospective

The agricultural tilling emission discrepancies, which are large in absolute terms but small relative to the size of the emissions source category, appear to result from the inevitable errors associated with forecasting levels of crop planting and conservation tillage activity. Therefore, no changes are recommended for forecasting agricultural tilling emissions in the second prospective.

Hazardous Air Pollutant Emissions

As the SAB suggested in its response to the first prospective, a more complete treatment of the Clean Air Act Amendments would include a comprehensive analysis of hazardous air pollutants (HAPs), including emissions of HAPs under the pre-CAAA and post-CAAA scenarios. Given current analytic and resource constraints, a comprehensive assessment of CAAA HAPs regulation is not possible for the second prospective. EPA plans, however, to include HAPs in later editions of the Section 812 analysis. In support of these future efforts, the Agency plans to include a benzene case study as an appendix to the second prospective. In addition, for the second prospective, we plan to estimate mercury emissions based on estimates available in the 1999 National Emissions Inventory. Mercury emissions from EGUs in future years can be predicted by IPM.

CHAPTER 4 - COST ESTIMATES

Our proposed approach to estimating the costs of complying with the requirements of the Clean Air Act Amendments (CAAA) of 1990 includes analysis of costs directly associated with compliance, such as the purchase and operation of new emissions control equipment, and assessment of the broader, economy-wide implications of these direct costs. The goal is to provide as full an assessment as possible of the cost-side impacts of the regulations, within the limits of our ability to reliably assess these impacts.

This chapter consists of three sections. The first section summarizes the approach we used in the first prospective. The second section presents refinements we propose to the direct cost estimation approach for the second prospective. In the third section, we discuss options for broadening the scope of the quantitative analysis of costs to include social costs and other impacts associated with the Amendments, effects which we addressed in a qualitative manner in the first prospective. A more detailed discussion of these options is included in Appendix A.

Approach in First Prospective

The quantitative analysis of costs in the first prospective was an analysis of direct costs that largely reflected expenditures necessary to comply with the Act. The cost estimates reflected the difference in direct costs that would be incurred under the two primary scenarios, the Pre-CAAA and Post-CAAA scenarios, for two target years, 2000 and 2010. We closely integrated the modeling of direct compliance costs with emissions projections by maintaining consistency among control assumptions (i.e. emissions scenarios) used as inputs in the cost estimation modeling and in the analysis of emissions projections and benefits.

The analysis relied on two models to estimate costs, the Emission Reduction and Cost Analysis Model (ERCAM) and the Integrated Planning Model (IPM). These models generated cost estimates for the Post-CAAA scenarios in two projection years, 2000 and 2010. We used ERCAM to estimate costs associated with regulating particulate matter (PM), volatile organic compounds (VOCs), and non-utility source oxides of nitrogen (NO_x). ERCAM is essentially a cost-accounting tool that provides a structure for modifying and updating changes in inputs while maintaining consistency in assumptions used in both the emission and cost analyses. For example, if emissions reductions are to be achieved through implementation of a particular technology, a cost estimate for that specific technology is reflected in the model. Cost scenarios and assumptions were developed for each non-utility source category (e.g., point, area, nonroad, and motor vehicle sources) and in response to specific provisions and emission targets. The model estimated costs based on inputs such as capital and operating cost per ton for relevant control technologies, source-specific cost equations, incremental production, and operating cost estimates. The relevant inputs were derived from information presented in regulatory impact assessments (RIAs), background information documents (BIDs), regulatory support documents, and Federal Register notices.

To estimate the costs of reducing utility NO_x and sulfur dioxide (SO_2) emissions, we used the Integrated Planning Model (IPM). IPM allowed us to estimate the control costs of several pollutants while maintaining consistent control scenarios and forecasts of key parameters affecting the electric power industry (e.g., fuel prices). The model assessed the optimal mix of pollution control strategies subject to a series of specified operating constraints at a representative set of model plants, which are then extrapolated to the full population of plants. Key inputs and constraints in the model included targeted emissions reductions (on a seasonal or annual basis), costs and constraints of control technology, and economic parameters (e.g., forecasted demand for electricity, power plant availability/capacity, etc.)

To assess the costs of reducing emissions of pollutants or within sectors not covered by our two models, we estimated costs using the best available cost equations or other types of analyses. For example, we estimated non-utility SO_2 emission control costs for point sources by applying source-specific cost equations for flue gas desulfurization (FGD)/scrubber technology to affected sources in 2000 and 2010. While we did not explicitly model CO attainment costs, we included in the analysis the costs of programs designed to reduce CO emissions, such as oxygenated fuels and a cold temperature CO motor vehicle emission standard. Finally, to estimate costs of the rate of progress/reasonable further progress (ROP/RFP) provisions, measures under Title I that require ozone nonattainment areas to make steady progress toward attainment, we first estimated the emissions reduction shortfall that was to be achieved in each target year in each nonattainment area, and then applied a cost per ton estimate from a schedule of measures that could be applied locally to meet the necessary ROP/RFP requirement.

We presented the results as total annualized costs (TAC) in 2000 and 2010. Annualized costs included both capital costs, such as costs of control equipment, and operation and maintenance (O&M) costs.[1] TAC does not reflect actual cash flow in a given year, but is rather an estimate of average annual burden over the period during which firms will incur costs. In annualizing costs, we converted total capital investment to a uniform series of total per-year equivalent payments over a given time period using an assumed real cost-of-capital of five percent. We then added O&M and other re-occurring costs to the annualized capital cost to arrive at TAC.

[1] For a few VOC source categories, we estimated that capital investment would not be necessary; for these sources, compliance costs reflect O&M costs only. We re-calculated the control cost estimates from regulatory documents that use a seven or ten percent discount rate so that the costs would be consistent with the five percent discount rate assumption used in the first prospective.

Proposed Direct Cost Estimation Approach for Second Prospective

The primary refinements we propose for direct cost estimation in the second prospective cost analysis are:

- extending the analysis from 2010 to 2020;
- estimating all annualized costs using a 3 percent discount rate for the primary estimates, and alternative cost estimates based on the 7 percent rate required by OMB;
- incorporating information for rules and regulations that have been promulgated since 1999;
- updating control cost equations and modeling tools, where appropriate, to include new compliance cost information for control techniques, including revision and/or updating of cost estimates that were used in the first prospective;
- enhance validation of model results by conducting selective comparisons of model output with available historical data and estimates generated by similar models.

Extension of the analysis to 2020 is a relatively straightforward refinement. Some effort will be required to ensure that cost estimates based on mid-1990's vintage rulemaking support documents remain relevant for the 2020 target year. Most newer rulemaking support documents include projections of compliance costs through 2020 (e.g., recent mobile source rulemakings).

Our cost analysis may overestimate the costs attributable to the Clean Air Act Amendments, as some of the process and equipment changes captured in our cost analysis may have been motivated by other objectives. Due to data limitations, we are unable to capture these changes in the pre-CAAA scenario. Nonetheless, we will incorporate this potential source of error in our qualitative treatment of uncertainty.

Incorporating New Provisions

While some of the 7- and 10-year MACT standards may not yet be established, it should be possible to estimate costs for each of these newer MACT standard source categories using information from the final and draft RIAs for these standards. Even though some of the RIAs are still in progress, EPA anticipates that enough information will be available to make reasonable cost estimates.

As the MACT standard-setting process nears completion, EPA will turn to the Title III residual risk program. For cancer risk, the goal is to ensure that the risk of cancer from exposure to air toxics *after MACT standards are in place* remains less than 1 in 1 million for at least 95 percent of the population. For non-cancer risk, the goal is to ensure that the probability of exposure to air toxics at levels above any defined reference concentration is less than 5 percent. In addition, the ecological risk objective is to ensure that no ecosystem experiences air toxics concentrations exceeding a no observed adverse effects level more than once in three years.

EPA is beginning its assessment of cancer risk near facilities affected by MACT standards. After a residual risk assessment is performed for a source category, an ample margin of safety analysis is performed. Then, the technical feasibility and cost of controls to reduce HAP emissions beyond MACT standard levels is evaluated. This is followed by an economic analysis of the control alternatives. This may turn out to be a 2- to 3-year process for each source category. After such residual risk assessments are completed, it may be found that there is no need to set additional standards. If this is the case, the cost of the residual risk program will be zero.

One such completed study examined the air toxic concentrations near (within 50 kilometers of) the five MACT coke oven facilities. Dispersion modeling was used to estimate multi-pathway risk to residents that live near these facilities. Information for this residual risk standard will be available in time for inclusion in the second prospective, but information to characterize the costs for other source categories will likely not be available. We propose to provide some qualitative characterization of the likelihood of further residual risk standards based on analyses prepared to support EPA's National Air Toxics Assessment.

Updated Models and Cost Evaluation Tools

IPM

We propose to continue to rely on the Integrated Planning Model (IPM) for utility source compliance cost estimates. The model continues to be used within EPA's Clean Air Markets Division for utility provision analyses, and as a result undergoes ongoing scrutiny and refinement, particularly with respect to key input parameters. For an overview of IPM, refer to Appendix A.

To calculate the difference in costs between the Pre-CAAA and Post-CAAA scenarios, at least thirteen separate runs of IPM will be necessary for the analysis:

- We plan to conduct one run for the 1990 base year. The estimated costs from this run will then be compared to historical data to assess the accuracy of IPM.
- Since the analysis includes three target years of 2000, 2010, and 2020, three separate runs will be necessary for the Pre-CAAA scenario.
- An additional three runs will generate cost estimates for these same target years for the Post-CAAA scenario.

! We will also run additional iterations of IPM to estimate costs under a supplemental regulatory scenario. Since the Post-CAAA case for the year 2000 is the base year for the supplemental scenario, we will only need to run IPM for the years 2010 and 2020 under this scenario.

! To gauge model sensitivities to factor prices, we propose additional runs of IPM under different factor price scenarios.

! Subject to resource constraints, additional runs may be necessary to obtain cost estimates for utilities that reflect learning effects.

EPA proposes a comparison of IPM results for 2000 with utility environmental compliance cost data collected through the 1999 Pollution Abatement Costs and Expenditures (PACE) survey. Although PACE data do not differentiate between costs attributable to the Amendments and costs attributable to the original Clean Air Act, EPA can compare PACE data with total CAA and CAAA compliance costs estimated by IPM. However, EPA suspects that the PACE results may be inaccurate for the following reasons:

- **Multimedia Abatement in PACE:** The PACE survey allows respondents to report multimedia abatement costs. Some expenditures related to air regulation were more than likely reported in this category. Assuming multimedia expenditures are proportionally consistent with other abatement expenditures, air pollution abatement makes up 60 percent of these costs, in which case total 2002 air pollution abatement costs increase by $115 million.

C **Respondent Ambivalence about the Purpose of an Abatement Expenditure:** The instructions to the abatement portion of the PACE survey state, "For this survey, include only those expenditures with the primary purpose of protecting the environment. . . .only consider those expenditures where environmental protection is the primary purpose." Given these instructions, respondents may exclude relatively new production technologies that are both more efficient and help a facility meet CAA or CAAA requirements.

C **Difficulty in Accurately Reporting the Cost of Prevention Activities:** Several aspects of prevention are integrated with other firm activities, such as training, the selection of raw materials, and worker safety. With prevention so fully integrated with other aspects of facility operations, survey respondents may have underestimated prevention costs.

C **Exclusion of Insurance:** The PACE instructions explicitly instruct facilities not to report insurance expenditures related to pollution abatement and prevention.

In its review of the first Draft Analytic Plan, the SAB advised EPA to use alternative cost estimates as cross checks on modeled estimates. In response to this advice, we propose the use of another model as a check on IPM's estimates. EPA is currently exploring the use of Resources for the Future's (RFF) Haiku model and Argonne National Laboratory's All-Modular Industry Growth Assessment Model (AMIGA) for this purpose.

Haiku: Haiku can generate estimates of utilities' direct costs of CAAA compliance, and it can also produce a rough approximation of the social costs associated with utilities' CAAA compliance. The model simulates regional electricity markets and interregional electricity trade and contains a fully integrated algorithm for compliance with NO_x, SO_2, and CO_2 emissions regulations. Designed to measure the effects of EPA regulations, Haiku simulates changes in electricity markets stemming from public policy choices and uses an iterative convergence algorithm to search for multiple equilibria in multiple linked markets. For further information on Haiku, refer to "The RFF Haiku Electricity Market Model" in the supporting documentation to this draft analytic blueprint.

All-Modular Industry Growth Assessment Model (AMIGA): AMIGA has the capacity to measure both the direct costs and the social costs of the Clean Air Act Amendments. Containing a separate module for utilities, the model can calculate the direct costs of CAAA compliance for this sector. This module of AMIGA captures a variety of technologies available to utilities and contains a dispatch routine allowing for the retirement and dispatch of individual units.

EPA plans on incorporating learning effects into its estimates of direct costs, and our research indicates that both Haiku and AMIGA have the ability to account for these effects. However, the two models capture learning in different ways, Haiku through changes in assumptions about technological change and AMIGA through adjustments of the discount rate. We are currently examining whether these methods are suitable for quantifying learning effects.

ERCAM/ControlNET

The first prospective used ERCAM-VOC to estimate VOC control costs for many source categories, and Emission Reduction and Cost Analysis Model (ERCAM)-NO_x to estimate NO_x control costs, but more recent control cost evaluations tools and data bases that have been prepared for EPA have been organized by sector, rather than by pollutant. This design is preferred for its ability to evaluate multi-pollutant strategies. During 1999, EPA's Innovative Strategies and Economics Group compiled and updated its control cost equations and applied them to the 1996 NET inventory; the product of this analysis is called ControlNET. We propose to use ControlNET in the second prospective, with updates to some of the stationary source NO_x control cost equations to provide the means to estimate post-CAAA compliance costs for non-EGU point sources. To assess ControlNet's sensitivity to factor prices, we also propose additional model runs under different factor price scenarios. For more information on ControlNET, refer to the ControlNet Users' Guide in the supporting documentation to this draft analytic blueprint.

Similar to utility compliance costs, we propose to compare ControlNet results for 2000 with results from the 1999 PACE survey. However, as explained above, EPA suspects that the 1999 PACE results may be inaccurate.

Econometric Methods for Estimating Direct Costs

Over the past several years, economists have utilized a number of techniques for econometrically estimating the direct costs of environmental regulations. The SAB has advised EPA to consider employing such techniques to estimate the direct costs of the Clean Air Act Amendments in the second prospective "both because econometric models can capture the cost of process changes and because they can provide valuable error bounds, at least conditional on the appropriateness of the estimating specification" (EPA-SAB-COUNCIL-ADV-01-004, 2001). A survey of the literature suggested by the SAB revealed three points about econometric estimation of costs relevant to the present analysis:

- Using the appropriate type of estimator (e.g. a fixed effects estimator or pooled estimator) is essential to estimating costs accurately. An improper estimator can lead to biased estimates or incorrect standard errors. Biased estimates of direct costs would have serious ramifications for estimates of social costs since direct costs are used as an input to compute social costs. Similarly, incorrect standard errors would adversely affect the accuracy of estimated error bounds.

- Econometric techniques can be useful for estimating how different aspects of a firm's activities affect either total costs or the costs of producing conventional output.

- Econometric estimates of costs, not unlike other estimates of costs, are sensitive to assumptions. This point is particularly relevant for estimates of costs that extend far into the future because the uncertainty associated with assumptions increases as estimates extend further into the future.

Although we recognize that the econometric techniques described in detail below are useful in certain contexts, we propose that costs not be econometrically estimated for this analysis. It is not clear that econometric tools would be able to capture the incremental costs of the Clean Air Act Amendments. For example, econometric methods provide little flexibility in defining the regulatory scenarios (e.g., Post-CAAA versus Pre-CAAA) that affect costs. In the remainder of this section we provide a summary of several econometric cost estimation efforts and outline our proposal for how those efforts can be used in the second prospective.

Summary of Methodologies in the Literature

In its response to the Draft Analytic Plan, the SAB referred to Carlson et al., (2000); Morgenstern et al., (1998); Barbera and McConnell, (1986); and Barbera and McConnell, (1990) as examples of how EPA could employ econometric methods to estimate direct costs. These articles all employed different methodologies, some of which relate more closely to the second prospective analysis than others.

Barbera and McConnell

Both of the Barbera and McConnell articles assess the impact of pollution control on productivity in the paper; chemicals; stone, clay, and glass; and metals industries. These analyses do not assess the impacts of individual pieces of legislation but instead evaluate the productivity effects of environmental regulation in general. The article published in 1986 offers relatively little guidance on methods of econometric cost estimation because it does not include an econometrically estimated cost function. Instead, the authors use factor demand equations for four separate manufacturing industries to estimate the effect of abatement capital purchases on average factor productivity. Incorporating the relationship between productivity growth and abatement capital into their equations for factor demand, Barbera and McConnell use Zellner's seemingly unrelated regression technique to compute productivity growth rates for the 1960-1972 and 1973-1980 periods.

The 1990 Barbera-McConnell study uses econometric estimation of a variable cost function to gauge the relationship between total factor productivity and the amount of abatement capital in place. Total factor productivity is defined as growth in costs not accounted for by growth in prices and output. Therefore, Barbera and McConnell define total costs as follows:

$$C^{*}=C(Q, P_K, P_L, P_M, P_E, A, t) + C_A \tag{1}$$

where Q represents output; P_K, P_L, P_M, P_E are the prices of capital, labor, materials, and energy; A is the amount of abatement capital in place; t is a time trend; and C_A represents the cost of abatement capital. This total cost function captures the effect that the level of abatement capital might have on the cost of producing ordinary output. From this equation, Barbera and McConnell decompose changes in total costs into individual source components by selecting a four-input translog variable cost function with constant returns to scale. Summing those components of the change in total costs not accounted for by changes in prices or output then yields net productivity growth. These components include the change in costs due to technical change, the shift in costs due to altering the composition of non-abatement inputs, and the growth in direct costs due to the purchase of abatement equipment.

Morgenstern, Pizer, and Shih

The Morgenstern, et al. study examines the relationship between total environmental protection expenditures and economic costs in the manufacturing sector. The article provides some guidance on how costs might be econometrically estimated; however, it focuses almost exclusively on the relationship between abatement expenditures and conventional production costs. Like Barbera and McConnell, Morgenstern et al. use a cost-function modeling approach that distinguishes costs for conventional output from direct abatement costs. However, the authors estimate costs using a fixed effects estimator, which they claim is a more appropriate estimator of costs because it takes into account any unobservable plant-specific effects, purging the estimates of omitted variable bias. Conventional production costs are specified with output and the prices of capital, labor, energy, and materials as independent variables. The equation also includes regulatory expenditures as an independent variable to reflect the potential influence of abatement expenditures on conventional production costs. The specification follows the translog functional form:

$$\log(PC) = \alpha_i + \alpha_{i,x}^{'} X + \frac{1}{2} X' \beta_x X + \alpha_r \log R \qquad \textbf{(2)}$$

where: X= [log Y, log P_k, log P_t, log P_e, log P_m, t],
$\alpha_{i,x}$=[α_y, $\alpha_{i,k}$, $\alpha_{i,t}$, $\alpha_{i,l}$, $\alpha_{i,e}$, $\alpha_{i,m}$, α_t]',
β_x=[β_y, β_k, β_l, β_e, β_m, β_t], etc., and
R represents expenditures on abatement.

The parameters estimated from this cost equation and a series of share equations were then used to calculate non-environmental offsets--the effect of environmental expenditures on non-environmental costs.

Carlson, Burtraw, Cropper, and Palmer

Carlson, et al. use an econometrically estimated total cost function to estimate marginal abatement costs and the gains from trade for the sulfur dioxide tradable permit program created under Title IV of the Clean Air Act Amendments. Gains from trade are estimated by calculating the difference between the cost of meeting a uniform emissions standard and the cost of complying with a national emissions cap with a tradable permit program in place. Similar to Morgenstern et al., the authors capture fixed effects by including dummy variables for each plant included in their analysis. The econometric model is comprised of three parts: the cost function, input share equations, and an equation for the firm's mean annual emissions rate. A translog functional form was used to estimate costs. In addition, the authors illustrate in detail how different assumptions about technological progress and fuel prices can have a significant effect on cost estimates. Therefore, any estimates of future costs will be sensitive to assumptions about technological progress and fuel markets.

Econometric Estimates in the Second Prospective

Two of our concerns related to econometric estimation are practical ones. First, it is not clear that econometric tools would be able to capture the incremental costs of the Clean Air Act Amendments. Econometric methods provide little flexibility in defining the regulatory scenarios (e.g. Post-CAAA versus Pre-CAAA) that affect costs. One of the strengths of the methods employed in previous Section 812 analyses was that they were easily adapted to the regulatory nuances related to the incremental costs of the Clean Air Act (for the retrospective) and the Amendments (for the first prospective). Econometric tools might misattribute costs associated with the Clean Air Act to the Amendments.

Since an econometric forecast of costs would require estimation of independent variables, there would be much uncertainty associated with the cost estimates. Reliable data on the future values of the independent variables used to estimate costs are not available. Since these data must be estimated, calculations of direct costs based on these estimates would not be precise. Further exacerbating this problem is the fact that existing data would not fully capture the relationship between newer regulations and costs. Some regulations associated with the Clean Air Act Amendments have just recently gone into effect. Since few data are available on such regulations, econometric estimates would not reflect these recent changes.

The econometric literature pointed out other issues to consider as well. Based on our review of the literature, there is a great deal of uncertainty as to what would be the most appropriate type of estimator to use in econometrically estimating costs. Scholars have utilized a number of estimators in studies related to costs and do not appear to agree on a best estimator. For example, while Morgenstern et al. based their conclusions on fixed effects estimation, Barbera and McConnell do not employ this estimator in either of their studies.

Much of the literature related to cost estimation focuses more on the relationship between individual variables and total costs than on total costs alone. Since this type of application differs from generating cost estimates, the techniques and choices employed for such applications are not necessarily transferable to an estimation of costs. For example, Morgenstern, et al. use fixed effects estimation because they believe it will purge their estimates of omitted variable bias. They do so knowing that fixed effects might increase the variance in their estimates: "This potential loss of efficiency is the cost of protecting ourselves against omitted-variable bias" (Morgenstern, et al., p.10). Clearly, tradeoffs such as those between unbiasedness and efficiency must sometimes be made in choosing the best econometric technique for the purpose at hand. Nonetheless, it is not clear that the decisions associated with such choices would necessarily be the same when estimating costs instead of the effect of different variables on costs.

Finally, any econometrically generated estimates of future costs would necessarily depend on the relationship between emissions reductions already implemented and the costs associated with those efforts. It is not clear that the relationship between emissions reductions and the cost of such reductions will remain consistent as further reductions in emissions are required.

Given these uncertainties, we propose to estimate direct costs without using methods from the econometric literature. Although most other methods do not have the ability to estimate error bounds, we are confident that EPA can obtain accurate estimates of direct costs, including the costs of process changes, with the tools described in other sections of this chapter.

Nonetheless, EPA proposes to use estimates from the econometric literature as a check on its estimates and will provide some explanation of why these two sets of estimates should differ. These estimates may be most useful in examining EPA's estimates of the costs associated with Title IV, which was not part of the original Clean Air Act, and perhaps some components of Title II.

Learning Effects

The first prospective did not explicitly include efficiency gains related to cumulative production, "learning effects," in its estimates of the direct costs of pollution abatement. However, managers have long observed that per-unit production costs decrease as cumulative production increases. Economists have suggested that this decrease results in part from "learning" within the producing organization as workers become more experienced. Learning can also result from declines in the cost of material inputs and incremental changes in production and managerial technologies. Studies have found that marginal production costs tend to diminish with increased cumulative production, decreasing to a fraction of their previous total. For a brief summary of the findings of these studies, refer to the paper by Manson, *et al.* included in the supporting documentation to this blueprint. These studies have consistently shown that a doubling in the cumulative production of a good results in per-unit production costs falling to approximately 80 percent of their former value (a P-value of 80 percent).

EPA has used this "80 percent rule" in several recent regulatory efforts, including the Tier II sulfur regulations (1999), the Heavy Duty Diesel rule (2000), and the Phase 2 Final Rule on Handheld Spark-Ignition Engines (2000). For the second prospective, we propose employment of the 80 percent rule as a general guide to estimate the impact of learning effects on the direct costs of pollution abatement. Since industry specific factors may influence learning effects, our proposed application of the 80 percent rule will vary by source category. Exhibit 4-1 provides a summary of our approach to incorporating learning effects by emissions source category.

The Clean Air Act Amendments have led to the adoption of numerous abatement technologies to reduce emissions from motor vehicles. Reformulated gasoline, catalytic converters, particulate filters, vapor recovery nozzles on gas pumps, and electronic engine control units are among the more important technologies. Learning may occur in the production and application of each of these technologies. Moreover, since motor vehicles are produced in such large quantities, improvements in production efficiencies due to learning are likely to be significant. As a result, we plan to apply the 80 percent rule to account for learning effects, using automobile and truck production as a metric of cumulative production.

Exhibit 4-1: Learning and Estimation of Learning Effects by Source Category

Source Category	Pollution Abatement Technology by Source Category	Learning Effects	Method for Estimating Learning Effects	Rationale for the Applied Rule
Motor Vehicles	Reformulated Gasoline, Catalytic Converters, Particulate Filters, Vapor Recovery Nozzles on gas pumps, Positive Crankcase Ventilation Valve, Electronic Engine Control Unit, EGR System	Learning in design of different catalytic converters and particulate filters for every model year. Improvements in assembly of converters and particulate filters. Improvements in the incorporation of catalytic converters and particulate filters into the assembly of automobiles and trucks.	Apply 80% Rule, using autos and trucks (with converters and filters) produced as the metric of cumulative production.	Since the bulk of the abatement devices in this source category are installed in every unit produced, cumulative unit production of cars and trucks is an appropriate measure of cumulative production. Time should not be used as a proxy for cumulative production because of variation in annual production figures.
Nonroad Sources	Switch from 2-stroke to 4-stroke engines, Reformulated gasoline, Catalytic converters, Single-annular combustor, Double-annular combustor, Particulate filters, Electronic engine control unit, EGR system, Positive crankcase ventilation valve	Learning in design of 4-stroke engines, different catalytic converters and particulate filters for every model year. Improvements in assembly of converters and particulate filters. Enhancements in the incorporation of catalytic converters and filters into the assembly of construction equipment and other nonroad sources.	Apply 80% Rule, using final production figures of non-road sources (lawnmower, aircraft engines, etc) as the measure of cumulative output.	Non-road sources are similar to road vehicles in that most abatement devices are installed in individual units. One complication is that cumulative production figures will have to be obtained for a number of different goods. Time should not be used as a proxy for cumulative production because of variation in annual production figures (especially aircraft engines).

Exhibit 4-1: Learning and Estimation of Learning Effects by Source Category				
Source Category	**Pollution Abatement Technology by Source Category**	**Learning Effects**	**Method for Estimating Learning Effects**	**Rationale for the Applied Rule**
Industrial Point Sources (including toxics)	Dry ESP Wire Plate, Wet ESP Wire Plate, Fabric Filters, Paper/Nonwoven Filters, Wet Scrubber	Learning in design as more sources require ESP's. Learning in design and use of fabric filters in that users learn how to change gas filtration velocity and what cleaning mechanisms make it more efficient.	Apply 80% Rule, using abatement technologies, such as scrubbers and filters, as the metric of cumulative production.	Since the bulk of compliance costs are likely to be associated with capital costs, most learning will probably occur in the production and installation of abatement devices.
Utilities	Dry ESP, Fabric Filters, SO_2 Scrubber, Selective Catalytic Reduction, Selective Noncatalytic Reduction, Low-NO_x burners.	Learning in design and use of all these technologies.	Apply the 80% Rule through IPM by altering the model's assumptions about future technology.	IPM already incorporates some learning effects in its model. Therefore, it is important both to account for unmeasured learning and avoid double counting.
Area Sources	Alternative Solvents that reduce the use of perchloroethylene, Dry to Dry Laundry machines, Refrigerated Condensers, Cyclones	Better management practices for application of alternative solvents and new machinery, such as dry to dry laundry machines. Reduced materials wastage with increased use.	Apply 80% Rule, using time as a proxy for cumulative production. Important to address learning on a case-by-case basis.	Area sources vary dramatically in their usage of abatement technologies. Moreover, it is difficult to quantify cumulative production of area source abatement technologies. Therefore, time represents the best proxy for cumulative production.

Non-road sources use many of the same pollution abatement technologies as motor vehicles. However, some producers of non-road sources have developed technologies unique to certain mobile sources, such as single and double annular combustors used in some aircraft engines. Learning can reduce costs for most of these technologies. Therefore, we propose use of the 80 percent rule to approximate learning effects for non-road sources. We also propose to use final production figures of non-road sources (e.g. the number of lawnmowers and tractors produced) as the measure of cumulative output. Thus, metrics of cumulative output for non-road sources will include information on lawnmower production, aircraft engine production and other specific non-road sources. Some of the non-road cost estimates will be based on EPA RIAs that take learning into account, and we will be careful to apply the 80 percent rule only once in these cases.

Industrial point sources tend to use end-of-pipe abatement technologies such as electrostatic precipitators (ESP's), filters, and scrubbers to reduce their emissions. Learning is likely to occur in both the production and installation of these technologies. In addition, costs are likely to decline as factory managers and operators learn how to use and manage these technologies more efficiently. For instance, minor changes in the gas filtration velocity can make a significant difference in the efficiency of fabric filters. Two recent studies evaluated the impact of learning effects on scrubber technologies. Taylor, et al. (2000) and Greening, et al. (2001) find that scrubbers have a P-value of 83 and 88 percent, respectively. Although these P-values imply less significant cost reductions than those predicted by the 80 percent rule, both of them fall within one standard deviation of a P-value of 80 percent. In addition, other studies have found P-values of less than 80 percent for other technologies. Consequently, we propose use of the 80 percent rule to model the impact of learning effects on industrial point sources. Finally, since the bulk of compliance costs will usually be associated with capital costs, we plan to use the production of scrubbers and other abatement technologies as the metric of cumulative output. Cumulative production figures will reflect past production of existing abatement technologies.

Utilities use many of the same abatement technologies as industrial point sources. In addition, utilities make extensive use of several other technologies, such as selective catalytic reduction and low-NO_x burners. Learning effects can occur in the production, installation, and usage of these technologies. As a result, we plan to apply the 80 percent rule to determine the effect of learning on abatement costs in the utility industry. IPM already includes some learning associated with capital costs in its modeling framework; however, demand side learning and certain aspects of supply side learning are not included. We propose to account for the difference between the learning effects incorporated into IPM and 80-percent-rule learning effects. Subject to resource constraints, we plan to run additional iterations of IPM with the assumptions about future technology altered.

Area sources include a wide variety of relatively unrelated industries. As a result, the abatement technologies that area sources use vary dramatically. For example, the dry cleaning industry has reduced its emissions through increased use of alternative solvents and dry to dry laundry machines.[2] However, the livestock industry is unlikely to incorporate new technologies or designs. Instead, emissions reductions are likely to come through better management practices and reduced materials wastage. Due to the dramatic variation in abatement technologies in this source category and the difficulty in quantifying cumulative production for area source abatement technologies, we plan to use time as a proxy for cumulative production, rather than using the cumulative production of specific abatement technologies. For example, an incremental compliance cost for dry cleaners will fall with every doubling in the number of years since dry cleaners first adopted the particular abatement technology associated with the cost. We will apply the 80 percent rule to many of the abatement cost figures for area sources, but given the diversity of this category, we propose to address learning on a case-by-case basis.

Due to the variation in learning across different area sources, we propose a comparison of learning effect cost reduction rates across several types of area sources for the 2010-2020 period. This exercise will allow us to ensure that sector-specific area source compliance costs are consistent with pre-specified learning rates.

Mobile Sources

The compliance cost analysis for motor vehicles will examine all of the costs associated with meeting post-CAAA emission standards and fuel regulations. The practice in the first prospective was to estimate motor vehicle costs as an incremental per vehicle price differential for emission standards, as a fuel price differential for fuel regulations, and as a cost per registered vehicle for vehicles in inspection/maintenance areas. SAB comments in response to the first draft analytic blueprint were mostly about cost estimates for emission standards. The concern seemed to be that estimated price differentials might not include all of the increased research and development costs, or increased production costs incurred by motor vehicle manufacturers, if these costs are all not being passed through to the consumer. As a general rule, the EPA RIAs that are typically relied on for these incremental cost estimates do incorporate estimates of these production costs, but we plan to review them to ensure that this is the case.

As an example, the Tier 2 exhaust and gasoline sulfur standards analysis considered both near-term and long-term costs. The capital costs associated with the manufacture of vehicles meeting Tier 2 standards is amortized over five years. In the sixth year of production, a portion of the capital costs becomes zero, and the total costs of production drop. Manufacturers also gain knowledge about the best way to meet new standards as time goes on, which results in their operating costs decreasing over time. The cost implications of this learning curve are estimated as a 20 percent drop in operating costs in the third year of production (Morgenstern et al., 1998). Near term costs represent the highest costs of the program, as they include all capital costs and no cost savings due to the manufacturers' learning curve. Long term costs represent the lowest costs of the

[2] Dry-to-dry laundry machines perform the washing, extraction, and drying steps of the dry cleaning process. The older transfer method of dry cleaning requires the transfer of garments from one machine to another between the washing and drying steps of the dry cleaning process, allowing a great deal of the cleaning solvent to escape into the atmosphere.

program, which occur after a portion of capital cost amortization has ended, and all learning curve cost savings have been accounted for.

More judgment has to be applied in estimating the long term price difference between a vehicle meeting Federal emission standards, and one meeting zero emission vehicle requirements. In the first prospective, a zero-emission vehicle (ZEV) was estimated to cost $5,000 more than a baseline vehicle (based on price analysis). If the current research and development plus production costs for ZEVs were averaged across sales, the cost difference would be astronomical. Ultimately, prices for new, advanced technology vehicles must be competitive with others in the marketplace, or there will be few buyers. With the last analysis year being 2020, additional consideration will be given to performing a vehicle technology forecast for that year's cost analysis. Then, consideration will be given to how to amortize expected production costs for new technologies across expected sales in the projection year.

The ZEV program was originally adopted in 1990, as part of the first Air Resources Board (ARB) low emission vehicle regulations. Under the 1990 regulations, the largest auto manufacturers were required to produce ZEVs beginning with model year 1998. In 1996 the ARB modified the regulations to allow additional time for the technology to develop. Program modifications occurred again in 1998 and 2000. These modifications affect ZEV and related sales volumes in the prospective study projection years. The program applies in California and the NE States that have adopted California emission standards.

Our second prospective cost analyses will examine manufacturer production costs, and not just per vehicle price increases. In doing so, we may want to examine technologies in addition to battery EVs. Others might include stored hydrogen fuel cell vehicles and methanol reformer fuel cell vehicles. We can apply different relationships for amortizing research and development costs over the program lifetime. The ARB recently concluded that near-term full function ZEV incremental costs above conventional vehicles are about $17,000 per vehicle.

One of the key relationships in determining long-term incremental vehicle costs is production volume vs. cost. At low production volumes, it will be difficult for ZEVs to be cost competitive with conventional vehicles. Our analysis will take into account the low number of required ZEVs nationally, compared with other motor vehicle programs, but we anticipate that overall the total ZEV program cost will remain small by comparison to the total cost of these other programs.

Estimates of expected costs to meet California low-emission vehicle program requirements will be revisited because the Air Resources Board modified its program recently as part of its periodic review. There are now some new vehicle standard categories that did not exist under the program that was evaluated in the 1999 report. In addition we propose to explore the possible effect of tax incentives for hybrid vehicle purchases as proposed in the Bush Administration's energy plan.

NAAQS Attainment

The first prospective evaluated potential PM and ozone NAAQS attainment costs using two different methods. For PM_{10} nonattainment areas, a model attainment plan was developed and evaluated, and this plan was based on a package of what EPA termed reasonable available control measures (RACM). It was generally acknowledged that this approach probably overstated PM_{10} attainment costs, because the model did not factor in the possibility that areas could reduce point source emissions in a more cost effective manner than RACM measures. In reality, some areas did find more affordable measures than those assumed as part of the RACM package. Thus, for the second prospective, we intend to improve the PM_{10} nonattainment analysis by estimating the costs of measures that were included in each area's SIP. The ozone analysis simply included an estimate of the cost to meet progress requirements for each one-hour NAAQS nonattainment area from 1990 until their attainment year. As with PM_{10}, this analysis could be improved by estimating the costs of the measures included in each area's approved ozone attainment plan (or we could just focus on the severe/extreme areas because they bear a high percentage of these costs).

For $PM_{2.5}$, the 1997 NAAQS analysis used an optimization model to estimate the *least cost* set of control measures that would be needed on a dollar per microgram per cubic meter of $PM_{2.5}$ reduced basis to meet $PM_{2.5}$ standard alternatives. EPA-OAQPS is in the process of upgrading the PM analysis tools that would allow similar analyses to be performed soon. However, these tools may not be ready for an analysis that would need to be completed in early 2004.

In order to perform an analysis of the 8-hour ozone NAAQS, it will be necessary to have some clarification of the nonattainment area classifications and attainment deadlines as well as the the proposed implementation policy for this standard in the wake of the Supreme Court decision. One way to estimate the cost of meeting the 8-hour ozone NAAQS is to establish emission targets for VOC and NO_x, then apply controls (and estimate costs on a unit cost per ton basis) until the targets are met in each area. Alternatively, a progress requirement-like control set can be applied until the attainment deadline is reached. However, it is unclear at this time whether any such approach is going to be part of the EPA policy for implementing the 8-hour NAAQS. Finally, the 8-hour NAAQS cost could be estimated by applying broad sets of regional strategies that might be used to meet the 8-hour NAAQS. An example might be the recent OTC State Memorandum of Understanding for additional VOC and NO_x controls in those States, although this regional strategy is designed to meet the one-hour standard in severe one-hour nonattainment areas, and the 8-hour standard elsewhere.

Stratospheric Ozone Cost Analysis

Our presentation of cost estimates for the stratospheric ozone protection provisions of Title VI in the first prospective was, by necessity, different from other titles. Ideally, we would have liked to compare the costs of actions taken in a given year to the benefits attributable to these actions. For Title VI, a cost-benefit comparison of any given year requires assumptions that result in potentially misleading figures. The difficulty is due to the differing time horizons and the complexity of the process by which ozone-depleting substances (ODSs) cause adverse effects on human health and the environment. Title VI provisions incur costs over significantly varying time horizons; for example, the cost analysis of Sections 604 and 606 provisions spans 85 years (from 1990 to 2075). At the same time, the analysis of Section 611 extends from 1994 to 2015. In response to this analytic difficulty, we based our comparison of Title VI costs to Title VI benefits on net present values.

We propose to apply a similar approach for the second prospective for this largely separable component of the CAAA provisions. The net present value of Title VI program costs will again reflect selected actions and their associated costs from Sections 604, 606, 608, 609, and 611. Examples of these actions include: replacement of ozone-depleting chemicals with alternative technologies and materials; recycling and storage of unused chlorofluorocarbons; labeling; training; and administration. Consistent with the remainder of the analysis, however, we will apply a three percent discount rate for the primary estimates of Title VI costs. Additional detail on the specific sources of our Title VI cost data is included in Appendix E.

Computable General Equilibrium Modeling of Social Costs

EPA continues to evaluate the potential use of a computable general equilibrium (CGE) modeling approach to estimate economic impacts and social costs of the 1990 Clean Air Act Amendments (CAAA) for the second prospective. EPA's retrospective analysis (*Benefits and Costs of the Clean Air Act: 1970 to 1990*) included a CGE analysis of the GDP, employment, and price effects associated with the implementation of the Clean Air Act's provisions, using the Jorgenson/Ho/Wilcoxen dynamic CGE model of the U.S. economy. The CGE analysis in the retrospective was a critical step in the overall analytic chain, reflecting the historical expenditure data for the factual case (with the Clean Air Act) and generating estimates of economic growth and industrial output that was used to drive emissions estimates for the counterfactual case (without the Clean Air Act).

The first prospective analysis, however, did not include general equilibrium modeling due in part to the level of effort required to calibrate and run a CGE model. For the second prospective, EPA proposes the application of a CGE framework as a post-processing analysis, to provide further insights on the economy-wide implications of the imposition of direct costs of CAAA compliance. As part of this analysis, EPA anticipates comparing sector-level CGE outputs with sector-level direct costs entered as inputs into the model. As implied by the overall analytic process outlined in Chapter 1, we are not currently contemplating the use of CGE outputs as driver data for the emissions estimation process. Instead, EPA proposes the presentation of CGE results as supplemental information not to be compared to direct benefits estimates.

Several recent efforts estimate net impacts of a policy by incorporating productivity-linked benefits (e.g., avoided health effects) into modeling scenarios. Using output and data from the first prospective, the National Center for Environmental Economics (NCEE) recently used the Jorgenson/Ho/Wilcoxen CGE to estimate productivity-linked benefits of the Clean Air Act Amendments between 1990 and 2010. A modified version of the same model was used to estimate benefits of carbon emissions reductions in China. In addition, a 2000 paper by Roberton Williams specifies a general equilibrium model that takes into account the benefits resulting from the interaction between environmental regulation and the tax system. Therefore, he concludes that the sign of the tax interaction effect is ambiguous.

Since the development of the first prospective, advances in software and computing power have reduced the cost and time associated with running CGE models, and developments in modeling approaches have raised the possibility that CGE modeling may be cost-effectively used to estimate both social costs and social benefits associated with regulation. EPA has been examining recent modeling efforts to determine whether available models could be useful in the current study. [3] Under the SAB's advisement, EPA has also considered using sectoral models since a national CGE is unlikely to capture all of the intricacies of different industries and regulations (EPA-SAB-COUNCIL-ADV-01-004, 2001). Nevertheless, since sectoral models often lack the dynamic, inter-industry capabilities of a national CGE, the sum of the costs generated by a series of sectoral models would not necessarily reflect a complete accounting of social costs. In addition, it is unclear how valuable cross-sector cost comparisons would be since models of different sectors of the economy often employ different methodologies to estimate output. A national CGE would provide a fairly accurate estimate of social costs at the national level and would also enable EPA to make reasonable cross-sector cost comparisons.

In light of the advantages of a national approach, we have reviewed recent CGE modeling efforts that address environmental policy. We have identified two available modeling options for use in the second prospective:[4]

- **Jorgenson/Ho/Wilcoxen Model of the U.S. Economy:** J/H/W is an update of the dynamic national CGE model used to assess the social costs of the Clean Air Act in EPA's retrospective analysis. The model is currently being updated to address benefits in an integrated fashion and to perform prospective assessments of impacts. In addition, model updates include a more sector-specific measurement of technological change. The updated version of the model will also use demographic data to create an array of model households, each of which makes its own labor-leisure decision. This component of the model is not expected to be complete until summer of 2004 at the earliest. In the model's current form, one nationally representative household makes the labor-leisure tradeoff decision. For further information on J/H/W, refer to Appendix A.

- **Argonne National Laboratory's All Modular Growth Assessment System (AMIGA):** AMIGA is a multiple-sector national CGE. The model includes separate modules for

[3] For a brief overview of the use of different types of general equilibrium models (i.e., input/output models, linear programming models, and CGE models) as well as partial equilibrium and multi-market models, in the assessment of costs related to environmental regulation, see EPA's *Guidelines for Performing Economic Analyses*, September 2000, EPA 240-R-00-003.

[4] In addition, a number of available "world models" (e.g., Wilcoxen's G-Cubed Model and MIT's EPPA recursive-dynamic CGE model, and CRA's Multi-sector, Multi-regional Trade (MS-MRT) model) address general equilibrium effects of international environmental policy issues, such as efforts aimed at reducing greenhouse gas emissions. While many world models have regional (i.e., national or multi-national) capabilities, the level of aggregation in these models is generally too high to address specific sectors within a single national economy.

household demand, production of goods, motor vehicles, electricity supply, and residential and commercial buildings and appliances. In the past, AMIGA has mainly been used to evaluate climate change mitigation policy, but it has been modified in recent years to evaluate policies that require reductions in NO_x, SO_2, and mercury emissions. AMIGA has the intertemporal optimization capabilities necessary to model cap and trade programs, and its estimates of output account for tax interaction effects. For more information on AMIGA, refer to the model documentation in the supporting materials to this analytic blueprint.

Exhibit 4-2 provides information on both models. As the exhibit illustrates, J/H/W and AMIGA share several characteristics:

- Measurement of employment impacts,
- Sector-level results on output and employment,
- Inclusion of technological change,
- Forward-looking households and firms,
- Ability to exogenously enter productivity increases resulting from health improvements,
- Inclusion of distortionary taxes.

Exhibit 4-2

Comparison of J/H/W and AMIGA General Equilibrium Models

Traits	**Jorgenson/Ho/Wilcoxen**	**AMIGA**
Calibration/ Estimation	Econometrically estimated from 25 years of data.	Calibrated to 1992 BEA data.
Number of Sectors	35 sectors included in model	200 sectors included in model
Reporting	Economy wide and by industry	Economy wide and by industry
Employment Impacts	Reported in model	Reported in model
Treatment of Technology	Exogenous and endogenous components of technological progress.	Extremely rich representation of technology. Technology assumptions based on EIA projections of technology cost and efficiency. Updated periodically.
Treatment of taxation	Captures effects resulting from the interaction of taxes and environmental policy.	Captures effects resulting from the interaction of taxes and environmental policy.
Intertemporal Optimization	The model calculates a dynamic equilibrium where consumers and capital owners optimize with consideration for the future.	The model calculates a dynamic equilibrium where consumers and capital owners optimize with consideration for the future.
Treatment of Productivity Increases from Health Improvements	Can introduce exogenously. Improves the quality component of labor.	Can introduce exogenously by entering estimated change in worker productivity.
Peer Reviewed/ Published works	Theoretical basis of the model peer reviewed in several journal articles. The model itself is not available for review.	Peer reviewed paper forthcoming in *Energy Economics*. Unpublished reviews from Cornell, MIT, and EMF. The model code is available for review.
Past Uses	CAA Retrospective, NCEE applications	Jeffords-Lieberman request on a multi-pollutant emissions strategy, Possible use for Lieberman-McCain greenhouse gas proposal
Cost	Unclear	Less than $100,000 for this application.

Exhibit 4-2

Comparison of J/H/W and AMIGA General Equilibrium Models

Traits	**Jorgenson/Ho/Wilcoxen**	**AMIGA**
Availability	Current Production Changes: Summer 2003. Consumption changes: Summer or Fall 2004	Summer 2003

The models differ in several important ways:

- J/H/W is econometrically estimated using data dating back to 1977, whereas AMIGA is calibrated to 1992 data provided by the Bureau of Economic Analysis.
- J/H/W disaggregates the economy into 35 sectors; AMIGA provides detail on 200 sectors.
- The theory embedded in J/H/W has appeared in several peer-reviewed academic journals. However, AMIGA has only limited representation in the peer-reviewed literature, with one article forthcoming in *Energy Economics*. Aside from the forthcoming article, three independent, unpublished reviews of AMIGA have been written and are available from the model owners upon request.
- EPA has a fairly extensive history with J/H/W, having used it for the Section 812 retrospective analysis and a number of NCEE-sponsored studies. However, EPA has only used AMIGA for the Jeffords-Lieberman multi-emissions strategy request.
- J/H/W is a more expensive model to run than AMIGA.

Based upon our review of these models, we have concluded that both J/H/W and AMIGA would be suitable for estimating the social costs of the Clean Air Act Amendments. Both models include the tax interaction effect in their output estimates, and both allow for dynamic interaction among an array of industries. In addition, both J/H/W and AMIGA can analyze the effects of increased productivity and population levels resulting from improvements in health.

Preliminary CGE Model Choice

Although a final decision on a CGE model intended for use as a post-processor can be made later in the analytic 812 sequence, our current plan is to employ the AMIGA modeling system to measure social costs. We base this preliminary choice on several factors. First, AMIGA disaggregates the US economy to a finer degree than J/H/W. Generating output estimates for 200 sectors of the economy, AMIGA could provide much more information than J/H/W on how the CAAA affects specific industries. AMIGA also contains a richer representation of technology than J/H/W, in both production and consumption. For example, AMIGA allows consumers to purchase any of 48 types of light-duty vehicles. This detailed representation of technology would allow for a more precise and flexible analysis of alternative energy futures than would be possible with J/H/W.

Finally, unlike J/H/W, AMIGA's programming code is available upon request, which would allow EPA conduct its own review of the model.

We also base our preliminary choice on three favorable peer reviews of AMIGA.[5] Overall, the impressions of the reviewers were positive, with all three concluding that AMIGA's theoretical foundation is consistent with generally accepted economic principles. The concluding remarks of Duane Chapman's review reflect this sentiment: "I am greatly impressed by the breadth of this work and its original combination of realism and economic theory." The reviewers were also impressed by the level of detail and flexibility built into the model. As Babiker notes in his review, "The level of sectoral disaggregation embodied in AMIGA is an important feature. If individual sectors possess different technologies or have different factor intensities, such a disaggregation would be necessary to conduct appropriate assessment of policies addressing energy-efficiency and adoption of new technologies."

Although the reviewers responded favorably to AMIGA, they identified a few minor concerns, many of which have already been addressed. Most of these issues are of little practical importance since they would not significantly affect model results. Nevertheless, a few may be significant if they have not yet been addressed. One reviewer identified possible double counting in the calculation of net labor intensity. In addition, AMIGA includes only capital costs in estimating the incremental cost of adopting energy-efficient equipment; it fails to include the saving (or usage) of other inputs. Also, the formula for the price of a good assumes fixed proportions between imports and domestic goods, which is inconsistent with the international trade assumptions specified later in the model. Finally, for consumption of goods other than transportation and housing-related services, the model's implicit assumption of zero substitutability may not be supported empirically.

Tax-Interaction Effect

In the first prospective, EPA chose to address the issue of tax interaction effects qualitatively. The qualitative discussion focused on the implications of adopting alternative approaches to modeling costs (e.g., direct compliance costs, partial equilibrium, general equilibrium); as part of this discussion, the first prospective identifies the tax interaction literature as one possible source for characterizing the differences in measures. The SAB advised EPA's first prospective authors to consider seriously the tax interaction effect in estimating CAAA compliance costs, noting that "the cost of the tax interaction effect is 1.25 to 1.35 times any increase in direct costs" (EPA-SAB-COUNCIL-ADV-00-003, 1999).

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[5] The reviews referred to here are as follows:
Babiker, Mustafa. *Review of AMIGA Model*, personal communication to Donald Hanson;
Chapman, Duane. (1999). Personal communication to Donald Hanson, September 17.
Huntington, Hillard. (1999). Memorandum, *Review of AMIGA Model*, personal communication to Donald Hanson, July 28.

The tax-interaction effect literature analyzes the effects of various pollution control policies on net welfare, specifically noting that net welfare effects can be very different when analyses depart from the “first-best” setting which is implicitly adopted in EPA’s and most Federal government analyses. The tax interaction literature shows that social costs and, consequently, net welfare can be very different when assessed in a world with pre-existing market distortions (i.e., second-best world) than if assessed in a world absent of market distortions (i.e., first-best world). Two commonly cited examples of the tax-interaction effect literature are Goulder et al. (1999) and Parry et al. (1999).[6] Those citations are the source of the 1999 SAB recommendation.

The tax-interaction literature attributes the higher efficiency costs of environmental regulations (as evident in a second-best setting) to two welfare effects. The first effect is the "tax-interaction effect." This effect accounts for how regulations give rise to higher production costs which leads to the higher prices of consumption goods. This increase in the price of consumption effectively reduces real wages and discourages labor supply. The reduction in labor supply is a first order effect; it shifts the labor supply curve and, therefore, is not incremental. It results in a welfare loss (i.e., generating a deadweight loss). The second welfare effect is the "revenue-recycling effect." To the extent that the policy raises revenues that can be recycled to reduced pre-existing labor tax, this effect generates an "efficiency benefit."[7] The tax-interaction literature finds that the revenue-recycling effect only partially offsets the tax-interaction effect.[8]

More recently, new economic literature has emerged that further assesses factors that drive differences between welfare measured in a first-best world (i.e., absence of market distortions) and a second-best world (i.e., presence of market distortions). This new literature provides a closer examination of the analytic models and assumptions built into the analyses presented in earlier tax interaction literature. The findings of more recent literature confirm that the effects of pre-existing market distortions are real, affecting measures of net welfare and comparisons of policy instruments' relative cost-effectiveness. The emerging literature also suggests that there is more uncertainty as to the magnitude of the difference than initially reported and collectively highlights the fact that further research is necessary in this area of economics. The new literature includes, for example, work by Burtraw and Cannon (2000); Jaeger (2000); Murray, Thurman, and Keeler (2000); and Williams (1999); some of this work was sponsored by EPA, as was some of the literature available for the first prospective.

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[6] These citations reflect the published date of the papers. It is worth noting that these papers first appeared as drafts in 1997 and 1998. Consequently, this blue print refers to "more recent literature" in later sections as papers that have been drafted by the authors subsequent to the two aforementioned articles.

[7] Fullerton and Metcalf (1997) find that efficiency gains should be attributed to a policy's ability to capture scarcity rents rather than generate pollution tax revenues.

[8] The extent to which the revenue-recycling effect offsets the efficiency loss is highly dependent upon how well the policy generates revenues. The tax interaction literature finds few cases where the revenue recycling effect is larger than the tax-interaction effect.

EPA agreed with SAB advice conveyed during review of the first prospective study that understanding the interaction of environmental regulation with the tax system is a potentially useful direction for research. In particular, there appear to be important insights from this literature that may affect the appropriate choice of policy instruments for key industries affected by the CAAA. The recent literature, however, emphasizes a number of reasons for proceeding with caution in using estimates of tax interaction effects to make policy decisions:

- Recent papers on the heterogeneity of abatement costs suggest that the relative costs (and effects on net welfare) of policy instruments are a function of how costs are incorporated (e.g., aggregate abatement cost functions versus a more complete characterization of the heterogeneity of abatement costs - see Burtraw and Cannon, 2000). In other words, the level of aggregation in cost estimates can affect the magnitude of the tax-interaction effect, but there is not yet a clear consensus on how to reflect the full range of cost heterogeneity in an analytically tractable model.

- The benefits provided by air pollution control programs need to be considered. Key estimation issues remain, however, including the choice of the form of utility function used, the potential influence of benefits on critical labor-leisure decisions, and the estimated change in the productivity of labor as a production input (see, for example, Williams 1999). Environmental improvements can be analyzed in the form of reduced medical expenditures, reduced time lost to sickness, and increased longevity, as has recently been done with the J/H/W CGE model.

- Assuming constant returns to scale (CRS) might lead to biased estimates of the tax interaction effect. Many models that measure the tax interaction assume constant returns to scale, but CRS might not hold when factor inputs are scarce (e.g. capital fixity or fixed natural resource endowments) or when technology is heterogeneous across producers. As Murray et al. point out, assumptions about returns to scale have significant implications for estimates of the tax interaction effect. Under the CRS assumption, price changes that lead to a decline in the real wage tend to equal abatement costs. However, if decreasing returns to scale were assumed to hold, estimates of tax interaction effects would be lower since price changes would be smaller than abatement costs. Similarly, estimates of tax interaction effects would be higher under the assumption of increasing returns to scale.

- It is not clear that estimates of tax interaction effects should be used to evaluate environmental policy or tax policy. If tax policy did not lead to distortions in the economy, then policies that correct externalities, such as socially inefficient emissions levels, would not lead to exacerbation of the distortions that taxes create. Nevertheless, distortions that result from taxation would be less severe if emissions regulations were not in place. It is not obvious which policy is responsible for this extra cost, and policymakers face a significant challenge in devising the best way to use such information.

Given the uncertainty associated with estimating both tax interaction effects and any benefits that might mitigate these effects, we propose not to include tax interaction effects in the primary cost estimates in the second prospective. Despite these uncertainties, we nonetheless propose generating alternative estimates of social costs that reflect tax interaction effects. Our reasons for measuring the tax interaction effect in this alternative paradigm are twofold:

- Most importantly, an abundance of economic theory and quantitative evidence has indicated that tax interaction can have a significant impact on total costs. Given the potential magnitude of the tax interaction effect, social cost estimates that do not include tax interaction could significantly underestimate costs. Although estimates of the size of the tax interaction effect are highly sensitive to model methodologies and assumptions, such imperfect estimates nonetheless provide potentially useful information to policymakers.

- Improvements in the CGE models that EPA is considering for this analysis have made it possible to account for tax interaction effects more precisely. Finer levels of disaggregation and the inclusion of more up-to-date demographic data have contributed to this greater precision. In addition, the CGE models EPA has considered for the second prospective can capture benefit-side effects resulting from health improvements.

CHAPTER 5 - AIR QUALITY MODELING

Air quality modeling is a critical analytical step in the prospective analysis that provides the link between emissions changes and the physical effects resulting from changes in atmospheric concentrations of pollutants that may affect human health and the environment. The air quality modeling step of the analysis employs complex computer models that simulate the transport and transformation of emitted pollutants in the atmosphere. The result of these model runs are base- or future-year predictions of pollutant concentrations under each of the different emission control scenarios specified in Chapter 2 of this Analytical Blueprint. These predicted concentrations are then used as inputs to the human health and environmental effect estimation models discussed in Chapters 6 and 7.

This chapter consists of three parts. First, it reviews EPA's approach to air quality modeling in the first prospective. Second, it discusses potentially major issues or uncertainties associated with the approach employed in the first and second prospective analyses. Finally, it discusses the key changes in the air quality modeling approach that EPA expects to implement in the second prospective in response to the issues raised. In short, EPA is proposing to follow an approach similar to the one taken in the first prospective. The most significant change will be a greater reliance on air quality models that can be employed nationwide for each criteria pollutant, rather than aggregating the results of multiple models to characterize nationwide air quality benefits. This change will add speed and simplicity to the overall analytic process, and facilitate the disaggregation of benefits. Additionally, the model to be used for $PM_{2.5}$ and visibility assessment has been improved with regard to the modeling of secondary organic aerosols.

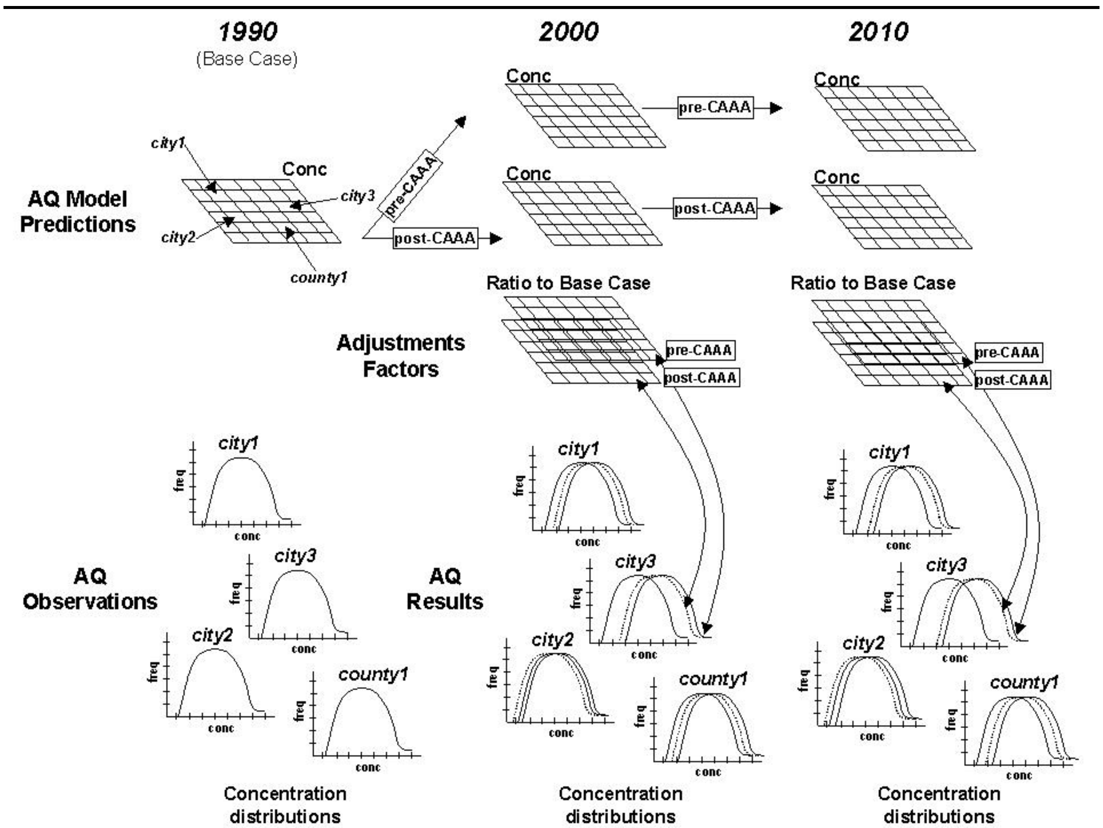
Air Quality Modeling in the First Prospective Analysis

The overall air quality modeling framework that EPA employed in the first prospective analysis consisted of the following three steps:

- Step 1: Compile 1990 air quality monitor data for criteria pollutants (ozone, PM, SO_2, NO, NO_2, and CO) from EPA's Aerometric Information Retrieval System (AIRS).
- Step 2: Use air quality modeling to calculate adjustment factors for each future year of each emissions scenario, based on the ratio of predicted future year pollutant concentrations to model-predicted 1990 baseline concentrations
- Step 3: Estimate 2000 and 2010 concentrations of each pollutant under each emissions scenario by applying adjustment factors to the 1990 monitor data.

The use of modeling results in a relative sense to estimate future-year concentrations by modifying observational data may enhance the reliability of future-year concentration estimates, provided the uncertainty in the modeled values is greater than the uncertainty in a given model's response to emission changes. A schematic of this monitor adjustment procedure used in the first prospective analysis is included in Exhibit 5-1 below:

Exhibit 5-1:
Schematic diagram of the future-year concentration estimation methodology



NOTE: The exhibit illustrates how model results and observations are used to produce the air quality profiles (concentration distributions) for the benefits analysis. The figure shows model runs at the top; four sets of "ratios" of model results in space in the middle; and frequency distributions of pollutant monitor concentrations and the space-dependent scaling of these by the ratios of the model predictions on the bottom.

The models were typically applied for all or for some subset of the 48 contiguous U.S. states. EPA conducted separate model runs for the 1990 base year and the future target years for each projection scenario. Primary model inputs consisted of emissions estimates corresponding to the year and scenario being modeled and meteorological data corresponding to a past time period (the "simulation period"). With the exception of the "roll-back" models applied for SO_2, NO, NO_2, and CO (SONOCO), all models simulate both physical transport and chemical transformation processes in the atmosphere. EPA employed the following models for each of the criteria pollutants, acid deposition, and visibility:

PM. EPA used two different three-dimensional grid-cell models to estimate daily PM_{10} and $PM_{2.5}$ concentrations. For the eastern U.S., EPA employed the Regional Acid Deposition Model/Regional Particulate Model (RADM/RPM) with an 80 x 80 km grid for randomly selected 5-day simulation periods over 4 years. For the western U.S., EPA used the Regulatory Modeling System for Aerosols and Acid Deposition (REMSAD), with a 56 x 56 km grid for a 10 day period at the beginning of each of the four seasons.

Ozone. EPA employed the three-dimensional variable-grid Urban Airshed Model (UAM-V) separately for the eastern and western United States to obtain regional-scale estimates of ozone concentrations for each target year and scenario. The eastern U.S. analysis relied on the modeling databases developed as part of the Ozone Transport Assessment Group (OTAG) regional-scale analysis. The scale of the grid for UAM-V modeling in the west (56 km x 56 km) was coarser than the grid for the east (36 km x 36 km). EPA augmented the western analysis with higher resolution ozone modeling (using the fine grid UAM-IV) for Los Angeles, Phoenix and the San Francisco Bay Area. Similarly, EPA used a 12 km x 12 km "nested" grid to model ozone in "inner OTAG" states where population density is high and ozone transport is a major problem. These models were run only for specific summertime ozone episodes, and the model results were extrapolated to generate hourly ozone concentration estimates for May through September.

SONOCO. EPA estimated future-year pre- and post-CAAA ambient concentrations of SO_2, NO, NO_2, and CO by using a linear "roll-up" model to adjust 1990 monitor concentrations of these pollutants. The adjustment factors were derived by calculating future year to base-year emissions ratios, based on grid-cell specific REMSAD emissions data. For REMSAD grid cells without 1990 monitor concentrations data, interpolation was used to estimate base-year concentrations and adjustment factors were applied to these estimates. This approach assumes a linear relationship between changes in emissions and changes in ambient concentrations of the emitted pollutant in a given geographical area. No atmospheric chemistry algorithms are involved in this type of modeling.

Acid Deposition. EPA modeled acid deposition in the eastern U.S. using the results of the RADM/RPM modeling.

Visibility. RADM and REMSAD modules for estimating atmospheric visibility were applied as part of the PM modeling procedure described above.

Major Issues Associated with AQM Approach of the First Prospective Analysis

Below are several key issues identified by the SAB and others associated with the air quality modeling approach of the first prospective. The issues listed below are those thought to have a potentially significant effect on the results of the first prospective analysis.

- **Use of Multiple Models.** The previous analysis used separate air quality models for individual pollutants and, for ozone and PM, for different geographical regions. The use of different models operating at different scales introduced additional uncertainty into the analysis. Furthermore, such an approach precludes a fully integrated analysis of pollutants and their interactions.

- **PM Estimation in Eastern U.S.** The previous analysis estimated changes in PM concentrations in the east based on sulfate and nitrate particle changes alone. It did not account for changes in organic and primary particulate fractions. Although nitrates and sulfates constitute major components of PM, especially $PM_{2.5}$, in the east, this approach is likely to have underestimated PM changes.

- **Limited Monitoring of $PM_{2.5}$.** The number of ambient $PM_{2.5}$ monitors throughout the U.S. was limited at the time of the first prospective analysis. In the previous analysis, $PM_{2.5}$ was cross-estimated from PM_{10} and TSP to complete the 1990 monitor data set of observed concentrations. This estimation introduced uncertainty into the baseline concentration estimates of $PM_{2.5}$, which play a critical role in the analysis because they are linked with premature mortality.

- **Extrapolation to Unmonitored Areas.** Use of the three-step adjustment factor approach described above requires the extrapolation of monitor results to areas greater than 50 km from an air quality monitor (only 81 percent of the U.S. population resides within 50 km of a monitor). Two approaches to extrapolation were considered in the last analysis, Voronoi Neighbor Averaging (VNA) and homology mapping. While the initial SAB reviews of these methods were generally favorable, EPA was encouraged to incorporate information provided by the model runs themselves. A modified VNA approach (e-VNA) which incorporated some of these data was then developed and applied in the first prospective analysis. The SAB endorsed the use of the e-VNA approach in the previous analysis, but encouraged EPA to consider further evaluation and development of both the VNA and homology mapping methods.

Major Issues Associated with AQM Approach of the Second Prospective Analysis

Below are several key issues identified by the SAB associated with the initial air quality modeling approach presented for the second prospective. The issues listed below are those thought to have a potentially significant effect on the results of the analysis.

- **Procedure for Evaluating and Selecting Preferred Models.** The SAB recommended that EPA establish a protocol outlining the necessary attributes for an air quality model and the level of performance required to meet the 812 study objectives. In doing so, EPA should consider the strengths and limitations of other modeling efforts and select its model accordingly.

- **Model Performance Procedures.** The Council further requested that EPA specify procedures for model evaluation and for checking the quality of observational data used in comparing the models with observations.

- **Patriculate Matter Modeling Issues.** To ensure that the selected air quality model (REMSAD) adequately captures changes in the levels of $PM_{2.5}$ components, EPA should compare modeling results for fine particle components with observed data. The components of primary concern are sulfate, nitrate, ammonium, organic and elemental carbon, and crustal material.

- **Ozone Modeling Issues.** The SAB noted that the previous draft of the analytical plan did not explicitly indicate how ozone formation would be modeled. They also suggested that EPA evaluate CAMx as an alternative to REMSAD for ozone modeling.

The model selection process for the second prospective study was strongly influenced by a program of analytical methods evaluation conducted by EPA/OAR over the past year. OAQPS'OAR's evaluation program was intended to develop procedures for improved data and model management, and to support more rigorous and consistent data and model selection for major upcoming OAR analyses (including the upcoming section 812 study). A major goal of this effort is to provide for more transparent analyses at appropriate levels of technical and scientific rigor to support regulatory and policy activities in a timely fashion, with adequate consistency and coherence among them, thereby facilitating more meaningful intercomparisons among analyses. EPA achieved significant successes in this regard in 2002-03, for instance, in the selection of consistent and current methodologies, emissions, and air quality data bases used in multiple regulatory assessments for the proposed nonroad engines rule, implementation programs for $PM_{2.5}$ and ozone, as well as analyses of the air quality impacts and economic benefits of the Clear Skies Act.new policy In the coming year, EPA intends to further improve upon this process, exploring further upgrades in several of the modeling tools, such as IPM and Mobile 6, moving to a 1999 National Emissions Inventory that incorporates emissions from Canada and Mexico, updating the temporal, spatial, and speciation data for emissions modeling, and evaluating the most recent revisions to air quality models to determine the most appropriate model for regulatory application during this period. To promote greater understanding of how changes in methods could affect the outcomes of analyses already underway, this effort is expected also to include analyses of the impacts of all such refinements relative to the current set of methods and data bases. This approach is consistent with standard practice in the software industry where specific versions of a program are evaluated, issued, and supported for applications even as development efforts continue for future upgrades and new releases. The second prospective analysis will benefit from this approach by using an air quality model set approved for use during the prevailing period. This approach will also aid in ensuring that the air quality models used in the 812 analysis will have undergone rigorous data and model evaluation, while at the same time eliminating pressure to wait for and apply expected data and model updates which, while intended to address known data or model deficiencies, are not yet fully developed, evaluated, or validated.

Procedure for Evaluating and Selecting Preferred Models

In comparing and evaluating available air quality models for selection and application, EPA has relied on the following criteria and considerations:

1. Scientific Credibility

(a) Identification of major components and review of their documented scientific bases
(b) Evaluations of model performance
(c) Evaluation of the extent of prior applications and sensitivity tests to stress the model
(d) Peer review status

2. Suitability for Intended Applications

(a) Physical and chemical processes and output species
(b) Model run time

3. Additional Considerations

(a) Response to emissions changes
(b) Organizational issues such as ease of use
(c) Extent of user base

Additionally, EPA evaluates the advantages and disadvantages of each model considering scientific uncertainties and limitations which are important to the intended applications concerning our current understanding of the physical and chemical processes involved, model formulation, emissions, and measurements. From this evaluation, EPA determines whether there is consensus as to which model best reflects the combination of appropriately sound science, consistent acceptable performance (including responses to changes in emissions of component species), and adequate computational speed relative to the intended applications.

Model Performance Procedures

To assess model performance, EPA conducts modeling for an appropriate base year for which validated air quality measurements have been obtained, including individual pollutant species where appropriate. Statistical evaluations of modeled and observed concentration pairs are performed. To ensure the robustness of any evaluation, EPA typically seeks to use base years having a substantial quantity of quality-assured data.

Described below are the definitions of statistics used for the evaluation. These are formatted such that negative values indicate model predictions less than their observed counterparts, while positive statistics indicate model overestimation of observed concentrations. The statistics are calculated for the entire modeling domain, and may be calculated for specific subregions or quadrants and local areas.

Particulate Matter Issues

Mean Observation: The mean observed value (in ug/m3) averaged over all monitored days in the year and then averaged over all sites in the region.

$$OBS = \frac{1}{N} \sum_{i=1}^{N} Obs_{x,t}^{i}$$

Mean Model Prediction: The mean predicted value (in ug/m3) paired in time and space with the observations and then averaged over all sites in the region.

$$PRED = \frac{1}{N} \sum_{i=1}^{N} Pred_{x,t}^{i}$$

Ratio of the Means: Ratio of the predicted over the observed values. A ratio of greater than 1 indicates on overprediction and a ratio of less than 1 indicates an underprediction.

$$RATIO = \frac{1}{N}\sum_{i=1}^{N}\frac{Pred_{x,t}^{i}}{Obs_{x,t}^{i}}$$

Mean Bias (ug/m3): This performance statistic averages the difference (model - observed) over all pairs in which the observed values were greater than zero. A mean bias of zero indicates that the model over predictions and model under predictions exactly cancel each other out. Note that the model bias is defined such that it is a positive quantity when model prediction exceeds the observation, and vice versa. This model performance estimate is used to make statements about the absolute or unnormalized bias in the model simulation

$$BIAS = \frac{1}{N}\sum_{i=1}^{N}(Pred_{x,t}^{i} - Obs_{x,t}^{i})$$

Mean Fractional Bias (percent): Normalized bias can become very large when a minimum threshold is not used. Therefore fractional bias is used as a substitute. The fractional bias for cases with factors of 2 under- and over-prediction are -67 and + 67 percent, respectively (as opposed to -50 and +100 percent, when using normalized bias, which is not presented here). Fractional bias is a useful model performance indicator because it has the advantage of equally weighting positive and negative bias estimates. The single largest disadvantage in this estimate of model performance is that the estimated concentration (i.e., prediction, Pred) is found in both the numerator and denominator.

$$FBIAS = \frac{2}{N}\sum_{i=1}^{N}\frac{(Pred_{x,t}^{i} - Obs_{x,t}^{i})}{(Pred_{x,t}^{i} + Obs_{x,t}^{i})} \times 100$$

Mean Error (ug/m3): This performance statistic averages the absolute value of the difference (model - observed) over all pairs in which the observed values were greater than zero. It is similar to mean bias except that the absolute value of the difference is used so that the error is always positive.

$$ERR = \frac{1}{N}\sum_{i=1}^{N}\left|Pred_{x,t}^{i} - Obs_{x,t}^{i}\right|$$

Mean Fractional Error: Normalized error can become very large when a minimum threshold is not used. Therefore fractional error is used as a substitute. It is similar to the fractional bias except the absolute value of the difference is used so that the error is always positive.

$$FERROR = \frac{2}{N} \sum_{i=1}^{N} \frac{\left|Pred_{x,t}^{i} - Obs_{x,t}^{i}\right|}{Pred_{x,t}^{i} + Obs_{x,t}^{i}} \times 100$$

Ozone Issues

Domainwide unpaired peak prediction accuracy: This metric simply compares the peak concentration modeled anywhere in the selected area against the peak ambient concentration anywhere in the same area. The difference of the peaks (model - observed) is then normalized by the peak observed concentration.

Peak prediction accuracy: This metric averages the paired peak prediction accuracy calculated for each monitor in the subregion. It characterizes the ability of the model to replicate peak (afternoon) ozone over a subregion. The daily peak model versus daily peak observed residuals are paired in space but not by hour.

Mean normalized bias: This performance statistic averages the normalized (by observation) difference (model - observed) over all pairs in which the observed values were greater than 60 ppb. A value of zero would indicate that the model over predictions and model under predictions exactly cancel each other out.

Mean normalized gross error: The last metric used to assess the performance is similar to the above statistic, except in this case it is the absolute value of the residual which is normalized by the observation, and then averaged over all sites. A zero gross error value would indicate that all model concentrations (in which their observed counterpart was greater than 60 ppb) exactly matched the ambient values.

Air Quality Modeling for the Second 812 Prospective Analysis

Overall, EPA's approach for estimating air quality for the upcoming analysis is similar to the approach in the first prospective. A key objective in the second prospective is to streamline the air quality modeling approach, reducing the number of models employed, which will minimize the overall uncertainty in the results and facilitate disaggregation of results by reducing the resources necessary to conduct multiple model runs. An updated and streamlined approach to estimating PM concentrations will also help address the issues discussed in the previous sections.

EPA plans to employ well-established, peer-reviewed models to generate predicted concentrations for each of the pollutant categories analyzed in the first prospective analysis. Consistent with both the OAR/OAQPS model evaluation program and the 812-specific model selection process, a number of modeling frameworks were considered for the second prospective analysis, but in the end the latest version of REMSAD (Version 7) was chosen to model all criteria pollutant categories except ozone. To address SAB concerns about ozone modeling as well as the acknowledged limitations of REMSAD, EPA will make use of the Comprehensive Air Quality Model with Extensions (CAMx) to model ozone.[1] These outcomes are consistent with the current lockdown model set for PM and ozone modeling applications. EPA's selection of these models was based on a careful analysis of the strengths and limitations of a number of air quality models. First and foremost, EPA needed a model that would show skill in predicting air quality on a national scale. REMSAD was designed to serve as a tool for such nationwide air quality assessments, and it has therefore been successfully used and tested on the national scale for a number of applications (see Appendix B for more information on REMSAD model performance and evaluation). The model accounts for spatial and temporal variations as well as differences in the reactivity of emissions. Competing models such as the Community Multiscale Air Quality (CMAQ) modeling system (the primary component of the Models-3 integrated modeling system) predict the combined effect of all major pollutant source categories. Currently, EPA is completing a significant reexamination and upgrade to CMAQ for deposition and nitrate gas phase and hetergeneous chemistry. A similar effort has stared for organic aerosols. Over the next 6 to 9 months EPA will be testing and evaluating this new version of CMAQ. In the interim, we intend to rely on REMSAD and CAMx for the second prospective analysis.

In addition to having an advantageous modeling domain, REMSAD has been thoroughly peer-reviewed by EPA. This peer review resulted in four major performance improvements in the latest version of the model, as outlined in the EPA's Draft Regulatory Impact Analysis: Control of Emissions from Nonroad Diesel Engines (U.S. EPA, 2003). First, there were significant updates in the "micro-CB4" gas phase chemistry mechanism including new treatment for NO3 and N2O5 species and the addition of several revisions to better account for the wide ranges in temperature, pressure, and concentrations that are encountered for regional and national applications. Second, the PM chemistry was updated to include calculations of particulate nitrate concentrations through the use of the MARS-A equilibrium algorithm and internal calculation of secondary organic aerosols from both biogenic and anthropogenic VOC emissions. Third, the aqueous phase chemistry has been updated to incorporate the oxidation of SO2 and to include the cloud and rain liquid water content from MM5 meteorological data directly in sulfate production and deposition calculations. Additional information comparing CMAQ, REMSAD, and other competing models can be found in Appendix B.

[1]The latest REMSAD user's guide suggests that "simplified ozone chemistry [in REMSAD] may not adequately represent ozone concentrations... [or] the interactions of ozone with other pollutant species (e.g., PM)."

When conducting comparisons of the models, the SAB has suggested comparing the air quality modeling results of the second prospective analysis to corresponding monitor data and emissions inventories. EPA maintains that, while appropriate in some cases, this approach raises difficulties in disentangling whether variation arises from air quality modeling issues or from the emissions inventory calculation approach itself.

We discuss below aspects of EPA's planned approach to air quality modeling specific to each of the pollutant categories. In addition to the discussion below, Appendix B provides a collection of relevant evaluations of the selected models along with recent examples of their performance.

PM. For the current prospective analysis, EPA plans to use a single model, REMSAD Version 7, to simulate base-year and future-year concentrations of PM under Pre- and Post-CAAA emissions scenarios nationwide. REMSAD was used to estimate PM for EPA's HD Engine Diesel Fuel Rule. Details on that version can be found in the Technical Support Document for that analysis (U.S. EPA, 2000b).

Previous versions have been used in the first prospective analysis and for EPA's analysis of the Acid Deposition and Ozone Control Act (Senate Bill 172). REMSAD Version 7 includes improvements that address comments EPA obtained during the 1999 peer review of REMSAD Version 4.1 (Seigneur et al., 1999), including the incorporation of a secondary organic aerosol module. In addition to the overall updates outlined earlier, the latest version includes a revision to the gas phase chemistry module that avoids overestimation of NOx during stagnant meteorological conditions.

The REMSAD modeling domain consists of 36 km x 36 km grid cells covering the 48-contiguous United States, and REMSAD can perform a full-year simulation, generating predictions of hourly PM concentrations (including both $PM_{2.5}$ and PM_{10}) at each grid cell. These hourly predictions will form the basis for the monitor adjustment factors.

This approach should address several of the issues associated with the previous PM analysis. First, the use of REMSAD (instead of RADM) generates $PM_{2.5}$ estimates nationwide based not only on sulfate and nitrate predictions, but on primary fine particles and organic (and other) secondary particles as well. The availability of monitoring data for fine PM has improved since the first prospective with the 1999 addition of over 1,000 Federal Reference Method $PM_{2.5}$ sites, and the use of year 2000 monitor data for fine particles will help reduce $PM_{2.5}$ measurement uncertainty in the Post-CAAA scenario. Finally, the use of a single model reduces uncertainty and should facilitate efforts to disaggregate results.

An alternative to the use of year 2000 fine PM monitor data is the direct use of PM model predictions as inputs to the health effect models, an approach employed in EPA's Heavy Duty Diesel RIA (U.S. EPA, 2000a). While EPA would prefer to use actual monitor data where possible, this approach has certain advantages. It eliminates the need to cross-estimate $PM_{2.5}$ monitoring data under both the Pre- and Post-CAAA scenarios and eliminates potential uncertainties associated with VNA extrapolation methods in unmonitored or sparsely monitored areas. However, such an approach would introduce uncertainty in the form of model measurement error, which is minimized when the results are used in a relative sense (i.e., adjustment factors). With this in mind, we plan to apply the same monitor adjustment with VNA approach used in the first prospective study.

Ozone. EPA plans to use CAMx Version 3 to estimate ozone concentrations, contingent on the results of a comparative model performance evaluation of the model. Because it accounts for spatial and temporal variations as well as differences in the reactivity of emissions, CAMx is especially useful for assessing the impacts of changes in ozone concentrations in the context of the second prospective analysis. Another reason for selecting CAMx over REMSAD for ozone modeling is that it has a stronger algorithm for source apportionment (or the process of relating source emissions to their quantitative impact on ambient air pollution). In addition, CAMx has stronger diagnostic features than REMSAD or other models. Based on the methodology employed in the EPA's Non-Road Heavy Duty Engine Diesel Fuel Rule (U.S. EPA, 2003), EPA plans to apply CAMx separately to the Eastern and Western U.S. These efforts will then be integrated into one set of results for the nationwide assessment of ozone air quality. Although the model tends to underestimate observed ozone (especially over the western U.S.), it exhibits less bias and error than any past regional ozone modeling application conducted by EPA. Documentation of one nationwide application of the CAMx model, including model performance statistics, can be found in EPA's Non-Road Heavy Duty Engine Diesel Fuel Rule (refer to Appendix B).

SONOCO. EPA will follow the same approach to estimating concentrations of these pollutants in this analysis as in the previous prospective analysis (i.e., the linear "roll-up" model approach). EPA will estimate future-year pre- and post-CAAA ambient concentrations of SO_2, NO, NO_2, and CO by adjusting 1990 monitor concentrations of these pollutants using future year to base-year emissions ratios, and then scale up these concentrations in REMSAD grid-cells. Although this technique does not take into account pollutant transport or atmospheric chemistry, we believe linear scaling generates reasonable approximations of changes in ambient concentrations of gaseous pollutants such as SO_2, NO, NO_2, and CO.

Acid Deposition. For the second prospective, EPA intends to use REMSAD Version 7 to model deposition of sulfur and nitrogen in the Eastern U.S. (where acidification effects are most significant).

Visibility. As in the first prospective, EPA will use the REMSAD atmospheric visibility post-processing module to generate estimates of changes in visibility in the west. In addition, REMSAD will now be used instead of RADM-RPM to estimate visibility changes in the east.

Mercury. EPA is considering modeling mercury transport and deposition as part of the second prospective analysis using REMSAD Version 7. REMSAD is currently being used by EPA to evaluate mercury deposition as part of its mercury Total Maximum Daily Load (TMDL) pilot study in Devil's Lake, Wisconsin. Results from this analysis should provide data to evaluate the potential use of REMSAD mercury outputs in the second prospective. More detail on the specific deposition and air quality algorithms applied by REMSAD for mercury can be found in the user's guide (Sections 2.4 and 2.7).

Biogenic Emissions. Among the improvements in REMSAD Version 7 is a more comprehensive treatment of biogenic emissions. This includes provisions for secondary organic aerosols, monoterpenes, and isoprene. The Council also suggested that EPA consider using the latest version of the Biogenic Emissions Inventory System (BEIS) for the estimation of biogenic emissions inputs to the air quality models. Given this recommendation and the fact that "understanding [the] contribution of natural sources to ozone formation has significant implications toward the choice and extent of controls needed on anthropogenic sources," EPA plans to use BEIS-3 for the treatment of CB-4 species. Whereas BEIS-2 accounted for just five CB-4 species, BEIS 3 expands to 12. In addition, the new version increases the resolution of the vegetation database to 1-km and includes 230 different land use types. Version 3.10 of BEIS normalizes emission factors for 34 chemicals, includes a new soil nitric oxide emissions algorithm that accounts for soil moisture, crop canopy coverage, and fertilizer application, and provides speciation factors for the CB-4, RADM2 , and SAPRC99 chemical mechanisms. More specifics regarding the improvements of BEIS-3 over BEIS-2 can be found in the BEIS documentation in Appendix B. Although these improvements are significant, it is important to note that large uncertainties remain overall with respect to estimating biogenic emissions.

Using this pollutant specific approach, each model will be run to generate results for the 1990 baseline year and for the target years 2000, 2010, and 2020 for each of the emissions control scenarios. These scenarios are expected to include the baseline Pre-CAAA scenario, a main Post-CAAA scenario, a set of emissions control scenarios in which certain sectors of emissions (e.g. mobile source, point sources) are "turned off", and a number of expected supplemental scenarios. A detailed description of the scenarios to be modeled is provided in Chapter 2.

As before, EPA plans to use model results from the Pre- and Post-CAAA scenarios to develop adjustment factors that are then applied to monitor data to forecast future concentrations. The adjusted monitor data are then spatially extrapolated using the VNA techniques employed in the first prospective analysis. A key update to this approach will be the use of year 2000 monitor data for criteria pollutants (including $PM_{2.5}$) as the basis for adjustment under the Post-CAAA scenario. That is, for the Pre-CAAA scenario we will adjust 1990 monitor data (as in the first prospective) to construct concentration estimates in the absence of the CAAA, but for the post-CAAA scenario we will use actual monitor data for both 1990 and 2000 and will apply adjustment factors to the year 2000 data to forecast the rest of the Post-CAAA scenario.

CHAPTER 6 - HUMAN HEALTH EFFECTS ESTIMATION

Reductions in criteria air pollutant emissions are likely to lead to substantial health benefits (measured as the value of avoided adverse health effects), as evidenced by the associations in the scientific literature between air pollution and increased incidence of illness and mortality. As part of the evaluation of the effects of CAAA controls on criteria air pollutant emissions, we will identify and, where possible, develop quantitative, monetized estimates of these health benefits. This chapter describes the first step in this process, the estimation of changes in the incidence of adverse health effects.

We propose to use an approach similar in most important respects to that used in the first prospective study. However, the analysis for the second prospective study will include some important updates and revisions. Many of these updated and revised methods have been employed in recent EPA regulatory analyses, such as the Non-Road Diesel Vehicle benefits analysis (Abt Associates, 2003). Consistent with methods used in both the first prospective 812 analysis and the recent rulemaking analyses, the analysis involves taking the estimates of changes in ambient pollutant concentrations predicted by air quality modeling for each CAAA control scenario (relative to the baseline scenario) and converting them into estimates of changes in the incidence of adverse health effects using concentration-response (C-R) functions. The key differences between the approaches to human health effect estimation in the first and second prospective analyses are 1) the benefits analysis model has been updated, 2) many of the C-R functions used to estimate health effects have been changed or modified, 3) better accounting for sensitive subpopulations, and 4) updates to the sensitivity analyses. Perhaps the most significant change is the update to the C-R function relating changes in ambient $PM_{2.5}$ concentrations with premature mortality. While the first prospective analysis used a C-R function for mortality derived from Pope et al., 1995, the second prospective analysis will use a C-R function for mortality based on the results of the recent Health Effects Institute (HEI) re-analysis of PM epidemiological studies (including Pope et al.,1995).

This chapter consists of two parts. The first part summarizes the analytical framework used to estimate health benefits in the first prospective analysis. The second part presents the key changes to this approach that we propose for health benefits estimation in the second prospective analysis.

Approach to Human Health Effects Estimation Used in First Prospective

For the first prospective study, we estimated the impact of the 1990 CAAA on human health by analyzing the difference in the expected incidence of adverse health effects between the Pre-CAAA and Post-CAAA regulatory scenarios. For each regulatory scenario, we used the Criteria Air Pollutant Modeling System (CAPMS) to estimate the incidence of health effects for 2000 and 2010. The CAPMS model requires three types of inputs: (1) estimates of the changes in air quality for the Pre- and Post-CAAA scenarios in 2000 and 2010; (2) estimates of the number of people living at a given location; and (3) concentration-response (C-R) functions that link changes in air pollutant concentrations with changes in adverse health effects. We discuss each of these inputs in greater detail below.

Air Quality. The development of criteria pollutant concentration estimates for use in the CAPMS model consisted of two steps. First, air quality modeling and 1990 base-year monitoring data were used to project ambient pollution levels at monitors (or, for PM, counties) throughout the 48 contiguous states in the years 2000 and 2010. Second, because significant percentages of the U.S. population do not live within 50 km of a monitor (or monitored county), concentration data at monitors was extrapolated to non-monitored areas in order to generate a more comprehensive air quality data set covering the 48 contiguous states and the District of Columbia. Details on air quality modeling and extrapolation can be found in Chapter 5.

Population. Because the expected changes in pollutant concentrations vary from location to location, individuals in different parts of the country may not experience the same level of health benefits. Thus, we apportioned benefits among individuals by matching the change in air pollutant concentration in each CAPMS grid cell with the size of the population that experiences that change. We derived CAPMS grid-cell-specific population counts for 1990 from U.S. Census Bureau census tract level population data. Grid cell population estimates for future years were extrapolated from 1990 levels using the ratio of future-year and 1990 state-level population estimates provided by the U.S. Bureau of Economic Analysis.

C-R Functions. C-R functions are equations that relate the change in the number of individuals in a population exhibiting a "response" (in this case an adverse health effect such as respiratory disease) to a change in pollutant concentration experienced by that population. The C-R functions we used estimate changes in the incidence of an adverse health effect using the following inputs: (1) the grid-cell-specific change in pollutant concentration estimated from the monitor adjustment results; (2) the grid-cell-specific population; (3) an estimate of the change in the number of individuals that suffer an adverse health effect per unit change in air quality (derived from the C-R functions in the scientific literature); and (4) an estimate of the baseline incidence of the adverse health effect. The resulting grid-cell specific estimates of annual incidence change were then summed to yield an estimate of the change in incidence nationwide.

An epidemiological study typically focuses on a particular age cohort (e.g., adults age 30 and older), and we cannot be sure that the C-R relationship found in a particular study can be generalized across broader age categories. Therefore, to avoid the possibility of overestimating the benefits of reduced pollution levels, we applied C-R relationships only to those age groups corresponding to the cohorts studied. In fact, the age cohort studied may be more a function of data availability than of the age-specific nature of the disease. We recognize that limiting the application of a C-R function to the age cohort matching the one used in the study may have resulted in an underestimation of the benefits of reductions in pollutant exposures because it implicitly assumes zero impact on those ages that were not included in the study.

For C-R functions that required baseline incidence data associated with ambient levels of pollutants, we used, in order of preference: 1) county-level data; 2) national-level data; and 3) the baseline incidence from the study from which the C-R function was derived (i.e., the baseline incidence in the study population was assumed to represent the baseline incidence nationally). Our primary source of 1990 county-specific and national- level baseline incidence rates was Vital Statistics of the United States 1990, from the Centers for Disease Control National Center for Health Statistics (1994). National-level baseline hospitalization admission rates were based on the Centers for Disease Control National Hospital Discharge Survey (Graves and Gillum, 1997).

Using these inputs, CAPMS predicted changes in health effects associated with incremental changes in ambient pollutant concentrations between the Pre- and Post-CAAA scenarios for the population residing within each of the 8 km by 8 km CAPMS grid cells that cover the 48 contiguous states. The annual incidence changes for a given scenario and target year were then summed across all grid cells to generate national health benefits.

Changes to the Human Health Effects Estimation Method for the Second Prospective

We propose to use the same overall framework used in the first prospective analysis to estimate human health effects in the second prospective analysis. The framework includes the following steps:

- Combine the results of sophisticated photochemical air quality models with air quality monitoring data, to estimate baseline and post-control ambient air pollution concentrations.

- Calculate the change between baseline and post-control estimates, and then combined this change with population forecasts, to give the change in population-level exposures due to the proposed policy.

- Use the changes in potential population exposure as an input to concentration-response functions, which allow us to estimate the associated change in the incidence of health effects for each individual concentration-response (C-R) function.

- Where multiple C-R functions are available for an endpoint, pool the estimated change in incidence using fixed or random effects pooling methods.

Though the overall framework will remain consistent with the first prospective study, there are many updates and changes at each step of the health effects estimation procedure for the second prospective study. This section describes those changes in four broad categories: updates to the air benefits model, updates to the primary health effect estimates, accounting for sensitive subpopulations, and updates to the sensitivity analyses.

Updates to the Air Benefits Model

For the first prospective study, we estimated potential population exposure using the Criteria Air Pollutant Modeling System (CAPMS), a population-based geographic information system for modeling changes in potential population exposure and estimating the associated health and welfare benefits. To forecast potential population-level exposure to ambient air pollutants for the second prospective analysis, we will use BenMAP, the Environmental Benefits Mapping and Analysis Program. BenMAP, a next generation version of CAPMS, uses both air quality modeling and monitoring data files, as well as demographic data from the Census and population projections, to estimate potential population exposures to air pollutants. BenMAP aggregates population to air quality model grids and calculates changes in air pollution metrics (e.g., daily averages) for input into C-R functions. BenMAP uses grid cell level population data and changes in pollutant concentrations to estimate changes in health outcomes for each grid cell.

Unlike the first prospective analysis, health benefits for the second prospective analysis will be based on health effect incidence changes due to predicted air quality changes in 2020, as well as predicted air quality changes in 2000 and 2010. Integral to the estimation of such benefits are future population projections. The underlying data BenMAP uses to create county-level population projections are based on county level allocations of national population projections from the U.S. Census Bureau (Hollman, Mulder and Kallan, 2000). County-level allocations of populations by age, race, and sex are based on economic forecasting models developed by Woods and Poole, Inc., which account for patterns of economic growth and migration. Growth factors are calculated using the Woods and Poole data and are applied to 2000 U.S. Census data. Details about the population growth factors used to adjust 2000 U.S. Census data are provided in Appendix C.

Exhibit 6-1. Human Health Effects of Pollutants Evaluated in the Second Prospective Study

Pollutant/Effect	Quantified and Monetized in Primary Estimate [a]	Quantified and/or Monetized Effects in Alternative or Sensitivity Analyses [b]	Unquantified Effects
Ozone/Health	Hospital admissions - respiratory Emergency room visits for asthma Minor restricted activity days School loss days	Chronic Asthma [b] Asthma attacks Cardiovascular emergency room visits Premature mortality – acute exposures [b] Acute respiratory symptoms	Increased airway responsiveness to stimuli Inflammation in the lung Chronic respiratory damage Premature aging of the lungs Acute inflammation and respiratory cell damage Increased susceptibility to respiratory infection Non-asthma respiratory emergency room visits
PM/Health	Premature mortality Bronchitis - chronic and acute Hospital admissions - respiratory and cardiovascular Emergency room visits for asthma Non-fatal heart attacks Lower and upper respiratory illness Minor restricted activity days Work loss days	Premature mortality – short term exposures Asthma attacks (asthmatic population) Respiratory symptoms (asthmatic population) Infant mortality	Low birth weight Changes in pulmonary function Chronic respiratory diseases other than chronic bronchitis Morphological changes Altered host defense mechanisms Cancer Non-asthma respiratory emergency room visits
Carbon Monoxide/Health	Hospital Admissions - All Respiratory and All Cardiovascular	Non-asthma respiratory emergency room visits	Behavioral effects Other hospital admissions Other cardiovascular effects Developmental effects Decreased time to onset of angina Premature mortality Ancillary reductions in accidental deaths due to acute CO poisoning

Pollutant/Effect	Quantified and Monetized in Primary Estimate [a]	Quantified and/or Monetized Effects in Alternative or Sensitivity Analyses [b]	Unquantified Effects
Nitrogen Oxides/Health	Respiratory illness Hospital Admissions - All Respiratory and All Cardiovascular	Non-asthma respiratory emergency room visits	Increased airway responsiveness to stimuli Chronic respiratory damage / Premature aging of the lungs Inflammation of the lung Increased susceptibility to respiratory infection Acute inflammation and respiratory cell damage Premature Mortality
Sulfur Dioxide/Health	Hospital Admissions - All Respiratory and All Cardiovascular In exercising asthmatics: Chest tightness, Shortness of breath, or Wheezing	Non-asthma respiratory emergency room visits	Changes in pulmonary function Respiratory symptoms in non-asthmatics

[a] Primary quantified and monetized effects are those included when determining the primary estimate of total monetized benefits.

[b] Alternative quantified and/or monetized effects are those presented as alternatives to the primary estimates or in addition to the primary estimates, but not included in the primary estimate of total monetized benefits. Note that while no causal mechanism has been identified linking new incidences of chronic asthma to ozone exposure, two epidemiological studies shows a statistical association between long-term exposure to ozone and incidences of chronic asthma in exercising children and some non-smoking men (McDonnell et al., 1999; McConnell et al., 2002). Premature mortality associated with ozone is not currently separately included in the primary analysis; as noted in the text, we seek SAB comment on its potential inclusion. It is assumed that the American Cancer Society (ACS)/ Krewski, et al. (2000) C-R function captures both PM mortality benefits and any mortality benefits due to other air pollutants.

Concentration-Response Functions

Fundamental to the estimation of health benefits is our utilization of the epidemiology literature. We rely upon C-R functions derived from published epidemiological studies that relate health effects to ambient concentrations of PM and ozone, as well as sulfur dioxide (SO_2), nitrogen oxides (NOx) and carbon monoxide (CO). The specific studies from which C-R functions are drawn are presented in Appendix D. Note that we have no proposed changes to the SO_2, NOx and CO health effect endpoints in the second prospective study at the moment. We plan to continue to review the emerging epidemiological literature throughout the course of the 812 analysis, however, to evaluate whether C-R functions should be added or adjusted. (The final set of C-R functions will be submitted for review by the SAB prior to finalization of the 812 report.) For the rest of Chapter 6, we frame all of our discussion regarding health effects estimation for the second prospective study in terms of PM- and Ozone-related endpoints.

While a broad range of serious health effects have been associated with exposure to elevated PM and ozone levels, we include only a subset of health effects in this benefit analysis due to limitations in available C-R functions and concerns about double-counting of overlapping effects (U.S. EPA, 1996). Since the first prospective study, we have added and/or changed a number of health effect endpoints. These include:

- Premature mortality from particulate matter in adults 30 and over, PM (Krewski et al., 2000);
- Hospital admissions for all cardiovascular causes in adults 20-64, PM (Moolgavkar et al., 2000);
- ER visits for asthma in children 0-18, PM (Norris et al., 1999);
- Non-fatal heart attacks, adults over 30, PM (Peters et al., 2001);
- School loss days, Ozone (Gilliland et al., 2001; Chen et al., 2000);
- Hospital admissions for all respiratory causes in children under 2, Ozone (Burnett et al., 2001); and,
- We have changed the sources for concentration-response functions for hospital admission for pneumonia, COPD, and total cardiovascular from Samet et al., 2000 (a PM10 study), to Lippmann et al., 2000 and Moolgavkar, 2000 (PM2.5 studies).

Exhibit 6-2 displays each of the endpoints and studies we will use to estimate the health effects for the second prospective study.

Exhibit 6-2
Primary Endpoints and Studies Used to Calculate Total Monetized Primary Health Benefits

Endpoint	Pollutant	Applied Population	Source of Effect Estimate(s)	Source of Baseline Incidence
Premature Mortality	$PM_{2.5}$	>29 years	Krewski, et al. (2000)	CDC Wonder (1996-1998)
Chronic Illness				
Chronic Bronchitis	$PM_{2.5}$	> 26 years	Abbey, et al. (1995)	1999 HIS (American Lung Association, 2002b, Table 4); Abbey et al. (1993, Table 3)
Non-fatal Heart Attacks	$PM_{2.5}$	Adults	Peters et al. (2001)	1999 NHDS public use data files; adjusted by 0.93 for prob. of surviving after 28 days (Rosamond et al., 1999)
Hospital Admissions				
Respiratory	O_3	> 64 years	Pooled estimate: Schwartz (1995) - ICD 460-519 (all resp) Schwartz (1994a, 1994b) - ICD 480-486 (pneumonia) Moolgavkar et al. (1997) - ICD 480-487 (pneumonia) Schwartz (1994b) - ICD 491-492, 494-496 (COPD) Moolgavkar et al (1997) - ICD 490-496 (COPD)	1999 NHDS public use data files
	O_3	< 2 years	Burnett et al. (2001)	1999 NHDS public use data files
	$PM_{2.5}$	>64 years	Pooled estimate: Moolgavkar (2000) - ICD 490-496 (COPD) Lippman et al. (2000) - ICD 490-496 (COPD)	1999 NHDS public use data files
	$PM_{2.5}$	20-64 years	Moolgavkar (2000) - ICD 490-496 (COPD)	1999 NHDS public use data files
	$PM_{2.5}$	> 64 years	Lippman et al. (2000) - ICD 480-486 (pneumonia)	1999 NHDS public use data files
	$PM_{2.5}$	< 65 years	Sheppard, et al. (1999) - ICD 493 (asthma)	1999 NHDS public use data files

Exhibit 6-2
Primary Endpoints and Studies Used to Calculate Total Monetized Primary Health Benefits

Endpoint	Pollutant	Applied Population	Source of Effect Estimate(s)	Source of Baseline Incidence
Cardiovascular	$PM_{2.5}$	> 64 years	Pooled estimate: Moolgavkar (2000) - ICD 390-429 (all cardiovascular) Lippman et al. (2000) - ICD 410-414, 427-428 (ischemic heart disease, dysrhythmia, heart failure)	1999 NHDS public use data files
	$PM_{2.5}$	20-64 years	Moolgavkar (2000) - ICD 390-429 (all cardiovascular)	1999 NHDS public use data files
Asthma-Related ER Visits	O_3	All ages	Pooled estimate: Weisel et al. (1995), Cody et al. (1992), Stieb et al. (1996)	2000 NHAMCS public use data files; 1999 NHDS public use data files
	$PM_{2.5}$	0-18 years	Norris et al. (1999)	2000 NHAMCS public use data files; 1999 NHDS public use data files
Other Health Endpoints				
Acute Bronchitis	$PM_{2.5}$	8-12 years	Dockery et al. (1996)	American Lung Association (2002a, Table 11)
Upper Respiratory Symptoms	PM_{10}	Asthmatics, 9-11 years	Pope et al. (1991)	Pope et al. (1991, Table 2)
Lower Respiratory Symptoms	$PM_{2.5}$	7-14 years	Schwartz and Neas (2000)	Schwartz (1994, Table 2)
Work Loss Days	$PM_{2.5}$	18-65 years	Ostro (1987)	1996 HIS (Adams et al., 1999, Table 41); U.S. Bureau of the Census (2000)
School Absence Days	O_3	9-10 years 6-11 years	Pooled estimate: Gilliland et al (2001) Chen et al (2000)	National Center for Education Statistics (1996)
Worker Productivity	O_3	Outdoor workers, 18-65	Crocker and Horst (1981) and U.S. EPA (1984)	NA
Minor Restricted Activity Days	$PM_{2.5}$, O_3	18-65 years	Ostro and Rothschild (1989)	Ostro and Rothschild (1989, p. 243)

In this assessment we have made analytical judgements affecting both the selection of C-R functions and the application of those functions in estimating impacts on health outcomes. In general, we have selected C-R functions that 1) most closely match the pollutants of interest, 2) cover the broadest potentially exposed population, 3) have appropriate model specification, such as controlling for confounding pollutants, 4) have been peer-reviewed, and 5) are biologically plausible. Other factors may also affect our selection of C-R functions for specific endpoints, such as premature mortality.

While there is a consistent body of evidence supporting a relationship between a number of adverse health effects and PM and ozone exposure, there is often only a single study of a specific endpoint covering a specific age group. There may be multiple estimates examining subgroups (i.e. asthmatic children). However, for the purposes of assessing national population level benefits, we chose the most broadly applicable C-R function to more completely capture health benefits in the general population.

In May 2002, the Health Effects Institute (HEI) reported findings by health researchers at Johns Hopkins University and others that have raised concerns about aspects of the statistical methods used in a number of recent time-series studies of short-term exposures to air pollution and health effects (Greenbaum, 2002). Researchers working on the National Morbidity, Mortality, and Air Pollution Study (NMMAPS) found problems in the default "convergence criteria" used in Generalized Additive Models (GAM). These and other scientists reanalyzed the results of numerous series studies with alternative approaches that address these issues and have found a downward revision of some results. However, both the relative magnitude and the direction of bias introduced by the convergence issue is case-specific. In most cases, the concentration-response relationship may be overestimated; in other cases, it may be underestimated. Also, the preliminary reanalyses of the mortality and morbidity components of NMMAPS suggest that analyses reporting the lowest relative risks appear to be affected more greatly by this error than studies reporting higher relative risks (Domenici et al, 2002).

Among our morbidity endpoints, the endpoints potentially affected include hospital admissions and reduced respiratory symptoms. Note that the estimates derived from the long-term exposure studies, which account for a major share of the economic benefits described in Chapter 6, are not affected. Similarly, the time-series studies employing generalized linear models (GLMs) or other parametric methods, as well as case-crossover studies, are not affected.

The peer-reviewed report of the reanalyses will be available to the public by mid-May 2003. EPA will carefully consider the findings of this report and propose revisions to the analytical blueprint as appropriate. However, while we wait for further clarification from the scientific community, we anticipate that we will not use any time-series-based C-R functions derived using S-Plus GAM unless they have been re-analyzed using revised methods (e.g., GAM/S-Plus with improved convergence or GLM).

<u>Special Considerations for Mortality Concentration-Response</u>

Epidemiological analyses have consistently linked air pollution, especially PM, with excess mortality. Although a number of uncertainties remain to be addressed by continued research (NRC, 1998), a substantial body of published scientific literature documents the correlation between elevated PM concentrations and increased mortality rates. Community epidemiological studies that have used both short-term and long-term exposures and response have been used to estimate PM/ mortality relationships. Short-term studies use a time-series approach to relate short-term (often day-to-day) changes in PM concentrations and changes in daily mortality rates up to several days after a period of elevated PM concentrations. Long-term studies examine the potential relationship between community-level PM exposures over multiple years and community-level annual mortality rates. Researchers have found statistically significant associations between PM and premature mortality using both types of studies. In general, the risk estimates based on the long-term exposure studies are larger than those derived from short-term studies. Cohort analyses are better able to capture the full public health impact of exposure to air pollution over time (Kunzli, 2001; NRC, 2002). The second 812 prospective study will rely on cohort PM studies to estimate PM-related premature mortality benefits, conforming to the Kunzli, 2001 study.

Over a dozen studies have found significant associations between various measures of long-term exposure to PM and elevated rates of annual mortality, beginning with Lave and Seskin, 1977. Most of the published studies found positive (but not always statistically significant) associations with available PM indices such as total suspended particles (TSP). Particles of different fine particles components (i.e. sulfates), and fine particles, as well as exploration of alternative model specifications sometimes found inconsistencies (e.g. Lipfert, 1989). These early "cross-sectional" studies (e.g. Lave and Seskin, 1977; Ozkaynak and Thurston, 1987) were criticized for a number of methodological limitations, particularly for inadequate control at the individual level for variables that are potentially important in causing mortality, such as wealth, smoking, and diet. More recently, several long-term studies have been published that use improved approaches and appear to be consistent with the earlier body of literature. These new "prospective cohort" studies reflect a significant improvement over the earlier work because they include individual-level information with respect to health status and residence. The most extensive study and analyses has been based on data from two prospective cohort groups, often referred to as the Harvard "Six-City study" (Dockery et al., 1993) and the "American Cancer Society or ACS study" (Pope et al., 1995); these studies have found consistent relationships between fine particle indicators and premature mortality across multiple locations in the U.S. A third major data set comes from the California based 7th Day Adventist Study (e.g. Abbey et al, 1999), which reported associations between long-term PM exposure and mortality in men. Results from this cohort, however, have been inconsistent and the air quality results are not geographically representative of most of the US. More recently, a cohort of adult male veterans diagnosed with hypertension has been examined (Lipfert et al., 2000). The characteristics of this group differ from the cohorts in the ACS, Six-Cities, and 7th Day Adventist studies with respect to income, race, and smoking status. Unlike previous long-term analyses, this study found some associations between mortality and ozone but found inconsistent results for PM indicators.

Given their consistent results and broad geographic coverage, the Six-City and ACS data have been of particular importance in benefits analyses. The credibility of these two studies is further enhanced by the fact that they were subject to extensive reexamination and re-analysis by an independent team of scientific experts commissioned by the Health Effects Institute (Krewski et al., 2000). The final results of the re-analysis were then independently peer reviewed by a Special Panel of the HEI Health Review Committee. The results of these re-analyses confirmed and expanded those of the original investigators. This intensive independent re-analysis effort was occasioned both by the importance of the original findings as well as concerns that the underlying individual health effects information has never been made publicly available.

The HEI re-examination lends credibility to the original studies as well as highlighting sensitivities concerning (a) the relative impact of various pollutants, (b) the potential role of education in mediating the association between pollution and mortality, and (c) the influence of spatial correlation modeling. Further confirmation and extension of the overall findings using more recent air quality and a longer follow up period for the ACS cohort was recently published in the Journal of the American Medical Association (Pope et al., 2002).

In developing and improving the methods for estimating and valuing the potential reductions in mortality risk over the years, EPA has consulted with a panel of the Science Advisory Board. That panel recommended use of long-term prospective cohort studies in estimating mortality risk reduction (EPA-SAB-COUNCIL-ADV-99-005, 1999). This recommendation has been confirmed by a recent report from the National Research Council, which stated that "it is essential to use the cohort studies in benefits analysis to capture all important effects from air pollution exposure (NRC, 2002, p. 108)." More specifically, the SAB recommended emphasis on the ACS study because it includes a much larger sample size and longer exposure interval, and covers more locations (e.g. 50 cities compared to the Six Cities Study) than other studies of its kind. As explained in the regulatory impact analysis for the Heavy-Duty Engine/Diesel Fuel rule (U.S. EPA, 2000a), more recent EPA benefits analyses have relied on an improved specification of the ACS cohort data that was developed in the HEI reanalysis (Krewski et al., 2000). The particular specification yielded a relative risk based on changes in mean levels of $PM_{2.5}$, as opposed to the specification in the original study, which reported a relative risk based on median levels[1]. The Krewski et al. analysis also includes a broader geographic scope than the original study (63 cities versus 50). Specifically, the relative risk from which the Base estimate derived is 1.12 per 24.5 $\mu g/m^3$ for all-cause mortality (Krewski, et al. 2000, Part II, page 173, Table 31). The SAB has recently agreed with EPA's selection of this specification for use in analyzing mortality benefits of PM reductions (EPA-SAB-COUNCIL-ADV-01-004, 2001).

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[1]For policy analysis purposes, functions based on the mean air quality levels may be preferable to functions based on the median air quality levels because changes in the mean more accurately reflect changes in peak values than do changes in the median. Policies which affect peak PM days more than average PM days will result in a larger change in the mean than in the median. In these cases, all else being equal, C-R functions based on median $PM_{2.5}$ will lead to lower estimates of avoided incidences of premature mortality than C-R functions based on mean $PM_{2.5}$.

There are also several additional endpoints which the SAB recommended for evaluation and consideration during review of the first draft of this blueprint. Additional endpoints suggested for consideration which we plan to include in sensitivity analysis – but not in the primary quantitative benefit results – include (a) PM-related infant mortality and (b) ozone-related mortality.

The June 2001 draft analytical blueprint indicated EPA's intent to exclude PM-related post-neonatal infant mortality based on concerns expressed during a 1999 SAB review that the single available study (Woodruff et al.,1997) did not provide evidence adequate to support inclusion of this endpoint in the previous study.[2] However, in their September 2001 report reviewing the June 2001 draft blueprint for the current study (EPA-SAB-COUNCIL-ADV-004), the SAB cited new evidence reporting significant PM-related infant mortality including an eight-city study by Kaiser et al. (2001), Ha et al. (2001) in Seoul, and two others studies that relate PM_{10} to birthweight. Additional research is needed to explore these studies and how they might be incorporated into the second prospective study. We will provide the estimated effect of PM exposure on premature mortality in post neo-natal infants to show the specific impacts on an especially susceptible subpopulation. At this time, however, the estimates are not meant to be additive to the primary estimates of mortality.

We exclude ozone-related mortality from the primary analysis and include it as a sensitivity analysis because of concerns about double-counting the impact of PM and ozone on premature mortality. Additional research is needed to provide separate estimates of the effects for PM and ozone. To be conservative, we therefore include only the effect of PM on premature mortality in the primary analysis. We plan to explicitly address the uncertainty surrounding this endpoint, however, in our quantitative evaluations of uncertainty, as described in Chapter 9, and seek SAB input on the appropriate treatment for this endpoint.

Baseline Incidence

The baseline incidences for health outcomes we will use in the second prospective analysis are selected and adapted to match the specific populations studied. For example, we will use age- and county-specific baseline total mortality rates in the estimation of PM-related premature mortality. County-level incidence rates are not available for other endpoints. We will use national incidence rates whenever possible, because these data are most applicable to a national assessment of benefits. However, for some studies, the only available incidence information comes from the studies themselves; in these cases, incidence in the study population is assumed to represent typical incidence at the national level. Sources of baseline incidence rates are reported in Exhibit 6-2.

[2] "3.5.2 PM Neonatal Mortality. HEES recommends that PM-related infant mortality data not be included in the analysis, without further supporting peer-reviewed published reports. The Agency must have an adequate data base (i.e., at least two or more peer-reviewed published reports) in order to derive a C-R coefficient. The current information does not support the use of neonatal mortality. Thus, neonatal mortality should not be included in the Prospective Study." (EPA-SAB-COUNCIL-DV-99-005, page 12).

When possible, we have updated health effect incidence and prevalence data for the second prospective analysis. Updates to health effect incidence/prevalence data include:

- Updated county-level mortality rates (all-cause, non-accidental, cardiopulmonary, lung cancer, COPD) from 1994-1996 to 1996-1998 using the CDC Wonder database;
- Updated hospitalization rates from 1994 to 1999 and switched from national rates to regional rates using 1999 National Hospital Discharge Survey results;
- Developed regional emergency room visit rates using results of the 2000 National Hospital Ambulatory Medical Care Survey;
- Updated prevalence of asthma and chronic bronchitis to 1999 using results of the National Health Interview Survey (HIS), as reported by the American Lung Association (ALA), 2002;
- Developed non-fatal heart attack incidence rates based on National Hospital Discharge Survey results;
- Updated the national acute bronchitis incidence rate using HIS data as reported in ALA, 2002, Table 11;
- Updated the work loss days rate using the 1996 HIS data, as reported in Adams, et al. 1999, Table 41;
- Developed school absence rates using data from the National Center for Education Statistics and the 1996 HIS, as reported in Adams, et al., 1999, Table 46.
- Developed baseline incidence rates for respiratory symptoms in asthmatics, based on epidemiological studies (Ostro et al. 2001; Vedal et al. 1998; Yu et al; 2000; McConnell et al., 1999; Pope et al., 1991).

Estimating Effects for Multiple Age Groups

The second prospective benefits analysis is focused on the year 2000 and two future years, 2010 and 2020. The population age distribution is expected to change over time, with a greater percentage of the population moving into older age categories. Because baseline incidence rates for older populations tend to exceed those for younger populations for several health endpoints (most importantly, for mortality), this demographic shift has important implications for the estimation of future-year incidence change. If we were to apply a C-R function to an entire population, using one average baseline incidence, this demographic shift would be missed, and the future-year incidence change would be significantly underestimated.

To take into account projected demographic shifts and the corresponding implications for predicted incidence change, we will apply C-R functions to separate age groups within the entire population to which a C-R function is applicable, using projected populations in each age group. Projected baseline incidences (incidence rates times populations) used in the calculation of future-year pollutant-related incidence change will therefore better reflect the expected demographic shifts. We note that, because we will not attempt to estimate changes in baseline incidence rates (which may decline slightly over time), we may overestimate incidence change to the extent that baseline incidence rates decline.

Impacts on Sensitive Subpopulations

EPA is currently evaluating how air pollution related symptoms in the asthmatic population should be incorporated into the overall benefits analysis. Clearly, studies of the general population also include asthmatics, so estimates based solely on the asthmatic population cannot be directly added to the general population numbers without double-counting. In one specific case, upper respiratory symptoms in children, the only study available was limited to asthmatic children, so this endpoint is included in the calculation of total benefits. However, other endpoints, such as lower respiratory symptoms, are estimated for the total population of children.

Given the increased susceptibility of the asthmatic population, it is of interest to understand better the specific impacts on asthmatics. We will provide a separate set of estimated health impacts for asthmatic populations for the second prospective analysis. However, the reader should carefully note that these are not additive, nor can they be easily combined with other endpoints to derive total benefits. We will provide the estimates only to highlight the potential impacts on a susceptible population.

Several epidemiological studies have estimated concentration-response functions relating pollution to various symptoms (wheeze, cough, dyspnea, chest tightness, shortness of breath) among asthmatics. One or all of these symptoms may be considered indicators of an asthma episode when it occurs in an asthmatic. We currently have the following asthma exacerbation health endpoints in this analysis: asthma attack, moderate or worse, shortness of breath, wheeze, cough, and one or more symptoms.

To gain further understanding into the public health impact of the modeled change in air quality associated with the preliminary control options, we will examine the incidence of health effects occurring in three age groups: children (0-17), adults (18-64), and elderly adults (65 and older). Certain endpoints occur only in a subset of age groups, so not all endpoints are reported for all age groups. Two sets of age group estimates will be calculated. The first is based on the specific age ranges examined in the epidemiological studies, for example, the Dockery et al (1996) acute bronchitis study focused on a sample population aged 8 to 12. These are the estimates that will be used to derive total incidences. In many cases however, the study populations were defined as a matter of convenience or due to data availability, rather than due to any biological factor that would restrict the effect to the specific age group. In order to gain a more complete understanding of the potential magnitude of the health impact in the entire population, we will calculate a separate estimate including the health impact on all population within an age group.

We will also estimate respiratory symptoms and attacks occurring in the asthmatic population, based on the studies defined in Exhibit 6-3. As with the age group specific estimates, we provide two sets of calculations, one based on applying the C-R function only to the specific population subgroup included in a study's sample population, and another based on applying the C-R function to all populations within a broader population. It is important to note that the asthma symptom estimates are not additive to total benefits. They are provided to show the specific impacts on an especially susceptible subpopulation. Also note that the estimates are not additive even within the exhibit. We have grouped the estimates based on the type of symptoms measured, but there is the potential for considerable overlap. However, these estimates will provide an illustration of the consistency of the effects across studies and populations of asthmatics.

Exhibit 6-3
Studies Examining Health Impacts in the Asthmatic Population

Endpoint	Definition	Pollutant	Study	Study Population
Asthma Attack Indicators1				
Shortness of Breath	prevalence of shortness of breath; incidence of shortness of breath	$PM_{2.5}$	Ostro et al. (2001)	African American asthmatics, 8-13
Cough	prevalence of cough; incidence of cough	$PM_{2.5}$	Ostro et al. (2001)	African American asthmatics, 8-13
Wheeze	prevalence of wheeze; incidence of wheeze	$PM_{2.5}$	Ostro et al. (2001)	African American asthmatics, 8-13
Asthma Exacerbation	$1 mild asthma symptom: wheeze, cough, chest tightness, shortness of breath)	PM_{10}, $PM_{1.0}$	Yu et al. (2000)	Asthmatics, 5-13
Cough	prevalence of cough	PM_{10}	Vedal et al. (1998)	Asthmatics, 6-13
Other symptoms/illness endpoints				
Upper Respiratory Symptoms	$1 of the following: runny or stuffy nose; wet cough; burning, aching, or red eyes	PM_{10}	Pope et al. (1991)	Asthmatics 9-11
Moderate or Worse Asthma	probability of moderate (or worse) rating of overall asthma status	$PM_{2.5}$	Ostro et al. (1991)	Asthmatics, all ages
Acute Bronchitis	$1 episodes of bronchitis in the past 12 months	$PM_{2.5}$	McConnell et al. (1999)	Asthmatics, 9-15
Phlegm	"other than with colds, does this child usually seem congested in the chest or bring up phlegm?"	$PM_{2.5}$	McConnell et al. (1999)	Asthmatics, 9-15
Asthma Attacks	respondent-defined asthma attack	PM2.5, ozone	Whittemore and Korn (1980)	Asthmatics, all ages

Alternative Estimate

In two recent mobile source rulemaking analyses and in the benefits analysis for the Clear Skies Initiative, EPA included an "Alternative Estimate" in addition to a "Base Estimate" of total monetized benefits. The Alternative Estimates included in these three analyses differed with each other in some respects, but in each case they reflected some combination of alternative assumptions regarding key factors in the estimation of PM-related benefits, particularly premature mortality and chronic bronchitis. The specific differences from "Base Estimate" assumptions or methods used in each of these three analyses were confined to the valuation components of the Alternative Estimate - these are summarized in Chapter 8 of this document.

For mortality incidence, the alternative estimate assumes that the effect is related only to short-term exposure. As a result, mortality incidence in the alternative estimate involved the use of the Schwartz et al. (1996) short-term exposure study, adjusted using the ratio of distributed lag to single day coefficients from Schwartz et al. (2000). It does not incorporate any mortality effect of chronic-exposure. In addition, the alternative estimate assumes that death is advanced by six months for COPD-related mortality, and five years for all other causes. Advocates of the inclusion of these Alternative Estimates suggested that this alternative set of assumptions represent plausible best estimates for total monetized benefits for the associated rules, and therefore could be viewed as a replacement for the "Base Estimate."

The 812 Project Team is still evaluating the merits and utility of adding a similar Alternative Estimate to accompany the Primary estimates for benefits in the second prospective analysis, and seeks advice from the SAB regarding the value and utility of generating an Alternative Estimate, as well as advice concerning the technical/scientific reasonableness of each of the alternative assumptions or assumption sets, including specifically whether the focus on short-term studies as an alternative basis for PM mortality might affect SAB's recommendations on the additive nature of estimates of ozone mortality.

Sensitivity Calculations

In addition to the Primary and Alternative estimates of benefits, we present a series of sensitivity calculations that make use of other sources of concentration-response and valuation data for key benefits categories, as well as examining key analytical parameters, such as the form of the lag between changes in PM exposure and realization of changes in health outcomes. These estimates, however, are not meant to be comprehensive. Rather, they reflect some of the key issues identified by EPA or commentors as likely to have a significant impact on total benefits. Individual adjustments in the tables should not be added together without addressing potential issues of overlap and low joint probability among the endpoints. Exhibit 6-4 lists these sensitivity calculations.

In addition to these single-factor sensitivity tests, multi-factor sensitivity analysis examining the effect of combining uncertain health effect C-R functions with other key upstream and downstream analytical uncertainties will be conducted and presented in the uncertainty analysis chapter of the 812 report. These multi-factor sensitivity tests were recommended by the National Academy of Sciences in their recent report reviewing EPA's air pollution benefits methodologies (NRC, 2002).

Exhibit 6-5 displays each of the alternative C-R functions we will use to examine the relationship between long-term PM2.5 exposure and premature mortality. Although we use the Krewski et al. (2000) mean-based all-cause model exclusively to derive our Base Estimate of avoided premature mortality, we will also examine the impacts of selecting alternative C-R functions for premature mortality. Exhibit 6-6 summarizes the alternative C-R functions that we used from the original ACS study by Pope et al. (1995) and from the "Harvard Six-City Study" by Dockery et al. (1993), as well as the recent reanalyses by Krewski et al. (2000) and Pope et al. (2002).

Exhibit 6-4.
Sensitivity Calculations

Category	Description
Long-term Mortality	
Alternative studies for premature mortality	A number of studies provide an alternative estimate of the relationship between chronic PM exposure and mortality.
Alternative mortality lag structures	Calculate the impact different lag structures have on the estimation of benefits associated with avoided mortality incidence.
Thresholds	Calculate the impact varying threshold assumptions have on the estimation of mortality incidence based on the Krewski et al. (2000) study.
Overlapping endpoints	
Ozone-related mortality	Ozone-related mortality benefits estimated using a pooled analysis based on four U.S. studies.
Any-of-19 symptoms.	Due to the potential for overlap with health effects covered in the estimate of MRADs and both PM- and ozone-related asthma attacks, we present Any-of-19 Respiratory Symptoms separately.
Alternative and Supplementary Estimates	
Ozone ERVs	Apply American Lung Association (1996) scaling for ozone-related ERVs
Infant mortality	The Woodruff et al. (1997) study provides an estimate of the relationship between chronic exposure and infant mortality.
Chronic asthma	Avoided incidences of chronic asthma are estimated using the McDonnell et al. (1999) C-R function.
PM10 hospital admissions	Samet et al. (2000a) is used to estimate respiratory and cardiovascular hospital admissions.
Reversals in chronic bronchitis treated as lowest severity cases	Instead of omitting those cases of chronic bronchitis that reverse after a period of time, they are treated as being cases with the lowest severity

Exhibit 6-5
Alternative C-R Functions for Long-Term $PM_{2.5}$-Related Premature Mortality

Study	Mortality Category	Age	Pollutant	Metric
Pope et al. (2002)	All-cause	30+	$PM_{2.5}$	Annual Mean
Krewski et al. (2000) reanalysis of Pope et al. (1995)	All-cause	30+	$PM_{2.5}$	Annual Median
Krewski et al. (2000) reanalysis of Pope et al. (1995). Random effects, independent cities	All-cause	30+	$PM_{2.5}$	Annual Median
Krewski et al. (2000) reanalysis of Pope et al. (1995). Random effects, regional adjustment	All-cause	30+	$PM_{2.5}$	Annual Median
Pope et al. (2002)	All-cause	30+	$PM_{2.5}$	Annual Median
Krewski et al. (2000) reanalysis of Dockery et al. (1993)	All-cause	25+	$PM_{2.5}$	Annual Mean
Dockery et al. (1993)	All-cause	25+	$PM_{2.5}$	Annual Mean
Pope et al. (2002)	Cardiopulmonary	30+	$PM_{2.5}$	Annual Mean
Pope et al. (2002)	Lung Cancer	30+	$PM_{2.5}$	Annual Mean

Accounting for Potential Health Effect Thresholds

When conducting clinical (chamber) and epidemiological studies, C-R functions may be estimated with or without explicit thresholds. Air pollution levels below the threshold are assumed to have no associated adverse health effects. When a threshold is not assumed, as is often the case in epidemiological studies, any exposure level is assumed to pose a non-zero risk of response to at least one segment of the population.

The possible existence of an effect threshold is a very important scientific question and issue for policy analyses such as this one. The SAB Council has advised EPA that there is currently no scientific basis for selecting a threshold of 15 µg/m3 or any other specific threshold for the PM-related health effects considered in typical benefits analyses (EPA-SAB-Council-ADV-99-012, 1999). This is supported by the recent literature on health effects of PM exposure (Daniels et al., 2000; Pope, 2000; Rossi et al., 1999; Schwartz, 2000) which finds in most cases no evidence of a non-linear concentration-response relationship and certainly does not find a distinct threshold for health effects. The most recent draft of the EPA Air Quality Criteria for Particulate Matter (U.S. EPA, 2002) reports only one study, analyzing data from Phoenix, AZ, that reported even limited evidence suggestive of a possible threshold for PM2.5 (Smith et al., 2000).

Recent cohort analyses by the Health Effects Institute (Krewski et al., 2000) and Pope et al. (2002) provide additional evidence of a quasi-linear concentration-response relationship between long-term exposures to PM2.5 and mortality. According to the latest draft PM criteria document, Krewski et al. (2000) "found a visually near-linear relationship between all-cause and cardiopulmonary mortality residuals and mean sulfate concentrations, near-linear between cardiopulmonary mortality and mean PM2.5, but a somewhat nonlinear relationship between all-cause mortality residuals and mean PM2.5 concentrations that flattens above about 20 µg/m3. The confidence bands around the fitted curves are very wide, however, neither requiring a linear relationship nor precluding a nonlinear relationship if suggested by reanalyses." The Pope et al. (2002) analysis, which represented an extension to the Krewski et al. analysis, found that the concentration-response relationships relating PM2.5 and mortality "were not significantly different from linear associations."

Daniels et al. (2000) examined the presence of threshold in PM10 concentration-response relationships for daily mortality using the largest 20 U.S. cities for 1987-1994. The results of their models suggest that the linear model was preferred over spline and threshold models. Thus, these results suggest that linear models without a threshold may well be appropriate for estimating the effects of PM10 on the types of mortality of main interest. Schwartz and Zanobetti (2000) investigated the presence of threshold by simulation and actual data analysis of 10 U.S. cities. In the analysis of real data from 10 cities, the combined concentration-response curve did not show evidence of a threshold in the PM10-mortality associations. Schwartz, Laden, and Zanobetti (2002) investigated thresholds by combining data on the PM2.5-mortality relationships for six cities and found an essentially linear relationship down to 2 µg/m3, which is at or below anthropogenic background in most areas. They also examined just traffic related particles and again found no evidence of a threshold. The Smith et al. (2000) study of associations between daily total mortality and PM2.5 and PM10-2.5 in Phoenix, AZ (during 1995-1997) also investigated the possibility of a threshold using a piecewise linear model and a cubic spline model. For both the piecewise linear and cubic spline models, the analysis suggested a threshold of around 20 to 25 µg/m3. However, the concentration-response curve for PM2.5 presented in this publication suggests more of a U- or V-shaped relationship than the usual "hockey stick" threshold relationship.

Based on the recent literature and advice from the SAB, our base assumption is that there are no thresholds for modeling health effects. Although not included in the primary analysis, the potential impact of a health effects threshold on avoided incidences of PM-related premature mortality will be explored as key sensitivity analysis, as noted above. Our assumptions regarding thresholds are supported by the National Research Council in its recent review of methods for estimating the public health benefits of air pollution regulations. In their review, the National Research Council concluded that there is no evidence for any departure from linearity in the observed range of exposure to PM10 or PM2.5, nor any indication of a threshold. They cite the weight of evidence available from both short and long term exposure models and the similar effects found in cities with low and high ambient concentrations of PM.

Avoided Health Effects Associated with Provisions to Protect Stratospheric Ozone / Title VI of the Clean Air Act

For the second prospective analysis, EPA is proposing changes to its approach to estimating health benefits associated with emission controls on ozone depleting substances (ODS) required by Title VI of the Clean Air Act. Rather than rely on benefit estimates derived from previous regulatory impact analyses, the new approach will employ EPA's Atmospheric Health Effects Framework (AHEF) to estimate changes in cases of skin cancer and cataracts associated with exposure to UV-b rays. Appendix E presents details of our proposed revisions to the approach to estimate Title VI health benefits.

The SAB Council comments on the draft analytical plan also asked EPA to comment on whether tropospheric ozone reduction strategies could reduce shielding provided by the ground level ozone against the harmful effects of UV-b radiation. The great majority of this shielding results from naturally occurring ozone in the stratosphere, but the 10 percent of total “column”ozone present in the troposphere also contributes (NAS, 1991). A variable portion of this tropospheric fraction of UV-B shielding is derived from ground level or “smog” ozone related to anthropogenic air pollution. Therefore, strategies that reduce ground level ozone could, in some small measure, increase exposure to UV-B from the sun.

While EPA’s analyses demonstrate it is possible to provide quantitative estimates of benefits associated with globally based strategies to restore the far larger and more spatially uniform stratospheric ozone layer, the changes in UV-B exposures associated with ground level ozone reduction strategies are much more complicated and uncertain. Smog ozone strategies, such as mobile source controls, are focused on decreasing peak ground level ozone concentrations, and it is reasonable to conclude that they produce a far more complex and heterogeneous spatial and temporal pattern of ozone concentration and UV-B exposure changes than do stratospheric ozone protection programs. In addition, the changes in long-term total column ozone concentrations are far smaller from ground-level programs. To properly estimate the change in exposure and impacts, it would be necessary to match the spatial and temporal distribution of the changes in ground-level ozone to the spatial and temporal distribution of exposure to ground level ozone and sunlight. More importantly, it is long-term exposure to UV-B that is associated with effects. Intermittent, short-term, and relatively small changes in ground-level ozone and UV-B are not likely to measurably change long-term risks of these adverse effects.

For all of these reasons, EPA believes we will continue to be unable to provide reliable estimates of the changes in UV-B shielding associated with ground-level ozone changes. This inability lends an upward bias to the net monetized benefits of tropospheric ozone reduction that will be presented in second prospective criteria pollutant analysis. It is likely that the adverse health effects associated with increases in UV-B exposure from decreased tropospheric ozone would, however, be relatively very small from a public health perspective because 1) the expected long-term ozone change resulting from the CAAA is likely to be small in comparison to the sum of total column natural stratospheric and tropospheric ozone; 2) air quality management strategies are focused on decreasing peak ozone concentrations and thus may change exposures over limited areas for limited times; 3) people often receive peak exposures to UV-B in coastal areas where sea or lake breezes reduce ground level pollution concentrations regardless of strategy; and 4) ozone concentration changes are greatest in urban areas and areas immediately downwind of urban areas, where people are more likely to spend most of their time indoors or in the shade of buildings, trees or vehicles.

CHAPTER 7 - CHARACTERIZING ECOLOGICAL EFFECTS OF AIR POLLUTION

This chapter provides a summary of our plans for qualitatively and quantitatively assessing the effects of air pollution on ecological resources. We first review the basic approach used in the first prospective, then summarize our proposed revisions for the second prospective. We propose to supplement the quantitative approach employed in the first prospective with an illustrative case study aimed at demonstrating the potential magnitude of ecological benefits, describing the type and level of data necessary to carry an ecological impact assessment through to economic valuation, and highlighting data gaps to distinguish research areas for which improved information would be particularly advantageous. The second prospective will also incorporate an expanded review of the growing literature that attempts to link ecological impact assessment and economic valuation.

Review of Approach in First Prospective

In the first prospective analysis, we implemented a three step process in our analysis of ecological effects of air pollutants. First, we conducted a broad review of the effects of air pollutants on ecological systems. This included identification of major single pollutant-environment interactions, as well as synergistic impacts of ecosystem exposure to multiple air pollutants. The analysis focused on effects of pollutants that: a) are regulated by the CAAA; b) exhibit interactions with natural systems that are documented in peer-reviewed literature; and c) are present in the atmosphere in significant amounts to engender damages to ecosystems. These standards narrowed the body of potential air pollutants for study to acidic deposition, nitrogen deposition, hazardous air pollutants (HAPS), and ozone. The analysis then qualitatively detailed the effect of these environmental stressors on natural systems at various levels of biological organization (i.e., molecular and cellular, individual, population, community, local ecosystem, and regional ecosystem). The result was an exhaustive qualitative characterization of these effects on ecosystem structure, function, and health. In addition to acknowledging the importance and potential vulnerabilities of ecological resources to air pollution, the goal of this portion of the analysis was to apply and expand the growing body of information that can be used to assess the impacts of air pollutants on ecosystems.

While this first step addresses both non-market and marketable ecosystem services, the second step of the first prospective analysis focused on selecting a subset of effects amenable to economic analysis. It is only within the past few decades that ecological effects of air pollution has garnered significant public attention. As such, while qualitative characterizations of impacts are more discernible through acute observation, valuation of these impacts is greatly constrained by limited available methods and data. For example, potential spatial and temporal transferability of ecosystem impacts is not yet well-understood. We applied two criteria to identify a subset of impacts most amenable to quantitative analysis. The first specified that the endpoint be an identifiable service flow, and the second required a defensible link between the changes in air pollution emission and the quality or quantity of the service flow where peer-reviewed quantitative models were available to monetize these changes. These criteria greatly narrowed the body of potential pollutants to those listed in the "Quantified Effects" column of Table 7-1. This table summarizes the results of the first two steps of the process applied in the first prospective analysis.

In the third step, we conducted physical effects and economic modeling to generate quantified and monetized characterizations of the selected effects. The quantified effects included estimates of the reduced loadings of nitrogen to potentially sensitive coastal estuaries. The monetized estimates of this effect, based on displaced treatment costs to reduce other forms of nitrogen loadings in three selected estuaries, were not included in the primary central benefits estimates due to concerns about whether the nitrogen loadings budgets for these estuaries reflected binding agreements that would ensure the relevant treatment costs would actually be displaced.

While the breadth and complexity of air pollutant-ecosystem interaction did not allow for comprehensive economic analysis of all of the ecological benefits of the CAAA, stressing the importance of affected ecosystem services through our qualitative characterization served to highlight data gaps where future research may be focused in order to support future quantification of these impacts.

Table 7-1

Summary of Ecological Effects of Air Pollutants Assessed in First Prospective

POLLUTANT	QUANTIFIED EFFECTS	UNQUANTIFIED EFFECTS
Acidic Deposition	Impacts to recreational freshwater fishing	Impacts to commercial forests (e.g., timber, non-timber forest products) Impacts to commercial freshwater fishing Watershed damages (water filtration flood control) Impacts to recreation in terrestrial ecosystems (e.g. forest aesthetics, nature study) Reduced existence value and option values for nonacidified ecosystems (e.g. biodiversity values)
Nitrogen Deposition	Additional costs of alternative or displaced nitrogen input controls for eastern estuaries	Impacts to commercial fishing, agriculture, and forests Watershed damages (water filtration, flood control) Impacts to recreation in estuarine ecosystems (e.g. recreational fishing, aesthetics, nature study) Reduced existence value and option values for non-eutrophied ecosystems (e.g. biodiversity values)
Tropospheric Ozone Exposure	Reduced commercial timber yields and reduced tons of carbon sequestered	Impacts to recreation in terrestrial ecosystems (e.g. forest aesthetics, nature study) Reduced existence value and option values for on ozone-impacted ecosystems
Hazardous Air Pollutant (HAPS) Deposition	No service flows quantified	Impacts to commercial and recreational fishing from toxification of fisheries Reduced existence value and option values for non-toxified ecosystems (e.g. biodiversity values)

Source: U.S. EPA. 1999a. The Benefits and Costs of the Clean Air Act 1990 to 2010. EPA Report to Congress prepared by the Office of Policy and Office of Air and Radiation, November.

Proposed Approach for Second Prospective

The results of the analysis in the first prospective suggest that additional research ought to focus on developing credible estimates of the economic value of avoided ecological damage, particularly on characterizing the sometimes subtle and long-term effects of air pollution on ecosystem structure and function. In the roughly four years since the completion of the first prospective, some research progress has been made in this area, but the literature base continues to reflect largely conceptual advances in the characterization of the relationship of ecological health and economic welfare and productivity. Although this remains a promising research direction, the existing tools do not currently support a broader monetization of ecological effects than was conducted in the first prospective. In addition, the relatively diffuse nature of air pollution as an ecological stressor, relative to more concentrated stresses associated with water pollution or hazardous materials spills, make reliable ecological benefit characterization for air pollution even more difficult.

In general, the foundation of our ecological benefits reporting in the second prospective analysis will follow the approach used in the first prospective analysis. A comprehensive qualitative characterization of the effects of air pollutants on ecosystem services will be categorized according to ecosystem type and level of biological organization. Within this qualitative analysis, both non-market and marketable service flows will be contemplated. The comparatively progressive information regarding the human health benefits of air regulation, combined with the lack of quantified ecological effects, may lead to a perception that ecological benefits are less consequential than health effects. The ecologists on the Council strongly advocate that comprehensive measures of the benefits of an entire ecosystem are needed, rather than partial measures formed by using a linear sum of the empirically measured values of just a few individual ecological services. The Council does, however, acknowledge that it is not aware of any examples in the available literature of such a comprehensive valuation.

The Council therefore recommended the application of a prototype estimation amenable to economic valuation in order to provide a sharpened sense of the potential nature and magnitude of ecological benefits resulting from air pollution regulation. While this prototype could be a vehicle for demonstrating the current deficiencies in our knowledge about both the physical effects of air quality on ecological services and the value to society of these effects, the analysis should make clear that no individual ecosystem service is likely to account for the majority of the ecological benefits of the CAA.

The remainder of this chapter provides an overview of ongoing research pertaining to our objectives, proposes enhancements to the approach applied in the first prospective, and describes our proposal for a case study to illustrate monetization of ecological benefits.

Overview of Related Ongoing Research

Multiple initiatives are currently being pursued at EPA that are geared toward applying economic modeling techniques to assess ecological benefits of environmental regulation. These research efforts relate to the ecological benefits assessment of the CAAA in their objective to establish a strategy to bridge the data and methodology gaps between ecological risk assessments and economic valuation of non-market resources. They differ, however, in the specific resources and ecosystem services for which they are attempting to quantify value. Following is a list of examples of pertinent ongoing projects. We will consult with the Panel on Valuing the Protection of Ecological Systems and Services (Panel) and with the EPA agency-wide Ecological Benefits workgroup, both of which are currently being coordinated, regarding the potential relevance of each of these ongoing efforts to the second prospective analysis

- **Ecological Benefits Action Plan:** The EPA Office of Policy Economics and Innovation (OPEI), Office of Water (OW), Office of Research and Development (ORD), Office of Pollution Prevention and Toxic Substances (OPPTS), and the Office of Solid Waste and Emergency Response (OSWER) are currently partnering on this plan to advance EPA's ability to identify, measure, value, and communicate the ecological effects of its actions. This will include identifying the major data, method, model, and procedural deficiencies that complicate valuation of certain ecological services. Following a series of interviews with ecologists and economists in EPA and other Federal agencies to determine the state of the science and practice, this plan will recommend action items, both research and procedural. The Ecological Benefits workgroup held interviews in fall 2002 and winter 2003. The plan will address action items to be started during the years 2003 through 2008. Because this effort is focused on development of general methodologies, the product of this project should provide useful guidance for future prospective analyses of ecological benefits of environmental regulation.

- **Place-Based Integration of Ecological and Economic Data:** The EPA National Center for Environmental Assessment (NCEA) funded three case studies in 1999 to integrate economic research into ongoing ecological risk assessment studies of three watersheds (Clinch Valley in Virginia and Tennessee, Middle Platte River in Nebraska, and Big Darby Creek Watershed in Ohio). NCEA held a workshop in July of 2001 to evaluate the results of the studies in order to develop a conceptual framework for integrating ecological risk assessment and economic methods to support decision-making. A resulting report entitled "Selected Methods for Integration of Ecological Risk Assessment and Economics in Watersheds" is currently in internal review and is anticipated to be available in late 2003. Although the specific natural resources valued within these reports do not relate directly to those impacted by the CAAA, the framework used to guide these three case studies may provide helpful direction for the second prospective analysis.

- **Airborne Mercury Effects on Birds:** EPA's OAQPS is sponsoring ongoing research exploring impacts of airborne mercury on loons, including quantification of population effects. Following a comprehensive ecological risk assessment, research will focus on the potential to monetize the impact, and make apparent the limitations to integrating the ecological and economic quantitative methods. As this project relates directly to the CAAA, in the case that quantified results are available within the time frame for the second prospective analysis, a benefits transfer may be possible.

- **Integrated Modeling of Inland Stream Water Quality and Willingness to Pay:** An ongoing effort of the EPA Office of Water (OW) is assessment of willingness to pay (WTP) estimates for water quality using broad indices that incorporate aspects of ecological health. The National Water Pollution Control Abatement Model (NWPCAM) is linked to an economic valuation (Carson-Mitchell) study for use in evaluating policy decisions nationwide.[1] Dependent upon the particular water quality indicators selected for valuation within this study, a benefits transfer applying the resulting willingness to pay estimates may be possible for the second prospective analysis.

Enhancements to Approach Applied in First Prospective

The ecologists on the Council strongly advocate that comprehensive measures of the benefits of an entire ecosystem are needed, rather than partial measures formed by using a linear sum of the empirically measured values of just a few individual ecological services. Current literature supporting this "placeholder" approach, however, is limited and controversial. In debating the merits of the Costanza et al. (1997) study, they ask the questions "a) Are the Costanza et al. (1997) numbers and procedures adequate for back-of-the-envelope calculations? and b) Is it better to report range-finding estimates that have high uncertainty or to report no numbers?" Some members of the committee felt strongly that valuing the piecemeal marginal social benefits of ecosystem services is inadequate to achieve the growth of knowledge that is necessary for policy-making. They also believe that the second prospective analysis should establish tighter bounds on estimated ecosystem benefits.

Economists on the Council, however, do not wish to make generating a value for ecosystem service benefits a prerequisite for commencing with the upcoming Section 812 analysis. Current literature supporting the placeholder approach is controversial at best, and applying a benefits transfer of these studies may undermine the credibility of the quantitative benefits analysis in the

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[1] Carson, Richard, T. and Robert Mitchell. July 1993. The Value of Clean Water: "The Public's Willingness to Pay to Boatable, Fishable, and Swimmable Quality Water." *Water Resources Research* 29(7): 2445-2454.

second prospective analysis. More importantly, we interpret that a core motivation of the placeholder analysis is to ensure adequate attention and investment in ecological benefits research, and we believe that the EPA is committed to this pursuit (as demonstrated by the "Overview of Related Ongoing Research" in this Chapter and in Appendix F of this analytic plan) whether or not the placeholder approach is applied. Despite this, the Council economists acknowledge the lack of information on the environmental effects of marginal changes in air pollution, noting that until such data are available the 812 analysis will continue to substantially underestimate ecological benefits.

The following summarizes the enhancements the EPA will make to the ecological benefits approach employed in the first prospective analysis. We will consult with the Panel regarding each of these efforts.

- **Literature Review:** We will update our prior literature review in order track the evolution of ecological valuation literature and provide a basis for advising the agency on research needs in general, and more specifically to evaluate whether the literature provides a basis for estimating marginal ecosystem service benefits relevant to the context of the 812 analysis. We will review the relevance of Costanza's research to our objectives and will assess the applicability of the body of literature recommended by the Council in Appendix E of their review.[2]

- **Qualitative Characterization:** Our updated literature review will provide a more comprehensive and current qualitative characterization of ecological effects. This review will support a thorough qualitative assessment of the impacts of relevant air pollutants on both non-market and marketable service flows similar to that in the first prospective as described in the first section of this chapter. A bibliography of relevant studies reviewed thus far is provided in Appendix G. Table 7-2 is an example of the depth of the qualitative characterization process from the first prospective analysis.

[2] EPA-SAB-COUNCIL-ADV-01-004, September 2001.

Table 7-2

Interactions Between Nitrogen Deposition and Natural Systems At Various Levels of Organization

SPATIAL SCALE	TYPE OF INTERACTION	EXAMPLES OF INTERACTIONS: EUTROPHICATION AND NITROGEN SATURATION OF TERRESTRIAL LANDSCAPES	EXAMPLES OF INTERACTIONS: EUTROPHICATION OF COASTAL ESTUARIES
Molecular and cellular	Chemical and biochemical processes	Assimilation of nitrogen by plants and microorganisms	Assimilation of nitrogen by plants and microorganisms.
Individual	Direct physiological response.	Increases in leaf- size of terrestrial plants.	Increase in growth of marine plants.
	Indirect effects: Response to altered environmental factors or alterations of the individual's ability to cope with other kinds of stress.	Decreased resistance to biotic and abiotic stress factors like pathogens and frost. Disruption of plant-symbiont relationships with mycorrhiza fungi.	Injuries to marine fauna through oxygen depletion of the environment. Loss of physical habitat due to loss of sea-grass beds. Injury through increased shading. Toxic blooms of plankton.
Population	Change of population characteristics like productivity or mortality rates.	Increase in biological productivity and growth rates of some species.	Increase in biological productivity. Increase of growth rates (esp. of algae and marine plants).
Community	Changes of community structure and competitive patterns	Alteration of competitive patterns. Selective advantage for fast growing species and individuals that efficiently use additional nitrogen. Loss of species adapted to nitrogen-poor environments.	Excessive algal growth. Changes in species composition. Decrease in sea-grass beds.
Local Ecosystem (e.g., landscape element)	Changes in nutrient cycle, hydrological cycle, and energy flow of lakes, wetlands, forests, grasslands, etc.	Magnification of the biogeochemical nitrogen cycle. Progressive saturation of microorganisms, soils, and plants with nitrogen.	Magnification of the nitrogen cycle. Depletion of oxygen, increased shading through algal growth.
Regional Ecosystem (e.g., watershed)	Biogeochemical cycles within a watershed. Region-wide alterations of biodiversity.	Leaching of nitrogen from terrestrial sites to streams and lakes. Acidification of aquatic bodies. Eutrophication of estuaries.	Additional input of nitrogen from nitrogen-saturated terrestrial sites within the watershed.

- **Conceptual Basis for Linking Ecological Health to Economic Measures:** The Council has suggested applying the "value of a statistical life" method of estimating the value of reduced mortality risk to ecosystem impacts in order to estimate the "value of a statistical ecosystem." This effort would serve to demonstrate that ecosystem morbidity impacts are likely to be even more significant, though more difficult to quantify. The summary of the literature review for the second prospective analysis will reflect on the potential to estimate a defensible "value of a statistical ecosystem" for application in future benefits assessments. We will include a new summary section that reviews the conceptual literature linking ecological service flows and overall ecological health stratified by ecosystem type with economic measures such as household welfare and economic productivity. This type of discussion can serve to reinforce the multiple linkages between ecology and economics despite deficiencies in the data and methods necessary to quantify these relationships. We will consult with the Panel to ensure that non-market service flows are included to the fullest possible extent. Non-market services of ecosystems will be formally acknowledged, quantified, and included in the benefit-cost calculations and in a separate column of the tabulated benefits. These non-market valuations will serve to emphasize the advancements of ecological and economic models toward an aggregate measure of ecological benefits. Citations for Trudy Ann Cameron's recent research related to valuation of non-market resources is available at **http://ideas.repec.org/e/pca72.html.**

- **Commercial Timber:** We will explore possible enhancements to the biological effects characterization approach to employ the more recent TREGRO concentration-response functions applied in the Heavy Duty Diesel rule.

- **Prototype Estimation:** We will choose one ecosystem service to conduct a prototype benefits calculation. This case study will serve to: a) demonstrate how benefits calculations should be conducted for ecological services in general; b) highlight the current deficiencies in our knowledge about both the physical effects of air quality on ecological services and the value to society of these effects; and c) help define research needs and priorities. Any prototype analysis will make clear that no individual ecosystem service is likely to account for the majority of the ecological benefits of the CAA. The following discussion briefly describes our deliberation process, and introduces options for such a case study.

Considerations for Second Prospective Case Study

In developing a case study to serve as an illustrative example of the physical effects and of the economic modeling techniques available to assess benefits of a particular pollutant on an ecosystem service, we considered several factors. First, it is important that the case study involve well-documented impacts to a particular ecosystem function or service. Second, a key characteristic is ready determination of quantifiable *ecological and economic* endpoints. Third, it is critical that economic tools are available to monetize at least a subset of the identified endpoints. It is also helpful to consider the extent to which this effort can draw on existing EPA initiatives in order to maximize available resources, avoid redundant research, and provide a vehicle to demonstrate multiple applications of ongoing projects.

After careful consideration of these attributes, OAR has identified impacts of nitrogen deposition on coastal estuaries to be most amenable to an expansive ecological and economic analysis. Excess nitrogen causes eutrophication of estuaries which impacts both natural resources and non-market service flows from the ecosystem. In order to carry out as complete an analysis as possible, data must be available or derivable for four hierarchical levels: (a) source- in this case the source is the atmospheric deposition of nitrogen; (b) stressor- our ecosystem stressor is primarily nutrient enrichment, or eutrophication- note that the nature of airborne nitrogen loadings and the runoff of deposited nitrogen from terrestrial to estuarine ecosystems also magnifies the stress from this source, enhancing our ability to detect the air pollution "signal" in dynamic ecosystems; (c) effects- estuarine eutrophication typically results in changes in type and levels of submerged aquatic vegetation (SAV); and (d) endpoints- for example, changes in species populations or assemblages. EPA has several projects underway to develop a more complete and defensible characterization of the benefits of avoiding airborne nitrogen deposition in coastal estuaries.[3] These include refinements of the characterization of water quality impacts associated with nitrogen deposition; conceptual models of the links between water quality and monetizable service flows; and efforts to quantitatively characterize the incremental effect of reduced nitrogen deposition on economic welfare associated with commercial and recreational fishing. Descriptions of two potential sites for case study follow.

Waquoit Bay- Falmouth, MA

Waquoit Bay is a shallow estuary fed by groundwater and freshwater streams located on the southern coast of Cape Cod in Massachusetts. The bay encompasses approximately 21 square miles (53 square kilometers) and has an average depth of three feet. The Waquoit Bay National Estuarine Research Reserve (WBNERR) is co-managed by the National Oceanic and Atmospheric Administration's Office of Ocean and Coastal Resource Management, Estuarine Reserves Division and the Massachusetts Department of Environmental Management, Division of Forests and Parks. The goal of the WBNERR is to promote research to improve understanding of human-induced changes in the estuary in order to inform policy decisions. Proximity to Woods Hole Oceanographic Institute and Marine Biological Laboratories further allows Waquoit Bay the advantage of continuous intensive research and monitoring of pollution level, species health, and population statistics. The bay is also the site of an ongoing NCEA risk assessment project to identify stressors

[3] Relevant EPA research includes initiatives through the EPA Great Waters Program accessible at http://www.epa.gov/ oar/oaqps/gr8water/index.html, the EPA National Estuary Program accessible at http://www.epa.gov/owow/estuaries/about1.htm, and the research surrounding the two case studies as described in this chapter.

to the system and effects on selected endpoints focusing on impacts of nutrient enrichment on percent eelgrass cover and scallop abundance.[4]

The limited size of this bay makes it a particularly appealing area of study. The level and effects of stressors, such as nitrogen deposition, on ecological indicators may be more transparent due to the limited geographic scope. Consequently, data are available at each of the four aforementioned hierarchical levels as outlined below and highlighted in Exhibit 7-2.

- **Source:** Documented historical nitrogen loading models are available for the Waquoit Bay ecosystem.[5]

- **Stressor:** Eutrophication resulting from nitrogen loading is the focus of the ongoing EPA risk assessment at Waquoit Bay. The level of eutrophication occurring due to nitrogen loading in general, and atmospheric nitrogen deposition in general at Waquoit Bay is documented in this risk assessment.

- **Effects:** Selected effects of eutrophication, such as increased levels of macroalgae and phytoplankton and decreased expanse of eelgrass cover, are subject of past and ongoing research.[6] While quantitative changes in these variables have been plotted against changes in nitrogen load, targeted nitrogen loading-response functions are still being developed.

- **Endpoints:** Studied ecological endpoints that may be amenable to economic valuation include changes in percent eelgrass cover, shellfish abundance, and finfish assemblages.[7] Further, annual landings data and recreational harvest statistics are

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[4] U.S. Environmental Protection Agency, Office of Research and Development and National Center for Environmental Assessment. October 2002. Waquoit Bay Watershed Ecological Risk Assessment: The Effect of Land-Derived Nitrogen Loads on Estuarine Eutrophication. USEPA 600/R-02/079.

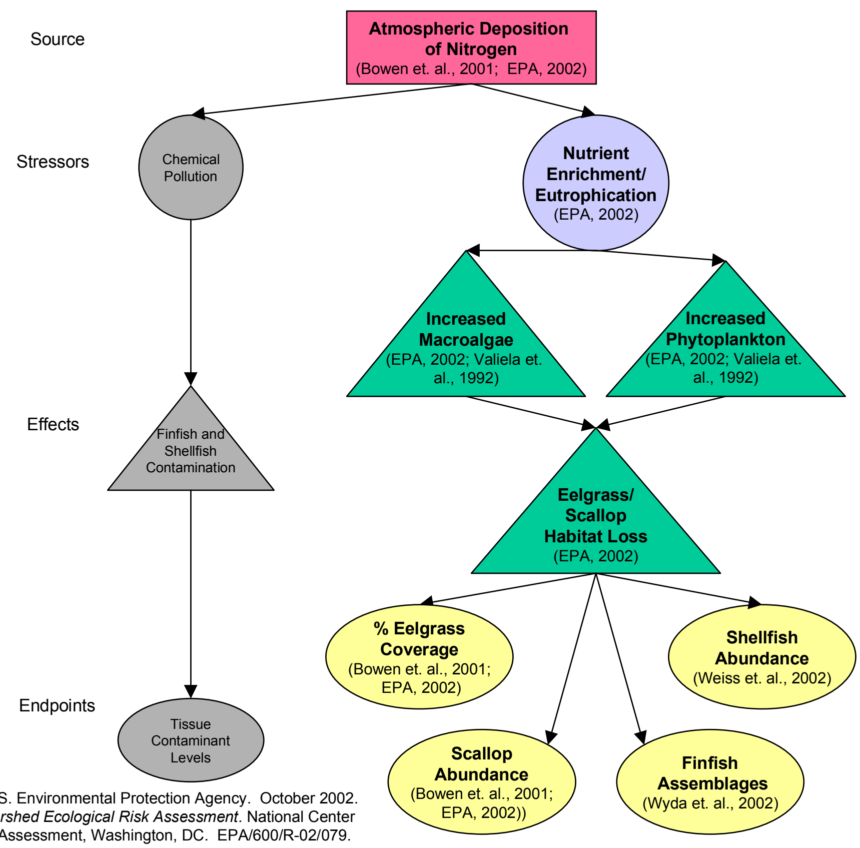
[5] EPA, 2002; and Bowen, J.L. and I. Valiela. 2001. The Ecological Effects of Urbanization of Coastal Watersheds: Historical Increases in Nitrogen Loads and Eutrophication of Waquoit Bay Estuaries. *Canadian Journal of Fisheries and Aquatic Science* 58: 1489-1500.

[6] EPA, 2002; and Valiela, I., et. al. 1992. Couplings of Watersheds and Coastal Waters: Sources and Consequences of Nutrient Enrichment in Waquoit Bay, Massachusetts. *Estuaries* 15: 443-457.

[7] Bowen et. al., 2001; EPA, 2002; Weiss, E.T., et al. 2002. The Effect of Nitrogen Loading on the Growth Rates of Quahogs (Mercenaria mercenaria) and Soft-shell Clams (Mya arenaria) Through Changes in Food Supply. *Aquaculture* 211: 275-289; and Wyda, J.C., et. al. 2002. The Response of Fishes to Submerged Aquatic Vegetation Complexity in Two Ecoregions of the Mid-Atlantic Bight: Buzzards Bay and Chesapeake Bay. *Estuaries* 25: 86-100.

available for certain species (e.g., winter flounder, tautog, Atlantic menhaden, scup, summer flounder, bay scallops, softshell clams, hardshell clams, and blue crabs).[8]

Exhibit 7-3
Ecological Effects of Atmospheric Nitrogen Deposition



Adapted from: U.S. Environmental Protection Agency. October 2002. *Waquoit Bay Watershed Ecological Risk Assessment*. National Center for Environmental Assessment, Washington, DC. EPA/600/R-02/079.

The extent to which changes in species population and assemblages can be conclusively linked to levels of eutrophication, and level of eutrophication further linked to level of atmospheric nitrogen deposition, is unclear at this time. These dose-response links are, however, subjects of continuous study at Waquoit, and data are currently available for particular species. For example, the impact of eelgrass decline on the lucrative bay scallop market is well-documented.[9]

[8] Commercial landings data is managed by the New England Fisheries Management Council; NOAA Fisheries tracks Atlantic Coast commercial landings and recreational harvest annually.

[9] EPA, 2002.

We also propose as part of a Waquoit Bay case study to include a qualitative description, with quantified effects where feasible, of socioeconomic effects of eutrophication. For example, we will describe impacts on recreational uses of the bay area such as fishing and boating. Impacts such as changes in residential property values may not be feasible at this site. Due to the small size of the bay, the level of eutrophication across the ecosystem is homogenous making baseline value estimates difficult to determine.

Chesapeake Bay- Virginia and Maryland

Chesapeake Bay is the largest estuarine system in the contiguous United States with a surface area of 3,562 square miles (9,226 square kilometers). The Chesapeake Bay watershed covers 64,000 square miles (166,000 square kilometers) and stretches from New York State to Virginia. The bay is cooperatively managed by the Chesapeake Bay National Estuarine Research Reserve, the Maryland Department of Natural Resources, Maryland-National Capital Park and Planning Commission, and various local government bodies. The EPA also manages a Chesapeake Bay Program with the objectives of collecting information regarding the bay's environmental quality, and determining appropriate measures to improve the bay and protect it's multiple resources. Development of an increasingly accurate nitrogen loading model at Chesapeake Bay that may be applied to estuaries nationwide is currently a subject of research under EPA's Great Waters Program. This program is also examining the potential for developing comprehensive integrated models to assess ecological and economic impacts. Such models are complicated by the sheer size of the bay and variations in stressors and ecological indicators across the system.

- **Source:** A Chesapeake Bay nitrogen deposition map is available through links with Regional Modeling System for Aerosols and Deposition (REMSAD).

- **Stressor:** The multiple sources of eutrophication of the Chesapeake complicate the definitive linking of eutrophication with specific sources.

- **Effects:** The multiple stressors affecting SAV makeup in the Chesapeake complicates definitive determination of effects due specifically to eutrophication of the system.

- **Endpoints:** Research is currently underway to determine the ecological indicators and a broad literature review has been conducted to determine the feasibility of linking these indicators to economic values.

At this time it is unclear whether a dose-response link exists to quantify SAV effects on species assemblages. Chesapeake Bay, however, is a highly productive ecosystem and a major commercial and recreational fishing, shellfish, and crabbing resource for the United States. Such linkages, therefore, would be beneficial to multiple industries that utilize the bay resource.

The Chesapeake Bay may also serve as a potential case study for property value effects of eutrophication in estuaries. The spatial variability in water quality lends itself to comparative property value study. A hedonic study was conducted in 2000 focusing on the effects of fecal coliform bacteria on property values along the bay.[10]

Recommendations for Case Study

To determine which site provides the best opportunity for case study, it is important to consider feasibility, accuracy, and transferability of results. Both ecosystems are sites of ongoing EPA-sponsored research relevant to the objectives of the second prospective analysis. While the small size of Waquoit Bay allows for more transparent environmental and economic impacts, the visibility and extent of ongoing research at Chesapeake Bay makes it an attractive option for case study as well. One advantage of Waquoit Bay is the availability of data linking SAV levels with species population effects. It is clear, however, that the results of an analysis of Waquoit Bay would not be nationally transferable. While Chesapeake Bay may be a more representative system, dose-response models pinpointing effects on ecological indicators are at this time unavailable. We plan to utilize a Waquoit Bay case study to qualitatively describe the physical impacts of atmospheric nitrogen deposition on the estuary, quantify the related impact to commercial fisheries, and describe, quantifying where possible, the impacts to recreation on the bay. We further intend to explore the feasibility of a residential property value study of the effects of eutrophication along the Chesapeake Bay as a means to bolster monetization of impacts of atmospheric nitrogen deposition to coastal estuary ecosystems. The specific goal of this feasibility analysis would be to determine if the eutrophication effects "signal" is strong enough to be discerned in property value data.

[10] Leggett, C.G., and N.E. Bockstael. 2000. Evidence of the Effects of Water Quality on Residential Land Proces. *Journal of Environmental Economics and Management* 39:121-144.

CHAPTER 8 - ECONOMIC VALUATION OF EFFECTS

The reduced incidence of physical effects is a valuable measure of the benefits of clean air; however, to aggregate or compare them, the benefits typically must be monetized. Assigning a dollar value to avoided incidences of each effect permits us to sum monetized benefits realized as a result of the CAAA, and compare them with the associated costs.

The best monetary measures of the benefits of clean air accurately reflect individuals' willingness to pay for the specific health and ecological risk reductions provided by reductions in the concentrations of ambient air pollutants. Limitations in the data and methods available to generate these monetary measures, however, often require the Agency to make judgements about the best available measures, considering the reliability, credibility, appropriateness, and comprehensiveness of existing estimates. A particular emphasis on the need for comprehensiveness in the economic valuation of benefit and cost effects in the 812 studies flows from the enabling statutory language for this series of studies, which states that "In any case where numerical values are assigned to such benefits, a default assumption of zero value shall not be assigned to such benefits unless supported by specific data."

This chapter provides a summary of EPA's efforts to continue to enhance the comprehensiveness of economic valuation of benefits within the limitations of credible and high-quality social scientific practice. We first review the basic approach used in the first prospective, then summarize our proposed revisions to the economic valuation strategy for mortality, morbidity, and environmental effects. Since July 2001, EPA has updated and revised the approach for mortality valuation and included a plan for a QALY-based cost-effectiveness analysis in response to SAB comments. In addition we ask the Council to comment on a new "alternative estimate" that includes a revised variant on the VSLY sensitivity test conducted in the First Prospective.

Review of Approach in First Prospective

In the first prospective analysis we monetized both health and welfare benefits. Monetized human health effects included mortality and morbidity endpoints, and monetized welfare effects included agricultural and selected ecological benefits, recreational visibility, and worker productivity. In general, we based our valuation estimates on reviews of the relevant economic literature, and reported the results in "dollars per case reduced" for health effects. For welfare effects, we used modeling approaches specific to the particular effect. We reported each of the monetary values of benefits applied in terms of a central estimate. In addition, for health endpoints, we also provided a probability distribution around that value. The statistical form of the probability distribution varied by endpoint. For example, we used a Weibull distribution to describe the estimated dollar value of an avoided premature mortality, while we assumed the estimate for the value of a reduced case of acute bronchitis is uniformly distributed between a minimum and maximum value.

The first prospective relied on estimates of mean WTP wherever possible. In cases where WTP estimates were not available, we used the cost of treating or mitigating the effect as an alternative estimate. For example, for the valuation of hospital admissions we used the avoided medical costs as an estimate of the value of avoiding the health effects causing the admission. These costs of illness (COI) estimates generally understate the true value of avoiding a health effect. They tend to reflect the direct expenditures related to treatment and not the utility an individual derives from improved health status or an avoided health effect. As noted above, we use a range of values for most environmental effects, to support the primary central estimate of net benefits. Table 8-1 summarizes the mean unit value estimates that we use in this analysis. We present the full range of values in Chapter 11, including those used to derive the primary low and primary high estimates.

Table 8-1
Central Estimates for Health Effects Unit Valuation
Used in the First Prospective (1990 dollars)

Endpoint	Pollutant	Valuation (mean est.)	
Mortality	PM_{10}	$4,800,000	per case
Chronic Bronchitis	PM_{10}	$260,000	per case
Chronic Asthma	O_3	$25,000	per case
Hospital Admissions			
All Respiratory	SO_2, NO_2, PM_{10} & O_3	$6,900	per case
All Cardiovasular	SO_2, NO_2, & CO PM_{10} & O_3	$9,500	per case
Emergency Room Visits for Asthma	PM_{10} & O_3	$194	per case
Respiratory Illness and Symptoms			
Acute Bronchitis	PM_{10}	$45	per case
Asthma Attack or Moderate or Worse Asthma Day	PM_{10} & O_3	$32	per case
Acute Respiratory Symptoms	SO_2, NO_2, PM_1, & O_3	$18	per case
Upper Respiratory Symptoms	PM_1	$19	per case
Lower Respiratory Symptoms	PM_{10}	$12	per case
Shortness of Breath, Chest Tightness, or Wheeze	PM_{10} & SO_2	$5.30	per day
Work Loss Days	PM_{10}	$83	per day
Mild Restricted Activity Days	PM_{10} & O_3	$38	per day

The welfare effects valuation approaches applied in the first prospective were as follows:

- **Recreational Visibility**: The physical effect on visibility was modeled using the RADM (in the East) and REMSAD (in the West) air quality modeling systems. Valuation was based on application of the Chestnut and Rowe (1990) study of WTP for visibility in national parks included in the Chestnut and Rowe study. Residential visibility was not monetized, primarily because of concerns by the Council that the unpublished McClelland et al. (1990) study of Atlanta and Chicago did not adequately account for "warm glow" and non-response biases. Recreational visibility nonetheless was the largest welfare benefit, with a central estimate of $2.9 billion in 2010.

- **Agriculture:** Effects on agriculture associated with reduced ozone concentrations were modeled using NCLAN dose-response functions and the AGSIM economic modeling system. We estimated the net monetized effects of air pollution on agriculture to be beneficial, with a central estimate of $550 million in benefits in 2010.

- **Worker Productivity**: Effects of reduced ozone concentrations on worker productivity were estimated based on the Crocker and Horst (1981) study. This category of benefits totaled $710 million in 2010.

- **Commercial Timber**: Effects of reduced ozone concentrations on the timber market were modeled based on application of the Net Photosynthesis and Evapo-Transpiration model II (PnET II) biological model of timber stand productivity. The results, generated by species and region, were then evaluated using the US Forest Service's Timber Assessment Market Model (TAMM) to generate a benefit estimate of $600 million in 2010.

- **Acidification:** Effects of reduced acid deposition on freshwater recreational fisheries were modeled using deposition estimates from the RADM air quality model, EPA's Model of Acidification of Groundwater in Catchments (MAGIC) to generate pH changes in lakes in the New York State Adirondack region, and an economic model of recreational fishing behavior in New York State (the Montgomery and Needelman (1997) random-utility model). Total benefits for this category were about $50 million in 2010.

In the first prospective, the benefit of avoided premature mortality risk reduction dominated the overall net benefit estimate. Of the total $110 billion in estimated benefits for 2010, we attributed $100 billion to avoided mortality, about $8 billion to avoided morbidity, and about $5 billion to ecological and welfare effects (totals do not add due to rounding). This result was, in part, due to the high monetary value assigned to the avoidance of premature mortality relative to the unit value of other health endpoints, but is also attributable to the current lack of data and defensible modeling approaches to characterize a broader range of ecological effects. SAB Council reviewers noted that, while the approach to mortality valuation likely represented the best current alternative, significant uncertainties in the application of the approach remained.

Revisions to Approach for Second Prospective - Mortality Valuation

Recent efforts by the Agency to improve the characterization of mortality valuation have included consultation with the SAB Environmental Economics Advisory Committee (summarized in EPA-SAB-EEAC-00-013, 2000 for mortality valuation in general, and EPA-SAB-EC-01-008, 2001 with a specific focus on fatal cancer case valuation). Those consultations focused on benefits transfer issues that arise out of the use of wage-risk and contingent valuation (CV) mortality scenarios that differ from the fatal risk scenario presented by air pollution exposure. Those benefits transfer issues are among the key uncertainties cited by the SAB Council in their review of the first prospective analysis.

We propose to follow the SAB advice from those consultations for the benefits transfer component of our valuation strategy, consistent with the application for the recent Nonroad Diesel rule (U.S.EPA, 2003), with a few significant revisions. We also intend to follow the advice of the SAB Council by including use of a meta-analysis for the base VSL estimate [EPA-SAB-COUNCIL-ADV-01-004, page 23]. We first discuss our strategy for generating a new central value of statistical life (VSL) estimate, and then discuss our approach to adjusting that value to address benefits transfer concerns.

Value of Statistical Life

To estimate the economic value of mortality benefits associated with air pollution reductions, economic theorists prefer estimates that reflect *ex ante* values of reducing the risk of mortality across the population (i.e., for individuals having different health states and other characteristics such as income level and risk perception). This requires an estimate of an individual WTP for a reduction in an involuntary risk that will change individuals' survival probabilities for a lifetime. Developing a valuation estimate based on this theoretically ideal approach, however, is currently subject to significant data and methodological problems. Moreover, many of the valuation methods that are frequently presented as an alternative to the value of statistical life (VSL) approach rely on VSL estimates and calculate values that depend on lifespan data, which may be difficult to measure given the current health data limitations. Consequently, EPA's current interpretation of the state-of-the-art in premature mortality valuation leads to adoption of the VSL approach for development of the primary benefit estimate.

In the June 2001 draft analytical plan, EPA proposed to rely on an updated review of empirical literature relevant to the valuation of avoided mortality. That review relied on a set of criteria for selecting the highest-quality and most rigorous empirical VSL studies from the economics literature, then applied the criteria to select a subset of VSL studies appropriate for valuation of avoided premature mortality. The approach used was consistent with informal SAB Council advice from the First Prospective.

SAB Council review of the draft analytical plan, however, suggested that a VSL meta-analysis could have significant advantages over the previously proposed approach. In particular, they cited as a key goal "furthering understanding of how VSL estimates vary with study methods, characteristics of the risk context, and the attributes of study subjects." In response to this guidance, EPA reviewed several existing meta-analytic studies, and participated in two new studies. We selected one of these studies, Kochi et al. (2003), which is specifically focused on combining estimates for application to environmental policy analysis, to serve as the basis for our selection of VSL values for the Second Prospective. A working paper that describes the study is provided in Appendix H.

The Kochi et al. (2003) study makes use of a hierarchical Bayesian technique for generating a meta-analytic function of VSL estimates. One key advantage of this approach is that it provides a revised estimate of the variance around a central VSL estimate that incorporates measurement uncertainty estimates from each of the individual underlying VSL study estimates. The study applies an initial screen to eliminate studies that do not provide useful information for this purpose, as suggested by the Council in its comments on the draft analytical plan. The result is a meta-analytic database that includes a total of 196 individual VSL estimates and study attributes from 40 selected VSL studies.

The estimated composite distribution of VSL estimates from this database, as derived from the meta-analysis, has a mean of $5.4 million and a standard deviation of $2.4 million.[1] The unadjusted composite estimates are somewhat lower than those EPA has traditionally applied. To provide context for this estimate, EPA's *Guidelines for Economic Analyses* recommends a VSL value of $6.4 million (U.S. EPA 2000d), Viscusi's (1992) recommended range of reasonable estimates is from $4.0 to $9.4 million, and the mean of all 60 studies identified in EPA's prior literature review is $8.3 million (before excluding studies for consistency with the selection criteria). Viscusi and Aldy (2003) have recently revisited the Viscusi (1992) recommended range and conclude that the value of statistical life for prime-aged workers has a median value of about $7 million in the United States.

It is not clear, however, that the composite mean from the Kochi et al. meta-analysis represents the correct value to use for this particular environmental policy context. For example, the composite mean includes estimates from populations outside the U.S., including lesser developed countries. In addition, the estimates are sensitive to the choice of valuation method (wage-risk or contingent valuation) and study location (i.e., country). We have as yet made no attempt to match study characteristics to those best suited to the Second Prospective. EPA seeks advice from the Council on the selection of the Kochi et al. study as the basis for mortality valuation, as well as advice on the most appropriate application of the meta-analytic function from this study for the purposes of the Second Prospective.

As outlined in the first prospective, and reiterated to some degree in the EPA *Guidelines for Economic Analysis*, EPA has in the past considered several alternative approaches for estimating a value for the reduction in risk of premature mortality. Each, however, has either methodological inconsistencies with the preferred utility-based approach, or does not provide a value estimate for a commodity comparable to that provided by reduced air pollution. Those alternatives include:

[1] Estimates are in 2001 US dollars.

- **Life Quality Adjustment:** This approach relies on VSL estimates applied to survey estimates of life-years (i.e., QALYs or DALYs) for the economic valuation. Currently, no generally accepted estimate or range of estimates of VSLY have been established. Instead, these values derive from various VSL studies and reflect numerous discount rates. In addition, the life years estimates require data sets that can account for the health states or utilities specific to a wide variety of health effects associated with air pollution. In many cases, these estimates are not available or are based on health professionals' perceptions of various health outcomes, and not necessarily based in economic utility theory. As described below, we seek the Council's comment on an alternative VSLY application. Despite these and other concerns expressed below, we plan to provide an estimation of adjunct QALY-based cost-effectiveness results for the Second Prospective; however, we do not plan to use the QALY estimates in the benefit-cost results.

- **Longevity:** The longevity valuation approach of Johannesson and Johansson (1996 and 1997) provides an estimate of the value for an identifiable one-year life extension. While the contingent valuation approach used may be consistent with utility theory, the commodity valued does not represent the commodity gained through improvement of ambient air quality. The Council's advice on the draft analytical plan clearly recommended against this approach for application in the Second Prospective.[2]

- **Cost Effectiveness:** An approach taken by Garber and Phelps (1997) reflects consideration of survival probabilities throughout an individual's lifetime, but the methodology is based on a utility function that makes specific assumptions about individual preferences to measure WTP rather than eliciting value from either a revealed or stated preference approach. Moreover, this approach measures a WTP that may be overly constrained by income. Where individual risks are small (usually less than one in ten thousand) relative to certain loss of life, individual WTP may also be small relative to income, and the medical treatment decision-making framework may be less applicable. As described below, we do plan to generate adjunct QALY-based cost-effectiveness results, but do not plan to apply the Garber and Phelps approach.

Adjustments to VSL Values

The "base value" VSL is our first step in developing a mortality risk valuation estimate applicable to the air pollution scenario. The two-step process we propose first requires the selection of a basis for generally applicable, policy-relevant estimates of mortality risk valuation, regardless of specific method or scenario, and then the application of benefits transfer procedures either to adjust the range of estimates developed or, alternatively, to adjust each of the selected estimates

[2] "The Johannesson and Johansson (1997) results should also be eliminated ... because they are estimates of value now for risk reduction much later in life. That is not the measure of VSL that EPA should be seeking for this analysis." [EPA-SAB-COUNCIL-ADV-01-004, page 22.]

individually to better fit the individual result to the air pollution risk reduction scenario.

Recent SAB deliberations on mortality valuation approaches suggest that some adjustments to unit values are appropriate to reflect economic theory (EPA-SAB-EEAC-00-013, 2000). There are two adjustments in particular that we propose to apply for these results: discounting of lagged effects (applies to the five-year distributed lag assumed for mortality incidence, and cancer risk from benzene exposures in the air toxics case study described in Appendix I of this document); and incorporation of the effect of changes in income over time on willingness to pay (WTP) to reduce health effects. We propose to discount lagged benefits using a three percent discount rate, and to estimate the effects of changes in income over time using the procedure outlined as an illustrative calculation in Appendix H of the first prospective, and subsequently applied with some refinement in recent regulatory support analyses. That procedure uses per capita income estimates generated from Federal Government projections of income and population growth, and applies three different income elasticities for mortality, severe morbidity, and light symptom effects. These adjustments are applied to develop the primary and any alternative benefits estimates.

As stated in the June 2001 draft analytical plan, a revised and updated literature review on available income elasticity estimates, current through September 2000, was applied in recent rulemakings, including the nonroad diesel rule. We propose to use that memorandum as the basis for our estimates, which are only slightly altered from those described in Appendix H of the first prospective.[3] Earlier this year, Viscusi and Aldy (2003) estimated an income elasticity using a meta-analytic technique and found that income elasticity for mortality valuation was roughly consistent with EPA's preferred approach (the central estimate of income elasticity for mortality valuation in EPA's approach is 0.4; Viscusi and Aldy found a central estimate of from 0.5 to 0.6). We believe this recent work provides additional support for EPA's approach, and suggests that the EPA approach may in fact be using conservatively low estimates for this adjustment. As suggested by the Council, however, we recognize there is substantial uncertainty about the magnitude of this elasticity, and that it might in fact be greater than one.[4] We therefore intend to reflect the uncertainty surrounding this elasticity in our uncertainty analysis. Specifically, we intend to explore whether existing data are adequate to define a probability distribution for this elasticity sufficiently valid and reliable to incorporate in the probabilistic assessment of the primary estimate. If a satisfactory distribution for the elasticity cannot be developed, the significance of the elasticity value will be explored in the context of sensitivity testing.

[3] The updated literature review is summarized in a September 30, 2000 memorandum to Jim DeMocker, EPA, from Naomi Kleckner and Jim Neumann, Industrial Economics Incorporated, "Update to Recommended Approach to Adjusting WTP Estimates to Reflect Changes in Real Income."

[4] "With regard to adjusting for income growth, EPA proposes to value future changes in mortality risk using a VSL that increases to account for anticipated increases in real income. This approach is conceptually appropriate, but there is substantial uncertainty about the appropriate income elasticity to use. Prior survey work by the EPA suggests a central value of 0.36 for this elasticity; careful meta-analysis may justify a different central value. Meta-analysis should also establish a reasonable range for this elasticity. EPA should also consider the possibility that the relevant income elasticity is larger than 1.0, as suggested by some international comparisons (e.g., Liu et al., 1997) and a time-series study in Taiwan (Hammitt et al., 2000)." [EPA-SAB-COUNCIL-ADV-01-004, pp. 23-24.]

Although there are other arguments for quantitative adjustments to be made to reflect theoretical economic considerations, EPA prefers not to draw distinctions in the monetary value assigned to the lives saved by environmental regulations even if they differ in age, health status, socioeconomic status, gender, or other characteristics of the adult population. We propose to conduct a select set of additional adjustments as part of a series of sensitivity analyses and alternative results. The first prospective included an adjustment for age, for example, using a VSLY approach. We seek the Council's comment on a modified VSLY approach that has been applied in recent regulatory rulemakings, as described below.

Finally, as in the first prospective we propose to discuss other relevant benefits transfer considerations qualitatively, including the potential impact of differences in the nature of the risk scenario. This includes discussion of the impact of such characterstics such as dread, involutariness, and uncontrollability as potentially important determinants of WTP to avoid mortality risk.[5]

Alternative Estimate

In two recent mobile source rulemaking analyses and in the benefits analysis for the Clear Skies Initiative, EPA included an "Alternative Estimate" in addition to a "Base Estimate" of total monetized benefits. The Alternative Estimates included in these three analyses differed with each other in some respects, but in each case they reflected some combination of alternative assumptions regarding key factors in the estimation of PM-related benefits, particularly premature mortality and chronic bronchitis. The specific differences from "Base Estimate" assumptions or methods for valuation used in each of these three analyses are summarized in Exhibit 8-2. Advocates of the inclusion of these Alternative Estimates suggested that they represent plausible best estimates for total monetized benefits for the associated rules, and therefore could be viewed as a replacement for the "Base Estimate." EPA seeks advice from the Council regarding the value of using an "alternative estimate" approach either in lieu of, or in conjunction with, a probabilistic treatment of uncertainty in the primary estimates. In addition, EPA seeks advice from the Council pertaining to the scientific and technical merits of the specific assumptions listed in Exhibit 8-2 which were incorporated in the "alternative estimates" presented in the three recent EPA analyses.

[5] Note that our currently proposed plan for addressing benefits of air toxics provisions does not include quantification or monetization of avoided cancer cases and/or cancer-related premature mortality. Valuation of avoided premature fatalities associated with cancer would involve an additional set of benefits transfer considerations, including a potential additional component of the valuation to reflect pre-fatality cancer morbidity.

Exhibit 8-2 Alternative Estimates that Replace Primary Analysis Assumptions

	Recent Analyses	
Alternative Estimate	**Recreational Vehicles and Clear Skies Initiative and two MACT analyses**	**Nonroad Diesel Vehicles**
Mortality Valuation - Short-term exposure	Addressed four key assumptions associated with mortality valuation: 1) Selected only five contingent valuation studies from a larger set of 26 studies recommended by Viscusi (1992); 2) Used an adjustment factor derived from Jones-Lee (1989) to approximate the relationship between age and willingness-to-pay for fatal risk reductions; and, 3) Assumed that deaths from chronic obstructive pulmonary disease are advanced by 6 months and deaths from all other causes are advanced by 5 years. 4) Applied a VSLY approach to valuation of these lost life-years	Addressed three key assumptions associated with mortality valuation: 1) Selected only five contingent valuation studies from a larger set of 26 studies recommended by Viscusi (1992); 2) Used a value of statistical life years approach, as opposed to a VSL approach, to recognize that each year late in the life span may have a higher monetary value than the average life year saved in the middle of the life span; and, 3) Assumed that deaths from chronic obstructive pulmonary disease are advanced by 6 months and deaths from all other causes are advanced by 5 years.
Chronic Bronchitis Valuation	Cost of Illness (COI) estimate based on Cropper and Krupnick (1990).	Cost of Illness (COI) estimate based on Cropper and Krupnick (1990).

Revisions to Approach for Second Prospective - Morbidity Valuation

We propose to estimate values for most avoided morbidity effects using unit values developed for the Non-Road Diesel RIA (U.S.EPA, 2003). In some cases, however, we propose to rely on a study by Dickie and Ulery (2002) that we expect to be published (or accepted for publication) by the time the second prospective analysis is carried out. The Dickie and Ulery study is the only study of which we are aware that attempts to estimate how much more parents are willing to pay to avoid respiratory symptoms in their children versus in themselves. Because most of the respiratory symptoms studies have focused on children, this distinction is particularly relevant. We summarize the details of our proposed approach in Exhibit 8-3 below.[6]

[6] In its review of the draft analytic plan, the SAB Council recommended that EPA develop valuation estimates for asthma symptom days based on a cost-of-illness approach [EPA-SAB-COUNCIL-ADV-01-004, page 25]. However, we are not aware of dose-response functions for that particular health endpoint.

Exhibit 8-3

SUMMARY OF PROPOSED MORBIDITY VALUATION STRATEGY

<table>
<tr><th>Endpoint</th><th>Basis for Valuation</th></tr>
<tr><td>Chronic Bronchitis</td><td>Value is the mean of a Monte Carlo distribution of WTP to avoid a case of pollution-related CB. WTP to avoid a case of pollution-related CB is derived by adjusting WTP (as described in Viscusi et al., 1991) to avoid a severe case of CB for the difference in severity and taking into account the elasticity of WTP with respect to severity of CB (US EPA, 1999a). This approach was also used in the first prospective analysis. As an alternative valuation approach, we propose to use COI estimates based on Cropper and Krupnick (1990), including both medical costs and opportunity cost from age of onset to expected age of death (assuming that chronic bronchitis does not change life expectancy).</td></tr>
<tr><td>Hospital Admissions: Chronic Obstructive Pulmonary Disease (COPD), Pneumonia, Asthma, All Cardiovascular</td><td>COI estimates. Medical cost component: Data on ICD code-specific hospital charges and lengths of stay from the Agency for Healthcare Research and Quality's (AHRQ's) Healthcare Cost and Utilization Project (HCUP), 2000 (www.ahrq.gov). Opportunity cost component: Value of time spent in hospital calculated as average length of hospital stay times value of a day lost, evaluated as year-2000 county-specific median annual wage divided by (52*5) – to get median daily wage. This approach was also used in the first prospective analysis; however, we are proposing to use an updated database and replace a national estimate of median wage with county-specific estimates.</td></tr>
<tr><td>Non-fatal myocardial infarction</td><td>COI estimates. Medical cost component based on cost-of-illness studies (Wittels et al., 1990; Russell et al., 1998), covering costs for a five-year period. Opportunity cost component based on estimated lost earnings over a 5-year period, using annual lost earnings estimates from Cropper and Krupnick (1990). Annual lost earnings depend on age of onset of the illness. This morbidity endpoint was not included in the first prospective analysis.</td></tr>
<tr><td>Emergency room visits for asthma</td><td>COI estimate based on two studies: Smith et al., 1997 and Stanford et al., 1999. In the first prospective analysis we used only Smith et al., 1997.</td></tr>
<tr><td>Upper Respiratory Symptoms (in children)</td><td rowspan="2">The first prospective analysis used combinations of the three symptoms for which WTP estimates were available that closely match those listed by Pope et al. (1995), resulting in seven different "symptom clusters," each describing a "type" of URS. A dollar value was derived for each type of URS, using IEc mid-range estimates of WTP to avoid each symptom in the cluster and assuming additivity of WTPs. The dollar value for URS was the average of the dollar values for the seven different types of URS. Similarly, the first prospective analysis used combinations of the four symptoms for which WTP estimates were available that closely match those listed by Schwartz et al. (1994), resulting in 11 different "symptom clusters," each describing a "type" of LRS. A dollar value was derived for each type of LRS, using IEc mid-range estimates of WTP to avoid each symptom in the cluster and assuming additivity of WTPs. The dollar value for LRS was the average of the dollar values for the 11 different types of LRS.

For the second prospective analysis, we propose to rely on a more recent CV study by Dickie and Ulery, 2002 (which we expect to be published by the time the second prospective analysis is undertaken). This study finds consistently across several models that parents are willing to pay about twice as much for their children as for themselves. At a minimum, we propose doubling the estimates used in the first prospective analysis. A possible alternative is to use the results of one of the Dickie and Ulery models of parental WTP as a function of the number of symptom-days. These results tend to be significantly larger than twice the estimates used in the first prospective analysis.</td></tr>
<tr><td>Lower Respiratory Symptoms (in children)</td></tr>
<tr><td>Acute Bronchitis (in children)</td><td>Six times the estimate of WTP per day of acute bronchitis, based on a typical duration of the illness being 6 days, as noted in Dickie and Ulery (2002) as well as in other sources (see, for example, www.mdainternet.com/topics_b/bronchitis_acute.htm); Per-day WTP estimate is average of low and high values recommended for use in the prospective series of analyses (Neumann et al., 1994) and was used in the first prospective analysis.</td></tr>
</table>

Exhibit 8-3

SUMMARY OF PROPOSED MORBIDITY VALUATION STRATEGY

Endpoint	Basis for Valuation
Asthma attacks	This morbidity effect is quantified but not valued in recent analyses; however, the project team is still considering whether to monetize this endpoint using Rowe and Chestnut (1986) and/or Dickie and Ulery (2002).
Acute/chronic bronchitis (in children)	No valuation method available.
Chronic phlegm (in children)	No valuation method available.
Work Loss Days	County-specific median annual wages divided by (52*5) to get median daily wage. U.S. Year 2000 Census, compiled by Geolytics.
School Loss Days	This morbidity endpoint was not included in the first prospective analysis. We propose to value a school loss day by valuing the corresponding work loss day, (1) estimating the probability that, if a school child stays home from school, a parent will have to stay home from work to care for the child, and (2) valuing the lost productivity at the person's wage. We acknowledge that this will understate the value of a school loss day – first, because it omits WTP to avoid the symptoms/illness which resulted in the school absence, and second, because it effectively gives zero value to school absences which do not result in a work loss day. A possible alternative approach would be to use one of the models in Dickie and Ulery (2002), e.g., estimating parental WTP to avoid a day of fever in a child (which would result in an absence from school).
Mild Restricted Activity Days (MRAD)	The first prospective analysis relied on WTP estimates from Tolley et al., 1986. We propose to rely on a more recent CV study by Dickie and Ulery, 2002 (which we expect to be published by the time the second prospective analysis is undertaken).

Plan for a QALY-based Cost-Effectiveness Analysis

In the previous prospective 812 study and in the June 2001 draft blueprint for the current study, EPA preferred not to report results in terms of QALY-based cost-effectiveness. This preference was motivated primarily by:

(1) the lack of generally accepted data and methods applicable to QALY computation in an air pollution context,

(2) potential biases in the implicit cost-effectiveness results caused by incomplete netting out of other health and ecological benefits from the numerator,

(3) concerns about the distortionary effect of the simplifying assumptions pertaining to time and quality trade-offs required to estimate QALYs, and

(4) the general disconnect between available QALY methodologies and standard economic utility theory.

In addition, EPA is seriously concerned about the requirement imposed by the QALY methodology to assign lower values to the lives, and the quality of the lives, of people of advanced age and/or impaired health status. However, the SAB Council in its review of the June 2001 draft blueprint recommended that EPA consider reporting results in terms of implied cost-effectiveness using QALYs or value of statistical life year (VSLY).[7] The remainder of this section describes the approach EPA plans to take to implement the SAB's recommendation.

As briefly summarized above, a life-quality adjustment approach relies on health preference index values that incorporate two dimensions of health, quality and longevity, into a single quantitative measure. Life quality approaches make strong assumptions about the utility function for health improvements. The most important assumptions are that the utility individuals derive from health is based on their physical condition and longevity, and that these attributes are independent random variables. However, neither of these assumptions are well supported by economic theory. In addition, it is difficult to apply a life quality adjustment approach to our analysis because information on health states or utilities specific to health endpoints associated with air pollution is often either unavailable or based on health professionals' perceptions of various health outcomes rather than on the preferences of affected individuals per economic utility theory. As a result, we believe that the life quality adjustment approach is not well suited for our base analysis. Instead, we plan to use this approach as an adjunct set of results to accompany our base results.

Specifically, we plan to use the Quality Adjusted Life Year (QALY) approach to develop a cost/QALY estimate of the cost effectiveness of the CAAA in 2000, 2010 and 2020. The QALY approach is the most common life quality adjustment methodology applied in the context of evaluating medical interventions. Starting from the conceptual framework of a two-attribute utility function (U(q,T)), the simplified computational method for aggregating QALYs is

$$\text{QALYs} = q_1 * T_1 + q_2 * T_2 + \ldots + q_n * T_n.$$

where q represents the quality of the health state rated on a scale of 0 to 1 in each of N time periods and T measures the corresponding quantity of time spent in that health state. Increases in q and T are assumed to improve aggregate utility.

[7] "If benefit-cost analysis is to be conducted in accordance with conventional, Kaldor-Hicks foundations, the Council agrees with EPA that VSL is the conceptually appropriate method for assessing the benefits of avoided premature mortality. Alternative measures, such as the value of a statistical life-year (VSLY) or the value of a QALY, are not consistent with the standard theory of individual WTP for mortality risk reduction. Nevertheless, these alternative metrics are widely used to evaluate other public-health interventions, and there are significant uncertainties about the correct values for VSL for this analysis. Given the significance of the valuation for mortality risk reductions in the benefit estimates for the CAA, the Council suggests that EPA consider reporting some results in terms of implied cost-effectiveness (e.g., dollars per life-year)." [EPA-SAB-COUNCIL-ADV-01-004, page 26.]

There are five steps to our proposed approach:

1) **Estimating Relevant Costs:** In order to facilitate comparison to a purely health-based effectiveness measure, the denominator of the cost/QALY equation should only include costs that are relevant for changes in health risk. If the costs of non-health improvements are not netted out of the cost estimate, the results are likely to underestimate the health benefits of a given scenario. Therefore, we plan to subtract the non-health benefits of the CAAA, such as visibility and ecological benefits, from the regulations' net costs to estimate cost/QALY. Note that this approach is likely to overstate net costs because there is likely a substantial unquantified component of ecological benefits.

2) **Identifying health outcomes of interest:** We plan to estimate the cost/QALY of health benefits associated with four key health endpoints with well-defined quantitative data on average utility values.

   - Premature Mortality
   - Chronic Bronchitis
   - Chronic Asthma
   - Nonfatal myocardial infarction

   Available data on the utilities associated with other endpoints, such as mild restricted activity days and acute bronchitis cases, are sparse. Therefore, we plan to subtract cost-of-illness estimates for these other endpoints from the net-cost figures to estimate the cost/QALY for benefits associated with the three quantified health endpoints.

   There are two factors that might lead this approach to overestimate net costs (and thus overestimate cost/QALY). First, the cost-of-illness estimates netted out of the analysis likely represent an underestimate of the benefits associated with those endpoints. In addition, the net costs will not account for health benefits associated with air toxics because the base analysis does not quantify the number or value of avoided health effects associated with air toxics control.

3) **Developing Health Preference Index Estimates For Each Health Effect:** We plan to estimate health state utility scores based on the existing QALY literature. The Harvard Center for Risk Analysis' Cost/Utility Analysis (CUA) database is one available source of information on the QALY literature.[8] Other available information sources to be considered by the project team include the WHO Global Burden of Disease database, Disability Weights for Diseases in the Netherlands, and other sources compiled by Bryan Hubbell and included in Appendix J of this blueprint. We describe our health state utility assumptions for each quantified endpoint below.

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[8] Another useful source for developing QALY scores is Ian McDowell and Claire Newell, *Measuring Health: A Guide to Rating Scales and Questionnaires*, New York: Oxford University Press, 1996.

- Premature Fatalities: We assume that there is a utility of 0 associated with death.
- Chronic Bronchitis: Based on Torrance et al (1999), we assume that the mean utility for chronic bronchitis patients receiving usual care treatment is 0.76.[9] Hollander et al. (1999) may be another source of quality of life values for chronic bronchitis.[10]
- Chronic Asthma: Based on Paltiel et al (2001), we assume that chronic asthma patients have an average utility of 0.80.[11]
- Nonfatal myocardial infarction: Based on Johannesson et al (1997), we assume that nonfatal myocardial infarction reduces patients' utility by 0.10.[12]

We plan to continue to monitor the QALY literature for studies that might address other air-pollution-induced health effects.

4) **Developing Estimates of "Time in State" for Each Health Effect:** After we have identified QALY scores, the next step is to estimate the duration over which the QALY scores apply. The QALY scores make up the "quality" dimension in the simplified utility model that underlies this approach, and estimates of "time in state" are the "quantity" dimension. Data on remaining life expectancy for the relevant affected population is needed for both the baseline state and CAAA scenarios.

   We plan to use a variety of sources for time in state data:

   - For premature fatalities, we will estimate age-of-death and life-years lost based on the age distribution of premature fatalities developed for the primary analysis.[13]

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[9] Torrance G, et al, Economic Evaluation of Ciprofloxacin Compared with Usual Antibacterial Care for the Treatment of Acute Exacerbations of Chronic Bronchitis in Patients Followed for 1 Year, *Pharmacoeconomics*, November, 1999. Note that this is the only high-quality article on the average utility of chronic bronchitis patients that we were able to identify.

[10]

[11] Specifically, we assume that patients have 70% of normal lung function and we estimate average utility using the formula: Utility = 0.521 + 0.003958 * (% normal lung function). Paltiel, AD et al, Cost-effectiveness of Inhaled Corticosteroids in Adults with Mild-to-Moderate Asthma: Results from the Asthma Policy Model, *Journal of Allergy Clinical Immunology*, 108(1), July, 2001.

[12] Johannesson, Magnus, David Meltzer, and Richard M. O'Conor. "Incorporating future costs in medical cost-effectiveness analysis: Implications for the cost-effectiveness of the treatment of hypertension," *Medical Decision Making*, 17: 382-389, 1997.

[13] See Chapter 6 of this document.

- For non-fatal health endpoints (e.g. chronic bronchitis and chronic asthma), we will calculate incidence based on the estimates in the primary analysis and we will assume that the age-distribution of the air pollution related incidence is the same as the age-distribution of the incidence in the general population.[14] This will provide the age distribution of incidence for air pollution related cases. We will assume that patients suffer from the health effect for the rest of their lives, and use standard life expectancy tables to obtain time in state estimates.

5) **Aggregating and Analyzing the Results:** The final step in the analysis is to apply the quality of life scores presented in Step 4 to the time-in-state estimates. First, we will subtract the quality of life scores from one to generate the marginal gains associated with an avoided case-year in a given health state. Then, we will multiple this marginal QALY gain by the time in state results for each health state and aggregate the increase in QALY's for each health effect. Finally, we will divide the net costs by the total increase in QALY's to produce cost/QALY estimates.

Preliminary Evaluation of Relevant QALY Literature

In our initial literature search to obtain relevant QALY studies, we used three criteria to identify applicable studies:

- First, we used the CUA database to identify high quality studies that examine relevant health endpoints. The CUA database includes quality "scores" which provide a guide to how studies compare to a set of best practices defined by the database developers.
- Second, we eliminated studies that did not provide quality of life and time in state values for health states of interest. This step narrowed the range of relevant articles significantly. Because the objective of the health literature is to determine the most cost effective treatment for a given health effect, studies often report quality of life values for treatment regimens rather than for the health states associated with the health effect.
- Finally, we eliminated studies that did not provide adequate documentation of how quality of life and time in state were obtained or that were not well suited for the environmental policy context.

Our initial literature search produced three suitable articles. The first article (Torrance et al. 1999), examined the cost-effectiveness of different treatments for acute exacerbations of chronic bronchitis. The study estimated utility values based on the responses of the 222 outpatient adult men

[14] To obtain the age distribution of incidence in the general population, we will consult current CDC data.

and women in the study to a survey using the Health Utilities Index. The study found that patients receiving usual care treatment have an average utility score of approximately 0.76.

The second study (Paltiel et al. 2001) estimated the cost-effectiveness of inhaled corticosteroids for adults with mild-to-moderate chronic asthma. It used the results of a companion study of 100 adults with asthma in the Lexington, Kentucky area for its health state utility values. This study used several instruments to obtain utility values, including direct utility assessments with time trade-tradeoff (TTO), standard gamble, and rating scale questions, and multi-attribute utility scores via the Health Utilities Index and the Asthma Symptom Utility Index. The study then estimated the relationship between lung capacity and utility scores separately for each assessment technique using ordinary least squares regressions. Based on recommendations from the U.S. Panel on Cost-Effectiveness in Health and Medicine,[15] the study used TTO preferences as its preferred utility function. This function takes the form: U = 0.521 + 0.003958 * (FEV), where U is equal to the utility value and FEV is equal to the predicted percent of normal lung function.

The third study (Johannesson et al 1997) estimated the impact of including net consumption resulting from changes in longevity as a cost component in cost-effectiveness analyses of stroke and coronary heart disease treatment. The study used an existing computer simulation model based on the Framingham Heart Study as the basis for health status profiles. In order to adjust health profile states for quality of life associated with respective health conditions, baseline health preference indices were derived from a EuroQol rating scale survey of the Swedish general population. Based on the results of the survey, the study assigned health quality weights of 0.71 for adults aged 75 and over, 0.78 for those ranging from 65 to 74 years of age, 0.82 for those ranging between 50 and 64 years of age, and 0.86 for those aged 35 to 39. The study used a literature review to estimate utility values for coronary heart disease patients. Based on this literature review, the study estimated that heart disease reduces patients' quality of life by 0.10, regardless of age. For example, adults aged 35 to 39 have quality of life equal to 0.86 without coronary heart disease and 0.76 with coronary heart disease. The study found that including net consumption increases cost/QALY somewhat, particularly for older patients.

Several factors limited the number of suitable articles obtained through the literature search. First, relatively few studies examine relevant health endpoints. Instead, the bulk of the QALY literature is focused on cancer and cardiovascular diseases. In addition, many studies of relevant endpoints do not include information on the average utility score associated with an endpoint. Indeed, most QALY studies examine the cost-effectiveness of treatments for a given health endpoint and these studies generally contain information on the utility and time-in-state associated with various treatments for the endpoint, rather than the endpoint itself.

[15] Gold, MR, et al, Cost-effectiveness in Health and Medicine, Report on the Panel of Cost-effectiveness in Health and Medicine, New York: Oxford University Press, 1996.

Plan for Assessing Distributional Effects

In its review of the draft analytic plan, the SAB Council recommended that we supplement the section 812 benefit-cost analysis with an assessment of the distributional consequences across different sub-populations defined by income or other characteristics. In the second prospective, we plan to conduct an assessment of the distributional consequences across sub-populations defined by age, income, and race. At a minimum, this analysis will be conducted based on 2000 Census data at the county level because county level projections for income are not available for 2010 and 2020.

Revisions to Approach for Second Prospective - Environmental Effects

For the second prospective, we propose to adopt the welfare effects valuation approaches applied in the first prospective, with the following revisions:

- **Recreational Visibility**: We propose to use the same Chestnut and Rowe (1990) study as the basis for valuation of visibility in national parks, but to apply the preference calibration approach to benefits transfer of these estimates as in EPA's Regional Haze RIA (EPA 1999c).

- **Residential Visibility**: The concerns of the Council expressed in the first prospective are the impetus for new research being sponsored by EPA, but that research will not be completed in time for use in the second prospective. While monetized residential visibility benefits will not be part of the primary estimate for the second prospective, we propose to develop an alternative estimate for this category based on the unpublished McClelland et al. (1990) study of Atlanta and Chicago.

- **Agriculture:** We propose to use AGSIM for commodity crops and to explore the potential application of a California agricultural model for the high-value fruit and vegetable crops grown in that state.

- **Worker Productivity**: No change.

- **Commercial Timber**: Explore a possible updating of the biological effects characterization approach to employ the more recent TREGRO concentration-response functions applied in the Heavy Duty Diesel rule. We propose to continue to use the US Forest Service's Timber Assessment Market Model (TAMM) to monetize these effects; however, we also plan to evaluate a new model focused on eastern (Texas to New York) commercial forests called SRTS which has been developed by Bob Abt at NC State.

- **Acidification:** We propose to apply the same approach used in the first prospective, including valuation of lost recreational angling opportunities using the model described in Montgomery and Needelman (1997). We propose to use an updated version of their random-utility model for New York State.

- **Materials Damage:** Household soiling effects associated with particulate matter in ambient air were not modeled in the first prospective because the only available model relied on 1970's demand estimation and also reflected the now outdated TSP measure for particulate pollution. We plan to explore updating the household soiling model with a new estimation of the household demand for cleaning products and services. The proposed effort will involve some new data collection and model re-estimation. The original model utilized four types of data: (i) household expenditures, (ii) regional price information, (iii) demographics, and (iv) air quality data. Although there are some minor differences in the more recent data series, data from the 1994-95 Consumer Expenditure Survey could be used for re-estimating a model. Updating price information will be more difficult - the surveys used in the original effort are either no longer conducted or are aggregated differently (e.g., monthly versus annually).

CHAPTER 9 - UNCERTAINTY ANALYSIS

The second prospective analysis of the CAAA will provide a comprehensive economic analysis of air regulations using the best available methods and data. The cost and benefit estimates generated by this analysis will be uncertain, however, because of data and model limitations, measurement error, and the various modeling assumptions and choices necessary to implement such a complex and broad analysis. The identification and appropriate characterization of these uncertainties is an integral part of the second prospective analysis because it provides appropriate context for the results of this analysis.

This chapter presents our approach to characterizing uncertainty in the results of the second prospective analysis. This revised analytical plan reflects a significant new effort on the part of EPA to quantify previously unquantified uncertainties in the analysis, particularly in the areas of concentration-response uncertainties in the PM-premature mortality connection, and for benefits transfer uncertainties in our use of the value of statistical life. This focus for the second prospective, along with other research investments in the process or planning stages, is a major component of the Agency's response to the National Academy of Sciences (NAS) recommendations to EPA concerning estimates of the benefits of air pollution. The Agency's plans are farthest along in the areas of critical concentration-response and valuation issues, but our plan for this study also includes initial efforts in the areas of cost, emissions, and air quality modeling uncertainties, as well as a commitment to follow-up on these initial analyses with subsquent research targeted on those parameters most critical to the overall conclusions.

This chapter consists of three parts. The first outlines how uncertainty was addressed in the first prospective. The second provides an overview of our plans for addressing uncertainty in the second prospective, including our revised approach to characterizing cost and benefit uncertainties. The last section presents a list of the major uncertainties from the first prospective and indicates the potential effect of our analytical plan for the second prospective on those uncertainties.

Review of Approach in First Prospective

EPA made use of four methods for characterizing uncertainty in the first prospective: probabilistic modeling; sensitivity tests; alternative paradigms; and qualitative characterizations.

Probabilistic Modeling

In the First Prospective, probabilistic analysis was used to model uncertainty in the human health effects of criteria pollutants and in the economic valuation of human health effects. For example, the value of a statistical life (VSL) input was based on analysis of results of 26 mortality risk valuation studies. In order to characterize uncertainty in this important input parameter, we used the "discrete distribution of the best available estimates [i.e., the 26 studies] as a basis for quantitatively characterizing the probability of alternative values."[1]

The probabilistic approach in the First Prospective was limited in scope to those portions of the analysis where we could readily generate probabilistic characterizations of uncertainty - this included the concentration-response and valuation steps. In addition, the quantitative characterizations largely reflected measurement uncertainty and cross-study variability in those steps, and did not extend to model or paradigm uncertainty. The scope of the quantitative results also did not include quantitative characterizations of uncertainty in emissions, air quality modeling, or cost estimates.

Alternative Paradigms

The alternative paradigms approach was used in the First Prospective to examine the impact of several key methodological choices, including: the choice to use a statistical life approach, rather than a statistical life years approach, to estimate the economic benefits of reduced mortality; the choice of a single study to characterize the relationship between particulate matter exposure and premature mortality; and the choice to omit several quantifiable but less well-supported categories of environmental benefits (e.g., residential visibility). Ideally, we would have liked to examine these model choices using some sort of probabilistic analysis. Short of an expert elicitation approach, however, we found no reliable means to assess the relative likelihood of these model choices being "correct." As a result, the direction and magnitude of the uncertainty in these model choices was considered by examining the effects of employing alternative paradigms or models.

Sensitivity Tests

Sensitivity analysis was used in a number of different sections of the First Prospective. One of the most prominent examples was in the cost estimates, where sensitivity analysis was used to evaluate the effect of altering certain key input parameters. Sensitivity tests were used to examine the impact of key assumptions and data limitations on estimates of direct costs of six major cost-driving provisions, and qualitative characterizations were used to examine the potential impact of other factors on the overall uncertainty in cost estimates. The six provisions were: California Reformulated Gasoline, PM NAAQS controls, the LEV program (the National and California programs combined), Non-utility Stationary Source NOx controls, and the Tailpipe/Extended Useful Life standard.[2] In each of these sections, we found it difficult to assign a quantitative distribution

[1] First Prospective, p. 107.

[2] Collectively, these provisions accounted for approximately fifty percent of the direct compliance cost estimates for 2010.

to some of the input parameters, in part because resource and time limitations precluded even informal expert elicitation of variability and uncertainty.[3] Although this approach enabled us to characterize some of the important but uncertain inputs to the cost estimates, it did not allow us to describe either the likelihood of obtaining a given result or the probability distribution of results.

Sensitivity tests were also used to examine the effect of different assumptions regarding the discount rate. The analysis found that changes in the discount rate had only a small effect on annual cost and benefit estimates. Although changes in the discount rate had a larger effect on the net present value calculations, and a substantial effect on the Title VI results, the study's central conclusion that the benefits of the CAAA exceed its costs remained robust to alternative discount rate assumptions.[4]

Sensitivity analyses were also conducted to evaluate the potential effect of a threshold in the PM-mortality relationship, and the effect of introducing a new procedure for estimating changes in WTP as individual real income changes over time. Both of these sensitivity tests were confined to appendices in the first prospective. The threshold sensitivity analysis remains standard practice for EPA benefits analysis, though it is not used for primary results. The income elasticity adjustment, however, is now standard practice for primary benefits estimation throughout the Agency, with sensitivity analyses alternative estimates of the income elasticity also being conducted in many of the Agency's benefits analyses.

Qualitative Approaches

Qualitative approaches to characterizing uncertainty were used in virtually every component of the First Prospective, in an effort to be comprehensive in the identification of sources of uncertainty. They were used in the summaries of uncertainty in the cost analysis to examine the uncertainty associated with learning curves and tax-interaction effects and also to examine uncertainty regarding model specification.[5] In addition, qualitative tables were used extensively in the benefits analysis. For example, while it was impractical to quantitatively model uncertainty in the emissions estimation and air quality modeling components of the analysis, several specific uncertainties in these steps were assessed qualitatively, with estimates of the direction and magnitude of the uncertainty (e.g., the effect of incomplete characterizations of direct PM and precursor emissions composition). Qualitative tables were also used in the First Prospective to characterize uncertainty in the valuation of ecological benefits.

[3] First Prospective, p. 30-32.

[4] First Prospective, p. 113-114. Consistent with SAB advice, we do not plan to generate net present value estimates for the Second Prospective. Instead, we plan to focus on the annual results for the three target years of the analysis (2000, 2010, and 2020).

[5] First Prospective, p. 33-34.

Although we plan to use quantitative analysis of uncertainty where possible, in many cases quantitative information on input parameter values and model choices continues to be unavailable or incomplete. In these cases, we will use qualitative approaches to describe uncertainty in the Second Prospective. Qualitative assessments are likely to be used to characterize uncertainty in the first two stages of the benefits analysis (emissions and ambient air quality). They are also likely to be used to describe uncertainty in some of the benefits valuation estimates, such as ecological and non-market benefits.

Another area where qualitative approaches will be used again is to assess the impact of policy implementation forecasts. In reviewing the plans for the Second Prospective, the SAB Council recommended that we model uncertainty in "unpredictable policy-implementation choices." It appears that the SAB is referring to scenario design issues, such as how revised PM and ozone NAAQS translate to a suite of specific emissions limitations at the non-attainment area level. For these types of uncertainties, we have a two-part strategy: (1) evaluate alternative (or “supplemental”) scenarios for compliance where the effects of uncertainty are likely to be large and to the extent that resources allow; and (2) evaluate remaining policy-implementation uncertainties qualitatively. We do not plan to attache probabilities to weight the likelihood of each scenario outcome. Morgan and Henrion (1990) refer to these analytic inputs as “decision variables,” and argue that they are not amenable to probabilistic assessment, though perhaps they warrant sensitivity testing. Our approach is therefore consistent with the Morgan and Henrion view. In general, we plan to be explicit about the decision variable choices made for the primary analysis and estimate the quantitative impact of those decisions on key outcome variables where resources allow.

Proposed Approach for Second Prospective

As noted above, our approach to uncertainty analysis in the second prospective reflects significant additional effort to quantify previously unquantified uncertainties. We plan to expand the use of probabilistic analysis in the Second Prospective, consistent with advice from the SAB Council in their response to the draft analytic plan. The Council specifically recommended that parameter uncertainty, and as many types of model uncertainty as possible, be treated within a probabilistic framework.[6] Nonetheless, computational complexities, particularly in the air quality modeling steps, which simulate complex atmospheric chemistry over a nationwide domain, are likely to continue to present difficulties in applying this approach to all aspects of the analysis.

The Agency has made particular efforts to plan the results of these new analyses so that interim results can be available for use in ongoing regulatory efforts. Thus, we are approaching the uncertainty characterization in two phases. The items in each phase will be developed simultaneously. Phase one is considered a near-term effort that consists of several pilot projects that characterize some of the most influential aspects of a benefit analysis. While we characterize the

[6] SAB Response to the Analytic Plan for the Second Prospective (September 2001), p. 37.

initial efforts of phase one as pilot projects, it is important to recognize that we also intend to use the pilot results as they are available to guide other ongoing analyses, where possible. Phase two begins with a characterization of techniques used in the scientific community to estimate uncertainty. Then the phase two effort utilizes results from the pilot projects of phase one to investigate components of uncertainty in-depth.

The integration of plans for ongoing regulatory analyses with our plans for the Second Prospective introduces some additional challenges. Our plan also must be responsive to several key overall considerations. For example, EPA/OAR's current regulatory analysis methodology relies on a damage function approach that emphasizes state-of-the-art tools for analysis within each of four major disciplines: emissions estimation (demanding engineering expertise); air quality modeling (demanding advanced modeling of complex atmospheric chemistry and meteorology over mesoscale geographic spans); concentration-response assessment (demanding knowledge of epidemiologic and toxicologic assessment for human health, and ecological processes for environmental endpoints); and economics (with both cost-side and benefit-side sub-specialties). Understanding uncertainties requires a balance between advancing the state of knowledge within these analytic sub-disciplines, and moving ahead in a manner that recognizes the need to eventually treat quantified uncertainties in an integrated manner for the purposes of propagating uncertainty through to the primary analytic target: an estimate of net monetized benefits. Traditionally, there has been a focus on the former, with less emphasis on the latter.

There is a continuing need to focus on individual sub-disciplines, however, to ensure that decision-makers have the most accurate information and that EPA's regulations can stand up to challenge, and meet the rigorous demands of OMB's recent Data Quality Guidelines. At the same time, effective uncertainty analysis may demand a different focus, with much greater emphasis on developing integrated tools for the purposes of propagating uncertainty from the initial steps (emissions and AQM) into an overall assessment of uncertainty in key analytic outputs (emissions, monetized costs, physical effects benefits, and monetized benefits).

EPA's response to these considerations has been to follow a carefully planned process for quantifying uncertainties across the full range of the analysis, beginning in late 2002, shortly after the publication of the NAS report in September 2002. Most recently, in April of 2003, the Agency convened a planning workshop meeting of EPA staff to establish objectives for the uncertainty analysis for the second prospective and develop plans for pilot projects that are consistent with an integrative analysis. That planning process is ongoing, but we have initiated efforts to characterize the key components of a benefit-cost analysis that influence uncertainty and we plan to initiate or continue five pilot projects (the pilots on PM C-R and mortality valuation had already been initiated by OAQPS to support the Nonroad Diesel and other rulemaking analyses):

Characterizing Uncertainty

1. **Hierarchy of Methods.** The project team will utilize an expert in the field of uncertainty analysis to evaluate the scientific literature to determine methods that have been used to estimate uncertainty, and characterize the conditions for using each type of method. The expert will then develop a guidance tool that will allow EPA to select the most appropriate analytical method to characterize uncertainty in an analysis based on conditions that we see present in the analysis.

2. **Lexicon and Taxonomy.** Due to the multiple disciplines that will be integrated in an uncertainty analysis using highly specialized language specific to their disciplines, a defensible uncertainty analysis will require a common language to describe uncertainty. Therefore, we will develop a lexicon that provides a link to cross-disciplinary language in order to elicit major sources of uncertainty across the various components (e.g., emissions, dispersion, exposure, toxicity, benefits) which make up any analysis. We will also prepare a taxonomy of uncertainty (state of knowledge) which is inherent in our analysis. This will be accomplished by identifying major assumptions, modeling construct, and data which are the foundation of our analysis. This taxonomy will classify these uncertainties in a hierarchical manner, in detail as well across broad "families", and classify broad components of uncertainty (e.g., emissions, air quality, exposure, dose-response) into their component parts as we also define how they are related.

The project team, in the course of its recent deliberations, has conducted an informal evaluation of all components and assumptions of this analysis to develop an initial sense the analytic components that are most likely to be influential to the overall net benefit results. As part of this evaluation, the project team reviewed key uncertainties from the first prospective, and incorporated more recent analytic experience for regulatory support and evaluation efforts. The results of this informal influence analysis have be used to select targets for the pilot projects that are described below. Additional elements that contribute to uncertainty may be identified through the course of this and other analyses and may become targets for supplementary or follow-up analyses.

Pilot Projects

1. **Costs**. The 812 project team developed an initial proposal for characterizing uncertainty in costs for the draft analytical plan, but it largely focused on variability in costs inputs, and not on other systematic factors that might contribute to overall uncertainty. The proposal does not address potential covariances with emissions uncertainty representations. Cost analysis is not an area that the NAS report raises as an issue, but it has been raised by the SAB Council (particularly the covariance issues among emission and cost parameters), is important to address if uncertainty in net benefits is to be calculated, and could be important in considering effects of energy price variance on both cost and benefit outcomes. As part of this revised plan, EPA will first conduct a comprehensive influence analysis to guide subsequent efforts, and then follow-up with analyses targeted on key cost-driving

parameters. As an initial effort, however, we plan that the analysis be limited to quantifying uncertainty in engineering cost inputs and then assessing the impact of that uncertainty on the aggregate cost estimates.

2. **Emissions and Air Quality Modeling**. These two components of the analytic chain have likely represented a large source of unquantified uncertainty in past benefits estimates. Treating them as separate elements for the purposes of quantifying uncertainty, however, runs the risk that the resulting quantitative characterizations cannot be integrated without a very large commitment of time and resources. An alternative approach is being developed that will involve EPA experts working together to identify the major sources of uncertainty in these areas, and then working with a combination of off-line tools and formal and informal elicitation processes to develop a representation of uncertainty in emissions and, perhaps, key air chemistry calculations that can be used in downstream analyses.

3. **PM Mortality Concentration-Response**. This area has been a major concern of health impact analysts, both within and outside of EPA. The plan for this area includes an aggressively scheduled pilot project that involves a rigorously planned and executed expert elicitation. The main focus is to provide a broader representation of uncertainty surrounding the existence and magnitude of the relationship between acute and chronic exposure to PM and premature mortality, especially for use in national level health impact and economic benefits assessments.

4. **Ozone Mortality C-R Function.** In addition, we are considering a second project that would explore the ozone-mortality concentration-response literature. Specifically, it is intended to address uncertainties in the developing literature concerning the impact of short-term (daily or over a few days) fluctuations in ambient ozone concentrations on mortality rates. Of particular concern is the existence of this effect independent of the effect of short-term $PM_{2.5}$ exposures.

5. **Mortality Valuation**. There are several existing analyses of the uncertainty in mortality valuation, including the empirical Bayes analysis of roughly 60 high-quality studies that we propose to rely on for valuation (see Chapter 8 of this document). Those analyses focus on measurement of uncertainty in the base VSL value and do not address key benefits transfer considerations for applying existing VSL estimates to the benefits of air quality improvements. The purpose of the pilot in this area is to integrate the results of the existing work with a representation of the "context" uncertainty. Ultimately, the goals of longer-term efforts over the course of the Second Prospective will be both to provide better information on how to appropriately integrate information from wage-risk and contingent valuation studies, and to value alternative outcomes from the PM Mortality C-R Pilot as necessary.

In the remainder of this section, we describe our plans for each of the efforts in more detail.

Cost Uncertainties

One of the SAB Council comments on the first prospective focused on the incomplete treatment of uncertainty in cost estimates. The first prospective did include sensitivity tests of the impact of key assumptions and data limitations on estimates of direct costs of six major provisions, and qualitative characterizations of the potential impact of other factors on the overall uncertainty in cost estimates. We did not apply a comprehensive uncertainty analysis approach to the cost estimates, however, and we presented all aggregate direct costs in the first prospective as point estimates. In response to the SAB comments, however, one of the important objectives of the second prospective is to develop a better quantitative uncertainty characterization for the cost estimates.

EPA Science Advisory Board (SAB) committees have on several occasions commented on methods, data, and presentation issues related to uncertainty analyses. For example, at the conclusion of the process of developing the first prospective analysis, the SAB Council specifically endorsed the idea of characterizing uncertainty in cost-side factors:

> "b) Characterize Uncertainty about Costs. The costs imposed by air pollution regulations are highly uncertain. For example, the costs of sulfur dioxide abatement under the 1990 Clean Air Act have turned out to be a fraction of what was estimated in 1990. Unfortunately, uncertainty can lead to higher as well as lower costs. EPA has relied on engineering estimates of abatement costs. Even if these estimates were accurate estimates of the cost of equipment and operating costs, they would understate social costs because of tax-interaction and other effects. EPA needs to discuss and to quantify the following sources of uncertainty:
>
> (1) Uncertainty in the engineering cost estimates.
> (2) Costs in addition to the engineering estimates, such as tax-interactions.
> (3) Technical change due to the technology forcing that lowers costs.
> (4) Changes in the wage rate or prices of materials due to the changes in demand."[7]

As a first step, we propose to focus on the first of SAB's suggestions: characterizing uncertainty in the engineering cost estimates. Other facets of the cost analysis, however, will provide some insights into the other sources of uncertainty the Council named. The influence of tax-

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[7] See EPA-SAB-COUNCIL-ADV-00-003, Final Advisory on the 1999 Prospective Study of Costs and Benefits (1999) of Implementation of the Clean Air Act Amendments (CAAA), available at **http://www.epa.gov/sab/pdf/coua0003.pdf.**

interactions, for example, will be estimated in the computable general equilibrium modeling we plan to implement. The influence of learning-by-doing on costs, while distinct from induced technological change, is part of the base cost analysis as well.

The scope of the section 812 analyses encompasses such a wide range of programs, as well as cost-estimation techniques, that it is difficult to assess what aspects of the overall cost estimation approach might be linked directly to dynamic or even broad economy-wide changes in wage rates and materials prices. While it is possible that materials costs, wage rates, and plausible rates of technological change may be the most important drivers of the overall cost estimates, understanding the relative importance of these factors in the models we plan to use is beyond the scope of what we believe we can accomplish in the project. The provision-specific nature of our modeling frameworks complicate the task of identifying the influence of an aggregate input measure such as materials costs - for example, the materials costs and their underlying markets are completely different for industrial point NOx controls (e.g., selective catalytic or non-catalytic reduction) versus mobile source controls (e.g., on-board diagnostics). In addition, while a few of our cost estimates might be specified with an explicit materials cost or wage rate parameter, in most cases the materials cost or wage rate itself is embedded in an estimate of vendor costs for provision of a specific pollution control device, or even in a cost-per-ton value that may be precise for a specific set of rules to which it is applied but be difficult to disaggregate. It would be an enormous effort to standardize the cost estimating techniques to the point where we could readily evaluate uncertainty in an input such as materials costs.

To characterize uncertainties in engineering costs, we propose to perform the following tasks:

- ***Conduct an influence analysis on the underlying engineering costs.*** Our initial influence analysis will focus on the key drivers of two major cost estimation models employed for direct cost estimation: IPM and ControlNET. The specific structure of these models is described in more detail in Appendix A. Most of the existing experience with these models involves analysis of different regulatory scenarios - we plan to hold the regulatory scenario constant and focus on the influence of other parameters of the model.

  For this task, we will make use of existing sensitivity runs of the two models and discussions with the model developers to develop an initial set of factors likely to be most influential to aggregate cost outputs. Next, we will design a set of additional model runs that provide insights into the interaction among variables in the overall response-surface for aggregate cost outputs. While we are not confident that a response surface can be obtained, we believe that the insights to be gained from the limited set of runs will be valuable for subsequent uncertainty analysis.

- ***Targeted Analyses to Develop Plausible Ranges for Key Parameters.*** Once we have developed a short list of the key underlying parameters of greatest influence on engineering costs, we will conduct a set of targeted analyses and research projects to estimate plausible ranges and, where possible, distributions for these key parameters. These analyses might involve informal or formal expert elicitation; vendor surveys to characterize variability and time trends for the costs of key air pollution control devices; or re-estimation of engineering cost curves using alternative estimation techniques.

The details of how some of these analyses might be completed were described in the June 2001 draft analytical plan. For example, for an uncertainty analysis of non-EGU control costs, we could conduct two somewhat different approaches based on the configuration of the basic cost equations. Currently, a capacity-based equation is used to estimate capital and annual costs for boilers and turbines (see equation 1 below). To develop best estimate and upper and lower bounds on costs for these sources, we could to use the results of the Monte Carlo simulations to derive three sets of equations for each source and control combination. One equation will be for producing best estimates, while the other two will be for producing high and low estimates consistent with a 5^{th} and 95^{th} percentile estimate.

$$y = mx^b \qquad (1)$$

where:

y = capital or annual cost
x = capacity (MMBtu/hr)
m = coefficient
b = exponent

For all of the other source/control combinations (pods), the cost model parameters are simply cost effectiveness (i.e., $/ton reduced). For these pods, the project team could develop a Monte Carlo forecast to model best estimate and high and low estimates (i.e., mean and confidence interval for cost effectiveness).

- ***Parametric Analysis***. Using the results from the first step, we plan to re-run the cost estimation models using a matrix of alternative input assumptions developed from the second step. The key challenge in this step will be developing an efficient set of “index runs” that recognizes potential co-variances across the alternative parameter specifications and preserves information on the distribution of alternative parameter outcomes developed in the targeted analyses. Construction of these scenarios will involve further consultation with model developers and among the full project team.

The output of this analysis will be an estimate of the overall uncertainty in direct cost (engineering cost) estimation. At a minimum, this estimate will apply to the set of provisions whose costs are determined by those parameters identified in the influence analysis. In general, the degree of comprehensiveness of the uncertainty analysis will necessarily be dependent on subjective assessments of the breadth of the influence analysis. It is also important to note that the uncertainty will be conditional on a single set of projected economic scenario parameters (e.g., overall real wage rates). We hope that subsequent advances in the ease of operation of the cost models allows for future analyses to look more in depth at uncertainties associated with economic projections, perhaps through the use of a CGE as a key initial step in the development of emissions and cost estimates.

Benefits Uncertainties

We plan a significant expansion of the use of probabilistic characterizations of uncertainties on the benefits side. The overall propagation and aggregation of uncertainty will continue to be accomplished via Monte Carlo techniques, but we plan a significant expansion of the quantitative parameterization of the Monte Carlo model. In several cases, we plan to apply formal expert elicitation methods to develop estimates of the distributions of previously unquantified uncertainties (e.g., the relative weight to assign to alternative paradigms for PM-mortality concentration-response). In addition, we plan to continue to expand our usage of meta-analytic results, where possible (e.g., ozone-mortality relationships). In the remainder of this section, we describe the four projects we propose to quantify critical uncertainties in benefits estimation.

Emissions and Air Quality Modeling

We plan to take the initial steps in quantitatively characterizing uncertainty in these critical steps by completing the following three tasks:

- ***Influence Analysis:*** We will conduct internal EPA workshops that bring together EPA emissions and air quality experts to qualitatively assess the major factors that contribute to uncertainty in the air quality modeling outputs, including uncertainties in the emissions inputs. At this time, we anticipate that the highest priority will be attached to developing estimates of the influences of emissions estimation uncertainties on air quality modeling outputs, but we also wish to explore whether tools and data are available that would enable us to quantitatively evaluate a small set of atmospheric chemistry uncertainties. Our highest priorities for atmospheric chemistry uncertainties would be related to the modeling of fine particle formation from nitrate and organic aerosol particle formation. We hope that the results of this step will be a short list of critical emissions and perhaps atmospheric chemistry uncertainties for which we can develop quantitative characterizations of uncertainty.[8]

[8] Note that emission and air quality uncertainties can also influence the cost estimate, especially when using models that integrate both emissions and cost information in decision-making (e.g., IPM). In this pilot, however, we begin by focusing on the influence on benefits. Factors such as the potential for more complex relationships among uncertainties will at a minimum be addressed qualitatively when we ultimately link together the results of our pilots.

- ***Targeted Analyses:*** Similar to the procedure outlined above for engineering cost parameters, we plan to take the results of the emissions influence analysis and attempt to develop ranges and, if possible, distributions of the key emissions parameters. This step will necessarily be complicated by the spatial distributional aspects of emissions uncertainties, which may substantially limit the number of parameters we can analyze. Nonetheless, the goal of this step is to make use of existing information, literature reviews, engineering judgement, estimates of emissions variability, and perhaps informal expert elicitation to characterize parameter uncertainty.

- ***Carrying Emissions Uncertainties through Air Quality Modeling Step:*** EPA has recently developed a version of the REMSAD model that can be more efficiently run than the full REMSAD modeling system. We believe that it will be possible to use this new tool, called REMSAD ST (short-turnaround), to carry quantified emissions uncertainties through the air quality modeling step to estimate their ultimate impact on estimates of monetized health effects. We plan to use the tool, coupled with deterministic runs of the BENMAP benefits estimation model described in Chapter 6, to first develop a set of "range-finding" estimates of the overall impact of key emissions uncertainties. To the extent possible, we will also explore the development of estimated monetized benefit distributions that show the effect of key emissions parameter uncertainties, subject to our ability both to develop the input distributions required and to develop an efficient and informative set of emissions scenarios that can be run through both the REMSAD ST and BENMAP tools.

Near-Term Pilots

The remaining uncertainty projects reflect a more explicit integration of this analytical plan with the plan for completing the economic regulatory support analyses for the final nonroad diesel and other rulemakings. In the sections below, we outline three pilot project applications intended to address concentration-response relationships for, and valuation of, premature mortality. These elements of the overall analytic chain have been identified *a priori* by EPA and others as important contributors to overall uncertainty in estimates of total benefits. The pilot project format is designed to provide interim measures of uncertainty in these elements for incorporation into the benefits analysis for the final nonroad diesel rulemaking, which is scheduled to be released in Spring 2004, while setting the stage for a more complete analysis to be conducted over the next 18 to 24 months, which may allow incorporation of the final, rather than interim, results of the expert elicitation in the second prospective. To meet the Spring 2004 deadline the results from the pilot applications will have to be available in the Fall or early Winter of 2003.

These pilot application have two sets of objectives. The primary objectives deal with those uncertainty elements which are currently thought to have the most significant impact on the uncertainty surrounding EPA's base estimate of benefits. These primary objectives are broken into two parts. Phase I is designed to provide the preliminary results needed for the nonroad diesel final rulemaking. It should also provide some of the background information needed for later uncertainty treatments. Equally important, Phase I will provide a basis for comparison with the more rigorous methods of Phase II. Phase II results are not expected to be available in time for use in the nonroad diesel final rulemaking but will be used by EPA in subsequent benefits analyses for other EPA air pollution rulemakings.

$PM_{2.5}$ Mortality Concentration-Response Function

The first of these projects is intended to provide a representation of the uncertainty concerning the magnitude and shape of the C-R function relating premature death (loss of life expectancy) and long-term exposure to ambient $PM_{2.5}$. In the case of the C-R function relating $PM_{2.5}$ and premature mortality, there are a number of elements contributing to the uncertainty about the magnitude of the relative risk. These elements include composition of $PM_{2.5}$ in specific locations, age and health status of the exposed population, heterogeneity in the level of personal exposure to $PM_{2.5}$ (i.e. use of air conditioning across locations), potential confounding by co-pollutants, use of multi-year average ambient $PM_{2.5}$ measured at fixed-site monitors as a surrogate for personal long-term exposure to ambient $PM_{2.5}$, and others. Some of these elements may be addressed by additional analysis of empirical data, while others may require formal expert elicitation to characterize uncertainty. The overall aggregate uncertainty in the mortality C-R function obtained by combining the uncertainty estimates for each underlying element may be greater or less than the uncertainty obtained using expert judgment to characterize the overall aggregate uncertainty.

In this pilot, however we propose using expert judgment as the primary component of the overall analysis, reflecting the dearth of quantitative evidence to characterize certain aspects of uncertainty surrounding this important relationship. Subsequent, longer-term analyses may follow-on the results of the pilot to address other individual elements of the uncertainty in this C-R function. The pilot project will have as its main objective addressing uncertainty in the aggregate C-R relationship. We hope to have results from this first phase by December 2003. In phase two, we plan to develop disaggregated questions based on a decision tree.

The process we propose for the expert elicitation may involve a series of prior questions and/or a structured elicitation format that provides a useful decomposition of the objective into component parts (e.g., How much weight should be assigned to short-term versus cohort studies? How much weight should be given to alternative specifications of the concentration-response relationship that are species-specific? Do you support the concept of a threshold dose relationship for this pollutant-endpoint combination?). The experts will also be asked to provide their best estimates of the 5^{th} and 95^{th} percentiles of the increase in all-cause mortality, along with 90 percent credible intervals for their stated best estimates (expected value).

While the concept of using subjective judgment to characterize uncertainty is not new, its application to complex multi-faceted technical questions like that proposed by EPA is still relatively uncommon. The well-described, common pitfalls in elicitation of judgments -- the use of heuristics or the experts' own biases -- which can lead to biased and poorly calibrated judgments, pose particular challenges in a complex analysis. To generate a technically sound approach to the elicitation and analysis of expert judgments about uncertainty in the PM2.5 concentration-response function, EPA is considering engaging analysts experienced in expert judgment elicitation. The following tasks outline the process we envision for completion of the pilot.

- ***Defining elicitation scope and focus***: The first step will require that the elicitation analyst work with EPA staff responsible for the benefits analysis to define the specific questions to be answered. EPA has already made considerable progress in identifying the objective of the elicitation. However, the goal of this step will be to make sure that the questions both serve the needs of the benefits assessment and are suitable for posing to experts. The elicitation analyst will also work closely with suitable "domain" experts in defining the approach.

- ***Preparation of elicitation protocol***: The elicitation analyst will assist in the development of a technically sound and feasible elicitation protocol, based on the technical question, consideration of anticipated analysis of the judgments (e.g. distributional form, combination of the judgments), the phase of the project (pilot or longer-term analysis), and schedule.

- ***Identification and Selection of Experts***: The elicitation analyst will guide the process for identifying and selecting a group of experts with relevant expertise to participate in study. The process should be transparent, using clearly defined selection criteria. EPA is considering using the two existing NAS panels that have recently examined the PM mortality literature and its application to PM health impact assessment, effectively building our initial expert selection upon the process employed by NAS. These two NAS panels, the Committee on Estimating the Health-risk-reduction Benefits of Proposed Air Pollution Regulations, and the Committee on Research Priorities for Airborne Particulate Matter, have members with established credentials in the subject matter area, and have already been selected by their peers as experts. In addition, the use of NAS panels as a source for expert elicitiation has been documented in peer-reviewed applications of expert elicitation.

- ***Preparation of Briefing "Book"***: During an elicitation, standard materials are often made available to all experts involved in the form of a file or "briefing book". It may include a review of common pitfalls in giving subjective judgments, calibration exercises, as well as key papers or analyses relevant to the elicitation questions. The elicitation analyst, in collaboration with EPA and contractor staff, will develop a briefing book documenting key information pertinent to expert elicitation and the PM/chronic mortality issue.

- ***Pilot Testing of Protocol***: Prior to conducting elicitations with the selected experts, the elicitation analyst will conduct pilot testing of the protocol with individuals having relevant expertise in the question(s) being elicited. The goal of the pilot testing will be to determine any changes needed to improve the clarity of the questions and/or the feasibility of the elicitation approach. The output of this step will be a revised elicitation protocol reflecting the feedback obtained during pilot testing.

- ***Elicitation Workshop***: If necessary and feasible, the elicitation analyst will conduct a training workshop to train and calibrate the experts in developing expert judgments about uncertainty as well as to discuss the appropriate elements to include in the elicitation protocol (e.g. key assumptions on which the elicitation is conditioned or the structure of a probability tree).

- ***Individual Elicitation of Experts' Judgments***: The elicitation analyst , in conjunction with a "domain" expert to be identified, will conduct each of the elicitations with the individual experts. The output of this step will be a collection of individual elicitation reports from the chosen experts. The analysis will also include a recommendation for the aggregation and application of the expert judgements for the purposes of benefits analysis.

Ozone Mortality C-R Function

The second proposed pilot project is intended to address uncertainties in the developing literature concerning the impact of short-term (daily or over a few days) fluctuations in ambient ozone concentrations on mortality rates. Of particular concern is the existence of this effect independent of the effect of fluctuations in daily $PM_{2.5}$ concentrations, and the potential variability of this effect over regions of the U.S. with differing weather and copollutant patterns. For this pilot project, we plan to use a variety of meta-analytical techniques to evaluate and combine the available empirical evidence.

There are three sets of researchers who have conducted meta-analyses of air pollution related mortality. Two of these groups have published meta-analyses examining daily mortality associated with PM and one has analyzed daily mortality associated with ozone. Based on current understanding of the potential for $PM_{2.5}$ to confound the ozone mortality signal, and the recent findings regarding the proper application of certain statistical methods used to estimate C-R functions in some of the daily time-series studies, we deem it prudent to conduct a new set of meta-analyses of recent studies examining the ozone-mortality relationship with controls for potential $PM_{2.5}$ confounding. EPA plans to fund up to three groups of researchers to apply their meta-analytical techniques to a common set of literature that EPA will provide. The three groups and their methods include:

- F. Domenici, J. Samet, and S. Zeger. (Johns Hopkins School of Public Health) Two-stage Bayesian hierarchical meta-analysis.

- J. Levy, J. Hammitt, and J. Spengler (Harvard University) Empirical Bayes hierarchical meta-analysis.

- G. Thurston and K. Ito. (New York University) Two-stage random-effects meta-analysis.

Each of the three groups has approached meta-analysis in a rigorous fashion, while using somewhat different methods. To ensure the robustness of the findings from meta-analyses of ozone-mortality relationships, this pilot will evaluate and characterize the findings from three independent research groups and methodologies. Results of this pilot will be distributions of the percent increase in daily all-cause and/or cause specific mortality associated with a 10 ppb decrease in daily one-hour maximum, or multi-hour average ozone.

In the case of the C-R function relating ozone and premature mortality, the meta-analytic approaches may be capable of characterizing certain elements of uncertainty, including sampling error and cross-location heterogeneity, but there are likely additional sources of uncertainty that should be characterized, including the influence of co-pollutants and biological plausibility of mortality impacts at relatively low ozone concentrations. These elements may need to be addressed through some subsequent use of expert elicitation methods. The outputs of the meta-analyses might be used as inputs to the expert elicitation process, providing a common base of empirical data for the experts to consider in making their probability judgments.

Valuation of Reductions in the Risk of Premature Death from Air Pollution

The third proposed pilot is intended to address the uncertainties surrounding the value of reductions in the risk of premature death from air pollution, commonly referred to as the value of a statistical life (VSL). Of particular concern is the uncertainty in transferring values revealed in the context of on-the-job risks (through hedonic wage-risk studies), which are based on working age individuals in a largely voluntary risk environment, to an air pollution risk context where at risk individuals tend to be older than the average age worker and the risks are largely involuntary. Additional sources of uncertainty include the relationship between remaining life expectancy and VSL and the impact of quality of life on values for fatal risk reductions. We are proposing a two-part approach: (1) a meta-regression analysis of existing VSL estimates in the economics literature, and potentially (2) a formal expert elicitation analysis, to be conducted following review and evaluation of the meta-regression analysis. We provide more details on the first step below.

Meta-regression Analysis: EPA has recently completed a meta-analysis of the VSL literature (Kochi, Hubbell, and Kramer, 2003). As outlined in Chapter 8, that meta-analysis used empirical Bayes pooling methods to combine estimates from 40 wage-risk and stated preference studies into a single distribution, taking into account both within-study and between study variability. Pooled effect estimates of the kind generated by this type of meta-analysis can provide an improved central tendency estimate of VSL and a better estimate of variability around the central tendency, but do not systematically address or systematically eliminate between-study variability that may be associated with choice of estimation method and model, study location, target population, and demographic and risk characteristics (age, type of risk, etc.). Meta regression analysis has been widely applied in the health literature to pool results from clinical studies to examine how key factors influence health outcomes. In the economics literature, the approach has been used to examine determinants of willingness to pay for air quality improvement (Smith and Huang (1995) and Smith and Osborne (1996)) and determinants of VSL in hedonic wage studies (Mrozek and Taylor 2002).

Empirical Bayes meta-regression analysis uses a two stage hierarchical model to examine both within-study and between study variability. The first stage pooling completed by Kochi, Hubbell, and Kramer (2002) provides posterior estimates of VSL using information from all estimates in the literature. Additional work is necessary to provide further adjustment to the posterior estimates by specifying the VSL estimate as a function of study characteristics plus a between study variability term. The result of this analysis will be VSL distributions that are conditional on study characteristics. This will allow the analyst to calculate a VSL distribution that is appropriate to a given regulatory context. It will add to the growing literature on value of statistical life by systematically assessing that literature and shedding light on how study characteristics influence estimated VSL.

Applying the Newly Quantified Uncertainties

With the results of the focused analyses described above in hand, we plan to use a similar approach to propagating and presenting uncertainties in benefits estimates associated with CAAA provisions as the approach we adopted for the first prospective analysis. For each of the three target years of the analysis (2000, 2010, and 2020) we will generate distributions of monetized annual estimates for the human health and welfare effects that incorporate both the quantified uncertainty associated with each of the health effect estimates and the quantified uncertainty associated with the corresponding economic valuation strategy. The resulting range of estimates for monetized benefits we present will be more narrow than would be expected with a complete accounting of the uncertainties in all analytical components.

In the first step of our procedure, we will employ statistical analysis to generate mean estimates and quantified uncertainty measures for each C-R function for each endpoint-pollutant combination. For the many health and welfare effects where only a single study is available to serve as the basis for the C-R function, we will use the reported estimate in the study as the best estimate of the mean of the distribution of C-R coefficients. We will characterize the uncertainty surrounding the estimate of the mean C-R coefficient by the standard error of the reported estimate. This yields a normal distribution, centered at the reported estimate of the mean. If multiple studies are considered for a given C-R function, we will derive a normal distribution for each study, centered at the mean estimate reported in the study (replaced in the case of PM-mortality by the results of the expert elicitation). On each iteration of the Monte Carlo aggregation procedure, a computer will select a C-R coefficient from an aggregate distribution of C-R estimates for that endpoint. The aggregate distribution of C-R coefficients will be determined by a variance-weighted aggregate distribution of values.

In the second step, as discussed in Chapter 6, we will estimate incidence for each exposure analysis unit (i.e., each BENMAP grid cell) in the 48 contiguous states, and will aggregate the results into an estimate of the change in national incidence of the health or welfare effects. Through repeated iterations from the distribution of mean C-R coefficients, we will generate a distribution of the estimated change in incidence for each health and welfare effect due to the change in air quality between the Post-CAAA and Pre-CAAA scenarios.

Finally, in the third step we will use computerized statistical aggregation methods once again to characterize the combined uncertainty surrounding monetized benefits. For each distinct health and welfare effect, the aggregation procedure will randomly select an estimated incidence change from the distribution of changes for a given endpoint, plus a unit value for that endpoint from the corresponding economic valuation distribution and will multiply the two to generate a monetized benefit estimate. The Monte Carlo procedure repeats this process many times to generate a distribution of estimated monetized benefits for each endpoint-pollutant combination. Combining the results for the individual endpoints using the aggregation procedure will yield a distribution of total estimated monetized benefits for each target year. When presenting the results, we plan to present a range of values generated by the aggregation procedure described above, including a Primary Central estimate and Primary Low and Primary High estimates. The Primary High estimate will correspond to the 95th percentile value of the benefit distribution for a given health effect, and the Primary Low estimate will correspond to the 5th percentile value.[9]

We propose to adopt a different approach for ecological and welfare benefit estimates, which are not currently amenable to the same type of uncertainty analysis as health benefits. 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 and will require substantial resources simply to develop single estimates. The sources of uncertainty in these estimates, however, cannot easily be disaggregated into physical effects modeling and valuation components. We plan to present ranges of benefits estimates for these effects, including a best estimate derived from professional judgment and a low and high estimate reflecting reasonable alternative choices in key input variables. We plan to represent the range of estimates using the probabilistic distribution that best fits the available data (with a triangular distribution as the default). We will use this distribution to aggregate the ecological and other welfare effects analyses with the human health analyses.

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[9] Note that the newest versions of our valuation estimation tool, BenMAP, include a capability to assess whether individual components of the valuation methodology are dependent or independent (past analyses have assumed independence). At a minimum, we plan to examine the effect of dependence on the overall results.

The procedure used to generate health estimates is well-suited to analysis of uncertainties where the probability of alternative outcomes can be quantitatively characterized in an objective manner. For example, most studies that estimate concentration-response relationships report an estimate of the statistical uncertainty around the central estimate. It is important to recognize, however, that this procedure reflects only a portion of the range of possible sources of uncertainty in our benefits estimates. Thus, in addition to including qualitative discussions of major unquantified sources of uncertainty in benefits estimates, we also plan to include sensitivity analyses to assess the relative magnitude of the effects of using some of the alternative modeling approaches or employing alternative economic approaches (e.g., using alternative discount rates) on the Primary Central benefit estimates.

Although we plan to use quantitative analysis of uncertainty where possible, in many cases quantitative information on input parameter values and model choices continues to be unavailable or incomplete. In these cases, we will use qualitative approaches to describe uncertainty in the Second Prospective. Qualitative assessments are likely to be used to characterize uncertainty in the first two stages of the benefits analysis (emissions and ambient air quality). They are also likely to be used to describe uncertainty in some of the benefits valuation estimates, such as ecological and non-market benefits.

Addressing Key Uncertainties From the First Prospective

For many aspects or our analysis, including emissions estimates, air quality modeling, and unquantified categories of benefits, we expect there will be sources of uncertainty that are not amenable to quantitative analysis. In these cases, as in the first prospective study, we propose to identify and qualitatively characterize the major sources of uncertainty associated with each step of the analysis.

Table 9-1 summarizes key uncertainties from the first prospective analysis, provides a qualitative description of the likely effect of each uncertainty on the results of the analysis, and describes how our approach to the second prospective analysis might address each uncertainty. These uncertainties were drawn from the uncertainty tables at the end of each chapter of the first prospective study and include uncertainties related to emissions modeling, air quality modeling, human health and ecological effects modeling, and benefits valuation. The uncertainties included in this table were all judged to have a "potentially major" effect on the CAAA net benefits estimate.

Table 9-1

Key Uncertainties From the First Prospective Study

Potential Source of Error	Direction of Potential Bias for Net Benefits Estimate	Likely Significance Relative to Key Uncertainties in Net Benefit Estimate*	Addressed in the Analytical Plan for the Second Prospective?
$PM_{2.5}$ emissions are largely based on scaling of PM_{10} emissions.	Overall, unable to determine based on current information. Emission factors are likely to underestimate $PM_{2.5}$ emissions from combustion sources, implying a potential underestimation of benefits.	Potentially major. Source-specific scaling factors reflect the most careful estimation currently possible, using current emissions monitoring data. However, health benefit estimates related to charges in $PM_{2.5}$ constitute a large portion of overall CAAA-related benefits.	Potentially. Advances in emissions estimation techniques represent improvements at the margin, but some emissions estimates continue to rely on scaling. This topic might also be addressed in the emissions pilot.
Primary $PM_{2.5}$ emissions are based on unit emissions that may not accurately reflect composition and mobility of the particles. For example, the ratio of crustal to primary carbonaceous particulate material likely is high.	Underestimate. The effect of overestimating crustal emissions and underestimating carbonaceous when applied in later stages of the analysis, is to reduce the net impact of the CAAA on primary $PM_{2.5}$ emissions by underestimating $PM_{2.5}$ emissions reductions associated with mobile source tailpipe controls.	Potentially major. Mobile source primary carbonaceous particles are a significant contributor to public exposure to $PM_{2.5}$. Overall, however, compared to secondary $PM_{2.5}$ precursor emissions, changes in primary $PM_{2.5}$ emissions have only a small impact on $PM_{2.5}$ related benefits.	Yes, though limited by the availability of new emissions data. We propose to employ newly available data reflected in Mobile 6.1 emissions model.

Table 9-1

Key Uncertainties From the First Prospective Study

Potential Source of Error	Direction of Potential Bias for Net Benefits Estimate	Likely Significance Relative to Key Uncertainties in Net Benefit Estimate*	Addressed in the Analytical Plan for the Second Prospective?
PM_{10} and $PM_{2.5}$ concentrations in the East (RADM domain) are based exclusively on changes in the concentrations of sulfate and nitrate particles, omitting the effect of anticipated reductions in organic or primary particulate fractions.	Underestimate.	Potentially major. Nitrates and sulfates constitute major components of PM, especially $PM_{2.5}$, in most of the RADM domain and changes in nitrates and sulfates may serve as a reasonable approximation to changes in total PM_{10} and total $PM_{2.5}$. Of the other components, primary crustal particulate emissions are not expected to change between scenarios; primary organic carbon particulate emissions unknown fraction of the organic PM if from biogenic emissions, and biogenic emissions are not expected to change between scenarios. If the underestimation is major, it is likely the result of not capturing reductions in motor vehicle primary elemental carbon and organic carbon particulate emissions.	Yes. The use of a single model (REMSAD) nationwide will generate PM2.5 estimates based not only on sulfate and nitrate predictions, but on primary fine particles and organic secondary particles as well.
The number of $PM_{2.5}$ ambient concentration monitors throughout the U.S. is limited. As a result, cross estimation of $PM_{2.5}$ concentrations from PM_{10} (or TSP) data was necessary in order to complete the “monitor-level“ observational dataset used in the calculation of air quality profiles.	Unable to determine based on the current information.	Potentially major. $PM_{2.5}$ exposure is linked to mortality, and avoided mortality constitutes a large portion of overall CAAA benefits. Cross estimation of $PM_{2.5}$, however, is based on studies that account for seasonal and geographical variability in size and species composition of particulate matter. Also, results are aggregated to the annual level, improving the accuracy of cross estimation.	Partially. The proposed use of year 2000 monitor data to generate future-year Post-CAAA concentration estimates would reduce this uncertainty in the Post-CAAA scenario, though not in the pre-CAAA scenario.

Table 9-1
Key Uncertainties From the First Prospective Study

Potential Source of Error	Direction of Potential Bias for Net Benefits Estimate	Likely Significance Relative to Key Uncertainties in Net Benefit Estimate*	Addressed in the Analytical Plan for the Second Prospective?
Use of separate air quality models for individual pollutants and for different geographic regions does not allow for a fully integrated analysis of pollutants and their interactions.	Unable to determine based on current information.	Potentially major. There are uncertainties introduced by different air quality models operating at different scales for different pollutants. Interaction is expected to be most significant for PM estimates. However, important oxidant interactions are being used as designed. The greatest likelihood of error in this case is for the summer period in areas with NOx inhibition of ambient ozone (e.g., Los Angeles).	Yes. The second prospective will use single models such as REMSAD and CAMx nationwide.
Incomplete coverage of ecological effects identified in existing literature, including the inability to adequately discern the role of air pollution in multiple stressor effects on ecosystems.	Underestimate	Potentially major. The extent of unquantified and unmonetized benefits is largely unknown, but the available evidence suggests the impact of air pollutants on ecological systems may be widespread and significant. At the same time, it is possible that a complete quantification of effects might yield economic valuation results that remain small in comparison to the total magnitude of health benefits.	No. This is likely to remain a key uncertainty in the second prospective analysis, although the planned case study is an important first step.
Benefits transfer for mortality risk valuation, including differences in age, income, degree of risk aversion, the nature of the risk, and treatment of latency between mortality risks presented by PM and the risks evaluated in the available economic studies.	Unable to determine based on currently available information	Potentially major. The mortality valuation step is clearly a critical element in the net benefits estimate, so any uncertainties can have a large effect. As discussed in the text, however, information on the combined effect of these known biases is relatively sparse, and it is therefore difficult to assess the overall effect of multiple biases that work in opposite directions.	Yes. Updating the VSL value will result in a reduction of uncertainty, and the benefits transfer considerations are an explicit focus of the planned pilot project.

Table 9-1

Key Uncertainties From the First Prospective Study

Potential Source of Error	Direction of Potential Bias for Net Benefits Estimate	Likely Significance Relative to Key Uncertainties in Net Benefit Estimate*	Addressed in the Analytical Plan for the Second Prospective?
Application of C-R relationships only to those subpopulations matching the original study population.	Underestimate.	Potentially major. The C-R functions for several health endpoints (including PM-related premature mortality) were applied only to subgroups of the U.S. population (e.g., adults over 30) and thus may underestimate the whole population benefits of reductions in pollutant exposures. In addition, the demographics of the study population in the Pope et al. study (largely white and middle class) may result in an underestimate of PM-related mortality, because the effects of PM tend to be significantly greater among groups of lower socioeconomic status.	Partially. Consistent with the recent NAS Report recommendation to expand age group coverage for important health effects, supplemental calculations will be conducted to transfer C-R functions for selected health endpoints, such as asthma, to different age groups.
No quantification of health effects associated with exposure to air toxics.	Underestimate	Potentially major. According to EPA criteria, over 100 air toxics are known or suspected carcinogens, and many air toxics are also associated with adverse health effects such as neurotoxicity, reproductive toxicity, and developmental toxicity. Unfortunately, current data and methods are insufficient to develop (and value) quantitative estimates of the health effects of these pollutants.	Partially. This is likely to remain a key uncertainty in the second prospective analysis, but the planned case study is an important first step.

Table 9-1

Key Uncertainties From the First Prospective Study

Potential Source of Error	Direction of Potential Bias for Net Benefits Estimate	Likely Significance Relative to Key Uncertainties in Net Benefit Estimate*	Addressed in the Analytical Plan for the Second Prospective?
Use of long-term global warming estimates in Title VI analysis that show more severe warming than is now generally anticipated.	Overestimate (for Title VI estimate only)	Potentially major. Global warming can accelerate the pace of stratospheric ozone recovery; if warming is less severe than anticipated at the time the Title VI analyses were conducted, the modeled pace of ozone recovery may be overestimated, suggesting benefits of the program could be delayed, perhaps by many years. The magnitude of estimated Title VI benefits suggests that the impact of delaying benefits could be major.	Yes. We will review global warming estimates and the interactive impact of increased temperature and ozone depletion as part of our revisions to the Title VI benefits analysis.
The quantitative analysis of Title VI (see next section) does not account for potential increases in averting behavior (i.e., people's efforts to protect themselves from UV-b radiation).	Unable to determine based on current information.	Potentially major. Murdoch and Thayer (1990) estimate that the cost-of-illness estimates for nonmelanoma skin cancer cases between 2000 and 2050 may be almost twice the estimated cost of averting behavior (application of sunscreen). Our Title VI analysis relies on epidemiological studies, which incorporate averting behavior as currently practiced. Omission of future increases in averting behavior, however, may overstate the benefits of reduced emissions of ozone-depleting chemicals. Benefits could be understated if individuals alter their behaviors in ways that could increase exposure or risk (e.g., sunbathing more frequently). A recent European study by Autier et al. (1999) found that the use of high sun protection factor (SPF) sun screen is associated with increased frequency and duration of sun exposure.	No. This is likely to remain a key uncertainty in the second prospective analysis.

Table 9-1

Key Uncertainties From the First Prospective Study

Potential Source of Error	Direction of Potential Bias for Net Benefits Estimate	Likely Significance Relative to Key Uncertainties in Net Benefit Estimate*	Addressed in the Analytical Plan for the Second Prospective?
Analysis assumes a causal relationship between PM exposure and premature mortality based on strong epidemiological evidence of a PM/mortality association. However, epidemiological evidence alone cannot establish this causal link.	Unable to determine based on current information.	Potentially major. A basic underpinning of this analysis, this assumption is critical to the estimation of health benefits. However, the assumption of causality is suggested by the epidemiologic evidence and is consistent with current practice in the development of a best estimate of air pollution-related health benefits. At this time, we can identify no basis to support a conclusion that such an assumption results in a known or suspected overestimation bias.	Yes. The body of scientific literature supporting the assumption of causality has grown since the first prospective. Moreover, the expert elicitation for PM/mortality will provide additional information on the weight to assign to an alternative view held among readers not convinced by the available evidence.
Across-study variance / application of regionally derived C-R estimates to entire U.S.	Unable to determine based on current information.	Potentially major. The differences in the expected changes in health effects calculated using different underlying studies can be large. If differences reflect real regional variation in the PM/mortality relationship, applying individual C-R functions throughout the U.S. could result in considerable uncertainty in health effect estimates.	No. We believe the application of a single PM C-R function nationwide is currently the most well-supported approach to benefits estimation, despite the potential for regional variation. This is likely to remain a key uncertainty in the second prospective analysis
Estimate of non-melanoma skin cancer (NMSC) mortality resulting from reductions in stratospheric ozone is calculated indirectly, by assuming the mortality rate is a fixed percentage of non-melanoma incidence.	Unable to determine based on current information.	Potentially major. New data on the death rate for non-melanoma skin cancer may significantly influence the Title VI mortality estimate. Some preliminary estimates suggest that this estimate may need to be adjusted downward.	Yes. This approach will be updated to include improved estimates of NMSC mortality based on review of additional incidence data.

Table 9-1

Key Uncertainties From the First Prospective Study

Potential Source of Error	Direction of Potential Bias for Net Benefits Estimate	Likely Significance Relative to Key Uncertainties in Net Benefit Estimate*	Addressed in the Analytical Plan for the Second Prospective?
Age-specific C-R functions for PM related premature mortality not reported by Pope et al. (1995). Estimation of the degree of life-shortening associated with PM-related mortality used a single C-R function for all applicable age groups.	Unable to determine based on current information.	Unknown, possibly major when using a value of life years approach. Varying the estimate of degree of prematurity has no effect on the aggregate benefit estimate when a value of statistical life approach is used, since all incidences of premature mortality are valued equally. Under the alternative approach based on valuing individual life-years, the influence of alternative values for numbers of average life-years lost may be significant.	Potentially. The state of the current epidemiological literature on PM-related mortality does not support age-specific C-R functions. Nonetheless, this topic may be addressed in the PM/mortality expert elicitation.

*The classification of each potential source of error reflects the best judgement of the section 812 Project Team. The Project Team assigns a classification of "potentially major" if a plausible alternative assumption or approach could influence the overall monetary benefit estimate by approximately five percent or more.

CHAPTER 10 - DATA QUALITY AND INTERMEDIATE DATA PRODUCTS

An analysis as broad and complex as the second prospective requires vigilance to quality control checks. In past reports in the section 812 series, EPA has engaged in a wide range of quality control projects and, through the SAB Council's involvement, peer review, covering both data and methods. Internal quality control checks have been performed at every stage of the analysis. In most cases, an additional layer of quality control has been possible; for example, an analytic team receiving data checks it throughly before performing the next step in the analysis (e.g., the air quality modelers check the emissions data; the physical effects modelers in turn check the air quality outputs).

For the second prospective, we propose to provide an enhanced ability for researchers outside the project team to both use and quality check the data used in the analysis. Our overall plan is to make available through EPA's web site or other means intermediate information and data products produced in the course of the analysis. Our hope is that the provision of these data products both furthers external research in this area and yields helpful insights for the ongoing work. This chapter briefly outlines the intermediate data products we expect to make available and the consistency checks we plan to perform ourselves on the data.

Intermediate Data Products

Figure 10-1 repeats the analytic sequence from Figure 1-1, and includes a short summary of the points in the analysis where we plan to provide intermediate data products. Where possible, we plan to make these intermediate data products publicly available through EPA's web site, and provide a means for comments to be provided by the public. We provide additional details on our plans below:

- **Scenario Development:** In their response to the June 2001 draft analytical plan, the SAB Council requested development of schematic diagrams of the provisions of each Title of the CAAA, to better communicate the assumptions underlying our scenarios and the implications of each for emissions of each pollutant. The schematics we plan to develop will be scenario and Title-specific, grouped by scenario, and provide information on: major industrial sectors affected, the nature of the regulatory instrument (command-and-control, performance-based, cap-and-trade, Federally mandated vs. locally determined, etc.), and pollutants addressed.

- **Emissions Profile Development:** We plan to make the emissions profiles available for review once this step of the overall analysis is complete and quality-checked. The project team typically develops emissions profiles in a format that meet specifications developed by air quality modelers for input to the relevant models. We plan to provide summary data via the Web, along with metadata for the much larger and more extensive profiles themselves, and will provide the actual profiles on request to interested researchers.

- **Direct Cost Estimation:** Cost estimates will be generated by major source category and by provision. We plan to make the summary direct cost data available via the Web, for each of the three target years of the analysis (2000, 2010, and 2020), by source category and provision. The level of detail will be similar to that provided in Appendix B of the first prospective. EPA will also consider options for producing more detailed cost data to be made available at the completion of the project.

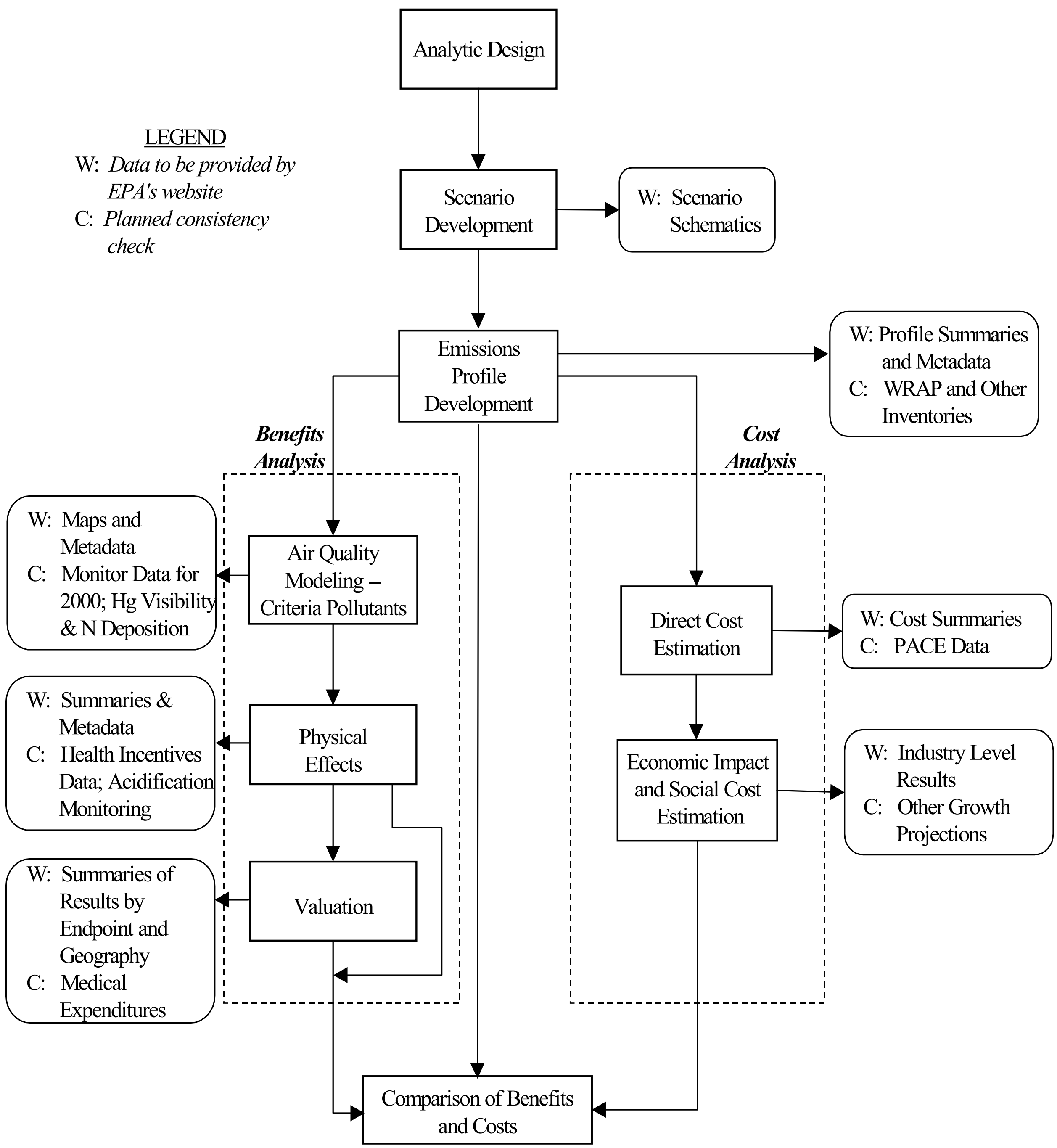
- **Air Quality Modeling:** Air quality modeling results can be categorized into six major groups: REMSAD ambient PM; CAMx ambient ozone; REMSAD light extinction (to measure visibility); REMSAD nitrogen deposition; and REMSAD mercury deposition. Within each category, a model run is performed and results are extracted for multiple scenarios and target years. The results consist of daily concentrations, extinction measures, or deposition rates - for ozone, hourly concentration values are developed. These are developed for each grid cell in a nationwide grid, 120 cells west to east and 80 cells north to south, for a total of just less than 10,000 cells. Making this enormous volume of data available therefore presents some significant challenges. We plan to develop summary maps, amenable to GIS format, for the major scenario results (i.e., the primary pre-CAAA and post-CAAA scenarios) for the three target years of the analysis (2000, 2010, and 2020). In addition, we will provide metadata for the full suite of scenario runs.

- **Physical Effects:** Data on incidence of health effects, as well as the results of modeling for agricultural and forestry yield losses, will be produced and made available at the state level, where possible. In some cases, it may also be possible to make available health effects incidence results by age (grouped into 10 year cohorts).

- **Economic Valuation of Benefits:** Data will be produced and provided at the state level, where possible, and grouped by pollutant-endpoint combination. In the case of state-level physical effects and economic valuation data, we will provide metadata that describes some of the uncertainties inherent in projections of state-level results ten or twenty years into the future, with particular reference to difficulties in generating accurate projections of state-level population estimates that take account of demographic, migration, and immigration trends.

- **Computable General Equilibrium Results:** We plan to make available the outputs from the CGE at the industry sector level, including relevant indicators of economic activity in the pre-CAAA and post-CAAA scenarios (e.g., industry level throughput or revenue) along with available price or price index data and employment data by industry.

Figure 10-1
Plans for Providing Intermediate Data Products in the Second Prospective Analysis



Consistency Checks

In its comments on the June 2001 draft analytical plan, the SAB Council recommended that the agency: 1) perform a comparison and evaluation between "old" (i.e., first prospective vintage) and "new" (i.e., second prospective vintage) assumptions, data, and models to examine how updates affected the results for costs and benefits; and 2) consider isolating a set of "observable variables" in the physical effects and economics areas that could be compared to actual data. An example of the latter would be health incidence data.

As part of the first recommendation, the Council referenced the Stanford Energy Modeling Forum format of comparing the results of multiple models using a standardized set of modeling inputs. While analytically attractive, this format would be largely unworkable for a comparison of first and second prospective modeling frameworks. One reason is the progress made in improving air quality models, the resolution and consistency of inputs, and the overall better "fit" between the resolution of models at various levels. As a result, the "old" versions of such models as CAPMS (for physical effects) are not designed to run with "new" air quality modeling outputs.

Alternative approaches to achieve similar objectives may be possible, however. The Council's intent appeared to be to identify those areas where past improvements would have the greatest effect. Some of the objectives of what the Council might have labeled a "retrospective influence analysis" may be achieved by the influence analyses contemplated as part of our uncertainty analysis strategy (summarized in Chapter 9). In addition, it is a relatively straightforward exercise to compare outputs from the same model years and draw qualitative conclusions about what changes in approach may explain the differences. While it may be difficult to separate the effects of changes in scenarios from changes in modeling approach, we believe some insights will be gained from such comparisons. At a minimum, EPA will provide an Appendix that compares results from the first and second prospectives.

The Council's second recommendation may also yield interesting insights. We plan to conduct the following consistency checks on the post-CAAA scenario results (i.e., the scenario designed to most closely track "real-world" conditions, and that will be most similar to the baseline scenario of other analyses):

- **Emissions:** We plan to compare the 2000, 2010, and 2020 results to other current emissions inventory results (e.g., Western Regional Air Partnership, or WRAP analyses), and will compare the 2000 results to measured emissions data for those categories where the data are available, for example, from Continuous Emission Monitors on EGUs.

- **Direct Cost and CGE results:** The recently released Pollution Abatement and Control Expenditure (PACE) data for 1999 provides a useful comparison point for direct cost results for 2000. We anticipate there may be some issues in comparing total pollution costs as estimated by PACE to our estimates of the incremental cost of the Clean Air Act

Amendments, but will attempt to reconcile these differences to the extent possible. In addition, we expect to compare CGE projects of national and industry-level growth in the post-CAAA scenario to other publicly available independent projections.

- **Air Quality Modeling:** We plan to compare grid cell results for the year 2000 to available ambient monitor data; establish nitrogen and mercury deposition estimates to 2000 monitor data; and estimated visibility to 2000 measurements.

- **Health Effects:** As recommended by the Council, we will compare output data from the BenMAP modeling to actual incidence data. It is important to note that our modeling looks only at differences between scenarios - we do not estimate absolute levels of mortality and morbidity incidence for each scenario. As the Council correctly pointed out, we will therefore be comparing our estimated change in incidence to the actual baseline incidence for the historical target year of 2000. We conducted a similar comparison in the first prospective.

- **Acidification:** It should be possible to compare modeled acidification estimates to actual acidification data for the Adirondack lakes in the MAGIC model set.

- **Economic Valuation Results:** One possible comparison point for morbidity effects is actual medical expenditures for select respiratory health effects. This comparison may simply amount to a comparison of unit WTP to COI values, or comparisons of health effect incidence where we use COI as the only available estimate of the value of avoiding a health effect.

EPA will continue to engage in the types of quality assurance measures it has adopted throughout the process of developing the 812 series of reports. Council review of methods, data, and assumptions is a critical part of that process. In addition, we have attempted to be explicit about our process of selecting specific studies on which to base our results, to ensure transparency and replicability, and have made efforts to make use of publicly available or open code models, where feasible, to ensure adequate peer review can be conducted.

CHAPTER 11: RESULTS AGGREGATION AND REPORTING

Results aggregation is a critical component of the overall cost-benefit analysis. While comparison of the cost and benefit results may appear to be a straightforward step, in practice an analysis this complex and broad requires many decisions about the level of detail at which results are presented, how non-quantitative results are incorporated, what discount rates should be used, and the types of comparisons and aggregations that are both appropriate and meaningful.

In this chapter, we present our planned approach for aggregating, reporting, and comparing the cost and benefit results. We first review the approach used in the first prospective, then present our plans for comparison of the results of the pre-CAAA and post-CAAA scenarios in the second prospective. We cover presentation of the aggregate results, results by sector, and benefits results by state and/or region for the primary central estimates, and the aggregation of the results of the cost and benefit uncertainty analyses.

Review of Approach in First Prospective

In the first prospective EPA compared costs to benefits for each of two target years - 2000 and 2010 - and also estimated the aggregate net present value of costs and benefits for the full 1990 to 2010 period. We linearly interpolated benefit and cost estimates between 1990 and 2000 and between 2000 and 2010 and then aggregated the resulting annual estimates across the entire 1990 to 2010 period of the study to yield a present discounted value of total aggregate costs, benefits, and net benefits for the study period. The aggregation used a five percent discount rate, with sensitivity calculations for alternative rates of three percent and seven percent. A linear interpolation was necessary because the air quality modeling was carried out only for the two target years (2000 and 2010). The resulting annual benefit estimates provided a temporal trend of monetized benefits across the period resulting from the annual changes in air quality.

These estimates did not, however, characterize the uncertainty associated with the yearly estimates for intervening years. In an attempt to capture uncertainty associated with these estimates, we relied on the ratios of the 5th percentile to the mean and the 95th percentile to the mean in the two target years. In general, these ratios were fairly constant across the target years, for a given endpoint. The ratios were interpolated between the target years, yielding ratios for the intervening years. Multiplying the ratios for each intervening year by the central estimate generated for that year provided estimates of the 5th and 95th percentiles, which we used to characterize uncertainty about the Primary Central estimate.

The modeling results in the first prospective supported estimates of annual and cumulative costs, benefits and net benefits for Titles I through V inclusive, and supported separate estimates for Title VI. The modeling in the first prospective did not support disaggregation of benefit or net benefit results by CAAA Title, although costs were presented by Title and major provision. In addition, the first prospective did not present results disaggregated by geographic area, with the exception of air quality modeling results and some spatially dependent ecological benefits categories (timber, nitrogen deposition, and acidification). The spatially disaggregated data were generally limited to presentation in report appendices.

We provided cumulative costs, benefits, and net benefits results for the Title VI analysis, but presentation of annual results presented major difficulties. We were able to track the overall progression of annual human health benefits from Title VI provisions, which steadily increased until about 2045, then decreased until 2165, the last year in the benefits analysis. The vast majority of the benefits (93 percent) accrued from 2015 to 2165. The modeling did not support development of comparable annual cost and benefit estimates, however. For example, it was not possible to link an estimate of stratospheric ozone depleter emissions with a particular cost estimate and, on the benefit side, with a particular atmospheric change, human health effect, and economic welfare impact. The annualized costs and benefits presented for Title VI were simply annuitized equivalents of the net present value of costs and benefits. The inability to accurately calculate annual Title VI costs and benefits for the study target years was not cited by the Council as a major limitation of the study, however, probably because the Title VI costs and benefits were separable from estimates for other Titles. Table 11-1 summarizes the primary central benefits and costs presented in the first prospective.

Table 11-1

Summary of Quantified Primary Central Estimates of Benefits and Costs for First Prospective (Estimates in million 1990$)

Cost or Benefit Category	Annual Estimates 2000	Annual Estimates 2010	Present Value
Costs:			
Title I	$8,600	$14,500	$85,000
Title II	$7,400	$9,000	$65,000
Title III	$780	$840	$6,600
Title IV	$2,300	$2,000	$18,000
Title V	$300	$300	$2,500
Total Costs, Title I-V	$19,000	$27,000	$180,000
Title VI	$1,400*		$27,000*
Monetized Benefits:			
Avoided Mortality	$63,000	$100,000	$610,000
Avoided Morbidity	$5,100	$8,000	$49,000
Ecological and Welfare Effects	$5,100	$5,000	$50,000
Total Benefits, Title I-V	$71,000	$110,000	$690,000
Stratospheric Ozone	$25,000*		$530,000*

*** Annual estimates for Title VI stratospheric ozone protection provisions are annualized equivalents of the net present value of costs over 1990 to 2075 (for costs) or 1990 to 2165 (for benefits). The difference in time scales for costs and benefits reflects the persistence of ozone depleting substances in the atmosphere, the slow processes of ozone formation and depletion, and the accumulation of physical effects in response to elevated UV-b radiation levels.**

Alternative Estimates

In addition to the primary central estimates of costs and benefits, in the first prospective EPA presented a series of alternative estimates of costs and benefits. EPA summarized both quantified and unquantified sources of uncertainty and our estimates of the impact of these sources of uncertainty on the primary central estimates of benefits and costs. The analysis addressed seven major categories of uncertainties: measurement uncertainties in physical effects and valuation components of the benefits analysis; measurement uncertainties in estimation of direct cost inputs; alternative assumptions for PM-related mortality valuation; alternative assumptions for PM-related mortality risk;uncertainties in the Title VI health benefits analysis; unquantified sources of error in emissions and air quality modeling; and omissions of key benefits categories. EPA summarized the quantitative analyses of uncertainty, characterization of unquantified uncertainty, and the potential effect of alternative modeling paradigms for costs and benefits. Additional treatment of alternative paradigms was necessary because reasonable people may disagree with methodological choices that underlie the primary central estimates, and these choices might be considered to significantly influence the results of the study.

Cost-Effectiveness Results

The first prospective also included discussion of the results of a cost-effectiveness calculation, the direct-cost-per-life-saved. Although premature deaths are one of many health and welfare benefits of the CAAA, the analysis revealed that this endpoint dominates the monetized benefit estimate. The cost-effectiveness estimate was designed to facilitate comparison of the CAAA with other alternative investments that prevent premature death, including alternative regulation and public health measures.

Proposed Approach for Second Prospective

Primary Central Results

For the second prospective, we propose to develop comprehensive estimates of costs, benefits, and net benefits for each of the three target years (2000, 2010, and 2020). In addition, EPA plans to calculate, but not emphasize, benefit/cost ratios. While we are cognizant of the SAB Council's comments on the June 2001 draft analytical plan, where they indicated a preference for net benefits estimates over benefit/cost ratios, we believe that a combination of these measures, with appropriate explanation and much more emphasis in the text and graphics on net benefits and the overall magnitude of total costs and benefits, provides the best summary information to readers of the analysis. EPA also considered developing cumulative, net present value estimates of costs, benefits, and net benefits using the same linear interpolation procedure used in the first prospective, as indicated in the June 2001 draft analytical plan. We no longer plan to develop the net present value estimates for criteria pollutant result, for the following reason: we conclude that the significant uncertainty introduced by the inter-target year interpolation procedure could suggest to some readers that these estimates are more precise than we believe them to be. While we assume a linear interpolation path for both costs and benefits, in fact the actual temporal paths of both of these series may differ substantially from the linear path. Available historical information supports a nonlinear path for emissions reductions, for example. In addition, many programs require upfront capital investments that yield benefits that increase over time; our ten-year spacing of target years provides only a limited glimpse of this process. Net present value calculations may be pursued in the future, however, because annual estimates for additional intervening target years, at a temporal resolution finer than a decade, can be more reliably estimated.

Sectoral Disaggregation

The significantly expanded set of scenarios and air quality modeling runs, described in Chapter 2 of this document, will allow us to present costs and benefits independently for each major air pollutant emitting sector affected by the CAAA. The presentation format in Exhibit 11-1, therefore, will be altered to present consistent national cost, benefit, and net benefit results for each major sector. Our plan for generating sector-specific benefits results involves the specification of independent scenarios that selectively omit emissions reductions for a single sector, setting the emissions rate for that sector at the pre-CAAA level, while preserving the post-CAAA status of provisions affecting all other sectors. Because of non-linearities in the marginal benefit curve for some pollutant-endpoint combinations, we expect that this approach may yield sector-specific cost and benefit results that will not sum to the total costs for all sectors. As a result, we plan to carefully present the sector-by-sector benefit/cost comparisons on an independent basis as well as in summary form in a table similar to Table 11-1, with text to remind readers of the design features of each specific scenario to which the results apply.

Spatial Disaggregation

The June 2001 draft analytical plan had proposed to present spatially disaggregated cost and benefit results. The cost and benefit modeling we will conduct supports generation of estimates on a state-by-state basis. We had initially acknowledged concern about the accuracy of cost and benefit estimates at that level of disaggregation as compromised by our relative lack of knowledge on the spatial distribution of population growth and new productive capacity over the next two decades. To address that concern, in the June 2001 draft analytical plan we had proposed to present multi-state regional results in the main text, and discuss these findings at the regional level, with state-level results provided in tabular form as back-up in the appendices.

The SAB Council's comments on the June 2001 draft analytical plan specifically advised against presenting spatially disaggregated costs, however, because of the difficulty in determining the ultimate incidence and impact of costs by geographical areas.[1] For example, while an electric utility in Indiana might initially incur costs to install a sulfur scrubber as a result of Title IV provisions, the ultimate incidence of those costs will be borne by some combination of the customers of the utility, who might be dispersed over a multi-state or even multi-regional area, and the stockholders of the utility, who are likely to be even more widely dispersed. Because costs cannot be reliably disaggregated on a spatial scale, the SAB also cautioned against disaggregating net benefits on a spatial scale, because of the reliance of disaggregated net benefits on a disaggregated cost estimate.

We do plan to develop estimates of the spatial disaggregation of benefits, where possible, with particular reference to the category of benefits. This spatial allocation of benefits is partly motivated by the objective to analyze the distributional outcomes of the various scenarios. In the case of health effects, a spatial disaggregation is relatively reliable, although it is subject to increasing limitations in our ability to project population and baseline incidence as we move to lower-than-national level resolution. For recreational visibility and other recreational benefits, it is not clear whether it is more appropriate to assign benefits to the location of the physical resource affected by air pollution (e.g., a national park) or to the residence of the individuals who visit the resource. As outlined in Chapter 10, however, our ability to evaluate the accuracy and plausibility of the benefit results depends in part on generating and reporting estimates at lower-than-national resolution. We plan to present the spatially disaggregated benefits information in the appendices to the report.

Pollutant-endpoint Disaggregation

The Council's comments on the June 2001 draft analytical plan urge EPA to develop and report estimates of the benefits of air pollutant control by pollutant-endpoint combination, where possible.[2] The comments acknowledge issues of joint products and additive separability, which can be issues in disaggregating by pollutant, for example, in attempting to discern the potentially independent effects of particulate matter and ozone on premature mortality. Nonetheless, there are many cases where we can identify specific pollutant-endpoint combinations that account for an identifiable benefit, and we will attempt to present this type of disaggregation where possible.

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[1] EPA-SAB-COUNCIL-ADV-01-004, September 2001, page 43.

[2] EPA-SAB-COUNCIL-ADV-01-004, September 2001, page H-2.

Results of Uncertainty Analyses

In the June 2001 draft analytical plan, EPA proposed to present a summary form of the uncertainty analyses by presenting low and high estimates for benefits, net benefits, and the benefit/cost ratio. We proposed to present results in much the same format as the first prospective (see Table 11-2 below), in part to facilitate comparisons to the first prospective, but anticipated being able to provide entries for the low and high cost estimates, rather than leaving them blank as was done in the first prospective. In addition, we proposed to generate primary central, primary low, and primary high net benefits and benefit/cost ratio estimates with a probabilistic aggregation procedure, rather than the straightforward "ratio" calculation presented in the first prospective. In other words, we planned to develop a distribution of net benefits and benefit/cost ratios based on a Monte Carlo simulation of the subtraction of costs from benefits (for net benefits) or the division of benefits by costs (for the benefit/cost ratio). The 5th percentile of the resulting distributions would be the low estimate, and the 95th percentile would be the high estimate.

Our general strategy for presenting the results of uncertainty analyses is largely the same as in the June 2001 presentation, but we expect to be able to provide a more detailed and descriptive analysis of the results of the significantly enhanced uncertainty analyses proposed in Chapter 9. We hope that the enhanced uncertainty analysis will both provide a more comprehensive basis for characterizing uncertainty, and an ability to assess the likelihood of at least some of the alternative paradigm outcomes (e.g., alternative C-R specifications for PM mortality). We continue to anticipate a need to supplement the primary central results by calculating alternative estimates for some uncertainties that may not be addressed in the enhanced uncertainty analysis. One new calculation that will be presented along with the results of any alternative paradigm results is the QALY-based cost-effectiveness analysis results. Our proposed methodology for this analysis is described in Chapter 8.

We further propose to assess the effects of using an alternative discount rate on the benefit and cost results, as was done in the first prospective. Consistent with the policy laid out in EPA's *Guidelines for Economic Analysis*, for the second prospective we propose to limit our discount rate analysis to the primary central discount rate of 3 percent and the application of one alternative estimate using a discount rate of 7 percent. The change in discount rate is likely to have a negligible effect on the results if we are not performing net present value calculations. It would affect any calculations we perform that are based on statistical life-years estimates, if for example an alternative estimate such as that described in Chapters 6 and 8 is to be included in the analysis. As we stated in those two chapters, the 812 Project Team is still evaluating the merits and utility of adding an alternative estimate to accompany the primary estimates for benefits in the second prospective analysis, and seeks advice from the SAB regarding the value and utility of generating an alternative estimate, as well as advice concerning the technical/scientific reasonableness of each of the alternative assumptions or assumption sets.

Table 11-2
Summary Comparison of Benefits and Costs in First Prospective
(Estimates in millions 1990$)

	Titles I through V			Title VI	All Titles
	Annual Estimates		Present Value Estimate	Present Value Estimate	Total Present Value
	2000	2010	1990-2010	1990-2165	
Monetized Direct Costs:					
Low [a]			*Not Estimated*		
Central	$19,000	$27,000	$180,000	$27,000	$210,000
High [a]			*Not Estimated*		
Monetized Direct Benefits:					
Low[b]	$16,000	$26,000	$160,000	$100,000	$260,000
Central	$71,000	$110,000	$690,000	$530,000	$1,200,000
High[b]	$160,000	$270,000	$1,600,000	$900,000	$2,500,000
Net Benefits:					
Low	($3,000)	($1,000)	($20,000)	$73,000	$50,000
Central	$52,000	$93,000	$510,000	$500,000	$1,000,000
High	$140,000	$240,000	$1,400,000	$870,000	$2,300,000
Benefit/Cost Ratio:					
Low[c]	less than 1/1	less than 1/1	less than 1/1	less than 4/1	less than 1/1
Central	4/1	4/1	4/1	20/1	6/1
High[c]	more than 8/1	more than 10/1	more than 9/1	more than 33/1	more than 12/1

[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.

CHAPTER 12 - PROJECT SCHEDULE

Exhibit 12-1 lists each of the key components and the currently anticipated completion date for that analytical step. The project schedule is predicated on EPA's plan to initiate analytical efforts immediately after the June 11-13, 2003 SAB review meeting, following the methodological plans described in the May 2003 analytical plan. We recognize, however, that these plans may be revised pursuant to SAB advice received during and after June 11-13, and by analytical issues and opportunities which emerge during study implementation (e.g., an option to employ a newly-released model or database, or new peer-reviewed effects literature).

EPA also anticipates requesting an in-progress review by the SAB in the October-November 2003 timeframe focused on (a) the interim results from the emissions and direct cost results, and (b) final methodological plans for the air quality modeling, physical effects, valuation, and uncertainty analyses.

Exhibit 12-1
Project Schedule

Component	Expected Completion
Analytical Design	Analytical plan: *May 2003*
Scenario Development	Scenario definitions: *June 2003*
Emissions Profiles	Emissions inventories for all scenarios: *September 2003*
Air Quality Modeling	Air quality modeling results: *December 2003*
Physical Effects Modeling	BenMAP health effect model results: *March 2004* HAP case study: *March 2004* Ecological case study: *March 2004* Title VI analysis: *March 2004*
Cost Estimation	Complete direct cost estimates: *October 2003* CGE modeling results: *May 2004*
Economic Valuation	Health effect valuation: *April 2004* Welfare and ecological effect valuation: *April 2004*
Uncertainty Analysis and Results Aggregation	Cost-benefit results aggregation, uncertainty analysis, sensitivity analysis: *April 2004*

Exhibit 12-1 Project Schedule	
Component	**Expected Completion**
Report Generation	Initial draft of Report to Congress: *June 2004* SAB review of initial draft Report to Congress: *July 2004* Publication of final Report to Congress: *October 2004*

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