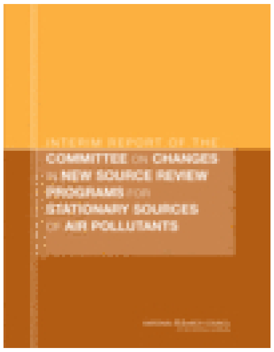

# Interim Report of the Committee on Changes in New Source Review Programs for Stationary Sources of Air Pollutants

Committee on Changes in New Source Review Programs for Stationary Sources of Air Pollutants, National Research Council

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# INTERIM REPORT OF THE COMMITTEE ON CHANGES IN NEW SOURCE REVIEW PROGRAMS FOR STATIONARY SOURCES OF AIR POLLUTANTS

Committee on Changes in New Source Review Programs for
Stationary Sources of Air Pollutants

Board on Environmental Studies and Toxicology

Division on Earth and Life Studies

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# Preface

The United States Congress directed the U.S. Environmental Protection Agency (EPA) to arrange for an independent study by the National Research Council (NRC) to evaluate potential air quality, public health, and other impacts of EPA's final rules of December 31, 2002, and October 27, 2003, relating to the New Source Review (NSR) programs that are part of the Clean Air Act. In response, the National Research Council established the Committee on Changes in New Source Review Programs for Stationary Sources of Air Pollutants. Biographical information on the committee members is presented in Appendix A. In response to Congress, the committee is providing this interim report and will deliver its final report in 2005.

In the course of preparing this report, the committee met three times. At two of the meetings, which were held in Washington, DC, officials from local, state, and federal agencies and representatives from the private sector and nongovernmental organizations, including regulated industries and advocacy groups, were invited to meet with the committee and present their views on changes to the NSR programs. Interested members of the public at large were also given an opportunity to speak on these occasions.

The committee received oral and written presentations from the following individuals: William Becker, State and Territorial Air Pollution Program Administrators (STAPPA) and the Association of Local Air Pollution Control Officials (ALAPCO); Robert Bessette, Council of Industrial Boiler Owners; F. William Brownell, Hunton and Williams; Norbert Dee, National Petrochemical & Refiners Association; John Dege, DuPont Company; Peggy Duxbury, Calpine; Jerry Golden, Tennessee Valley Authority; William Harnett, Jeffrey Holmstead, Michael Ling, Philip Lorang, all of the U.S. Environmental Protection Agency; David McIntosh, Natural Resources Defense Counsel; Christopher Miller, U.S. Senate Committee on Environment and Public Works; William Pedersen, William F. Pedersen PLLC; Eric Schaeffer, Environmental Integrity Project; Scott H. Segal, Electric Reliability Coordinating Council; John Shanahan, U.S. Senate Committee on Environment and Public Works; Robert Slaughter, National Petrochemical and Refiners Association; Joseph Stanko, Hunton and Williams; Margaret Taylor, University of California at Berkeley; Michael Vince, Louisiana Department of Environmental Quality; Steve Wilson, Southern Company; James Witkowski, International Paper and the American Forest and Paper Association; Samuel Wolfe, New Jersey Department of Environmental Protection; and Tammy R. Wyles, Georgia-Pacific Corporation and the American Forest and Paper Association.

In addition to the information provided in those presentations, the committee is using peer-reviewed scientific literature, reports from government agencies and nongovernmental organizations, databases, and other types of information. The committee has not completed the process of information gathering and analysis; therefore, readers of this interim report should not assume that the committee has reached any final conclusions or recommendations in response to its charge from Congress. Those will be presented in the committee's final report.

We wish to thank William Happer for his valuable service as chair of the committee during the early stages of this study. He resigned appropriately from the committee to serve on the Science and Technology Advisory Committee for the U.S. Department of Homeland Security. The committee's work for this interim report was assisted by staff of the NRC's Board on Environmental Studies and Toxicology (BEST). We wish to thank Raymond Wassel, project director, and James Reisa, director of BEST. Scientific and technical information was provided by Eileen Abt, Leah Probst, Mirsada Karalic-Loncarevic, Bryan Shipley, Sammy Bardley, and Alexandra Stupple. Invaluable logistical support was provided by John Brown and Kemi Yai. The report was ably edited by Cay Butler.

Charles Stevens, *Chair*
Comittee on Changes in New
Source Review Programs for
Stationary Sources of Air
Pollutants

# Acknowledgment of Review Participants

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the NRC's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their review of this report:

Wayne T. Davis, University of Tennessee; Jeremy Hales, Envair Corporation; Jay Hofmann, Trinity Consultants; Morton Lippmann, New York University School of Medicine; Janet G. McCabe, Indiana Department of Environmental Management; Jana B. Milford, Environmental Defense and University of Colorado; Robert O'Keefe, Health Effects Institute; Richard Revesz, New York University School of Law; Ralph L. Roberson, RMB Consulting & Research, Inc.; James Jay Schauer, University of Wisconsin; Robert N. Stavins, Harvard University; and Samuel A. Wolfe, New Jersey Department of Environmental Protection.

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations, nor did they see the final draft of the report before its release. The review of this report was overseen by

David Allen, University of Texas. Appointed by the NRC he was responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

# Contents

# INTERIM REPORT OF THE
# COMMITTEE ON CHANGES IN NEW SOURCE REVIEW PROGRAMS FOR STATIONARY SOURCES OF AIR POLLUTANTS

# Summary

Since 1977, the Clean Air Act (CAA) has included programs—known as New Source Review (NSR)—that regulate the construction and modification of large stationary sources of air pollution, such as factories and electricity-generating facilities. Under NSR programs, each new large stationary source of pollutants must apply for a permit before beginning construction. The permit-granting process is also required when a physical change to an *existing* large stationary source would result in a significant increase in pollutant emissions. NSR programs allow construction or modification of an emission source only if the operator first shows that emissions will be reduced as much as practicable. The operator must also show that the construction or modification will not result in significant deterioration of air quality in areas that meet the National Ambient Air Quality Standards (NAAQS)[1,2] or interfere with

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[1] The NAAQS specify the maximum allowable concentrations of criteria pollutants in ambient air that are protective of public health and welfare. The six criteria pollutants are carbon monoxide, lead, nitrogen dioxide, ozone, particulate matter, and sulfur dioxide. Pollutants for which there are NAAQS are known as criteria pollutants because the U.S. Environmental Protection Agency prepares “criteria documents” describing the sources and effects of these pollutants.

[2] An applicant for a permit in an area that meets the NAAQS must show that the new or modified facility will, for each regulated pollutant emitted in significant amounts, limit emissions to the level achievable through the use of best available control technology (BACT). The applicant also must show that the facility will not cause a violation of the NAAQS or of prevention of significant

progress toward attainment of satisfactory air quality in areas where current air quality violates the NAAQS.[3]

This interim report focuses on changes made to the NSR programs over the past few years that affect modifications to existing stationary sources of pollutants. In December 2002, the U.S. Environmental Protection Agency (EPA) made a number of revisions to the NSR programs, including revisions to methods used to determine whether particular physical changes to a facility would result in significant emission increases that would be subject to NSR. Regulatory revisions were also made in October 2003 concerning the extent of equipment replacements or other modifications for which an NSR permit would not be required, even if pollutant emissions increased significantly, so long as the source did not exceed its maximum level of allowable emissions.[4] EPA and other supporters of the revisions say the changes will provide greater flexibility in operating the facilities, increase energy efficiency, and help to modernize American industry, all without damaging the environment. Opponents say that the EPA revisions will slow progress in cleaning the nation's air, thus damaging human health, and that the NSR changes are not necessary to provide operating flexibility to industry.

## CHARGE TO THE COMMITTEE

Because of the controversy over EPA's revisions, Congress requested that EPA arrange for an independent study by the National Research Council (NRC) to estimate the potential impacts of EPA's final NSR rules of December 2002 and October 2003. Congress called for an assessment of changes in emissions of pollutants regulated under the NSR programs; impacts on human health; and changes in energy efficiency, pollution prevention, and pollution control activities at facilities

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deterioration (PSD) increments that limit growth in concentrations of certain pollutants.

[3] To ensure that the construction or modification will not disrupt progress toward attaining the NAAQS, the operator must obtain emission reductions (offsets) from other sources. Also, the operator must show that the new or modified source will emit at the lowest achievable emission rate (LAER).

[4] Sources often emit at a rate less than their maximum level of allowable emissions. Therefore, it is often possible for a source to increase emissions without exceeding its maximum allowable emissions.

subject to the revised NSR programs. In response to the request, the NRC established the Committee on Changes in New Source Review Programs for Stationary Sources of Air Pollutants. For its interim report, the committee was charged to present all conclusions and recommendations the committee determined to be feasible and appropriate by January 2005. A final report will be provided at the end of 2005.

Congress did not ask the committee to determine the desirability of the NSR revisions or to recommend whether they be revised or repealed. Such conclusions involve considerations that go beyond science and involve value judgments (for example, how to weigh environmental protection against other societal goals). Congress also did not ask the committee to appraise whether EPA acted within the scope of its authority and, if so, whether EPA's decision was reasonable. In addition, Congress did not ask the committee to investigate any effects of the NSR changes other than on human health (such as changes in atmospheric visibility, climate, or ecological consequences of pollutant deposition). Because Congress requested an evaluation of changes in emissions of pollutants regulated under the NSR programs, the committee did not include emissions of greenhouse gases, such as carbon dioxide and methane, in its assessment. EPA does not consider those gases to be regulated under the CAA.

## COMMITTEE'S APPROACH FOR ITS INTERIM REPORT

This interim report provides a synthesis of background information on relevant health effects, air quality indicators, emissions, and industry activities in a regulatory context that will serve as a basis for the committee's final report. The interim report also describes the committee's approach to assessing the impacts it has been asked to address. This approach will be refined as the study progresses.

As it carries out its charge, the committee is considering a number of relevant scientific and technical documents prepared by EPA, other federal agencies, states, industry, and environmental and other nongovernmental organizations. Although the committee does not present evaluations of those documents in this report, they have been used to inform the committee's deliberations. The committee expects to provide its perspectives on several of those documents in the final report. The committee also will gather information on how the revised NSR regulations may affect emissions, air quality, public health, and industry actions concerning pollution control, pollution prevention, and energy efficiency. Because it has not completed the process of information gathering and analyses, the committee has not reached its final conclusions or recommendations in response to its charge from Congress. Those will be presented in the committee's final report.

## OVERVIEW OF RELEVANT BACKGROUND INFORMATION

### Health Effects of Air Pollution

EPA has set NAAQS for six "criteria" pollutants. Much of the CAA consists of mechanisms, including NSR, to control emissions of the criteria pollutants and their precursors (such as volatile organic compounds). A large and growing body of published epidemiologic and toxicologic research establishes associations between exposure to the criteria pollutants and various health effects, including increased occurrence of cardiopulmonary disease, cardiopulmonary and cancer mortality, poor birth outcomes (low birth weight and small for gestation age), and impaired growth of lung function in children. The associations between exposure to air pollutants and health hazards are most consistent for children, particularly those with asthma, and for older people, particularly those with underlying cardiovascular disease and diabetes. Given that, according to EPA, more than half the U.S. population lives in counties that exceed the NAAQS for ozone and/or particulate matter, air pollution is an important potential health hazard.

Unlike the clarity of overall associations, the extent to which various health effects can be attributed to a given pollutant or combinations of pollutants, and at what concentrations, is less apparent. These limitations must be considered when examining the quantitative estimates of health effects attributed to pollutants. In the case of particulate matter, the problem is compounded by the complex physical-chemical mixture of particulate matter whose components probably interact with other criteria pollutants (such as ozone) in a number of ways that can affect health outcomes. Characterizing overall pollutant mixtures with respect to health implications is a major challenge for air-pollution-related health-effects research.

In addition to the criteria pollutants, emissions addressed by the NSR programs include volatile organic compounds, which comprise a diverse group of air contaminants. Although these compounds are addressed by NSR because of their contributions to the formation of ozone, many of them are also of concern because of their toxicity. Effects of concern involve mutagenicity, cancer, irritation (inflammation), neurotoxicity, or modulation of immune responses.

## Pollutant Emissions

Large stationary sources of emissions are not evenly distributed across the United States. Such sources are typically located on the periphery of urban areas and near convenient transport facilities or near sources of raw materials. Large stationary sources contribute substantial emissions of nitrogen oxides, sulfur dioxide, particulate matter, and volatile organic compounds nationwide, including areas with concentrations of criteria pollutants associated with an increased risk of adverse health impacts. Therefore, it is important to assess a variety of types and locations of stationary sources that are affected by the NSR changes under review by this committee. The age of the facilities may be an important consideration, because older facilities are more likely to undergo maintenance, repair, and replacement of key components than are newer ones.

Data on the age of facilities are more readily available and linkable to the emission data for the electricity-generating sector than for the other industrial facilities. Older coal-fired facilities tend to have higher emissions per megawatt-hour of total electricity generation than new facilities and tend to contribute proportionately more to total emissions than they contribute to total electricity generation.

Because of the long-range transport of some pollutants, important emission sources may be far from the locations where measured pollutant levels exceed the NAAQS. Thus, for areas experiencing higher ambient concentrations of fine particulate matter[5] and ozone, controlling those emissions is typically a regional, often multistate, problem, not a local one.

## Existing Emission Sources Covered by NSR Programs

On the basis of preliminary data collected by the committee, permits for modifications of industrial facilities comprise 25-48% of the

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[5] Fine particulate matter ($PM_{2.5}$) is operationally defined as those particles having an aerodynamic diameter of 2.5 micrometers or less.

reported total amount of permitted emissions among all NSR permits, depending on the pollutant. NSR permits for modifications have been issued for a wide variety of emission-source categories. Whether measured by number of permits or by amounts of permitted emissions, the primary industrial categories are electric utilities; stone, clay, and resulting products; paper and allied products; chemicals and allied products; and food and kindred products.[6]

Although the mix of industries appears to be diverse, the emission processes are often similar across industries. For example, many industries use common unit operations, such as industrial furnaces to generate steam for process use, or other combustion sources, such as tunnel or rotary kilns.

A review of common repair and replacement practices for selected types of process facilities showed that such practices can vary considerably in frequency and cost.[7] Likewise, a wide range of pollution prevention and control options can vary in effectiveness and cost for a given emission source, such as a utility boiler.

Typically, “pollution control” refers to “end-of-pipe” techniques for removing pollutants from an exhaust gas after the pollutants have been formed in an upstream process. For example, in a coal-fired power plant, pollutants such as nitrogen oxides ($NO_x$), sulfur dioxide ($SO_2$), and PM are formed during combustion. Postcombustion control technologies such as selective catalytic reduction, fuel gas desulfurization, and electrostatic precipitation, respectively, can be used to reduce or capture these pollutants. In contrast, pollution prevention approaches are aimed at reducing or eliminating sources of pollution, typically through feedstock substitutions or process alterations. For example, in the case of a coal-fired power plant, methods that more carefully control and stage mixing of fuel and air can prevent the formation of a portion of $NO_x$ that otherwise would have been created. As another example, evaporative volatile organic compound (VOC) emissions can be prevented by substituting water-based solvents for VOC-based solvents used at a manufacturing facility. Emission sources, pollution prevention techniques, and pollution control technology are expected to change over time, and regu-

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[6] The committee will not necessarily focus on these industrial categories in its final report.

[7] The committee takes no position on whether these repair and replacement activities are “routine” within the meaning of EPA’s old or new regulations.

lations such as the ones considered here can be part of the motivating factors for such change. However, the effects of regulations can vary greatly, depending on the specifics of the programs.

## ANALYTIC METHODS FOR ASSESSING EFFECTS OF NSR CHANGES

A number of methods can be used to assess the effects of NSR changes made by EPA in 2002 and 2003. Methods are available that focus on the responses to NSR changes by individual firms or facilities, entire industry sectors, multiple sectors, or the entire economy. Assessing all the factors of interest requires an evaluation of how the firms, industry sectors, or economy will alter investments and operations (including pollution control and pollution prevention) in response to changes in the NSR rules and the resulting changes in efficiency and pollutant emissions. The assessment also involves an evaluation of how the emission changes might affect human exposures and health.

The approaches discussed in this report will be relevant to the committee's final report. No assessment results are provided in this interim report.

### Possible Indicators for Assessing Outcomes

Table S-1 provides a list of possible indicators that could be used to assess magnitudes and trends in pollution control and prevention, energy efficiency, emissions, air quality, and health effects. Many of the indicators vary over time and space or from one facility to another, and some degree of averaging must be done before the data can be analyzed. In many cases, the data are not available from a single comprehensive source (or even distributed among many sources), and incomplete data must be used for drawing inferences. Furthermore, the list in Table S-1 includes factors that are quantitative and directly indicative of the targeted outcome—such as emissions for individual facilities, industries, and states—and other factors that are more qualitative and difficult to measure, such as the rate of innovation for pollution prevention and control technology.

Because many outcomes and indicators are affected by a number of factors outside the NSR rules (or even pollution control laws in gen-

**TABLE S-1** Possible Indicators for Assessing Outcomes of Interest

| Outcome | Possible Indicators to Assess Outcome |
|---|---|
| Pollution control | • Innovation in new technologies<br>—Expenditures for research and development<br>—Inventions and patents<br>• Implementation of new technologies<br>—Adoption by industry and utilities<br>• Improvements in use (“learning by doing”)<br>—Performance histories for selected technologies |
| Pollution prevention (source reduction) | • Innovation, implementation, and improvements in industrial processes to be less polluting<br>—Expenditures for research and development<br>—Adoption by industry and utilities<br>—Performance histories of selected technologies<br>—Trends in emissions generated per unit of product produced<br>• Life-cycle material-use impacts, considering economy-wide impacts through the supply chain and product delivery use, reuse, and disposal<br>—Number of products introduced into commerce with reduced hazardous properties<br>• Substitution of materials with less polluting substances |
| Energy efficiency | • Innovation, implementation, and improvement in use of new technologies that enable energy efficiency in electricity generation and industrial processes<br>• Energy efficiency of operating units and plants<br>• Industry sector-wide energy use<br>• Life-cycle energy-use impacts, considering economy-wide impacts through the supply chain and product delivery, use, reuse, and disposal |
| Emissions | • Trends in emissions for individual units, plants, industries, states, regions, and the nation as a whole<br>• Relationships between emissions and unit and plant operating costs and use<br>• Life-cycle emission impacts |
| Air quality | • Ambient concentrations of relevant emitted primary pollutants and pollutants formed in the atmosphere over various spatial and temporal scales |
| Health effects | • Human exposure and dose<br>• Mortality and disease<br>—Population incidence<br>—Incidence for particular subpopulations (regional or socioeconomic)<br>—Risks to highly exposed individuals |

eral)—such as economic conditions, government investment in research and development, fuel supplies and prices, and meteorological conditions—other factors and data must also be considered in analyses that attempt to assess the impact of NSR rule changes on the outcomes of interest. Thus, any assessment (explicitly or implicitly) involves a comparison of two outcome estimates: (1) an estimate of what would happen without the rule changes, and (2) an estimate of what would happen with the rule changes. Both outcomes are subject to substantial uncertainty, and a range of possible scenarios must be considered for the economic and environmental assumptions that are applied to compare expected "new-rule" and "no-new-rule" outcomes.

### Use of Models

Assessments of an individual firm's behavior in response to regulation can be based on anecdotal reports, directed case studies, surveys of multiple firms, and conceptual economic models. Economic models estimate how a firm behaves in response to different incentives on the basis of rational choice and profit maximization. Process engineering models that estimate the performance (for example, efficiency), emissions, and cost, given alternative capital investments and operating decisions at individual facilities, can be included as a part of, or a precursor to, economic models.

The possible response of an entire sector of U.S. industry to government policies, technological change, and economic conditions can be estimated with generalizations of the results from tools used for individual firms within that sector, including anecdotal reports and representative case studies or surveys. In addition, economic models are available to estimate the behavior of a group of facilities that may or may not interact in some way in response to common constraints and incentives. Some computer models of the electricity-generating sector appear to be sufficiently detailed and sensitive to allow a first assessment of how changes in NSR rules might affect technology adoption and emission trends.

For industry sectors outside the electricity-generating sector, the models in use do not appear to have the capacity to represent alternative technologies in a long-term simulation, and the time and resources available to the committee are not sufficient to support the reformulation or construction of sector models for this purpose. For these sectors, therefore, any generalization from the estimates of facility-level responses to estimates of industry-sector responses will have to be undertaken more informally without reliance on an established model.

When firms modify their production levels or product designs in response to regulation or other incentives, the effects of these decisions ripple through the economy and affect other industries. Tracing such effects throughout the entire economy is the focus of multisector models. For the most part, the multisector models are even less sensitive than the sector models to the types of changes that the committee is assessing. Modifying the available models so that they reflect the NSR rule changes is substantially beyond the committee's capacity or resources. Therefore, any intersector impacts will also have to be assessed informally, and any estimates of their direction or magnitude are likely to be highly uncertain.

It remains to be determined which modeling approaches considered by the committee will have sufficient sensitivity to the NSR rule changes under investigation to be able to estimate their effects accurately. Nonetheless, insights into a firm's behavior will help in assessing how individual facilities might respond to the incentives created by the NSR rule changes. That assessment, in turn, might allow an assessment of the direction of change (positive or negative) in the impacts of concern (for example, whether emissions are likely to increase or decrease) and possibly an estimate of the magnitude of the impact for typical facilities in different industry sectors.

The most appropriate way to estimate the impacts on health and other outcomes of any emission changes expected on the basis of the above assessments will depend substantially on the amount and quality of information resulting from these assessments. The human health impacts, for instance, are likely to depend on which facilities modify their emissions in response to the rule changes, who is exposed to the emissions from those facilities, and the ambient air quality in the vicinity of those facilities before the modifications occur. In most cases, the committee will probably not be able to make assessments with such specificity. When we cannot do so, sophisticated modeling of human health impacts will have little validity. In such cases, we will be able to do little more than indicate the likely direction and the rough magnitude of these impacts, if any.

## USING SCENARIOS TO ASSESS IMPACTS OF NSR CHANGES

In the next phase of its study, the committee will assess the impacts of NSR changes on emissions, air quality, public health, energy efficiency, pollution control, and pollution prevention. Because NSR is not the only CAA program that affects air emissions from industrial facilities, the incremental effects of NSR changes on decisions at a particular facility or industry sector will also depend on developments concerning other relevant regulations. This dependence must be taken into account in the committee's framework.

Because of the many substantial uncertainties involved and the expected lack of substantial empirical data, the committee plans to assess NSR-related impacts by using alternative scenarios that include development of other regulations. The scenarios will also involve several interpretations of the NSR rules (for example, stringent versus less stringent interpretations). Because the potential impacts of the revised NSR programs can depend strongly on the scenario analyzed, the impacts of interest must be assessed under a variety of scenarios. Furthermore, because the effect of other regulations varies across types of sources, the committee assessments will be done separately for different industries.

For some industries, proposed non-NSR regulatory changes might not affect their emissions. For other industries, especially the electric-power industry, the strictness and scope of emission caps might be the relevant non-NSR regulation to consider. Other regulations also might be relevant to consider. The committee will consider the potential for synergy and antagonism across its matrix of regulatory landscapes, because the rule changes represent a package that firms or industries must consider when making emission-control decisions.

Because many of the rule changes provide some incentives that theoretically could increase actual emissions and others that could decrease them, the committee will systematically determine which incentives will likely dominate under various policy scenarios. The committee will then evaluate pathways by which the NSR changes could affect industry decisions and determine the plausibility of the pathways and the likely direction and magnitude of the emissions changes.

On the basis of this assessment, the committee will focus on the NSR program changes, industries, and pathways that appear likely to contribute substantially to changes in emissions of specific pollutants, pollution prevention, pollution control, and energy efficiency. The committee will conduct this analysis on a pollutant-by-pollutant basis, evaluating factors such as geographic location, stack height, and proximity to population centers that might, for example, cause an industry sector with lower emissions to have more significant public health impacts. Evaluating dominant pollutants and source characteristics will help determine the most significant contributors to population exposure and human health impacts and also will help the committee focus on data sources that may support additional quantitative analyses.

Implementing this analytical framework and approach will be complex. Data are sparse, the number of possible scenarios is large, and uncertainties are numerous. However, the committee concludes that this enumerative approach will help to uncover aspects of the NSR changes and the pathways that may influence the effects that the committee has been asked to study.

# 1

# Introduction

The Clean Air Act (CAA) includes New Source Review (NSR) permit programs that apply to large stationary sources of air pollution, such as factories and electricity-generating units. Under NSR programs, each *new* large stationary source must apply for a permit before beginning construction. The permitting process is also required when a physical change to an *existing* large stationary source would result in a significant increase in pollutant emissions. NSR programs allow construction or modification of an emission source only if the operator first shows that emissions will be reduced as much as practicable. In addition, the construction or modification cannot result in significant deterioration of air quality in areas that meet the National Ambient Air Quality Standards (NAAQS)[1] or interfere with progress toward attainment in areas where air quality violates the NAAQS.

On December 31, 2002 (67 Fed. Reg. 80186 [2002]), and October 27, 2003 (68 Fed. Reg. 61248 [2003]), the U.S. Environmental Protection Agency (EPA) promulgated changes to the NSR programs were published. The changes have resulted in substantial controversy. EPA and other supporters of the changes say these will provide greater flexibility to industry, increase the energy efficiency of industrial facilities,

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[1] The NAAQS specify the maximum allowable concentrations of criteria pollutants in ambient air that are protective of public health and welfare. The six criteria pollutants are carbon monoxide, lead, nitrogen dioxide, ozone, particulate matter, and sulfur dioxide. Pollutants for which there are NAAQS are known as criteria pollutants because EPA prepares "criteria documents" for these pollutants describing their sources and effects.

and contribute to the modernization of American industry—all without damaging the environment. Opponents say the changes will slow progress in cleaning the nation's air, thus damaging human health, and the changes are not necessary to provide flexibility (GAO 2004). (See Chapter 2 for a description of the NSR changes in the context of the CAA.)

## CHARGE TO THE COMMITTEE

Because of this controversy over the NSR changes, Congress mandated that EPA arrange for a study by the National Research Council (NRC) to assess potential impacts of EPA's final rules of December 2002 and October 2003. The NRC was asked to assess changes in emissions of pollutants regulated under the NSR programs; impacts on human health; and changes in energy efficiency, pollution prevention, and pollution control at facilities subject to NSR. In response to the request, NRC established the Committee on Changes in New Source Review Programs for Stationary Sources of Air Pollutants (see Appendix A). The committee was asked to estimate and evaluate the amount of uncertainty associated with the effects being considered. It was also asked to identify and recommend additional data collection that would be necessary in future years to assess impacts. Congress asked that an interim report on the committee's study be provided and that it include all conclusions and recommendations the committee determined to be feasible and appropriate at that stage in its study. The committee is providing this interim report in response. A final report will be provided at the end of 2005. (The congressional mandate for this study is in Appendix B and the committee's full Statement of Task is in Appendix C.)

Congress did not ask the NRC to determine the desirability of the new NSR rules or to recommend whether they be revised or repealed. Such conclusions involve considerations that go beyond science and involve value judgments (for example, how to weigh environmental protection against other societal goals). Congress also did not ask the NRC to appraise the legality of the changes—that is, whether EPA acted within the scope of its authority and, if so, whether EPA's decision was reasonable. That task falls initially to the United States Court of Appeal for the District of Columbia Circuit, which is currently hearing challenges to the rules (*State of New York v. Environmental Protection Agency*, D.C. Cir. 02-1387 [challenging the 2002 rules], *State of New York v. Environmental Protection Agency*, D.C. Cir. 03-1380 [challenging the 2003 rules]). In addition, Congress did not ask the NRC to investigate any effects of the NSR changes other than the effects on emissions, human health, and industry actions concerning energy efficiency, pollution control, and pollution prevention. Because the committee has been directed to focus on those specific effects, it did not consider other possible effects of the NSR changes such as effects on nonhuman biota (for example, agricultural crops and forests), atmospheric visibility, and materials (for example, monuments and buildings). Also, because Congress requested an evaluation of changes in emissions of pollutants regulated under the NSR programs, the committee did not include emissions of greenhouse gases, such as carbon dioxide and methane, in its assessment. EPA does not consider those gases to be regulated under the CAA.

Congress did not ask for an analysis of the effects of any changes in emissions of hazardous air pollutants (HAPs). Since 1990, a separate program has regulated the construction and modification of sources that emit HAPs (CAA § 112(d)(3), 42 USC § 7412(d)(3)). Emissions of HAPs may be affected by NSR, however, because many of these pollutants are subsets of volatile organic chemicals or particulate matter, both of which are regulated by NSR.

## COMMITTEE APPROACH

As it carries out its charge, the committee is considering relevant scientific and technical documents prepared by EPA, other federal agencies, states, industry, and environmental and other nongovernmental organizations. Although the committee does not present evaluations of those documents in this report, they have been used to inform the committee's deliberations. The committee expects to provide its perspectives on several of those documents in the final report. The committee will also gather information on how the revised NSR rules may affect emissions, air quality, public health, and industry actions concerning pollution control, pollution prevention, and energy efficiency. It will also gather background information on the types of facilities that may be subject to NSR rules, including the numbers of facilities, age distributions, emission trends, locations relative to NAAQS nonattainment areas, and population sizes downwind of facilities. The committee is also seeking information on how the new rules may affect pollution control, pollution prevention, and energy efficiency within a facility. Because of the various types of industries potentially affected by NSR, the committee can not consider the impacts of the rule changes for each type in detail; instead, it is focusing on a few representative industries.

Because many of the outcomes that the committee has been asked to consider can be affected by a number of factors outside the realm of the NSR rules, other factors, such as economic conditions and government investment in research and development, will be considered in the committee's analyses. The committee recognizes that future developments in other pollution laws and regulations can have a substantial influence on the impacts of NSR rule changes. Thus, the committee will strive to consider the plausibility, significance, and interactions of other relevant requirements. This approach will be refined as the study progresses.

Because it has not completed the process of information gathering and analyses, the committee has not reached its final conclusions or recommendations in response to its charge from Congress. Those will be presented in the final report.

## REPORT STRUCTURE

This interim report provides a synthesis of background information on relevant health effects, air quality indicators, emissions, and industry activities in a regulatory context. The report also describes the approach that the committee plans to use for assessing the impacts it has been asked to address.

To establish a background and context for the committee's technical and scientific analysis, Chapter 2 provides a regulatory overview of the NSR programs in the context of the CAA. It also describes and discusses the NSR rule changes that are the subject of the committee's evaluation. Chapter 3 examines contributions that emission sources subject to NSR may make to ambient air quality and relationships between specific air pollutants and health effects. Chapter 4 considers the categories of industrial sources involved in permitting activity under NSR, typical repair and replacement issues for those source categories, and typical technological considerations for those categories. Chapter 5 discusses various methods that have been used or that might be used in the future to assess the effects of the NSR rule changes, and it discusses other information that should be considered in analyses of the probable impacts of NSR rule changes. Chapter 6 provides the committee's planned general approach for considering the impacts of NSR rule changes as a guide to the analysis undertaken by the committee for its final report.

# 2

# Regulatory Overview

## INTRODUCTION

In 1977, Congress amended the Clean Air Act (CAA) to include a pair of programs that together are known as New Source Review (NSR). These programs set out requirements that must be met before a large "stationary source" (source with a fixed location) of pollution may be constructed or modified. One of these programs, known as Prevention of Significant Deterioration (PSD), applies to the construction or modification of any "major emitting facility"[1] in "attainment areas"—those classified as attaining the National Ambient Air Quality Standards (NAAQS) established by the U.S. Environmental Protection Agency (EPA) (CAA § 165(a), 42 USC § 7465(a)). The other, commonly called Part D New Source Review (Part D NSR), applies to construction or modification of "major stationary sources" (not the same as a major emitting facility) in "nonat-

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[1] If a source is in one of 28 named categories, it is a major emitting facility if its "potential to emit" any regulated air pollutant is 100 tons per year or more. Otherwise, the source is covered if its potential to emit is 250 tons per year or more (CAA § 169(1), 42 USC § 7479(1)). Potential to emit generally represents the source's emissions if operated at maximum design capacity. A source may reduce its potential to emit by agreeing to a legally binding limit on its emissions (40 CFR § 51.166(b)(4)). If the source agrees to a limit that reduces its potential to emit below the coverage thresholds, it is no longer a major emitting facility and therefore is exempt from the program.

tainment areas"—those classified as not meeting the NAAQS[2] (CAA § 172(b)(5), 42 USC § 7502 (b)(5)). An overview of both NSR programs is provided later in this chapter.

NSR covers modifications of existing sources as well as construction of new sources. The CAA defines a modification as "any physical change, or change in the method of operation of a stationary source" that significantly increases the emissions of air pollution from the source (CAA §111(a)(4), 42 USC § 7411(a)(4)).[3] This definition explicitly applies to both the PSD (CAA §169(2)(C), 42 USC § 7479(2)(C)) and Part D NSR (CAA § 171(4), 42 USC § 7501(4)) programs.

EPA regulations governing NSR (40 CFR 51.166 and 40 CFR 52.21)[4] elaborate on the statutory definition of a modification. In 2002 and 2003, EPA altered those regulations. The first of those revisions, published December 31, 2002 (67 Fed. Reg. 80186 [2002]), altered the rules in five ways:

- Nonutility sources may now calculate annual emissions before the physical change by averaging annual emissions in any 24-month period within the 10 years before the change. This average must be reduced to reflect any tightening of the source's emission limit since that 24-month period. The previous rules had required those sources to average their annual emissions over the past 2 years

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[2] The NAAQS specify the maximum allowable concentrations of criteria pollutants in ambient air that are protective of public health and welfare. The six criteria pollutants are carbon monoxide, lead, nitrogen dioxide, ozone, particulate matter, and sulfur dioxide. Pollutants for which there are NAAQS are known as criteria pollutants because EPA prepares "criteria documents" describing the sources and effect of these pollutants.

[3] As discussed below, EPA, with court approval, has exempted nonsignificant increases from NSR. EPA requires that, in judging whether a significant increase would occur, all other contemporaneous increases and decreases be considered; hence, the determination of whether there is a significant increase is done on a "net basis."

[4] Section 51.166 sets out the requirements that states must meet to have PSD programs approved as part of their state implementation plan. Section 52.21 specifies the elements of an EPA-run program in a state without an approved PSD program in its state implementation plan. The two sections are nearly identical, and so, for convenience, citations are to 51.166 only.

unless the operator could show that a different period was more representative of normal operations.

- Nonutility sources may now calculate annual emissions after a physical change by projecting actual emissions at the source after the change. (This is known as the actual-to-projected-actual approach. Utility sources were already permitted to use this approach.) Increases in emissions that result from increases in demand, rather than from the change, can be subtracted from calculating postchange annual emissions. If using the new methodology would exempt the project from NSR, and it is reasonable to believe that the project might result in a significant emissions increase, the source must track its postchange emissions for 5 years (10 years in some cases). The previous rules had used the source's postchange potential to emit (its maximum emissions if operated as designed, reduced by any legal limit on the source's emissions) as the measure of its postchange emissions. (This is known as the actual-to-potential test.) This method is now required only for new units of existing facilities. If a source's postchange potential to emit significantly exceeds its prechange actual emissions, then the source could escape NSR only by making a binding commitment to never significantly increase actual emissions over prechange levels.[5]
- Sources may seek permission to establish plant-wide applicability limitations (PALs)—a limit on emissions from the plant as a whole-to determine whether a given physical change increases emissions and therefore constitutes a modification. A PAL runs for 10 years and is renewable. Physical changes within the plant do not require an NSR permit so long as the PAL is not exceeded. The PAL's size for each pollutant is calculated by adding a "de minimis" level to the source's current emissions (calculated in the same way as prechange emissions). The previous rules had no similar provisions.
- Physical changes at "clean units" need not obtain an NSR permit so long as the changed unit continues to meet its maximum

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[5] Many industries believe that NSR should apply to a change that increases a source's potential to emit. EPA in 1982 promised to propose this approach in what is known as Exhibit B to the settlement in *Chemical Manufacturers Association v. EPA*. EPA proposed and rejected this approach in the 2002 rule making. Industry is challenging this rejection in the litigation surrounding the 2002 rules.

allowable emissions rate. A clean unit is one that meets emission limits that are equal in severity to those required under the NSR programs. The unit need not have actually passed through NSR so long as its operator presents analyses of its air-quality impacts that are like those required by NSR. The exemption lasts for 10 years after the pollution controls are brought into operation and is renewable if the pollution controls continue to be as strict as those required by NSR. The previous rules had no similar provisions.

- The existing exemption from NSR for pollution control projects (PCPs) is expanded. This exemption applies when a permitting authority deems the project to be environmentally beneficial, even though it would significantly increase emissions of an air pollutant other than the pollutant(s) reduced by the project. Sources no longer must show that reducing air pollution is the primary purpose of the PCP. In addition, the rule lists a number of projects presumed to be eligible for the exemption.[6] Those projects, along with the pollutant(s) that is controlled, are listed in Box 2-1. Other presumed environmentally beneficial PCPs include activities or projects undertaken to accommodate the following: (1) switching to different ozone-depleting substances with a less damaging ozone-depleting effect (factoring in the ozone-depletion potential and projected usage), and (2) switching to an inherently less-polluting fuel, to be limited to the following:

—Switching from a heavier grade of fuel oil to a lighter fuel oil or any grade of oil to 0.05% sulfur diesel (that is, from a higher sulfur content no. 2 fuel, or from no. 6 fuel, to about 0.05% sulfur no. 2 diesel).

—Switching from coal, oil, or any solid fuel to natural gas, propane, or gasified coal.

—Switching from coal to wood, excluding construction or demolition waste, chemical- or pesticide-treated wood, and other forms of “unclean” wood.

—Switching from coal to no. 2 fuel oil (0.5% maximum sulfur content).

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[6] For nonlisted projects, the rule established detailed requirements that go well beyond preexisting policy on PCPs for demonstrating project eligibility.

## BOX 2-1 Environmentally Beneficial Pollution Control Projects

| Control device/PCP | Pollutant controlled |
|---|---|
| Conventional and advanced flue gas desulfurization<br>Sorbent injection | Sulfur dioxide |
| Electrostatic precipitators<br>Baghouses<br>High-efficiency multiclones<br>Scrubbers | Particles and other pollutants |
| Flue gas recirculation<br>Low-nitrogen-oxides burners or combustors<br>Selective noncatalytic reduction<br>Selective catalytic reduction<br>Low-emission combustion (for internal combustion engines)<br>Oxidation/absorption catalyst (e.g., $\text{SCONO}_x$)[a] | Nitrogen oxides |
| Regenerative thermal oxidizers<br>Catalytic oxidizers<br>Thermal incinerators<br>Hydrocarbon combustion flares [FN36]<br>Condensers<br>Absorbers and adsorbers<br>Biofiltration<br>Floating roofs (for storage vessels) | Volatile organic compounds and hazardous air pollutants |

NOTE: For the purposes of these rules, "hydrocarbon combustion flare" means a flare used to comply with an applicable new source performance standard (NSPS) or maximum available control technology (MACT) standard (including the use of flares during startup, shutdown, or malfunction permitted under such a standard) or a flare that serves to control emissions from waste streams composed predominantly of hydrocarbons and containing no more than 230 mg of hydrogen sulfide per dry standard cubic meter (dscm).

[a] $\text{SCONO}_x$ is a technique for controlling emissions of nitrogen oxides and carbon dioxide from stationary sources without the use of ammonia.

Source: Adapted from 67 Fed. Reg. 80234 (2002).

—Switching from high-sulfur coal to low-sulfur coal (maximum 1.2% sulfur content).

In proposing a predecessor version of these rules in 1996, EPA stated that it would allow states to choose between following the old or the new rules. In contrast, EPA's final rule requires that all states adopt these or more stringent changes. The agency considers its new rules to be more environmentally beneficial than the old rules, and thus states do not have the option of continuing to follow the old rules (67 Fed. Reg. 80241 [2002]). Some state and local air program officials strongly disagree with this position (STAPPA/ALAPCO 2002, 2003). EPA has given the states until January 2, 2006, to submit state implementation plan (SIP)[7] revisions adopting the new or the more stringent measures. Few such revisions have been submitted so far. (This is not surprising given the many procedural steps involved in developing a SIP revision.) The changes went into effect March 3, 2003, in areas with no approved NSR programs in their SIPs.

In response to petitions for reconsideration, EPA announced in mid-2003 that it would take further comments on the agency's conclusion (EPA 2002a) that the new rules would benefit air quality (68 Fed. Reg. 44620 [2003]). Later that year, EPA decided to clarify some portions of the 2002 rule change but otherwise to leave them in place (68 Fed. Reg. 63021 [2003]).

EPA promulgated another rule change in October 2003 (68 Fed. Reg. 61248 [2003]). This rule change—known as the equipment replacement rule—defines certain kinds of equipment replacements as "routine maintenance, repair and replacement" and therefore not constituting "physical changes or changes in the method of operation." Hence these replacements do not need NSR permits even if a significant emissions increase (as calculated under the actual-to-projected-actual technique) can be expected to occur and as long as the source does not exceed its maximum level of allowable emissions (see Box 2-2).[8] Under the promulgated rule, replace-

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[7] Every state must prepare a plan to show how it will attain and maintain the NAAQS. This plan is known as a SIP.

[8] Sources often emit at a rate less than their maximum level of allowable emissions. Therefore, it is often possible for a source to increase emissions without exceeding its maximum allowable emissions.

**BOX 2-2 EPA Significance Levels for Criteria Pollutants**

Carbon monoxide: 100 tons per year (tpy)

Nitrogen oxides: 40 tpy

Sulfur dioxide: 40 tpy

Ozone: 40 tpy of volatile organic compounds

Lead: 0.6 tpy

Source: (40 CFR § 51.166(b)(23)(i)).

ment of components of a process unit with identical components (or their functional equivalents) is exempt from NSR if

- The cost of replacing the component (including the fixed capital cost and costs of the replacement activity, such as construction) is less than 20% of the replacement value of the process unit.
- The replacement does not change the unit's basic design parameters.
- The unit continues to meet enforceable emission and operational limitations—that is, the unit, while possibly emitting more than in the past because of greater utilization, does not emit more than is legally allowed.

Under the previous rules, EPA used a case-by-case approach in determining which equipment replacements constituted routine maintenance, repair, or replacement. The case-by-case approach continues to be available for a source whose project does not qualify under the categorical exception.

## FRAMEWORK OF THE CLEAN AIR ACT

The CAA requires EPA to set NAAQS for pollutants that may reasonably be anticipated to endanger public health or welfare and that come from numerous or diverse sources (CAA § 108(a)(1), 42

USC § 7408(a)(1)). Each NAAQS limits the maximum permissible concentration of a pollutant in the ambient air—that is, the outside air to which the public has access (40 CFR § 50.1(e)). Under section 109 (42 USC § 7409), primary NAAQS must protect the public health with an adequate margin of safety, and secondary NAAQS must protect the public welfare (e.g., effects on crops, other vegetation, and animals). As detailed in Chapter 3, EPA has set NAAQS for carbon monoxide (CO), lead (Pb), ozone ($O_3$), nitrogen dioxide ($NO_2$), particulate matter (PM), and sulfur dioxide ($SO_2$) (40 CFR Part 50).

Much of the CAA consists of mechanisms, including NSR, to control emissions of the NAAQS pollutants and their precursors (e.g., volatile organic compounds [VOCs] are regulated because they contribute to the formation of $O_3$). The following mechanisms apply to emissions from stationary sources:

- Under section 110 (42 U.S.C. § 7410), each state must prepare and enforce a SIP for the NAAQS pollutants. The SIP must demonstrate that it will result in attainment of the primary NAAQS by a given deadline and of the secondary standards as expeditiously as practicable. SIPs invariably regulate major stationary sources among other sources of air pollution.
- Under section 111 (42 U.S.C. § 7411), EPA establishes new source performance standards (NSPS) for categories of stationary sources that emit air pollution. NSPS emission limits are based on the degree of emission limitation that can be achieved by a source in a category through use of the best demonstrated technology. NSPS (with an exception not relevant here) apply only to sources that commence construction or modification after the NSPS for the category is proposed (CAA § 111(a)(2), 42 USC § 7411(a)(2)).
- Section 112 (42 USC § 7412) requires EPA to establish category-wide standards to limit the emission of hazardous air pollutants (HAPs). Because some HAPs are subsets of PM and VOCs, this requirement results in regulation of pollutants covered by the NAAQS.
- Section 169A (42 USC § 7491) requires EPA to regulate sources whose emissions degrade visibility in mandatory Class I areas (national parks and similar areas) where visibility is an air-quality-related value. (Mandatory Class I areas are more fully discussed later.) EPA has established rules for regulating “plume

blight"—visibility degradation that can be reasonably attributed to one or a few large stationary sources (40 CFR § 51.302). The program includes regulation of major new sources that are located in nonattainment areas (exempt from PSD) but might damage visibility in Class I areas (40 CFR § 51.307).

- Two "cap-and-trade" programs have been established to limit emissions from utility sources. These programs assign a reduction target to a region. Regulated sources are granted allowances in proportion to their historic emissions and are allowed to trade allowances so that the cap level can be achieved at the least cost.

—Utility sources are subject to the acid rain program of Title IV. By 2010, this program phases in an annual cap of 8.97 million tons of emissions of $SO_2$ from these sources. The program also includes requirements for controlling nitrogen oxide ($NO_x$) emissions from utilities. Generally, utility sources are issued allowances that equal 1.2 pounds per million British thermal units multiplied by the source's annual average heat input (a measure of the source's usage) for the period from 1985 to 1987.

—Section 110(a)(2)(D) requires each state's SIP to prevent emissions that "contribute significantly" to nonattainment of the NAAQS in other states or that interfere with another state's program to prevent significant deterioration of its air quality. In 1998, EPA found that $NO_x$ emissions in 22 states interfered with attainment of the $O_3$ NAAQS in other states. (The number of states was later reduced to 19.) EPA ordered that the states cut back $NO_x$ emissions by 28%, or more than a million tons a year, during the April-October period when $O_3$ concentrations are at their highest. This target represents the reduction that EPA found could be made through cost-effective measures (those costing less than $2,000 per ton of emissions eliminated) (*Michigan v. EPA*, 213 F.3d 663 [D.C. Cir. 2000]) (the court's decision upheld the program). The states may achieve the required reduction as they wish, but because existing utility plants are the most cost-effective sources to control, the brunt of the reductions falls on them. The states have followed EPA's suggestion to establish cap-and-trade programs to accomplish the reduction at the least cost.

EPA and the Bush Administration have proposed several new programs:

- EPA has proposed rules for regulating existing sources that contribute to regional haze (69 Fed. Reg. 25814 [2004]). The proposed rules would not apply in states covered by the proposed Clean Air Interstate Rule (CAIR) described below.
- In 2002 and 2003, the Bush Administration proposed "Clear Skies" legislation to establish lower caps on utility emissions of $SO_2$ and $NO_x$ than do the other stationary source programs that currently exist. $SO_2$ emissions would be capped at 4.5 million tons in 2010—half of what would be allowed by the acid rain program—and at 3 million tons in 2018. This represents a 73% decrease from year 2000 levels. Clear Skies also would reduce $NO_x$ emissions from 5 million tons annually in 2000 to 2.1 million tons in 2008 and 1.7 million tons in 2018—a two-thirds reduction.

Clear Skies has attracted opposition from utility and industrial groups, who say the goals are too stringent, and from environmental groups, who say the goals are too lax. Environmentalists have tended to favor Senator James Jeffords's proposed Clean Power Act. This rival proposal calls for more extensive and quicker emissions cuts. For instance, the Clean Power Act would cap $SO_2$ emissions at 2.25 million tons in 2007, compared with the Bush Administration's proposal for a 4.5-million-ton cap in 2010.

Neither of these proposals has been brought up for formal committee consideration in the Senate or the House of Representatives, and their futures are unclear. In January 2004, EPA proposed (but, at this writing, has not promulgated) the Interstate Air Quality Rule also known as the Clean Air Interstate Rule (69 Fed. Reg. 4566 [2004]). The proposal would adopt elements of Clear Skies by administrative means. EPA proposes to find that $SO_2$ and $NO_x$ emissions from 29 eastern and midwestern states are interfering with attainment and maintenance of the air-quality standards for $O_3$ and PM. Emissions of $SO_2$ from power plants in these states would be capped at 3.9 million tons in 2010 and at 2.7 million tons in 2015. EPA (2004a) estimated that those caps would result in a reduction of 3.6 million tons of $SO_2$ emissions in 2010 and an additional reduction of 2 million tons per year when the rules are fully implemented (approximately 70% below 2002 levels). Emissions of $NO_x$ from electricity-generating units would be capped at 1.6 million tons in 2010 and at 1.3 million tons in 2015. EPA estimated that $NO_x$ emission would be reduced by 1.5 million tons in 2010 and by 1.8 million tons in 2015 (about 65% below 2002 levels). As with the 1998 $NO_x$ cutback, the emissions goals are based on what can be done through relatively cost-effective technology. This proposal has attracted many of the same concerns as Clear Skies, and, like Clear Skies, its outlook is uncertain at this writing.

In general, NSR provides more stringent emission limits for new and modified major sources than EPA provides in other existing programs. The proposed programs are, in their current form, unlikely to change this. The visibility proposal would not affect the current treatment of new and modified sources. Clear Skies would exempt modifications at existing utilities from NSR and would exempt new utility plants from most NSR requirements.[9] In exchange, the NSPS for power plants would be tightened. But the new NSPS would not apply to all modifications currently covered by NSR. Moreover, as time passes, NSR-control-technology determinations become more stringent than NSPS because of advances in control technology. It is therefore unlikely that Clear Skies would result in emission limits at individual sources that are tighter than those achieved when NSR is triggered at the same sources.

The Clean Air Interstate Rule also is unlikely to require sources to do more than is required by NSR. This would occur only if the emission cap is so tight, and the cost of allowances is so great, that new sources would prefer to reduce their emissions beyond NSR levels rather than purchase allowances. EPA, though, has not projected such an effect of the Clean Air Interstate Rule. It should also be kept in mind that NSR programs require special protection for local areas (e.g., the increment system and the offset requirement) that are not included in cap-and-trade programs.

In general, NSR provides more stringent emission limits for new and modified major sources than do the programs listed here. A very stringent emission cap could provide an extra incentive for future new and modified sources to decrease emissions as well.

In 2001, EPA estimated that PSD control-technology determinations from 1997 to 2001 eliminated a potential increase of 1.4 mil-

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[9] New utility plants locating within 50 kilometers of a Class I area, such as a national park, would have to conduct an analysis of the air-quality impacts of the park. Present law does not limit the analysis to plants within 50 kilometers.

lion tons of air pollution annually. About 822,000 tons of these reductions, or approximately 60%, were in $NO_x$, emissions and about 420,000 tons, or about 35%, were in $SO_2$ emissions. This estimate does not take into account benefits that occur when source operators limit emissions so that the PSD permit process will not apply. Ninety percent of these benefits are believed to have occurred at new electricity-generating units (EPA 2001).

## NSR PROGRAMS

The NSR programs consist of the PSD program for areas that attain the NAAQS and the Part D NSR program for areas that do not. Each program goes beyond NSPS in two respects. First, each program requires an evaluation of whether a proposed new or modified source can control emissions beyond the requirements of NSPS. This often results in lower emissions because some individual sources can do more than the ordinary source in a category and because technology often advances more quickly than does EPA in revising an NSPS. Second, unlike NSPS, each program gives special attention to sources in or near sensitive areas; the Part D NSR program emphasizes areas that violate air quality standards, while PSD seeks to give special protection to national parklands and areas that are experiencing rapid growth in concentrations of $SO_x$, $NO_x$, and PM.

### PSD: Evolution and Summary

The PSD program was born in the early 1970s. The CAA Amendments of 1970 (Pub. L. 91-604) did not expressly stipulate whether states were required to include in their SIPs measures to prevent the deterioration of air quality that is superior to the NAAQS. EPA Administrator William Ruckelshaus ruled that states had no obligation to do so. The District Court for the District of Columbia overturned this interpretation of the Act (*Sierra Club v. Ruckelshaus*, 344 F. Supp. 253 [1972]). An equally divided U.S. Supreme Court eventually affirmed this decision without opinion (*Fri v. Sierra Club*, 412 U.S. 541 ([1973]). As a result, EPA created the PSD program in 1974 to impose requirements for the construction or modification of major sources in clean air areas (39 Fed. Reg. 42510 [1974]). Congress altered and codified PSD in the CAA Amendments of 1977 (Pub. L. 95-95, § 127). In section 160 of the Act (42 USC § 7460), Congress articulated several goals for the PSD program, such as protection of national parks and the prevention of health and welfare effects that can occur at levels allowed by the NAAQS (see Box 2-3). Later, by technical amendment, Congress made clear that the PSD program, as in EPA's 1974 rules, covers modifications (Pub. L. 95-190, § 14(a)(54) (adding CAA § 169(2)(C), 42 USC § 7479(2)(C)) (defining the term "construction" to include "modifications").

The PSD program requires a permit for the construction or modification of a "major emitting facility" that is located in an area to which the program applies (CAA § 165(a), 42 USC § 7475(a)) (see Box 2-4). The program applies in every area that attains at least one of the NAAQS (*Alabama Power v. Costle*, 636 F.2d 323, 364-368 (D.C. Cir. 1980), (CAA § 165(a), 42 USC § 7475(a)). Because no area violates all the NAAQS, PSD therefore applies nationwide. (It does not apply, however, to emissions of those pollutants for which the source's locale does not attain the NAAQS.) If a source is in 1 of 28 named categories, it is a major emitting facility if its "potential to emit" any regulated air pollutant is 100 tons per year or more. Otherwise, the source is covered if its potential to emit is 250 tons per year or more (CAA § 169(1), 42 USC § 7479(1)). Potential to emit generally represents the source's emissions if operated at maximum design capacity. A source may reduce its potential to emit by agreeing to a legally binding limit on its emissions (40 CFR § 51.166(b)(4)). If the source agrees to a limit that reduces its potential to emit below the coverage thresholds, it is no longer a major emitting facility and therefore is exempt from the program.

A modification of a major emitting facility is covered if it would increase the net emissions of a pollutant by a "significant amount" (see Box 2-2). Significance levels are based on the levels at which, in EPA's view, the benefits from regulation would be de minimis.

An applicant for a PSD permit must show that the new or modified facility will, for each regulated pollutant emitted in significant amounts, limit emissions to the level achievable through use of the best available control technology (BACT). The BACT determination is made on a case-by-case basis and must be at least as stringent

**BOX 2-3 Section 160 of the Clean Air Act**

The purposes of this part are as follows:

(1) to protect public health and welfare from any actual or potential adverse effect which in the Administrator's judgment may reasonably be anticipate[d] to occur from air pollution or from exposures to pollutants in other media, which pollutants originate as emissions to the ambient air[,] notwithstanding attainment and maintenance of all national ambient air quality standards;

(2) to preserve, protect, and enhance the air quality in national parks, national wilderness areas, national monuments, national seashores, and other areas of special national or regional natural, recreational, scenic, or historic value;

(3) to insure that economic growth will occur in a manner consistent with the preservation of existing clean air resources;

(4) to assure that emissions from any source in any State will not interfere with any portion of the applicable implementation plan to prevent significant deterioration of air quality for any other State; and

(5) to assure that any decision to permit increased air pollution in any area to which this section applies is made only after careful evaluation of all the consequences of such a decision and after adequate procedural opportunities for informed public participation in the decision-making process.

as whatever NSPS exists for the source's category (CAA § 169(3), 42 USC § 7479(3)). Since 1987, EPA has stated that BACT must be set at a level at least as stringent as a top-down approach: that is, BACT should be set at the most stringent level achieved by a source in the same category unless the applicant can show that level to be unachievable (61 Fed. Reg. 38250, 38272-38273 [1996] [proposing to formally incorporate this approach into EPA's rules]).

The applicant also must show that the new or modified source, in combination with emission increases from other sources, will comply with a system of increments that limit permissible growth in air pollutant concentrations over the baseline concentration—the

**BOX 2-4 Major Requirements for Obtaining a PSD Permit**

- Public hearing has been held on the application.
- Owner or operator has shown that the proposed project would not contribute to a violation of the NAAQS or the PSD increments.
- Proposed project is subject to the best available control technology for each pollutant emitted in more than de minimis amounts.
- Effects of the proposed project on the air-quality-related values of Class I areas have been analyzed.
- Applicant agrees to monitor the source's effects.

Source: Adapted from CAA § 165(a), 42 USC § 7475(a).

concentration that existed in an area when the first application was filed for a PSD permit (CAA § 169(4), 42 USC § 7479(4)). Increments currently exist for $NO_2$, $SO_2$, and PM (see Box 2-5). The size of the increments varies with the area's classification as Class I, II, or III. The loosest increments apply in Class III areas. The tightest increments apply in Class I areas, thus tending to shift new sources away from those areas. Congress designated 158 large national parks and wilderness areas existing in 1977 as mandatory Class I areas. Most of those areas are west of the Mississippi River; nearly one-quarter of them are in Utah, Arizona, New Mexico, or Colorado (Oren 1989). The remainder of the nation initially was classified as Class II. States and Indian tribes are allowed to redesignate areas as Class I or III. To date, a few Indian tribes have designated their reservations as Class I; no areas have been designated as Class III. The many national parks and wilderness areas created since 1977 (e.g., those created by Congress in 1980 in Alaska) have remained Class II areas.

As of June 2003, 39 states have obtained EPA approval for their SIP submissions incorporating the PSD program. In some of the remainder (e.g., New York), EPA runs the program itself, but delegates its responsibility to the state for most of the day-by-day

**BOX 2-5 PSD Increments**[a]

| | | |
|---|---|---|
| *Class I* | | |
| $SO_2$ | | |
| | Annual arithmetic mean | 2 |
| | 24-hour maximum | 5 |
| | 3-hour maximum | 25 |
| $NO_2$ | | |
| | Annual arithmetic mean | 2.5 |
| $PM_{10}$ | | |
| | Annual arithmetic mean | 4 |
| | 24-hour maximum | 8 |
| *Class II* | | |
| $SO_2$ | | |
| | Annual arithmetic mean | 20 |
| | 24-hour maximum | 91 |
| | 3-hour maximum | 512 |
| $NO_2$ | | |
| | Annual arithmetic mean | 25 |
| $PM_{10}$ | | |
| | Annual arithmetic mean | 17 |
| | 24-hour maximum | 30 |
| *Class III PSD increments* | | |
| $SO_2$ | | |
| | Annual arithmetic mean | 40 |
| | 24-hour maximum | 182 |
| | 3-hour maximum | 700 |
| $NO_2$ | | |
| | Annual arithmetic mean | 50 |
| $PM_{10}$ | | |
| | Annual arithmetic mean | 34 |
| | 24-hour maximum | 60 |

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[a] Increments are in concentration units of micrograms per cubic meter.
Source: 40 CFR §51.166 (c).

decisions. There are, though, jurisdictions where EPA has not delegated authority.

## Part D NSR

The 1977 amendments also included a NSR program for nonattainment areas—those whose air quality does not meet the NAAQS. This program also applies to major sources of VOCs in the ozone transport region in the northeast, even if located in attainment areas (CAA § 184(b)(2), 42 USC § 7511c(b)(2)).

In 1970, Congress required attainment of the primary standards no later than 3 years after approval of the state's SIP, with a possible 2-year extension. It became clear that this timetable would not be met. In late 1976, EPA published an interpretive ruling that outlined conditions under which new and modified major sources would be allowed in areas that failed to attain the air-quality standards on schedule (41 Fed. Reg. 55524 [1976]). Congress codified this program (known as Part D NSR because it is included in that part of the Act) in 1977 as part of a renewed effort to bring about attainment of the NAAQS (Pub. L. 95-95, § 129).

As with PSD, Part D NSR requires that the operator obtain a permit before construction or modification of a major stationary source (see Box 2-6). Generally, a major stationary source is defined as one that emits or has the potential to emit more than 100 tons per year of any air pollutant (CAA § 302(j), 42 USC § 7602(j)). These size cutoffs are lower for $NO_x$ and VOCs in $O_3$ nonattainment areas. For instance, in areas designated as "extreme" (currently, the Los Angeles area), the threshold is set at 10 tons per year. A major source is covered only to the extent that its emissions could contribute to nonattainment of a NAAQS. Thus, if the proposed source would emit two pollutants, and the area violates the NAAQS for only one, then the source is covered by Part D NSR for that pollutant and by PSD for the other.

A modification is covered under the Part D NSR program if it is "major"—that is, it would in itself require a permit if it were newly constructed (40 CFR § 51.165(a)(2)(I)) and if it would contribute to nonattainment of the NAAQS.

To obtain a permit to construct or modify, the operator must show that the new or modified source will emit at the lowest achievable emission rate (LAER), defined in the statute as the more stringent of the tightest emission limit achieved in practice or the tightest SIP limit for that category of source (unless the operator can show that level not to be achievable) (Section §173 (a)(2), 42 USC § 7503(a)(2)). The applicant must also (except in limited cases) obtain emissions offsets—emission reductions from other sources that are enforceable and not otherwise required, so that the construction or modification will not disrupt progress toward attaining the NAAQS. In areas that do not attain the ozone standard, the offset must be greater than one to one, with the exact magnitude depending on the severity of the nonattainment.

## Concerns About Modifications

The controversy about modifications stems from the CAA's differentiation between new and existing stationary sources. As mentioned previously, new sources must meet technology-based standards in addition to showing that they will not damage air qual-

**BOX 2-6 Part D NSR Permit Requirements**

- The applicant must obtain emissions offsets (or, in areas located in an economic development zone, fit within a margin for growth specified in the SIP). See EPA's "Emissions Offset Interpretive Ruling" (40 CFR 51, Appendix S). There are two requirements from the offset ruling:
  1) the applicant must show that all sources owned or operated in the state are in compliance, and
  2) the applicant must show a net air-quality improvement as a result of the project.
- The proposed source must comply with the lowest achievable emission rate.
- EPA must not have found that the area is not implementing its SIP.
- The benefits of the proposed source significantly outweigh the environmental and social costs.

Source: Adapted from CAA § 173, 42 USC § 7503.

ity. In contrast, most existing sources need accomplish only as much emission reduction as is necessary to enable their locales to meet and maintain the levels of the NAAQS set by EPA.

This differentiation has attracted controversy. Supporters assert that it is justified because new sources can most easily incorporate the latest pollution control technology. In addition, supporters argue, tight regulation of new sources is the best way to ensure against future air pollution problems and that the turnover of capital stock results in reduced emissions. Critics argue that the differentiation between old and new sources encourages industry to keep older, heavily polluting sources on line longer instead of building new sources. Emissions trading advocates urge that it would be preferable to allow trading between sources, whether new or existing, to achieve the needed emission reductions. This approach is reflected in the Bush Administration's proposal, so far unsuccessful in Congress, that the emissions from electric utility plants be capped and that NSR requirements be relaxed for new and modified utility plants. Opponents of this proposal argue that a trading approach by itself would not be sufficient to protect especially vulnerable areas from large new sources.

Existing plants pose an even more difficult question. Plants where changes are occurring are on the boundary between new and existing sources. For instance, inserting state-of-the-art technology when a source experiences a change is, at least sometimes, more problematic than including such controls at a new plant. Nonetheless, plants where changes are occurring often may be better targets for regulation than unaltered existing sources. For instance, changes at existing plants, if unregulated by NSR, might keep such plants on line longer and slow their replacement by new, cleaner facilities. Slowing replacement of existing plants may give a competitive advantage to those plants over new plants, thus perpetuating high emission levels. Also, adding control technology to an existing source when it is undergoing modification may well be easier than installing such controls at an existing source that is not undergoing modification.

These issues are reflected in the different viewpoints about how the term "modification" should be defined.

Environmental groups argue that a broad definition is needed because of the following:

- Health and the environment are endangered when existing sources increase actual emissions.
- Narrowing the definition would interfere with enforcement actions that are permanently lowering emissions and thus bettering air quality.
- Congress intended a broad definition of modification as a way of ensuring that older sources eventually would have to install the best available control technology.
- A narrow definition of the term "modification" would cover renovations that allow existing sources, particularly electricity-generating units, to remain in operation indefinitely through renovation. A broader interpretation would discourage those renovations and instead would lead to replacing those plants with new capacity that would be far cleaner than existing plants.

Industry groups counter by saying that a narrower definition is appropriate because

- Many projects that would be covered under a broad view of "modification" do not increase emissions and in fact reduce them by replacing older equipment with less-polluting replacements.
- The programs are quite complex, and it is difficult to determine whether an NSR permit is required for a given change.
- Preparing a permit application, obtaining any needed offsets, waiting for EPA or state officials to process the application, and complying with BACT for the modification may be costly and burdensome. The process of reviewing the application takes additional time.
- Other programs, such as caps on utility emissions, can constrain emissions at a lower cost than a stringent NSR program.

## EPA's NSR Rules and Their Interpretation

Congress's 1977 codification of PSD and Part D NSR made it necessary for EPA to revise its rules governing the programs. This was done via a rulemaking in 1978. The following year, the D.C. Circuit Court of Appeals in the *Alabama Power* decision overturned several important portions of the rules. EPA then promulgated new rules in 1980 (45 Fed. Reg. 52676 [1980]).

The 1980 rules cover both the "physical or operational change" aspect and the "any increase in emissions" aspect of the congressional definition of modification. The term physical or operational change was defined to exclude routine maintenance, repair, and replacement, a term that the regulations did not elaborate upon. An increase in emissions is defined in terms of an increase in actual emissions, taking into account contemporaneous increases and decreases in emissions. Emissions before the change were specified to mean the average emissions at the source over the previous 24-month period unless the source could show that a different consecutive 24-month period was more representative of normal source operation.

The 1980 regulations subjected postchange emissions to a special meaning of the term "actual emissions." If a unit had not yet entered normal operations, then the term actual emissions was defined as equal to the unit's potential to emit. Thus, for units that had not entered normal operations, the 1980 rules covered a physical change as a modification if the source's postchange potential to emit exceeded the source's prechange actual emissions by a significant (or, in the case of Part D NSR, a major) amount. This is commonly referred to as the "actual/potential" test. Because a source's potential to emit is often significantly greater than its actual emissions, an actual/potential test tends to lead to coverage of a project by NSR. The plant can escape coverage only by making a binding promise to never increase actual emissions significantly over prechange levels.

The 1989 case of *Puerto Rican Cement v. EPA* illustrates the workings of the test. Puerto Rican Cement had been running its kilns at 60% capacity and emitting 1,100 tons of $NO_x$ and 1,340 tons of $SO_2$ annually. The company planned to build a new cement kiln. If operated at the same 60% capacity as the older unit, the new kiln would emit 578 tons of $NO_x$ and 850 tons of $SO_2$ annually. But if the unit operated at full allowable capacity, it would emit 1,250 tons of $NO_x$ and 1,927 tons of $SO_2$ annually. EPA compared the latter numbers with the prechange annual tonnages of 1,100 and 1,340, respectively, and ruled that construction of the new kiln would increase emissions within the meaning of its 1980 regulations and therefore a PSD permit was required.

The U.S. Court of Appeals for the First Circuit upheld this approach in a decision written by now-Supreme Court Justice Stephen Breyer (*Puerto Rican Cement v. EPA*, 889 F.2d 292 [1st Cir. 1989]). The court rejected the company's argument that EPA's approach was arbitrary because it would discourage modernizations that decreased emissions at the present rate of use. Instead, the court wrote, EPA had decided to focus on the possibility that the introduction of new, more efficient equipment would lead a company to produce at higher levels and therefore increase emissions. Hence, the company needed a PSD permit for the new kiln unless it was willing to reduce the unit's potential to emit by making a binding commitment never to increase emissions by more than a de minimis amount over the prechange levels.

The court acknowledged, though, that in some situations EPA's actual/potential test might be unreasonable. For instance, the court suggested, it might be irrational to assume that a replaced peak-load generator would run at its full potential to emit.

This observation became important in the 1990 *Wisconsin Electric Power (WEPCO)* decision (*Wisconsin Electric Power v. Reilly*, 893 F.2d 901 (7th Cir. 1991)), which involved a so-called "life-extension project" at WEPCO's Port Washington plant. The plant consisted of five coal-fired steam generating units placed in service between 1935 and 1960. Over time, each had deteriorated from its design capacity of 80 megawatts, and one unit had been shut down because of the risk of catastrophic failure. The aim of the project was to keep the units operating beyond their original 1992 retirement date until 2010. As part of the project, WEPCO planned to replace air heaters, steam drums, and other major components on four units.

EPA held that a PSD permit was required on the grounds that the project did not constitute routine maintenance, repair, and replacement, and that the project would increase emissions using the actual/potential test of EPA's NSR regulations. Hence, the dispute involved the physical change as well as the emissions increase aspect of modification. The utility appealed to the U.S. Court of Appeals for the Seventh Circuit, which decided for EPA on the physical change issue, while holding that the project would not increase emissions for NSR purposes.

WEPCO argued that "like-kind" changes—the replacement of existing equipment—do not constitute a physical change because they do not alter the plant. EPA argued that the WEPCO project was unprecedented: "WEPCO did not identify, and EPA did not find, even a single instance of renovation work at any electric utility generating station that approached the Port Washington life extension project in nature, scope or extent" (*Wisconsin Electric Power v. Reilly,* 893. F.2d 901 [7th Cir. 1991], p. 911). The court agreed with EPA, saying that a contrary reading contravened Congress's intent to stimulate the advance of pollution control techniques by requiring controls when generating systems are extensively replaced.

The court also rejected WEPCO's argument that its project qualified as routine maintenance, repair, and replacement under EPA's rules. The court noted that EPA stated that it "makes a case-by-case determination by weighing the nature, extent, purpose, frequency and cost of the work, as well as other relevant factors, to arrive at a common-sense finding." In this case, EPA had relied on the magnitude of the project, the exclusion from the project of repetitive maintenance normally performed during outages, and the lack of similar projects at other power plants. The court held that EPA could use these factors and that EPA had reasonably applied them to the facts of the case. The court noted that WEPCO had stated that its project involved a life extension and that the project would involve items that normally would occur only once or twice during a unit's expected life cycle; this, according to the court, supported EPA's finding that the project did not constitute routine maintenance, repair, and replacement.

But the court did not accept EPA's argument that the project required a permit because it would lead to an increase in emissions. The court distinguished between the NSPS program and the NSR programs. In the NSPS program, EPA's regulations call for a comparison of prechange and postchange emission rates, as expressed in kilograms per hour, at maximum physical capacity (40 CFR § 60.14 (b); 57 Fed. Reg. 32314, 32316 [1992]). Because such an increase had occurred at three of the five units, the project needed to comply with the NSPS for the source's category for those units.

The court held that, by contrast, a project is subject to NSR if annual emissions increase. The court overturned EPA's use of the actual/potential methodology to determine whether an increase would occur. The court found it unreasonable for EPA to disregard past operating conditions at the plant and to regard the units as having never entered normal operation. The *Puerto Rican Cement* case was distinguished as involving a new unit at an existing site, unlike a "like-kind replacement" of equipment at an existing unit. The latter, the *WEPCO* court ruled, resembled the peak operating unit example in the *Puerto Rican Cement* decision.

EPA responded to the decision with what is known as the *WEPCO* rule (57 Fed. Reg. 32314 [1992]). Under this rule, utility units are excluded from the actual/potential test so long as the proposed project neither adds a new unit nor replaces an existing one. Instead, utility units may compare prechange actual emissions with postchange projected annual emissions. If the utility concludes that there would be no significant increase in emissions, thereby exempting the project from NSR, then the utility must submit documentation of its emissions for 5 years after the change to confirm that a significant increase in emissions did not occur as a result of the project. In addition, the calculation of postchange emissions may exclude emission increases attributable to increased market demand rather than to the physical change. This exclusion could apply to increases that legally and physically would have been feasible without the change.

EPA also altered the definition of prechange emissions for utility sources. Before the alteration, prechange emissions were calculated for any source by averaging emissions over the 2 years before the change unless the source could show that a different 2-year period was more representative. EPA changed this rule to allow utility sources to use any consecutive 2-year period in the past 5. In the preamble to the WEPCO rule, EPA promised guidance on what is "routine maintenance, repair, and replacement" (57 Fed. Reg. 32326 [1992]).

Finally, EPA excluded from the definition of physical change, and hence from NSR review, pollution control projects that "do not render the unit less environmentally beneficial." In this way, EPA asserted, the prospect of NSR review would not influence a utility's choice of how to cut emissions to comply with the acid rain control program that had been adopted by Congress in 1990.

These changes were confined to electricity-generating units because EPA believed that it did not have enough knowledge of other source categories to allow the changes to be extended to them. EPA later, however, issued guidance that extended the pollution control project exemption to nonutility source categories (67 Fed. Reg. 80232 [2002]).

## NEW SOURCE REFORM PROJECT

In 1992, EPA also launched an effort to simplify and streamline its NSR rules. EPA formed a subcommittee of its existing Clean Air Act Advisory Committee, composed of representatives of states, environmental groups, and industries. For several years, the task force members discussed possible changes in the rules. The task force did not achieve consensus, but, in EPA's view, its existence helped to make clear which issues were important.

In 1996, EPA published in the *Federal Register* a package of proposed changes to the NSR rules (61 Fed. Reg. 38250 [1996]). This proposal discussed the areas covered in the 2002 rule (e.g., expanded use of the actual-to-projected-actual methodology), although the 2002 rule differs in important respects. The proposed changes also included elements sought by environmental groups, such as greater protection for national parks and codification of the long-standing top-down method of determining what constitutes the best available control technology.

The 1996 proposal generated a great deal of comment. In 1998, EPA issued a "notice of availability" in which EPA expressed reservations about some of its proposed changes (e.g., the enforceability of the actual-to-projected-actual approach and of its proposal to allow sources to exclude emission increases due to demand growth in projecting future emissions) and solicited comment on possible alternatives (63 Fed. Reg. 39857 [1998]). EPA did not complete the rule-making process before the end of the Clinton Administration.

## Enforcement Initiative

EPA's 1996 proposal did not discuss the issue of which changes constitute routine maintenance, repair, and replacement. This issue became increasingly important in the late 1990s. EPA, frequently joined by environmental groups and northeastern states, asserted that some large utility plants had been undertaking modifications without obtaining NSR permits. According to EPA, these projects allow utilities to run the altered plants at higher capacity levels and therefore increase emissions from them. In addition, EPA claimed that the projects allow the plants to remain on line longer instead of being replaced by new, cleaner plants that would decrease emissions substantially from present levels. Utilities, on the other hand, contend that these projects should be considered to constitute routine maintenance, repair, and replacement and therefore exempt from NSR. The projects, according to utilities, have always been undertaken in the industry and are necessary to ensure adequate reliable generating capacity. A report by the National Coal Council states that coal-fired power plants more than 20 years old—a category that accounts for two-thirds of electricity generation from coal—have been derated—

reduced in power-generating capacity—and that a substantial amount of generation capacity (approximately 20,000 megawatts) could be regained by addressing the causes of derating (EPA 2001).

The cases brought against utilities by EPA and their status are listed in Table 2-1, as of July 2, 2004. In addition, EPA brought administrative enforcement actions against the Tennessee Valley Authority (TVA) and WEPCO. (The action against TVA eventually was judicially invalidated on procedural grounds [*Tennessee Valley Authority v. Whitman*, 336 F.3d 1236 {11th Cir. 2003}]); environmental groups have since brought actions against TVA on the same substantive grounds.) The actions regarding TVA, WEPCO, and those listed in Table 2-1 alleged that the companies had undertaken major modifications without obtaining NSR permits.

Several other actions have been settled, as shown in Table 2-2 from EPA.[10] As the table shows, the settlements, when fully implemented in 2010-2015, will reduce $SO_2$ emissions by more than 440,000 tons per year. (It is possible that some of these reductions might have been required by other programs under the CAA.) These reductions are permanent; that is, they reduce emissions to levels lower than the 8.95-million-ton national cap. Each settlement agreement includes a provision requiring the source to annually surrender $SO_2$ emission allowances. Surrendered allowances are retired by EPA, and so they become unavailable for use by other sources. In this way, the settlements will reduce $SO_2$ emissions below the present 8.95-million-ton cap described above. Similarly, the required reductions in $NO_x$ may not be used to generate $NO_x$ credits that can be sold to other sources.

Generally, the number of allowances surrendered annually equals the number of tons by which the settlement reduces the source's allowable $SO_2$ emissions. There are two exceptions. First, if the source already had more allowances than its presettlement emissions, then the source must surrender these surplus allowances in addition to the allowances represented by the settlement. If, on the other hand, the settlement would reduce a source's allowable emissions below its annual allowances, then the company need surrender only the difference between presettlement emissions and its allowances. (The Virginia Electric Power Company [VEPCO] settlement summarized below is an example of this.)

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[10] In 2000, EPA reached an agreement in principle to settle its action against Cinergy, Inc. This agreement has not been incorporated into a consent agreement, and so litigation between the utility and EPA continues.

**TABLE 2-1** Pending NSR Enforcement Actions Against Coal-Fired Power Plants (7/2/04) Arranged Chronologically by Date of Filing

| Case Title District Court Judge | Date Filed | Utility Defendants | Status |
|---|---|---|---|
| *U.S. and State of New York, et al. v. Ohio Edison Co., et al.* (S.D. Ohio)<br>Judge Sargus | Nov. 1999 | Ohio Edison Co. and Pennsylvania Power Co. (subsidiaries of FirstEnergy Corp.) | Liability ruling in favor of U.S. issued 8/03; remedy trial 1/11/05 |
| *U.S. v. Illinois Power Co., et al.* (S.D. Ill.)<br>Judge Reagan | Nov. 1999 | Illinois Power Co. and Dynegy Midwest Generation | Liability trial held June 2003, awaiting decision; remedy discovery complete, awaiting remedy trial date |
| *United States v. Cinergy Corp., et al.* (S.D. Ind.)<br>Judge McKinney | Nov. 1999 | Cinergy Corp., Cincinnati Gas and Electric Co., and PSI Energy, Inc. | Liability trial commences 8/8/05; liability discovery ongoing |
| *U.S. and State of New York, et al. v. American Electric Power Service Corp.* (“*AEP*”), *et al. consolidated with Ohio Citizen Action, et al. v. AEP, et al.* (S.D. Ohio)<br>Judge Sargus | Nov. 1999 | American Electric Power Service Corp., Appalachian Power Co., Cardinal Power Co., Central Operating Co., Columbus Southern Power Co., Indiana Michigan Power Co., and Ohio Power Co. | Liability trial June 2005; liability discovery ongoing; in mediation |
| *U.S. v. Georgia Power Co. and Savannah Electric and Power Co.* (N.D. Ga.)<br>Judge Carnes | Nov. 1999 | Georgia Power Co. and Savannah Electric and Power Co. (Southern Co. operating subsidiaries) | Judge held, awaiting final decision in *TVA v. EPA* |

*(Continued)*

**TABLE 2-1** *(Continued)*

| Case title District Court Judge | Date Filed | Utility Defendants | Status |
|---|---|---|---|
| *U.S. v. Alabama Power Co.* (N.D. Ala.) Judge Bowdre | Nov. 1999; refiled in N.D. Ala. Jan. 2001 | Alabama Power Co. (Southern Co. operating subsidiary) | Stay lifted 6/04; awaiting court schedule |
| *U.S. v. East Kentucky Power Cooperative* | Jan. 2004 | East Kentucky Power Cooperative | Answer filed 6/04; in settlement negotiations |
| *U.S. v. Duke Energy Corp.* (M.D. N.C.) Judge Bullock | Dec. 2000 | Duke Energy Corp. | Final judgment issued for defendants by stipulation 4/15/04; on appeal to 4th Circuit |

Source: Adapted from EPA, unpublished material, 2004.

The number of allowances surrendered might well be reduced if Congress or EPA lowers the $SO_2$ allowance cap of 8.95 million tons (e.g., through the CAIR or Clear Skies initiatives).

Table 2-2 also shows estimates of the capital cost of the required reductions. These costs are stated in today's dollars and so are not discounted for the value of postponing an investment for several years. Moreover, these cost figures are not annualized. Therefore, they cannot be used to generate cost-effectiveness numbers. According to EPA enforcement personnel, the costs of the reductions are approximately $500 per ton for SO2 and $900 to $3,000 per ton for $NO_x$. These costs are comparable to those for installing BACT generally.

The settlement between EPA and the VEPCO illustrates the kind of steps that an agreement to end the enforcement litigation may involve. There, the company has committed itself, among other things, to install scrubbers on 70% of its coal-fired generation capacity. That step will reduce $SO_2$ emissions by 176,500 tons per year by 2012. The company also will install by 2013 selective catalytic reduction technology on 67% of its coal-fired generation capacity, thereby reducing annual $NO_x$ emis-

**TABLE 2-2** Expenditures and Emission Reductions Resulting from Settled NSR Enforcement Actions

| Company | Settlement Date | Capital Spent on Controls ($mil) | Environ. Projects ($mil) | Annual Tons Per Year of | |
|---|---|---|---|---|---|
| | | | | $NO_x$ Removed | $SO_2$ Removed |
| Virginia Electric (VEPCO) | April 2003 | 1,200 | 13.9 | 61,651 | 176,545 |
| Wisconsin Electric (WEPCO) | April 2003 | 600 | 20.0 | 31,770 | 65,053 |
| Tampa Electric (TECO) | Feb 2000 | 1,000 | 11.0 | 53,000 | 70,000 |
| Public Service Electricity & Gas (PSE & G) | Jan 2002 | 330 | 6.0 | 18,273 | 35,937 |
| Southern Indiana Gas & Electric (SIGECO) | June 2003 | 30 | 2.5 | 4,232 | 6,384 |
| Alcoa | March 2003 | 330 | 2.5 | 15,482 | 52,899 |
| South Carolina Public Service Authority (Santee Cooper) | June 2004 | 400 | 4.5 | 29,500 | 37,500 |
| Totals | | $3,890 | $60.4 | 213,908 | 444,318 |

Source: EPA 2004b; EPA, unpublished material, 2004.

sions by 66,000 tons more than current EPA rules require. In addition, the company will surrender to EPA 45,000 allowances per year beginning in 2012 (EPA 2003a). Settlements can affect emissions significantly in an area. A settlement by EPA and New Jersey, with a utility plant on the outskirts of Trenton and another in Jersey City, will reduce $SO_2$ and $NO_x$ emissions in the state by 19% and 5%, respectively, by 2012 (EPA 2002b).

EPA enforcement officials have asserted that the cases they are currently pursuing could reduce annual $SO_2$ and $NO_x$ emissions in 10 years by 1,750,000 tons and 629,000 tons, respectively (EPA 2004b). It is not clear what the actual reductions would be. Of the pending actions, so far two have resulted in decisions by U.S. district courts on the merits (*U.S. v. Ohio Edison Co*. 276 F. Supp. 2d 819 (S.D. Ohio 2003); *U.S. v. Duke Energy Corp*, 278 F.Supp. 2d 619 (M.D. N.C. 2003)). These cases, although decided only 2 months apart, came to opposite conclusions on

- How to determine whether an increase in emissions has occurred. *Ohio Edison* allows the use of the actual-to-projected-actual method for determining whether a utility unit has increased emissions, while *Duke Energy* holds that an increase in the hourly emission rate also must have occurred.
- The test for deciding whether a particular change constitutes routine maintenance, repair, and replacement. *Ohio Edison* holds that the test hinges in part on whether a particular activity is routinely conducted at an individual plant, while *Duke Energy* looks to whether the activity is routine in an industry. Thus, the former decision, but not the latter, covers an activity that is performed only once or twice in the life of a plant but is performed at most plants in an industry.
- Who has the burden of proof in showing whether a change constitutes routine maintenance, repair, and replacement. *Ohio Edison* holds that the burden is on the source, while *Duke Energy* places it on the government.

Because both of these decisions were rendered by district courts, neither has superior status as a statement of the law, and so the eventual resolution cannot be predicted. Even if EPA's enforcement theory is correct, the change in regulation may well make it more difficult for EPA to persuade companies to settle or to obtain favorable judgments. As EPA has pointed out, the new rule is not retroactive, and therefore enforcement actions based on the previous rules may proceed. But, as a practical matter, a court might be reluctant to find liability, or to impose a substantial penalty, for violating rules that are no longer in force. Hence, the rule changes have the potential to diminish the size of future settlements. Again, estimating the magnitude of this change is difficult.

It is important to note that only enforcement actions against violators result in the surrender of allowances. If a utility complies without the need for an enforcement action (the utility requests a permit for changes that EPA would not consider to be routine maintenance, repair, and replacement), then it need not surrender allowances. Instead compliance by the utility would reduce the utility's need to find additional allowances to accommodate the emission increase that would have been caused by the change. These allowances would then be available to other sources, thus perhaps resulting in increases in emissions from those sources that might offset, in part or in whole, the effect of compliance.

## Events in 2001-2002

Shortly after his inauguration, President Bush directed Vice President Cheney to develop a national energy policy. In May 2001, the Vice President issued a report on behalf of the National Energy Policy Group (2001).

A report from that group in 2001 recommended that legislation be introduced to cap utility emissions of $NO_x$ and $SO_2$ at utility plants.[11] The report also recommended that EPA, in conjunction with the Department of Energy and other federal agencies, examine EPA's NSR regulations (including their administrative interpretation and implementation) and report on the impact of NSR on investment in new utility and refinery generation, energy efficiency, and environmental protection.

EPA undertook a 90-day review of the NSR program and in June 2001 issued a background report (EPA 2001) that became the basis for a report to President Bush in May 2002 (EPA 2002c). These reports concluded that the overall benefits of NSR are significant and that NSR has not substantially impeded the construction of new electricity-generating units or refineries. In contrast, the reports found that NSR "has impeded or resulted in the cancellation of projects which would maintain and improve reliability, efficiency and safety of *existing* energy capacity" (emphasis added) (EPA 2002c). In some cases involving refineries and other industries, the reports found, the impeded projects either would not have increased air pollution or would have decreased air pollution. These conclusions were based largely on anecdotal reports from companies that lack specifics about the projects (GAO 2003).

The report to the President recommended that changes in EPA's NSR regulations be made. EPA followed up on this recommendation by promulgating the December 2002 rule summarized above. This rule has

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[11] This legislation has not reached the floor in either house of Congress. The proposed Clean Air Interstate Rule, summarized above, attempts to implement part of the proposal administratively.

been challenged by some states and environmental groups before the D.C. Circuit Court of Appeals.

## Routine Maintenance, Repair, and Replacement

On the same day that EPA promulgated the NSR revisions summarized above, EPA proposed changes in its rules defining what projects constitute routine maintenance and are exempt from the NSR program. A modified version of the proposal, summarized above, was promulgated in August 2003 and published in October 2003. This rule has also been challenged before the D.C. Circuit Court of Appeals by some states and environmental groups. In December 2003, 2 days before the rule was to become effective in areas where EPA administers the PSD program, the D.C. Circuit Court issued a stay of the rule on the grounds that the petitioners had shown irreparable harm and the likelihood of success on the merits. This stay remains in place and so the new rule has not gone into effect.

On June 30, 2004, EPA announced a 180-day period for reconsideration of the rule. The agency requested comment on the rule's legality and on the choice of the 20% threshold (69 Fed. Reg. 40278 [2004]).

Following the regulatory overview of the NSR programs presented in this chapter, Chapter 3 examines contributions that emission sources subject to NSR may make to ambient air quality and relationships between specific air pollutants and health effects.

# 3

# Overview of Health Effects, Air Quality, and Emissions

## INTRODUCTION

New Source Review (NSR) programs are an important element in a large, complex, and evolving regulatory system. To understand how changes in NSR programs are likely to affect air quality and human health, it is necessary to examine the broader air pollution issues and the contributions that facilities subject to NSR may make.

This chapter begins with a brief discussion of the National Ambient Air Quality Standards (NAAQS) process for the criteria pollutants and then describes what is known about the health effects of criteria pollutants and volatile organic compounds (VOCs) regulated through NSR. It also describes progress that has been made toward NAAQS attainment and where further work is needed. The chapter discusses the inventory of emission sources, including stationary sources subject to NSR and the emissions contributed by the various industrial sectors. Because it is important to assess which existing stationary sources are affected by the NSR changes under review by this committee, the vintage of the facilities is considered.

## NATIONAL AMBIENT AIR QUALITY STANDARDS FOR CRITERIA POLLUTANTS

As discussed in Chapter 2, the Clean Air Act (CAA) requires the U.S. Environmental Protection Agency (EPA) to set primary NAAQS for selected air pollutants considered harmful to public health, including the health of "sensitive" populations such as people with asthma, children, and the elderly. Secondary NAAQS are intended to protect public welfare, such as crops and other vegetation. EPA has, for the most part, set the secondary standards at the same levels as the primary standards.[1]

EPA has set NAAQS for six pollutants (see Table 3-1): nitrogen dioxide ($NO_2$), ozone ($O_3$), carbon monoxide (CO), sulfur dioxide ($SO_2$), lead (Pb), and particulate matter (PM; $PM_{10}$ and $PM_{2.5}$).[2] Units of measure for the standards are parts per million (ppm) by volume, milligrams per cubic meter of air ($mg/m^3$), and micrograms per cubic meter of air ($\mu g/m^3$). Pollutants for which there are NAAQS are known as criteria pollutants because EPA prepares "criteria documents" for them describing their sources and effect.

Each NAAQS is composed of an indicator (e.g., $PM_{2.5}$), a level or concentration (e.g., 65 $\mu g/m^3$), an averaging time (e.g., 24 hours), and a statistical form (e.g., 3-year average of the 98th percentile of 24-hour concentrations at each population-oriented monitor). Although the concentration of the standard tends to receive the most public attention, the averaging time and statistical form are also important determinants of stringency.

The CAA mandates that the NAAQS be reviewed at 5-year intervals, although in practice, the interval often takes much longer—sometimes more than a decade. A typical review cycle for each pollutant involves developing a criteria document, a compendium of current knowledge about the pollutant, followed by development of a "staff paper," which summarizes knowledge considered most pertinent to decision making and proposes a range of actions for the EPA administrator's consideration. The range of actions and preferred options may include no change to the existing standard. Both documents are made available to the public for comment and are formally reviewed by the independent Clean Air Scientific Advisory Committee (CASAC) of the EPA Science Advisory Board, which complements the Committee with additional experts to form a review panel for each pollutant. The EPA administrator, after a lengthy period of public comment, makes the final decision on the standard to be promulgated. Although CASAC approval of ("closure on") the two documents is sought before the EPA administrator proposes

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[1] A separate secondary standard has been set for sulfur dioxide ($SO_2$).

[2] PM is regulated by mass concentration within aerodynamic size classes defined by the upper-bound particle size sampled with 50% efficiency by the inlets of air monitors (expressed in $\mu m$; $PM_{10}$, $PM_{2.5}$, and, $PM_{10\text{-}2.5}$) (EPA 2004c).

**TABLE 3-1** National Ambient Air Quality Standards

| Pollutant or Indicator | Primary Standards | Averaging Times | Secondary Standards |
|---|---|---|---|
| Carbon monoxide (CO) | 9 ppm (10 mg/m$^3$) | 8-hour[a] | None |
| | 35 ppm (40 mg/m$^3$) | 1-hour[a] | None |
| Lead (Pb) | 1.5 $\mu$g/m$^3$ | Quarterly average | Same as primary |
| Nitrogen dioxide ($NO_2$) | 0.053 ppm (100 $\mu$g/m$^3$) | Annual (arithmetic mean) | Same as primary |
| Particulate matter <10 $\mu$m aerodynamic diameter ($PM_{10}$) | 50 $\mu$g/m$^3$ | Annual[b] (arithmetic mean) | Same as primary |
| | 150 $\mu$g/m$^3$ | 24-hour[a] | |
| Particulate matter <2.5 $\mu$m aerodynamic diameter ($PM_{2.5}$) | 15 $\mu$g/m$^3$ | Annual[c] (arithmetic mean) | Same as primary |
| | 65 $\mu$g/m$^3$ | 24-hour[d] | |
| Ozone ($O_3$) | 0.08 ppm | 8-hour[e] | Same as primary |
| | 0.12 ppm | 1-hour[f] | Same as primary |
| Sulfur oxides ($SO_2$) | 0.03 ppm | Annual (arithmetic mean) | —— |
| | 0.14 ppm | 24-hour[a] | —— |
| | —— | 3-hour[a] | 0.5 ppm (1,300 $\mu$g/m$^3$) |

[a] Not to be exceeded more than once per year.

[b] To attain this standard, the expected annual arithmetic mean $PM_{10}$ concentration at each monitor within an area must not exceed 50 $\mu$g/m$^3$.

[c] To attain this standard, the 3-year average of the annual arithmetic mean $PM_{2.5}$ concentrations from single or multiple community-oriented monitors must not exceed 15 $\mu$g/m$^3$.

[d] To attain this standard, the 3-year average of the 98th percentile of 24-hour concentrations at each population-oriented monitor within an area must not exceed 65 $\mu$g/m$^3$.

[e] To attain this standard, the 3-year average of the fourth-highest daily maximum 8-hour average $O_3$ concentrations measured at each monitor within an area over each year must not exceed 0.08 ppm.

[f] (a) The standard is attained when the expected number of days per calendar year with maximum hourly average concentrations above 0.12 ppm is $\leq 1$ based on a 3-year average. (b) EPA will revoke the 1-hour NAAQS 1 year after the effective date of designating attainment and nonattainment areas for the 8-hour $O_3$ NAAQS. The effective designation date for most areas is June 15, 2004 (40 CFR 50.9; see 69 Fed. Reg. 23996 [2004]).

Source: EPA 2004d.

a standard, CASAC does not "approve" the standard promulgated by the agency.

Successful promulgation of a NAAQS typically is followed by a multiyear period before the standard is fully implemented. Monitoring data typically are used to determine areas of nonattainment, which may take some time if the pollutant indicator or averaging time differs from that of the preceding standard. EPA designates an area as one of three categories:

- *Nonattainment*—any area that does not meet the NAAQS or that contributes to violations of a NAAQS in a nearby area.
- *Attainment*—an area that meets the NAAQS and does not contribute to the violation of a NAAQS in a nearby area.
- *Unclassifiable*—an area that cannot be classified on the basis of available information as meeting or not meeting the NAAQS for a pollutant.[3]

## HEALTH EFFECTS OF AIR POLLUTION

This section provides brief descriptions of the status of health concerns associated with the criteria pollutants, excluding lead.[4] In addition, summary information is given for VOCs, which are also regulatory targets but are managed differently from the criteria pollutants.[5]

A large and growing body of published epidemiologic and toxicologic research establishes that the criteria pollutants are associated with a variety of health effects, including increased occurrence of cardiopulmonary morbidity, cardiopulmonary and cancer mortality, effects on birth outcomes (low birth weight, small for gestation age), and impaired growth of lung function in children. The associations are most consistent for children (particularly those with asthma) and for the eld-

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[3] Additional discussion of the setting and implementation of NAAQS is presented by NRC (2004).

[4] Lead is not included in this review because ambient concentrations of lead have decreased precipitously since it was removed from gasoline. A small number of stationary sources (e.g., smelter and battery plants) are the primary sources of lead emissions in the atmosphere; however, there have been no exceedances of the NAAQS since the mid-1990s.

[5] The committee does not discuss the detailed published data related to the effects associated with various VOCs.

erly (particularly those with underlying cardiovascular diseases and diabetes). In contrast to the clarity of the overall associations, the extent to which the various health effects can be attributed to any given pollutant or combinations of pollutants is less clear; this limitation must be considered when examining the quantitative estimates of association attributed to any single pollutant. In the case of PM, the problem is compounded by the fact that PM is a complex physical-chemical mixture whose components likely interact with other criteria pollutants (e.g., $O_3$) in a number of ways that may affect health outcomes. Characterizing the overall pollutant mixture with respect to its health implications is a major future challenge for air-pollution-related health effects research.

For two of the pollutants ($NO_2$, $SO_2$), the discussion that follows focuses on what is known about their direct associations with health outcomes. However, each also makes a substantive contribution to the formation of $PM_{2.5}$ in the atmosphere (also known as secondary $PM_{2.5}$) and undoubtedly contributes to some portion of the health effects attributed to $PM_{2.5}$. In addition, $NO_2$ plays a central role in the chemistry of $O_3$ formation (see Box 3-1).

The committee refers only briefly to the problem of investigating and estimating threshold effects from population data, which is important in determining whether health effects would be anticipated in NAAQS attainment areas. There is general agreement that detection of thresholds for various pollutants is difficult with population data because such data represent weighted averages (weights unknown) of pollutant-host interactions. By and large, the body of personal exposure data is insufficient to precisely determine pollutant thresholds.

## Carbon Monoxide

Concerns for the health effects of inhaled CO historically have focused on the various manifestations of its greater affinity for binding to blood hemoglobin than oxygen’s, thus reducing blood oxygen concentrations. Accordingly, the current NAAQS for CO is based on preventing significant health impacts by limiting blood carboxyhemoglobin concentrations (in normal nonsmokers) to approximately 2% or less (EPA 2000). The health effect driving the current NAAQS is angina (chest pain) in exercising individuals with coronary artery disease. The onset of angina signals ischemia (lack of sufficient oxygen) in heart muscle and not only limits the level and duration of exercise but also can increase the risk for arrhythmias and death.

### BOX 3-1 Noncriteria Pollutants That Contribute to Airborne Ozone and Particulate Matter

Air pollutants are often characterized by how they originate: pollutants emitted directly into the atmosphere are called primary pollutants; those formed as a result of chemical reactions within the atmosphere are called secondary pollutants. Many precursors are known to form secondary pollutants within a day or two of emission, while being transported downwind in the atmosphere. The formation of $O_3$ and PM in the atmosphere, as secondary pollutants, involves complex chemical and physical interactions of multiple pollutants from natural and anthropogenic sources. This complexity has resulted in ongoing difficulties in measuring and regulating those pollutants.

$O_3$ is formed during the production of NO from $NO_2$ in the presence of products of photochemical reactions of VOCs (labeled $RO_2$ in Figure 3-1). The reaction is self-perpetuating (or catalytic) in the presence of sunlight because $NO_2$ is photochemically reformed from NO. In this way, $O_3$ is controlled by both $NO_x$ and VOC emissions. The complexity of these interacting cycles of pollutants means that incremental decreases in one emission may not result in proportional decreases in $O_3$. Although these reactions and interactions are well understood, variability in emission source operations and meteorology creates uncertainty in the modeled $O_3$ concentrations to which downwind populations may be exposed.

Ambient PM is produced by a variety of emission sources. Some particles are emitted directly into the atmosphere from sources (such as metals from industrial processes). Secondary particles are produced by reactions that involve $SO_2$, $NO_x$, and VOCs and ammonia. Oxidizing agents, produced by $O_3$, VOCs and $NO_x$, convert $SO_2$ to sulfuric acid and then to sulfate; they also convert $NO_x$ to nitric acid and then to nitrate. These stable products form into particles and typically are neutralized by ammonium-forming salts. The same reactions in which $RO_2$ compounds are produced and $O_3$ is formed also make organic components that condense into particles. Aqueous-phase reactions in fog and cloud droplets also produce organic and inorganic products that contribute to mass in the condensed phase. Figure 3-1 summarizes the role that these four types of emissions play in producing PM.

Epidemiologic research since the last review of the CO NAAQS has provided some evidence of associations between increases in CO concentrations and increased rates of cardiopulmonary mortality and morbidity. Several studies focused on PM, but multipollutant models also appeared to show significant relationships between CO and mortal ity (EPA 2004e). Some studies suggest that in such cases CO serves as a

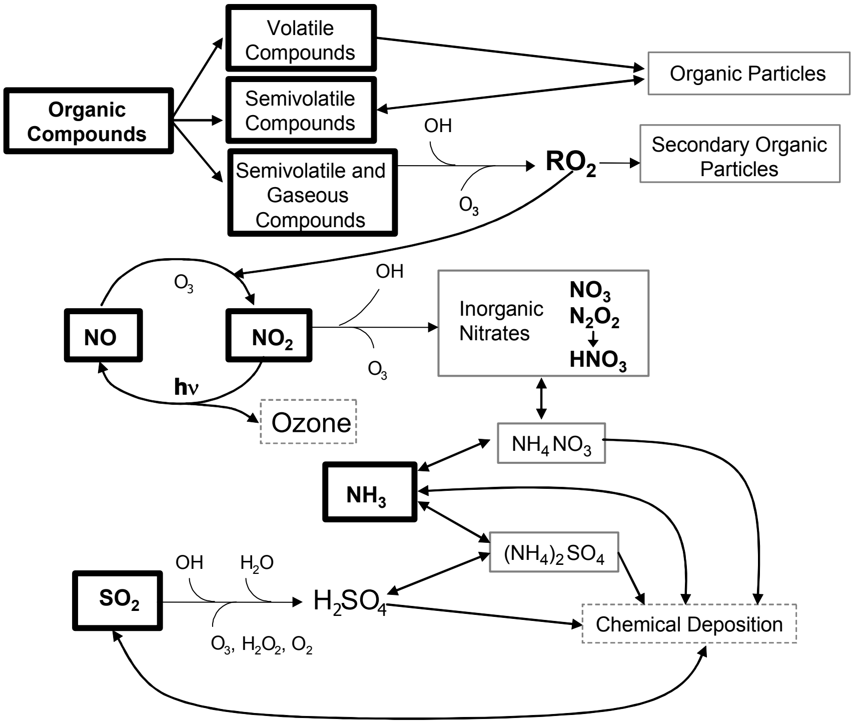


**FIGURE 3-1** Chemical links between $O_3$ and PM formation processes. Major precursors are shown in the boxes with thick sides. Secondary particle components are shown in the boxes with thin-sided solid sides. Source: NARSTO 2004. Reprinted with permission; copyright 2004, Cambridge University Press.

marker for mobile source contributions of several pollutants and perhaps even as a surrogate for toxic fine particles (putatively, those emitted directly from combustion sources). Whether CO affects mortality directly or serves as an indirect indicator of exposure to other toxicants is not resolved; however, the statistical link between CO and mortality cannot be disregarded.

Recent research has also demonstrated statistical associations between current ambient CO levels and low birth weight (Ritz and Yu 1999). This finding has not been replicated sufficiently to confidently evaluate either exposure-response relationships or the specificity of the effect of CO, but there is sufficient evidence to warrant concern.

CO can also exert central nervous system effects, including reductions in hand-eye coordination (driving or tracking) and in attention and vigilance. Present data, however, suggest that ambient concentrations are unlikely to cause such effects unless ambient exposures are superimposed on exposures from other sources, such as heavy smoking or hot spots caused by extreme traffic emissions (EPA 2000).

## Nitrogen Oxides

The term nitrogen oxides ($NO_x$) commonly refers to the sum of nitric oxide (NO) and nitrogen dioxide ($NO_2$). The symbol $NO_y$ commonly refers to the sum of $NO_x$ and other oxidized nitrogen compounds, such as nitric acid ($HNO_3$), nitrogen trioxide ($NO_3$), dinitrogen trioxide ($N_2O_3$), dinitrogen tetroxide ($N_2O_4$), dinitrogen pentoxide ($N_2O_5$), and peroxyacetylnitrate. Nitrous oxide ($N_2O$) is commonly excluded. NO and $NO_2$ have numerous sources, especially combustion emissions, and are present in ambient air in greater concentrations than the other species. $NO_2$ is toxic by virtue of its oxidation potential and has received the greatest health research and risk assessment attention. NO has lower biological toxicity but is increasingly recognized as a mediator or intermediate of cellular signaling and biochemical processes, both beneficial and detrimental. $NO_y$ is of concern not only for its toxicity but also because of its participation in the formation of $O_3$ (together with VOCs and sunlight) and secondary PM (nitrates).

$NO_x$ constituents are oxidants and thus may contribute to the wide range of respiratory health impacts thought to be associated with inhaling oxidants or mediated by oxidation pathways. Experimental and accidental inhalation of high $NO_2$ concentrations have been shown to cause respiratory symptoms (e.g., cough and wheezing), reduced lung function, and increased airway responsiveness of both normal and asthmatic individuals. The evidence for these effects at common ambient concentrations (less than 0.05 ppm based on an annual average) is equivocal (EPA 1995a). Among the many recent epidemiologic studies of the effects of particles and co-pollutants on respiratory and cardiovascular outcomes, $NO_x$ has seldom arisen as a significant factor. Prolonged high-level exposures of animals (e.g., 10 ppm and higher) have caused emphysema-like changes in some, but not all, studies. Tissue changes are unlikely at ambient exposure concentrations; however, the recent finding that ambient exposure to $O_3$, also an oxidant gas, affects lung development, suggests the possibility that $NO_x$ may contribute to similar effects. High indoor exposures of children (often associated with gas stove usage) have been linked to reduced resistance to respiratory infections and increased likelihood of respiratory illness (Hasselblad et al. 1992), including wheezing and persistent coughing (van Strien et al. 2004). In addition, recent evidence suggests that $NO_2$ exposures increase the severity of virus-induced asthma exacerbations (Chauhan et al. 2003). Although unconfirmed, it is possible that $NO_x$ emissions may contribute to the associations between respiratory illness in children and proximity to heavily traveled roadways (Wjst et al. 1993; Oosterlee et al. 1996; Brunekreef et al. 1997).

Research since the last review of $NO_x$ NAAQS indicates that $NO_x$ may retard lung growth in children (Gauderman et al. 2004). Differences between the rates of lung growth in children living in areas of relatively greater and lesser pollution were statistically associated with $NO_2$ and also with airborne acid and fine particles ($PM_{2.5}$), substances to which $NO_x$ contributes. $NO_2$ (along with other air pollutants) also may increase airway responsiveness to allergens (Rusznak et al. 1996; Jenkins et al. 1999).

Although it is both plausible and probable that $NO_x$ contributes to the impacts of air pollution on public health, it is likely that $NO_x$ species affect health more strongly via their contribution to the formation of $O_3$ and secondary PM than via their direct effects.

## Ozone

$O_3$ (along with PM) currently is one of the criteria pollutants of greatest health concern. There is little doubt that public health is measurably affected at exposure levels that exist in many areas in the United States (EPA 1996).

$O_3$ is an oxidant gas emitted directly from sources in only small amounts (e.g., electric motors); ambient $O_3$ is overwhelmingly formed in the atmosphere from reactions involving $NO_x$, VOCs, and ultraviolet light (sunlight) (see Box 3-1). It is one of several photochemical oxidants. In the respiratory tract, $O_3$ interacts with polyunsaturated fatty acids, electron donors (e.g., ascorbate, vitamin E), and the thiol, aldehyde, and amine groups of low-molecular-weight compounds and proteins. $O_3$ is very reactive, and it is likely that most harmful biological effects result from the products of initial reactions of $O_3$ with surface fluids and cell walls rather than from direct interactions between $O_3$ and intracellular targets. For people with chronic obstructive pulmonary disease or asthma, the antioxidant content of the lung lining can be reduced, potentially contributing to increased sensitivity to $O_3$ (Mudway and Kelly 2000).

$O_3$ has been associated with a spectrum of adverse effects, but the effects primarily driving the current standard are pulmonary function decrements in exercising children, adolescents, and susceptible (e.g., asthmatic) individuals. $O_3$ causes a neurogenic (reflex) inhibition of maximal inspiration that reduces maximal forced expiratory volume during lung function tests and ventilatory capacity during exercise. $O_3$ also causes increased airway responsiveness (constriction) to other materials (e.g., airway constricting drugs, allergens). Although the degree of increased responsiveness may not differ much between healthy people and people with asthma, the much greater baseline responsiveness of people with asthma makes the $O_3$-induced additional decrement potentially more serious. High $O_3$ levels are associated with more clinic visits and hospitalization of people with asthma and other preexisting respiratory diseases; there is also some evidence for increased deaths among these subpopulations (Thurston and Ito 2001, Bell et al. 2004). The National Morbidity, Mortality, and Air Pollution Study (Bell et al. 2004) finds a similar relative risk for $O_3$ above and below the NAAQS, although differences between personal $O_3$ exposures and ambient concentrations make it difficult to detect thresholds (Zhang and Lioy 1994, Brauer et al. 2002).

$O_3$ also acts as a respiratory and eye irritant, giving rise to noticeable, if not life threatening, discomfort that limits activity and reduces quality of life. $O_3$ may impair defenses against respiratory pathogens and inhaled particles. There is evidence (EPA 1996) that $O_3$ slows the clearance of particles from the lungs by damaging cilia and retarding the activity of macrophages; however, it is not clear whether this occurs in humans at actual exposure concentrations. Furthermore, Pope et al. (2002) observed a positive association between long-term exposure to summertime $O_3$ and increased risk of premature death in cohort studies, although the relationship was not statistically significant. Bell et al. (2004) found a statistically significant association between short-term changes in $O_3$ and mortality on average for 95 large U.S. urban communities.

Research since the 1996 $O_3$ Criteria Document (EPA 1996) reviews indicates that $O_3$ retards lung growth. Exposures of animals have produced alterations in the development of lung structure during growth (Schelegle et al. 2003). Epidemiologic studies have demonstrated that entering college students from areas with high $O_3$ concentrations have smaller lungs and less lung function than students from areas with low $O_3$ levels (Kunzli et al. 1997).

## Particulate Matter

PM encompasses a physically and chemically diverse class of ambient air pollutants of both anthropogenic and biological origin. The PM standard is the only NAAQS that does not target a specific chemical or family of chemical species. PM concentration is defined functionally as the change in mass of a filter through which ambient air is drawn under standardized conditions. PM can be solid, liquid, or composed of semivolatile species (partitioned between the PM and vapor phases depending on ambient conditions), and it can be either directly emitted from sources (primary; e.g., fly ash) or formed in the atmosphere (secondary; e.g., sulfate) from precursor gases. Regardless of composition, the aerodynamic size of PM determines its inhalability (ability to enter the mouth or nose) and the distribution of fractional deposition throughout the respiratory tract (EPA 2004e). There is no exclusive difference in the ability of PM at any aerodynamic diameter less than 10µm to reach different parts of the respiratory tract; both a 10-µm and a 10-nm particle could be deposited in the nose or the deep lung. However, the probability of deposition in different locations varies considerably with size. Most inhaled PM mass of a typical ambient size distribution is not deposited at all but is exhaled (EPA 2004e); however, there is clear evidence that the portion that does deposit can exert adverse health effects if the exposure level is sufficient.

A large range of health effects has been associated with exposure to PM in both epidemiologic and laboratory studies. The current $PM_{2.5}$ NAAQS (promulgated in 1997) was based on epidemiologic evidence of mortality. The range of human health effects associated with ambient PM levels or demonstrated in laboratory studies has expanded from earlier concerns for total mortality and respiratory morbidity to include cardiac mortality and morbidity, blood vessel constriction, stroke, premature birth, low birth weight, retarded lung growth, enhancement of allergic responses, reduced resistance to infection, degenerative lesions in the brain, and lung cancer (EPA 2004e).

Both short-term increases in PM exposure and longer-term exposure concentrations are of concern. Numerous time-series studies have correlated variations in ambient PM levels with concurrent or lagging variations in health outcomes; other studies have demonstrated differences in mortality and morbidity between populations with different long-term PM exposures (Dockery et al. 1993; Pope et al. 1995, 2002, 2004). The relationship between the effects of short-term spikes in exposure and the cumulative effects of longer-term exposure to both spikes and baseline levels is uncertain.

The quantitative relationship between PM exposure levels and health effects remains uncertain, as does the proportion of the criteria pollutant health effects attributable to PM versus co-pollutants. Despite the uncertainties and the attendant debates, it seems clear that current concentrations in some areas and at some times in the United States are associated with health burdens that warrant concern, with a causal interpretation of the epidemiologic evidence implying a public health burden from PM exceeding that of other criteria air pollutants (EPA 2004e). A critical uncertainty involves determining a population threshold for PM (a concentration below which no health effects would occur). Although epidemiologic evidence to date has not detected a threshold for mortality effects (Pope et al. 2002; Daniels et al. 2004), epidemiologic studies lacking accurate personal exposure data have a limited ability to detect thresholds were they to exist. Furthermore, although animal studies have provided insight into mechanisms of response and confirmed the toxicity of certain PM components, few statistically significant responses have been demonstrated in the laboratory at ambient exposure concentrations. Given this uncertainty, regulatory impact analyses typically evaluate the sensitivity of conclusions to the no-threshold assumption (EPA 1999).

Similarly, the relationship between PM composition (particle-size fractions and chemical components) and adverse health effects remains uncertain. Current PM NAAQS assume that all PM mass is of equal toxicity, but it is unlikely that the mechanisms of action and relative toxicities do not differ across constituents. Different PM components (e.g., metals, organics) drive different types of toxicity (some components are more toxic than others for certain effects), and the same PM composition administered in different particle sizes has different potencies. However, there has been insufficient systematic study of the impacts of composition and size differences on the different effects of concern upon which to base composition-specific standards. In part, size is incorporated into the NAAQS as a rough surrogate for composition (because most fine PM stems from the combustion of fossil fuel or biomass, whereas coarse particles tend to arise from fugitive dust, pollens and spores, and sea salt). However, particles of similar size can have vastly different origins and composition.

## Sulfur Dioxide

$SO_2$ is of concern both because it is a direct respiratory irritant and because it contributes to the formation of sulfate and sulfuric acid in PM. The current NAAQS for $SO_2$ is based primarily on preventing airway constriction in exercising, unmedicated asthmatic individuals (EPA 1994a). People with asthma are of particular concern, both because they have increased baseline airflow resistance and because their $SO_2$-induced increase in resistance is greater than in healthy people, and it increases with the severity of their asthma. $SO_2$ is thought to induce airway constriction via neural reflexes involving irritant receptors in the airways. The NAAQS is aimed at preventing stimulation of these reflexes in people with asthma.

Epidemiologic research since the last review of the $SO_2$ NAAQS (Krewski et al. 2000; Pope et al. 2002) has repeatedly demonstrated associations between ambient $SO_2$ and cardiopulmonary morbidity (illness) and mortality. Studies focused primarily on PM have often demonstrated significant or near-significant statistical associations between $SO_2$ and the health outcomes. The implications of these findings are somewhat unclear. As a respiratory irritant, $SO_2$ likely contributes directly to respiratory morbidity, and it might contribute directly to mortality with a respiratory origin. Through neural reflexes, it is possible that $SO_2$ also might contribute directly to cardiac arrhythmia and thus cardiac morbidity and mortality, but this possibility has not been explored in controlled studies.

To the extent that ambient concentrations of $SO_2$ are linked to concentrations of particulate sulfate and airborne acid at the same location, $SO_2$ also might be serving as a marker for ambient sulfate (and thus ambient fine PM), which might cause the effects. However, until we have a better understanding of the specific physical-chemical air-pollutant species causing cardiopulmonary morbidity and mortality, we cannot ignore the possible direct contribution from $SO_2$.

## Volatile Organic Compounds

In addition to the NAAQS pollutants, emissions addressed by the NSR program include a diverse group of air contaminants termed for regulatory purposes, volatile organic compounds (VOCs). VOCs encompass a range of chemical species that have in common a fundamental organic structure (primarily hydrocarbons, including oxidized and substituted hydrocarbons), a presence primarily or entirely in the gas phase under ambient conditions (vapor pressure generally greater than $10^{-4}$ millimeters of mercury, below which most organic compounds typically are considered semivolatile) and a reactivity leading to participation (together with $NO_x$ and sunlight) in atmospheric reactions resulting in the formation of $O_3$. Because of research on the role VOCs played in the formation of $O_3$ and efforts to identify and control emissions of its most reactive precursors, VOCs have long been targeted as a group to be regulated (EPA 1996). VOC emissions also contribute to the formation of airborne PM. The major classes of VOCs are alkanes, alkenes, aromatics, carbonyls, alcohols, and ethers. The substances included in VOC measurements can vary; some measurements target specific species and others (e.g., total nonmethane hydrocarbons) encompass multiple substances.

Although VOCs are addressed by NSR because of their contributions to health and welfare impacts as precursors of $O_3$, many members of the group are also of concern because of their toxicity. Those considered to have the most important primary health implications are also included within the regulatory group termed “hazardous air pollutants” (HAPs, also known as “toxic air pollutants” or “air toxics”). The CAA lists 188 HAPs species or classes. In its most recent National-Scale Air Toxics Assessment, EPA reviewed 32 of the 33 HAPs it identified in 1999 to be of greatest concern in urban areas, plus diesel PM (EPA 2002d). EPA terms the 33 key HAPs “urban air toxics” (64 Fed. Reg. 38706 [1999]); these are listed in Table 3-2, in which the 21 VOC members are indicated. Examples of VOC HAPs include benzene, which is found in gasoline; methylene chloride, which is used as a solvent and paint stripper by a number of industries; and perchloroethlyene, which is emitted from some dry cleaning facilities. The health effects of VOC HAPs differ among the species; summaries can be found at EPA (2004f). Most effects of concern involve mutagenicity, cancer, irritation (inflammation), neurotoxicity, or modulation of immune responses.

## ATTAINMENT STATUS OF NATIONAL AMBIENT AIR QUALITY STANDARDS

$SO_2$ and CO are directly emitted by sources (primary pollutants). Portions of $NO_2$, $PM_{2.5}$, and $PM_{10}$ are directly emitted (primary pollutants), and other portions form as a result of chemical reactions in the atmosphere (secondary pollutants). Very little $O_3$ is emitted directly; most forms from chemical reactions of oxides of nitrogen ($NO_x$, which is the sum of NO and $NO_2$ , expressed as $NO_2$) and VOCs (see Box 3-1).

$O_3$, $PM_{10}$, and $PM_{2.5}$ concentrations typically result from the contributions that are spread out over global (10,000 kilometers [km]), continental (1,000 km), regional (about 100 km), urban (about 10 km), neighborhood (1 km), and middle (intraneighborhood) (about 0.1 km) scales (Chow et al. 2002). Primary emissions from a single source may contribute large portions of primary emittants at the middle to neighborhood scales, but their relative contributions decrease with distance from the source.

There are currently no nonattainment areas for $NO_2$ (EPA 2004i). There are 10 designated nonattainment areas for CO, all near heavily traveled roadways, and only a few of them have experienced NAAQS exceedances in recent years (AirData 2004). None of the 17 designated nonattainment areas for $SO_2$ has experienced NAAQS exceedances during the past 10 years (EPA 2004i; Fred Dimick, EPA, unpublished data, November 2, 2004). The reduction in exceedances are mostly because of modifications or closures of nearby smelters and steel mills. Several years of ambient measurements that attain the NAAQS are required before EPA grants the attainment designation. CO and $SO_2$ NAAQS exceedances were often caused by, and traceable to, nearby sources that were reasonably identifiable as the cause of the exceedance. This can be

**TABLE 3-2** Urban Air Toxics

acetaldehyde[a]
acrolein[a]
acrylonitrile[a]
arsenic compounds
benzene[a]
beryllium compounds
1, 3-butadiene[a]
cadmium compounds
carbon tetrachloride[a]
chloroform[a]
chromium compounds
coke oven emissions
1,3,-dichloropropene[a]
dioxin
ethylene dibromide[a]
ethylene dichloride[a]
ethylene oxide[a]
formaldehyde[a]
hexachlorobenzene[a]
hydrazine[a]
lead compounds
manganese compounds
mercury compounds
methylene chloride[a]
nickel compounds
perchloroethylene[a]
polychlorinated biphenyls (PCBs)
polycyclic organic matter
propylene dichloride[a]
quinoline[a]
1,1,2,2-tetra chloroethane[a]
trichloroethylene[a]
vinyl chloride[a]

[a] Also a volatile organic compound (VOC).
Source: 64 Fed. Reg. 38706 (1999); EPA 2004g.

important because state and local pollution control authorities can more easily take steps to achieve attainment when the emission sources are within their jurisdiction.

Figures 3-2 through 3-4 show the extent of U.S. nonattainment areas for $O_3$, $PM_{10}$, and $PM_{2.5}$, respectively. Areas where the $O_3$ standard is exceeded cover multiple counties in central and southern California; Las Vegas, Nevada; Phoenix, Arizona; along the Colorado Front Range; the Houston, Dallas, and San Antonio areas in Texas; nearly the entire Midwest and Southeast; and the Washington to Boston corridor (Figure 3-2). $O_3$ can seldom, if ever, be reduced meaningfully by controlling single sources of precursors; reduction strategies need to encompass many different sources of $NO_x$ and VOCs. These groups of sources may be hundreds of kilometers from the locations where exceedances are measured and outside the jurisdictions of local air-quality authority (Seinfeld 1988; Sillman 1993, 1999; NARSTO 2000; Placet et al. 2000; Russell and Dennis 2000; Solomon et al. 2000; Watson et al. 2001). The rate of formation of $O_3$ can be limited by the amount of either $NO_x$ or VOCs. The critical precursor to target to reduce $O_3$ formation varies with location. For example, the rate of formation is often VOC-limited in urban areas and $NO_x$-limited in rural areas. Therefore, it is usually more important to reduce VOCs and $NO_x$ emissions in urban and rural areas, respectively. Indeed, $NO_x$ reductions in some urban areas may even increase $O_3$ levels, as evidenced by weekend versus weekday comparisons, where weekend $NO_x$ emissions are lower, and the resulting $O_3$ concentrations are higher (Fujita et al. 2003).

Figure 3-3, which shows the nonattainment areas for the annual average $PM_{10}$ NAAQS, indicates that most of the nonattainment areas are in the western United States. In the past, exceedances that occurred outside of California were often dominated by fugitive dust from disturbed land, construction, wintertime road sanding, and suspended road dust. $PM_{10}$ state implementation plans (SIPs) developed in the early 1990s implemented wood-burning and dust-reduction measures, so many of these areas currently are not showing excessive $PM_{10}$ concentrations. Several areas also had industrial sources that reduced emissions to comply with $SO_2$, $PM_{10}$, and Pb NAAQS requirements.

Figure 3-4 shows that nonattainment areas for the annual average $PM_{2.5}$ NAAQS are more numerous and are located primarily in California and the eastern United States. In addition, many areas of the eastern United States have $PM_{2.5}$ concentrations that approach the annual NAAQS of 15 $\mu g/m^3$.

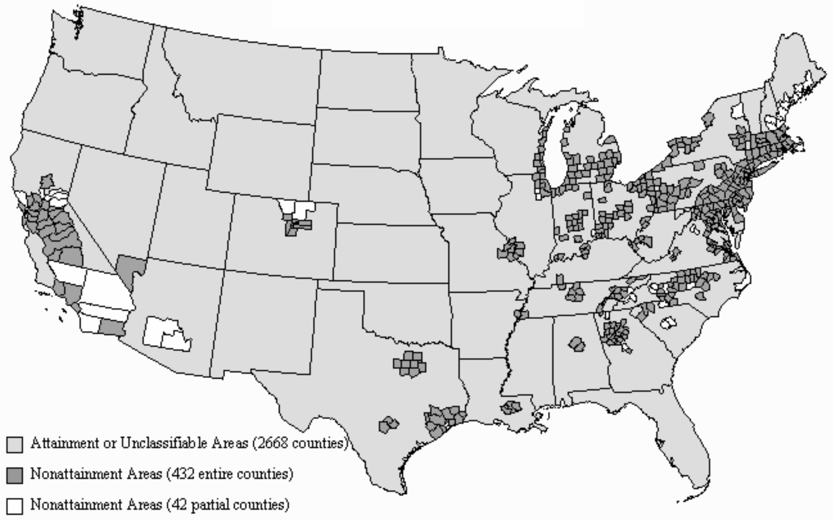


**FIGURE 3-2** Locations of ozone nonattainment areas for 2004 based on the 8-hour ozone standard. Source: EPA 2004j.

**FIGURE 3-3** Nonattainment areas for $PM_{10}$ NAAQS in 2004. Most of the nonattainment areas are designated for not meeting the 24-hour standard. Source: EPA 2004k.

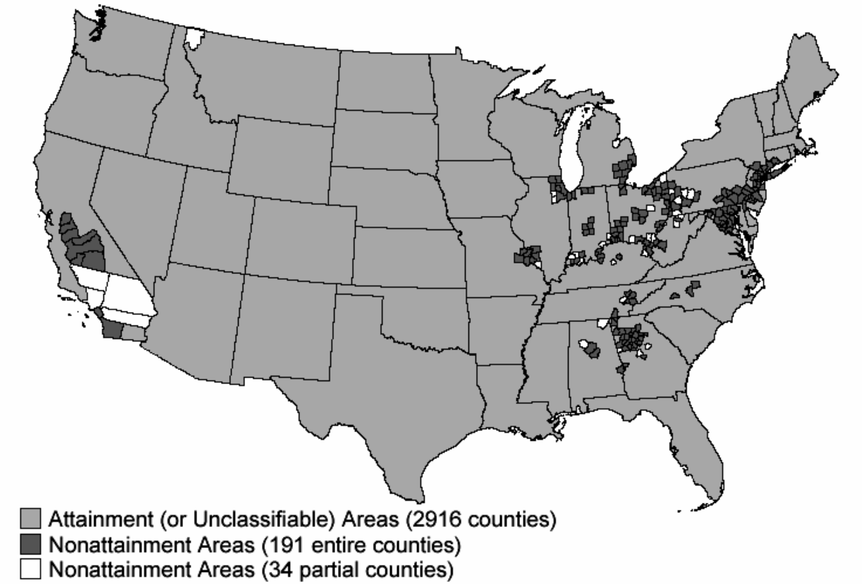


**FIGURE 3-4** Nonattainment areas for annual average $PM_{2.5}$ NAAQS. Source: EPA 2004l.

Unlike $O_3$, which is a single compound, PM is composed of multiple chemical components, and the $PM_{2.5}$ fraction displays more variability in its composition than does the $PM_{10}$ fraction. Figure 3-5 shows how this composition differs among different parts of the United States and among urban-scale and regional-scale monitors. Comparing Figure 3-5a and 3-5b shows that many of the urban sites contain a larger component of carbonaceous particles than the nonurban sites, probably due to more abundant primary emissions from traffic and fuel use. The exception is the large nonurban (and urban) carbon fraction in the Pacific Northwest due to extensive wildfires during the summer of 2002. Sulfate levels are much higher in the eastern United States than in the west, and the levels are similar at nearby urban and regional sites, consistent with a regional distribution. Nitrate constitutes a larger fraction of $PM_{2.5}$ in the west, especially in California. Sulfate and nitrate are usually found in the form of ammonium sulfate and ammonium nitrate, so ammonia emissions are also relevant to excessive $PM_{2.5}$ concentrations. Even though $SO_2$ and $NO_2$ NAAQS are largely attained, $SO_2$ and $NO_x$ emissions are relevant to $PM_{2.5}$, and further reductions are needed to attain the $PM_{2.5}$ NAAQS. Similarly, although VOCs and ammonia are not regulated by NAAQS,

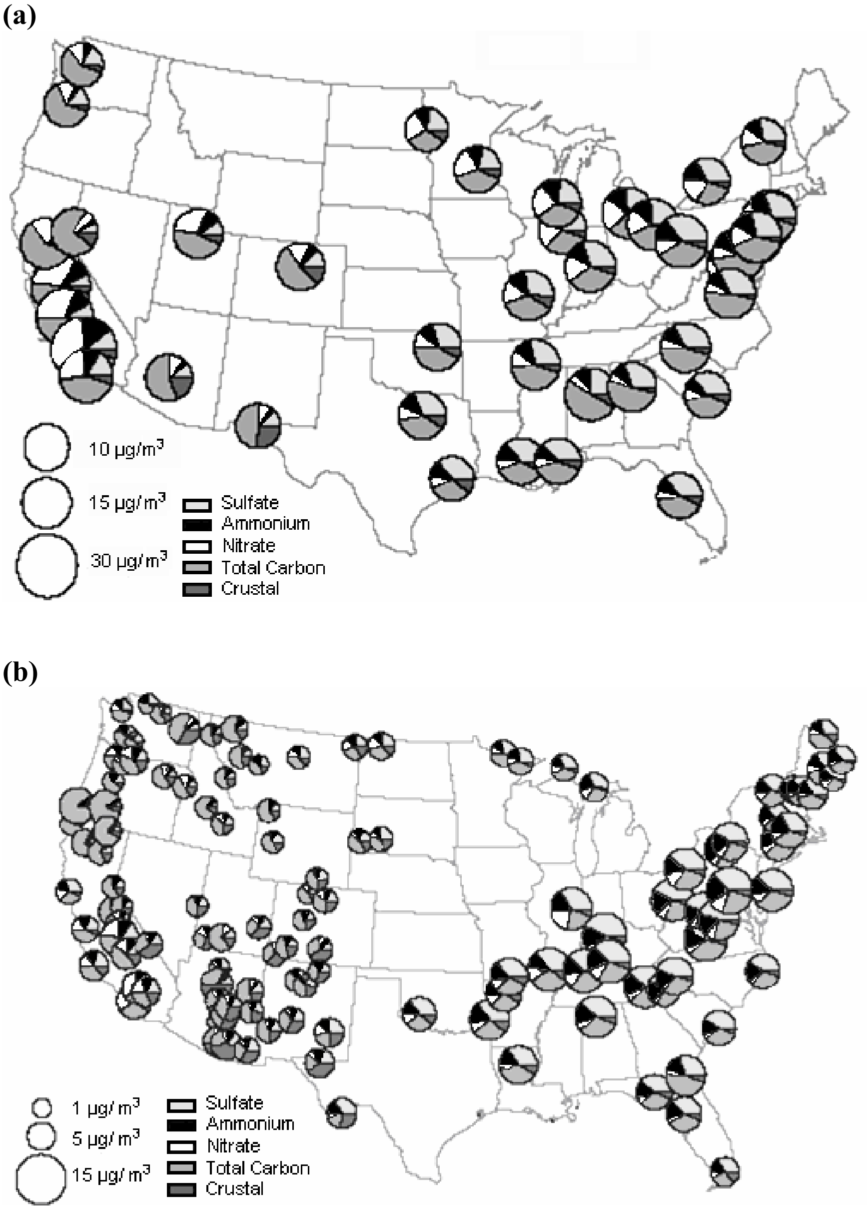


**FIGURE 3-5** 2002 annual average $PM_{2.5}$ chemical composition at (a) urban sites in EPA's Speciation Trends Network (STN) and (b) EPA's Interagency Monitoring of Protected Visual Environments (IMPROVE) network. Source: EPA 2003b.

VOCs are precursors of $PM_{2.5}$ and $O_3$, and ammonia is a precursor of $PM_{2.5}$. Therefore, their emissions must be considered as part of $PM_{2.5}$ and $O_3$ SIPs. Figure 3-6 shows the number of people in the United States who are exposed to exceedances of the NAAQS. More than half the U.S. population lives in counties that exceed the $O_3$, $PM_{2.5}$, or $PM_{10}$ NAAQS (see Figure 3-6).

## EMISSION SOURCES AND TRENDS

EPA prepares a national database of air emissions based on input from state and local air agencies, Indian tribes, and industry. The information is compiled and made available to the public as the National Emissions Inventory (NEI). Box 3-2 provides an overview of the NEI based on information from EPA's website (EPA 2004m).

In this section, the committee presents data from the EPA emissions inventory in relation to the air-quality issues presented earlier. The committee recognizes that the EPA emissions inventory data used in this report are under continual review and revision by the agency. However, the committee has made great efforts to present the most currently available information.

In general, the EPA inventory is based on data from states for major point-source emissions, whereas area and mobile source emissions are estimated by using surrogates such as fuel consumed, population density, vehicle-miles traveled, and land use. As noted in Box 3-2, EPA has developed a number of tools to ease the burden of states in estimating emissions for many source categories and to provide for the use of more uniform estimation methods across the country. For mobile and area sources, methods are used to simplify the process of estimating emissions by providing default emission factors and activity data. However, by necessity, these defaults tend to average out the local variations because they rely on the use of surrogates (e.g., household and population density, acres of farmland) available on a national basis to apportion the NEI.

In contrast, point source data, which rely on state or facility inputs for emission estimates, are considered more representative of the actual source emission characteristics than are the area- and mobile-source data discussed above. For some point sources, regulations require continuous emission monitoring (CEM) to document emissions. Therefore, the committee considers the point source data the most accurate of the emis-

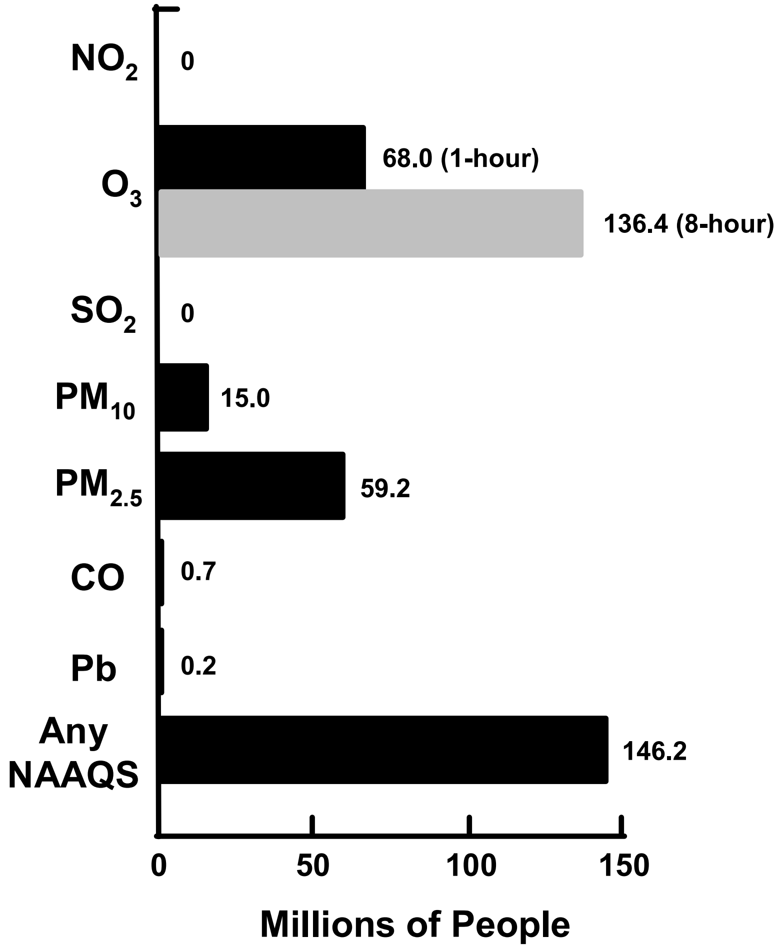


**FIGURE 3-6** Population exposure to pollutants in nonattainment areas. The people studied lived in counties with air-quality concentrations above the level of the NAAQS in 2002. The bar for $PM_{2.5}$ is based on EPA suggested nonattainment areas before designations were made. Source: EPA 2004n.

sions inventory categories, particularly for estimates of $NO_x$ and $SO_2$. In the absence of CEM data, states and facilities estimate emissions by multiplying emission factors (pounds per unit consumption) times an activity parameter (e.g., number of units consumed or produced). For example, a cement kiln might calculate its emissions by multiplying an emission factor for fuel oil by the amount of fuel consumed. A problem arises,

### BOX 3-2 National Emissions Inventory

The NEI database contains information on stationary and mobile sources that emit criteria air pollutants and their precursors as well as hazardous air pollutants (HAPs). The database includes estimates of annual emissions, by source, of air pollutants in each area of the country, on an annual basis. The NEI includes emission estimates for the following pollutants: carbon monoxide, nitrogen oxides, sulfur dioxide, particulate matter ($PM_{10}$ and $PM_{2.5}$), volatile organic compounds, and ammonia.

The NEI database defines three classes of criteria air pollutant sources:

— **Point Sources**: large stationary sources of emissions, such as an electric power plant, that can be identified by name and location. A major source emits a threshold amount (or more) of at least one criteria pollutant and must be inventoried and reported. Many states also inventory and report stationary sources that emit amounts below the thresholds for each pollutant.

— **Area sources**: small stationary sources, such as a home or office buildings, or a diffuse stationary source such as wildfires or agricultural tilling. These sources do not individually produce sufficient emissions to qualify as point sources. Dry cleaners are one example—a single dry cleaner within an inventory area typically will not qualify as a point source, but collectively the emissions from all the dry cleaning facilities in the inventory area may be significant and therefore must be included in the inventory.

— **Mobile sources**: any kind of vehicle or equipment with a gasoline or diesel engine, airplanes, or ships.

The main sources of criteria pollutant emissions data for the NEI are

— For electric generating units: EPA's Emission Tracking System/ Continuous Emissions Monitoring Data (ETS/CEM) and Department of Energy fuel-use data.

— For other large stationary sources: state data and older inventories where no state data were submitted.

— For on-road mobile sources: the Federal Highway Administration's (FHWA's) estimate of vehicle miles traveled and emission factors from EPA's MOBILE Model.

— For nonroad mobile sources: EPA's NONROAD Model.

— For stationary area sources: state data, EPA-developed estimates for some sources, and older inventories where no state or EPA data were submitted.

State and local environmental agencies supply most of the point source data. EPA's Clean Air Market program supplies emissions data for electric power plants. More information about the NEI database and the compilation of criteria pollutant and HAP emissions inventories, and links to the database, are available on the CHIEF NEI webpage (EPA 2004m).

however, from the difficulty in accounting for large emission spikes from stationary sources related to upsets, which are not captured in the average emission estimate for each source and may result in increased overall emissions (TNRCC 2003). The emission inventories developed from a compilation of various emission estimates are generally considered to have an uncertainty of about a factor of 2 or more (see NARSTO 2000), although the uncertainty factor is poorly defined (NRC 2004). A number of recent studies have aimed to quantify uncertainty in emission inventories for utility $NO_x$ emissions (e.g., Frey and Zheng 2002; Abdel-Aziz and Frey 2003a,b) and for hazardous air pollutants (e.g., Frey and Zhao 2004; Zhao and Frey 2004). The NRC and other organizations have often recommended that uncertainties in emission factors and inventories should be quantified in practice (e.g., NRC 2000; IPCC 2000).

EPA has been reporting emissions by source categories since the early 1970s (EPA 2004m). A variety of regulations controlling emission sources of pollution have been implemented over the past several decades and have been associated with declining emissions for some pollutants in some source categories. Because NSR is directed at large stationary sources, the focus is on these sources.

Figure 3-7 shows the trend of point source emissions since 1970 for $NO_x$, VOCs, $PM_{10}$, and $SO_2$. Point source $NO_x$ emissions have remained nearly constant over the last 30 years, with power-generating point sources dominating the emissions. Total point source $SO_2$ emissions have decreased over the last 30 years. Much of the early decreases in point source $SO_2$ emissions are the result of decreases in the metal smelting sector, whereas later decreases are due to reductions from the electric utility sector. Nevertheless, point sources remain a large fraction of $SO_2$ emissions, and point source emissions are responsible for a significant fraction of PM. $PM_{10}$ emissions declined substantially from 1970 to 1985 because of industrial emission controls; however, there have been no major changes since 1985. $PM_{2.5}$ has remained largely unchanged (not shown in the figure). VOC emissions declined over the last 30 years, for a variety of reasons (e.g., $O_3$ SIPs).

To examine the contributions of specific industries to total point source emissions (Figure 3-7), data by pollutant and by industry are presented below for 1999 (see Figures 3-8 through 3-11). For $PM_{2.5}$, about 50% of point source emissions is due to fuel combustion in the electric utility industry; is about 40% of point source emissions is due to coal combustion. Other important source categories include wood, pulp, and paper; metals; and mineral processing (Figure 3-8). Based on emissions data for 1999, point sources compose about 18% of $PM_{2.5}$ emissions and about 7% of $PM_{10}$ emissions (EPA 2003c). Primary $PM_{2.5}$ and $PM_{10}$ emissions compose a minor fraction (<10%) of measurable ambient PM concentrations (Chow and Watson 2002; EPA 2004o).

Point sources are important contributors to pollutants ($SO_2$, $NO_x$, and VOCs) that participate in the formation of secondary aerosols. For $SO_2$, 75% of point source emissions are attributable to coal combustion by the electric utility industry, with the remaining contributions due to fuel combustion from other industrial sources (Figure 3-9). In contrast, only about 50% of $NO_x$ point source emissions are due to coal combustion from electric utilities, with the remainder divided equally among other fuel combustion activities (Figure 3-10). In contrast to the predominance of fuel combustion activities for $NO_x$ and $SO_2$, point sources of VOCs are primarily attributable to petroleum and related industries, chemical manufacturing, and other industrial processes, including pulp and paper, food, rubber, and plastics manufacturing (Figure 3-11). VOC-derived organic aerosol may represent an important fraction of $PM_{2.5}$ in U.S. regions when photochemical transformation predominates (Cabada et al. 2004; Dechapanya et al. 2004). Individual VOCs can differ substantially in the rates at which they react in the atmosphere and the ef-

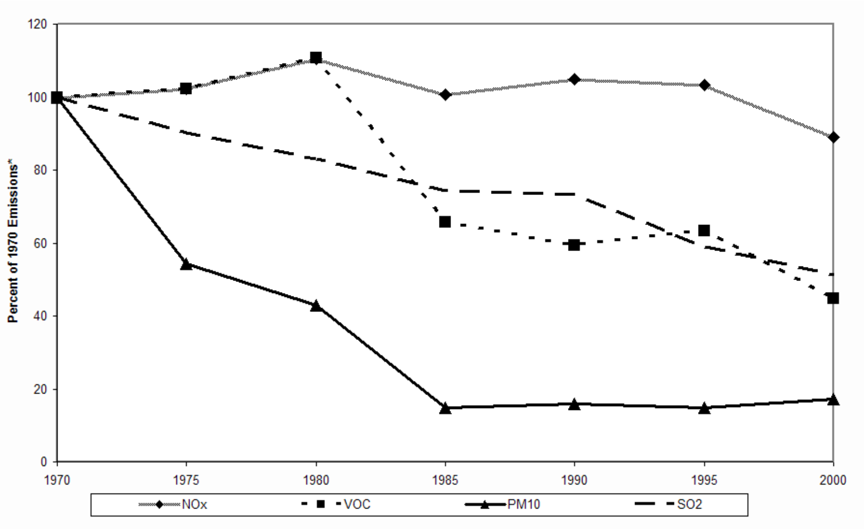
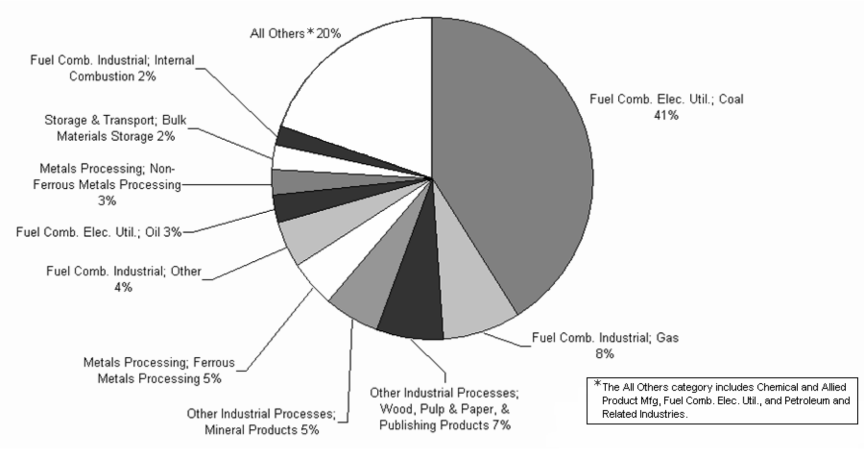
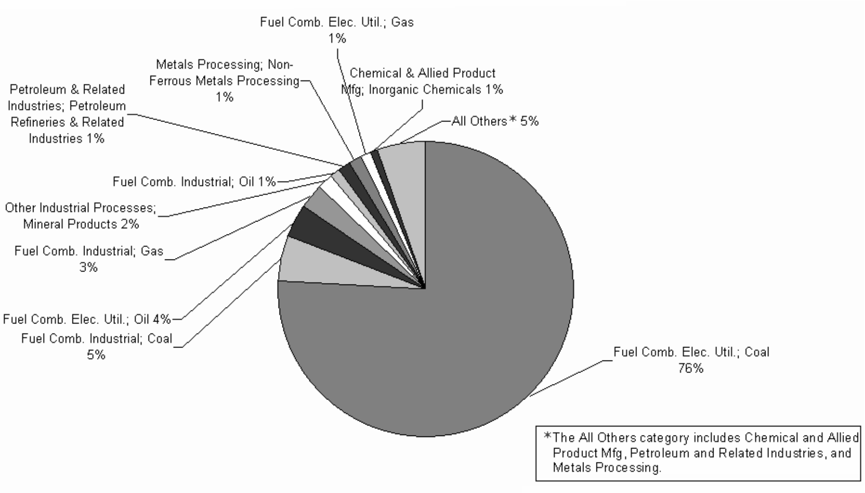


**FIGURE 3-7** Criteria pollutant emission trends for point sources. Source: Data from EPA 2004n.



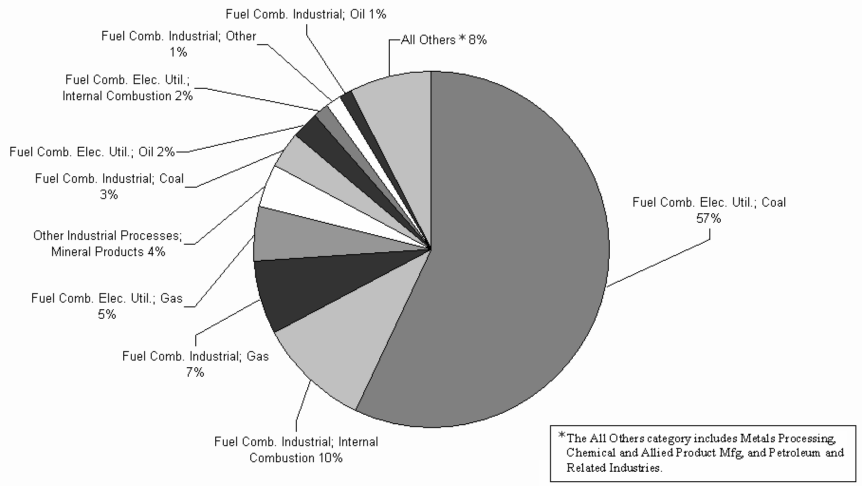
*The All Others category includes Chemical and Allied Product Mfg, Fuel Comb. Elec. Util., and Petroleum and Related Industries.

**FIGURE 3-8** Top 10 $PM_{2.5}$ point source emission categories (1999). Source: EPA 2003c.



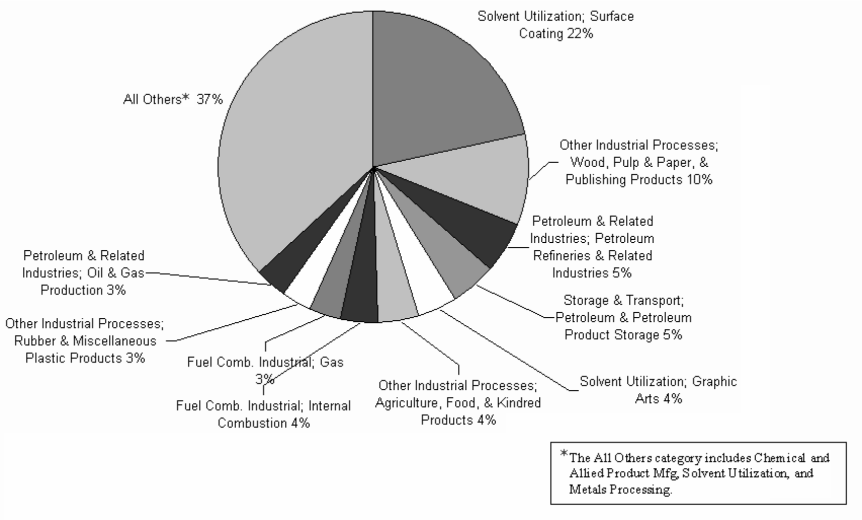
*The All Others category includes Chemical and Allied Product Mfg, Petroleum and Related Industries, and Metals Processing.

**FIGURE 3-9** Top 10 $SO_2$ point source emission categories (1999). Source: EPA 2003c.



*The All Others category includes Metals Processing, Chemical and Allied Product Mfg, and Petroleum and Related Industries.

**FIGURE 3-10** Top 10 $NO_x$ point source emission categories (1999). Source: EPA 2003c.



*The All Others category includes Chemical and Allied Product Mfg, Solvent Utilization, and Metals Processing.

**FIGURE 3-11** Top 10 VOC point source emission categories (1999). Source: EPA 2003c.

fects that they have on the formation of $O_3$ and PM (Carter 1994; Atkinson 2000; NARSTO 2004). Another important contributor to secondary aerosol formation is ammonia emissions. Nationally, point sources contribute only a minor fraction of ammonia emissions compared with agricultural sources (EPA 2004o).

Point source emissions are not evenly distributed across the United States. Large industrial sources are located on the periphery of urban areas and near convenient transport facilities or near their sources of raw materials. Figures 3-12 through 3-14 show the point source emissions of $SO_2$, $NO_x$, and VOCs by county across the United States overlaid on the nonattainment areas discussed previously.

As shown in Figure 3-12, $SO_2$ emissions from point sources are located predominantly in the eastern United States, with particularly high concentrations in the Ohio River Valley, in the southern Appalachians, and along the northeastern seaboard. $NO_x$ point sources also are predominantly observed in the eastern United States (Figure 3-13) and mirror the spatial pattern of $SO_2$ emissions, although there are fewer counties with major point sources of $NO_x$ emissions in the west. For VOCs (Figure 3-13), the pattern is completely different and is determined primarily by the location of petrochemical industries along major waterways—California, the Gulf Coast, the Eastern seaboard, the Great Lakes, and the Ohio River Valley.

As discussed earlier, sulfates, nitrates, and organics are important contributors to observed ambient particle concentrations. In viewing Figures 3-12, 3-13, and 3-14, it is apparent that PM and $O_3$ nonattainment areas are correlated with emissions of $SO_2$, $NO_x$, and VOCs. With respect to Figure 3-14, it is also important to note that organic materials compose a substantial component of observed aerosols. The VOC emissions, which are primary contributors to organic aerosols, may be associated with natural biogenic sources from non-point-source emissions but also may be due to VOC emissions from point sources as depicted in the NEI or from emissions not currently reflected in the point source VOC emission inventory.

As shown above, point sources contribute substantially to $NO_x$, $SO_2$, PM, and VOCs in areas of the United States that are experiencing air-quality concentrations at levels associated with adverse health effects. Therefore, it is important to assess which of the point sources are most affected by the NSR changes under review by this committee. Also, some point sources may not be subject to NSR requirements because of their relatively small size and location.

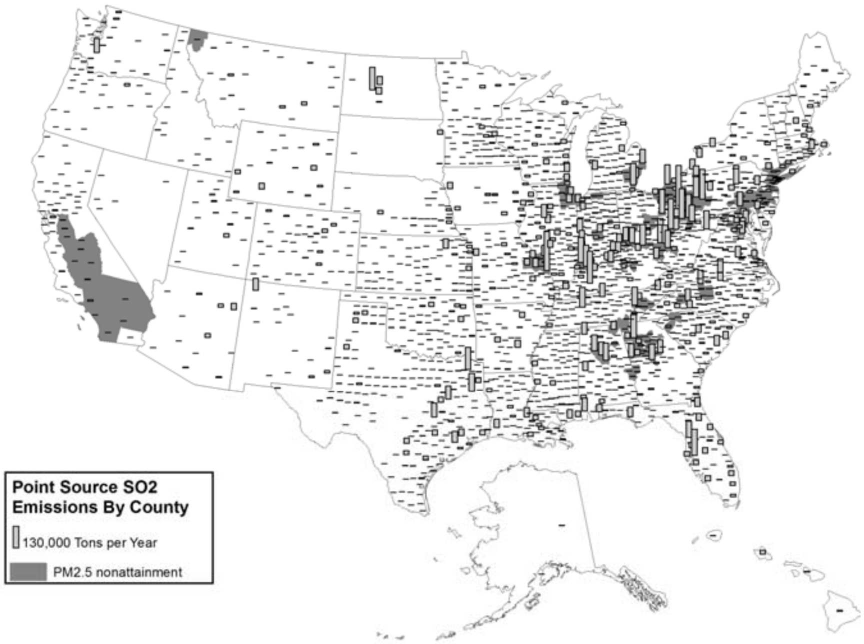


**FIGURE 3-12** Point source $SO_2$ emissions and $PM_{2.5}$ nonattainment, 1999. Nonattainment areas are EPA suggested and not final. Point source emission inventory date, 1999. Sources: AirData 2004; EPA 2004l. Map drawn by Sean M. Raffuse, Sonoma Technology, Inc.

## VINTAGES OF EMISSION SOURCES

Information on vintages of different facilities within most of the major NSR-affected industries is difficult to obtain.[6] Linking these emissions data to information about vintage is difficult to do without access to the facility-level information from the U.S. Census.

The one industry for which vintage data are more readily available and linkable to the emission data is the electricity sector. Data on vintage are collected and maintained by the U.S. Energy Information

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[6] The U.S. Census Bureau does have information on construction dates in its facility-level databases for manufacturing sectors (SIC codes 20-39), but these data are not available to the general public and access to the databases is costly and involves obtaining security clearance.

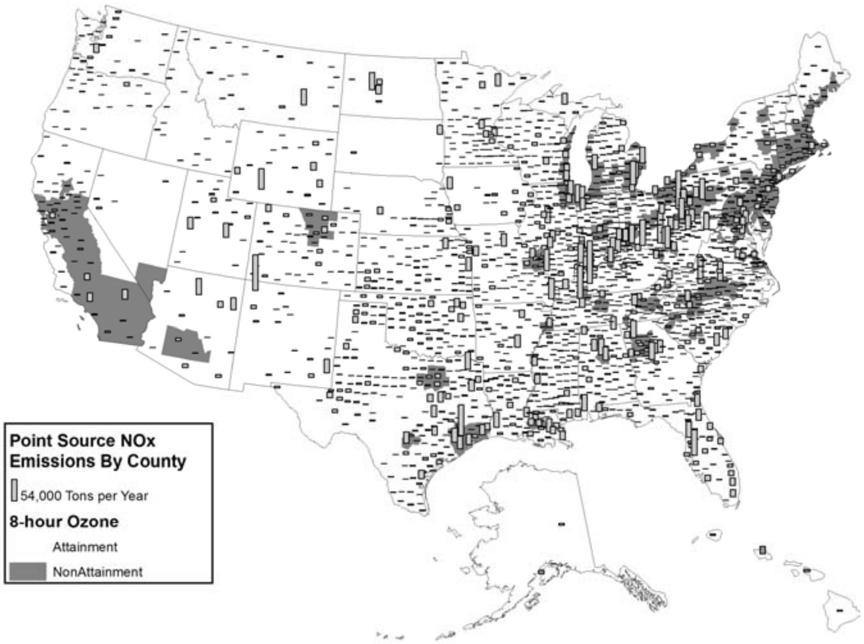


**FIGURE 3-13** Point source $NO_x$ emissions and 8-hour ozone nonattainment, 1999. Nonattainment areas effective date May 2004. Point source emission inventory date 1999. Sources: AirData 2004, EPA 2004j. Map drawn by Sean M. Raffuse, Sonoma Technology, Inc.

Administration (EIA) and emissions data are available from the EPA's CEM database. Table 3-3a and 3-3b provides summaries of $NO_x$ and $SO_2$ emission rates, respectively, from coal-fired generators in 2002 by vintage of generating unit, where vintage is assigned based on the year that a power plant came into service. The table also provides information on how much each vintage class (with classes arranged by decade) contributed to both total generation and total capacity of coal-fired generation in 2002. The $SO_2$ table (Table 3-3b) includes information on average capacity factor (actual generation divided by potential generation) of generators by vintage and the average heat rate (British thermal units of heat input from fuel combustion per kilowatt hour of electricity generated) for generators within each vintage class.

Table 3-3a and 3-3b clearly shows that older facilities have higher emission rates than newer facilities, and older facilities tend to contribute more to total emissions than they do to total electricity generation from coal units. Older generators also have lower capacity factors than newer

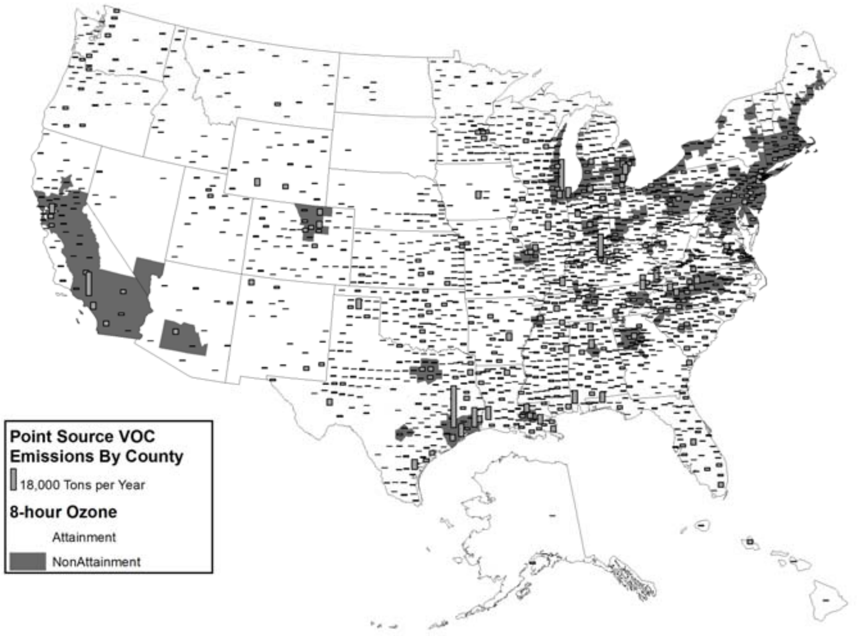
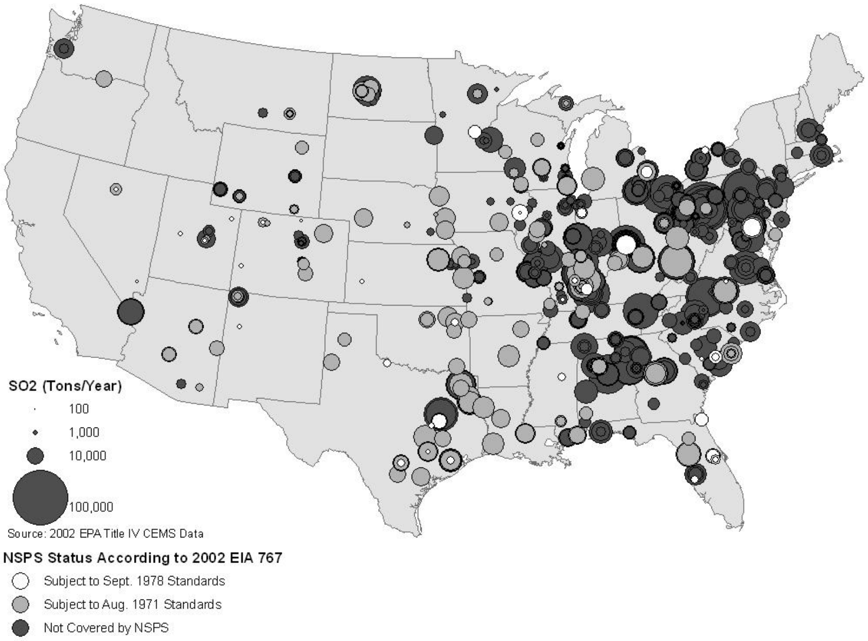


**FIGURE 3-14** Point source VOC emissions and 8-hour ozone nonattainment, 1999. Nonattainment areas effective date May 2004. Point source emission inventory date 1999. Source: AirData 2004; EPA 2004j. Map drawn by Sean M. Raffuse, Sonoma Technology, Inc.

generators, which are run more often. The data also show that, with perhaps one exception, heat rates are lower for newer power generators than they are for older units. This piece of data needs to be interpreted with caution because older generators have lower capacity factors than newer generators and, if those generators were operated more, their average heat rates likely would be lower. There is a selection bias in the data whereby the generators with lower heat rates of any vintage typically are the ones that are operated more.

Table 3-3c and 3-3d displays the same data organized a different way. Coal-fired generating units are classified by a New Source Performance Standards (NSPS) category according to information from EIA Form 767 for 2002 (EIA 2004a). Most of the capacity and generation falls into the category that is not subject to NSPS standards. Generators in this category typically have much higher $SO_2$ and $NO_x$ emission rates (in units of pounds of pollutant per megawatt-hour of electricity generated) than generators that were permitted under the NSPS standards that



Source: 2002 EPA Title IV CEMS Data

**FIGURE 3-15** 2002 $SO_2$ emissions for utility-scale coal-fired generators that operated in 2002. Source: EIA 2004a; EPA 2004p. Map drawn by Sean M. Raffuse, Sonoma Technology, Inc.

came into effect in 1971. The generators in the post-1978-standard category have substantially lower $SO_2$ emission rates than those subject to earlier standards but $NO_x$ emission rates virtually identical to the earlier group, reflecting the fact that new source standards for $NO_x$ did not change much in 1978 (Burtraw and Evans 2004). Note that NSPS regime depends on when construction was started, whereas the vintages in Tables 3-3a and 3-3b are determined by when a generator comes into service.

Figures 3-15 and 3-16 show the annual emissions of $SO_2$ and $NO_x$, respectively, in 2002 from generating facilities categorized by NSPS status according to the EIA 767 data. The coal`-fired generating units not covered by NSPS are located predominantly in the eastern United States, with large concentrations in Pennsylvania and Ohio, upwind of major East Coast population centers, and with other clusters in Kentucky, southern Illinois and Indiana, the Carolinas, and Alabama. These units tend to have higher annual emission rates of $SO_2$ than plants permitted under the 1971 and 1978 NSPS standards. There is less variation in total

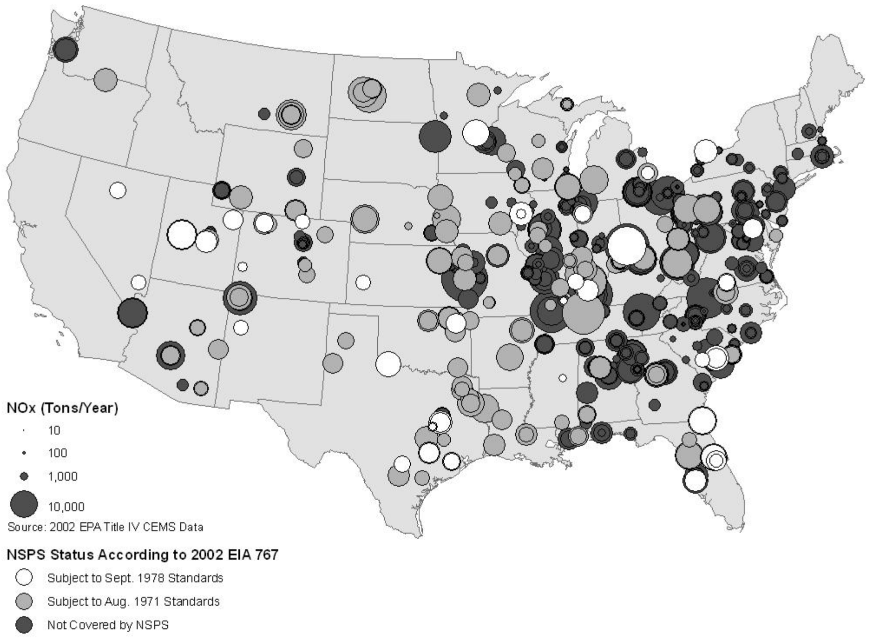


**FIGURE 3-16** 2002 $NO_x$ emissions for utility-scale coal-fired generators that operated in 2002. Source: EIA 2004a; EPA 2004p. Map drawn by Sean M. Raffuse, Sonoma Technology, Inc.

annual emissions of $NO_x$ across the different categories of NSPS status, which is consistent with the smaller differences in average $NO_x$ emission rates across these different classes of generating units. Most of the emitting units are in the east, but new units can have total annual emissions as high as older units, reflecting in part the higher capacity factors at the newer units. Geographic concentrations of $NO_x$ emissions typically are found in the same locations as they are for emissions of $SO_2$.

## SUMMARY

The committee draws the following conclusions:

- Large stationary sources (point sources) are substantial emitters of $NO_x$, $SO_2$, and VOCs into areas of the United States that are experiencing concentrations of criteria pollutants at levels associated with an increased risk of adverse health effects. Because large stationary sources are not distributed evenly throughout the United States and because many different industries contribute to stationary source emissions, it is important to assess a variety of types and locations of large stationary sources that are affected by the NSR changes. The age of the facilities may be an important consideration because older facilities are more likely than newer facilities to undergo maintenance, repair, and replacement of key components.

- Because of the long-range transport of some pollutants, important emission sources may be far from the locations where measured pollutant concentrations exceed the NAAQS. Thus, for areas experiencing higher ambient concentrations of pollutants, such as fine PM and $O_3$, controlling emissions of those pollutants and their precursors is typically a regional, often multistate, problem not a local one.
- Data presented from electricity-generating facilities (coal plants) show that older facilities have higher emission rates than newer facilities, and older facilities tend to contribute proportionately more to total emissions than they contribute to total electricity generation.

Although this chapter broadly describes the connection between emissions and health effects, in many places, it relies on incomplete data about the consequences of air pollution, its causes, and the specific contributions that can be attributed to individual sources. The approaches needed to address these areas of uncertainty will be developed further as the committee goes forward with its charge.

**TABLE 3-3** Emissions from Coal-Fired Electricity Generation by Vintage

**a)** 2002 $NO_x$ Emissions and Share of Generation of Coal-Fired Capacity by Vintage

| Power Plant Vintage | Avg. $NO_x$ Emission Rate (lb/MWh) | % Total $NO_x$ Emitted | % of Coal-Fired Electricity Generation | % of $NO_x$ Emitted per % of Electricity Generated[a] | % of Coal-Fired Electricity Capacity |
|---|---|---|---|---|---|
| Pre-1950 | 5.51 | 0.65 | 0.50 | 1.31 | 0.92 |
| 1950-1959 | 5.07 | 15.11 | 12.56 | 1.20 | 14.32 |
| 1960-1969 | 4.56 | 21.27 | 19.65 | 1.08 | 20.51 |
| 1970-1979 | 4.28 | 39.31 | 38.76 | 1.01 | 38.13 |
| 1980-1989 | 3.53 | 21.74 | 25.97 | 0.84 | 23.84 |
| Post-1990 | 3.15 | 1.92 | 2.56 | 0.75 | 2.27 |

**b)** 2002 $SO_2$ Emissions and Performance of Coal-Fired Capacity by Vintage

| Power Plant Vintage | Avg. $SO_2$ Emission Rate (lb/MWh) | % of Total $SO_2$ Emitted | % of Coal-Fired Electricity Generation | % of $SO_2$ Emitted per % of Electricity Generated[a] | Average Capacity Factor (%)[b] | Average Heat Rate (Btu/kWh generated) |
|---|---|---|---|---|---|---|
| Pre-1950 | 20.58 | 1.02 | 0.50 | 2.04 | 36.35 | 12,549 |
| 1950-1959 | 15.78 | 19.64 | 12.56 | 1.56 | 58.93 | 10,668 |
| 1960-1969 | 13.92 | 27.12 | 19.65 | 1.38 | 64.37 | 10,150 |
| 1970-1979 | 9.31 | 35.75 | 38.76 | 0.92 | 68.29 | 10,270 |
| 1980-1989 | 6.02 | 15.49 | 25.97 | 0.60 | 73.17 | 10,401 |
| Post-1990 | 3.88 | 0.98 | 2.56 | 0.38 | 75.80 | 9,982 |

**c)** 2002 $NO_x$ Emissions and Share of Generation of Coal-Fired Capacity by NSPS Standard[c]

| NSPS Status According to EIA 767 | Avg. $NO_x$ Emission Rate (lb/MWh) | % Total $NO_x$ Emitted | % of Coal-Fired Electricity Generation | % of $NO_x$ Emitted per % of Electricity Generated[a] | % of Coal-Fired Electricity Capacity |
|---|---|---|---|---|---|
| Unknown | 2.93 | 0.16 | 0.23 | 0.69 | 0.27 |
| Not Affected by NSPS | 4.67 | 65.90 | 59.51 | 1.11 | 62.62 |
| Subject to Aug. 1971 Standards (D) | 3.57 | 26.73 | 31.58 | 0.85 | 29.56 |
| Subject to Sept. 1978 Standards (Da) | 3.50 | 7.21 | 8.68 | 0.83 | 7.56 |

**d)** 2002 $SO_2$ Emissions and Performance of Coal-Fired Capacity by NSPS Standard[c]

| NSPS Status According to EIA 767 | Avg. $SO_2$ Emission Rate (lb/MWh) | % of Total $SO_2$ Emitted | % of Coal-Fired Electricity Generation | % of $SO_2$ Emitted per % of Electricity Generated[a] | Avg. Capacity Factor[b] (%) | Average Heat Rate (Btu/kWh generated) |
|---|---|---|---|---|---|---|
| Unknown | 4.56 | 0.10 | 0.23 | 0.45 | 56.58 | 11,247 |
| Not Covered by NSPS | 12.93 | 76.25 | 59.51 | 1.28 | 63.85 | 10,250 |
| Subject to Aug. 1971 Standards (D) | 6.66 | 20.86 | 31.58 | 0.66 | 71.79 | 10,519 |
| Subject to Sept. 1978 Standards (Da) | 3.23 | 2.78 | 8.68 | 0.32 | 77.17 | 10,185 |

[a] If the generators of a particular vintage (or in a particular NSPS category) emitted a particular pollutant in proportion to its share of total electricity generation, the value would be 1.

[b] Capacity factor of units that operated that are strictly associated with boilers in CEMS database.

[c] The Subpart D standards are those that apply to fossil-fuel-fired steam boilers for which construction began after August 17, 1971. The Subpart Da standards affect those boilers that began construction after September 18, 1978. For those boilers not covered by NSPS construction commenced before August 17, 1971.

Notes: All quantities, including percentages of emissions and generation capacity, are calculated with reference only to coal-fired generating units. Percentages (taking account of rounding) add to 100% because other types of generating capacity are not considered.

These tables and the associated data set were constructed by David Evans of Resources for the Future. Data used to make these tables come from three sources; emissions data are from EPA's Continuous Emissions Monitoring System Database; generation and capacity data are from the EIA's 767 data set; and information on vintage of generating units is from the EIA's 860 data set.

Abbreviations: EIA, Energy Information Agency; Btu/kWh, British thermal unit per kilowatt-hour; lb/MWh, pound per megawatt-hour.

Source: EIA 2004a,b; EPA 2004p.

# 4

# Emission Sources and Technology Options

## INTRODUCTION

The purpose of this chapter is to address the following key questions:

- What source categories account for the greatest permitting activity pertaining to modifications under New Source Review (NSR)?
- Are modifications an important part of all NSR permitting?
- What kinds of repairs and replacements are most often done in these industries?
- What are the typical technology options or considerations for these source categories?

The answers to these questions provide insight into the emissions, energy use, and other implications of technological choices regarding preventative measures, repairs, and replacements. In this chapter, we use language that implies the colloquial meaning, as opposed to the "legal" terminology of "maintenance" and "modification" as these terms are used in NSR permitting. It is common jargon in many industries to refer to repair and replacement activities as maintenance (in a nonlegal sense) and for maintenance costs to be considered a routine part of the annual operating cost of a facility. To avoid confusion with legal terminology, in this chapter we use the terms "repair" and "replacement" instead of maintenance and modification.

The main focus here in terms of pollutants is on criteria pollutants, especially sulfur dioxide ($SO_2$) and oxides of nitrogen ($NO_x$) but also including carbon monoxide (CO), particulate matter (PM) with an aerodynamic diameter smaller than about 10 micrometers (µm) ($PM_{10}$), and PM with an aerodynamic diameter smaller than about 2.5 µm ($PM_{2.5}$). An ozone precursor of volatile organic compounds (VOCs) is also included.

With respect to identifying technology options, the focus here is on the current status of emission-source technologies and current options for repair and replacement. However, because technology changes over time, explicit consideration is given to the process of technology change and the implications for technology change in the future. Furthermore, we consider both pollution control and pollution prevention technologies. Typically, “pollution control” refers to “end-of-pipe” techniques for removing pollutants from an exhaust gas after the pollutants have been formed in an upstream process. For example, in a coal-fired power plant, pollutants such as $NO_x$, $SO_2$, and PM are formed during combustion. Postcombustion control technologies such as selective catalytic reduction, fuel gas desulfurization, and electrostatic precipitation, respectively, can be used to reduce or capture these pollutants. In contrast, pollution prevention approaches are aimed at reducing or eliminating sources of pollution, typically through feedstock substitutions or process alterations. For example, in the case of a coal-fired power plant, methods that more carefully control and stage mixing of fuel and air can prevent the formation of a portion of $NO_x$ that otherwise would have been created. As another example, evaporative VOC emissions can be prevented by substituting water-based solvents for VOC-based solvents used at a manufacturing facility. A way to evaluate the effect of pollution prevention measures is to compare emissions and energy use with those of a more traditional feedstock or facility design.

In addition, cost is always a consideration when evaluating and choosing options for repair and replacement. Therefore, cost implications of alternatives for repair and replacement are summarized.

## OVERVIEW OF NSR PERMITS

The purpose of this section is to identify and evaluate the frequency of NSR permitting activity with respect to industrial categories for the purpose of determining which emission sources represent the highest priority for assessment. However, a substantial challenge is that there is not a readily available database that summarizes NSR permitting activity. For example, an EPA database[1] (EPA2004q) containing case-specific information on best available control technology (BACT)/lowest achievable emission rate (LAER) does not readily distinguish among permits for new sources versus permits for modifications. In principle, such data could be obtained individually from each state. However, the availability of such data varies among states. Thus, the approach taken here, as a first step, was to request a summary of permitting data from the EPA (see Table 4-1) and to supplement the summary with data from several states. The data EPA has provided to the committee in this table are preliminary, unpublished, not subjected to review, and not distributed outside of EPA. These data are based on information collected internally by EPA from its regional offices, that were obtained from state and local permitting authorities. These data were summarized by EPA for the committee in terms of the NSR permitted emissions (in tons) by the two-digit Standard Industrial Classification (SIC) code, as well as by the number of permits. Permits were categorized as "greenfield," new at existing sources, and modifications. The main focus here is on modifications. These data do not include information regarding facilities that made modifications but did not obtain permits via the NSR programs. Although the information presented in the table is sorted by pollutant, it is possible for a modification to involve more than one pollutant.

For $NO_x$, the largest share of modification permits is for SIC type 49 (electric, gas, and sanitary services), in terms of both the number of permits and the NSR permitted emissions. SIC type 49 includes utility power plants of all types, and most of the permits and permitted emissions were for SIC code 4911, electric utilities. SIC types 32 (stone, clay, and products) and 26 (paper and allied products) also had a significant share of the reported NSR permitted emissions for modifications, although the number of permits for these SIC types was substantially fewer than for SIC type 49. For SIC type 32, the most significant source category was SIC code 3241, hydraulic cement. Pulp mills (SIC code 2611) were the most commonly permitted source for modifications under SIC type 26. $NO_x$ emission sources at these types of facilities are typically industrial or utility furnaces but can include a variety of other combustion-based sources such as heaters, kilns, ovens, and others.

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[1] The database is referred to as the "RACT/BACT/LAER clearinghouse." RACT means reasonably available control technology.

For $SO_2$, the key emission-source category in terms of number of modification permits and NSR permitted emissions for modifications is SIC type 49 (electric, gas, and sanitary services), for which SIC code 4911 (electric utilities) was the most significant subcategory. However, other source categories with significant totals for NSR permitted emissions for modifications include SIC type 28 (chemicals and allied products, particularly industrial inorganic chemicals and phosphatic fertilizers), SIC type 32 (stone, clay, and products, particularly hydraulic cement), and SIC type 26 (paper and allied products, particularly pulp, paper, and paperboard mills). $SO_2$ emissions typically are associated either with combustion of sulfur-bearing fuels or with processing of sulfur-bearing feedstocks or ores (e.g., crude oil, metal ores).

For CO, the largest number of permits for modifications was issued to SIC type 49, which includes electric, gas, and sanitary services[2], and SIC type 33, which includes primary metal industries. With respect to NSR permitted emissions for modifications, the largest categories (in descending order) were SIC type 26, paper and allied products (primarily paperboard mills); SIC type 32, stone, clay, and glass products (primarily hydraulic cement and concrete block and brick); SIC type 33, primary metal industries; SIC type 20, food and kindred products (primarily cane sugar); and SIC type 49, electric, gas, and sanitary services (primarily electric utilities).

For PM, the highest frequency of NSR permits for modifications was for SIC types 49 (electric, gas, and sanitary services) and 33 (primary metal industries). Although both of these SIC types also contributed significantly to the NSR permitted emissions for modifications, these emissions are widely distributed among six categories. Other categories include SIC types 28 (chemical and allied products, primarily including carbon black, phosphatic fertilizers, and industrial organic chemicals), 26 (paper and allied products, primarily including paperboard mills, pulp mills, and coated and laminated paper), and 20 (food and kindred products, primarily cane sugar).

For VOCs, the highest frequency of permits for modifications was for SIC types 49 (electric, gas, and sanitary services), 33 (primary metal

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[2] This group includes establishments primarily engaged in the generation, transmission, and/or distribution of electricity or gas or steam. It also includes irrigation systems and sanitary systems involved in the collection and disposal of garbage, sewage, and other wastes.

**TABLE 4-1** Summary of Estimated Number of Permits and Permitted Emissions Under New Source Review for Greenfield Facilities, New Facilities at Existing Locations, and Modifications, During 1977-1999

| | | Number of Permits | | | | NSR Permitted Emissions (tons) | | |
|---|---|---|---|---|---|---|---|---|
| SIC | SIC Type | Greenfield | New at Existing Location | Modifica-tions | Number of Permits by SIC | Greenfield | New at Existing Location | Modifica-tions |
| | | | | CO | | | | |
| 10 | Metal mining | 0 | 2 | 0 | 2 | — | 1,831 | - |
| 12 | Coal mining | 0 | 0 | 2 | 2 | — | — | 3,696 |
| 13 | Oil and gas extraction | 3 | 3 | 3 | 9 | 3,047 | 1,286 | 253 |
| 14 | Nonmetallic minerals except fuels | 0 | 4 | 0 | 4 | — | 2,020 | — |
| 20 | Food and kindred products | 1 | 7 | 6[b] | 14 | 135 | 7,029 | 16,366 |
| 24 | Lumber and wood products | 0 | 3 | 6 | 9 | 0 | 797 | 2,953 |
| 26 | Paper and allied products | 1 | 10 | 7[b] | 18 | 215 | 18,691 | 24,878 |
| 27 | Printing and publishing | 1 | 0 | 0 | 1 | 15 | — | — |
| 28 | Chemicals and allied products | 0 | 12[b] | 5 | 17 | — | 1,896 | 7,699 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 29 | Petroleum and coal products | 0 | 4 | 5 | 9 | — | 1,070 | 2,033 |
| 32 | Stone, clay, and glass products | 3 | 16 | 6 | 25 | 15,198 | 19,456 | 18,001 |
| 33 | Primary metal industries | 2 | 11 | 17 | 30 | 3,880 | 16,987 | 17,084 |
| 49 | Electric, gas, and sanitary services | 114 | 96[b] | 38[b] | 248 | 88,743 | 51,365 | 15,890 |
| 51 | Wholesale trade—nondurable goods | 0 | 1 | 0 | 1 | — | 55 | — |
| 82 | Educational services | 0 | 1 | 0 | 1 | — | 170 | — |
| 96 | National security and intl. affairs | 0 | 1 | 0 | 1 | — | NA | — |
| Total tons | | 125 | 171 | 95 | 391 | 111,233 | 122,653 | 108,853 |
| | | | | PM | | | | |
| 10 | Metal mining | 0 | 1 | 0 | 1 | 0 | 35 | 0 |
| 12 | Coal mining | 0 | 0 | 3 | 3 | 0 | 0 | 505 |
| 13 | Oil and gas extraction | 2 | 2 | 0 | 4 | 423 | 45 | 0 |
| 14 | Nonmetallic minerals except fuels | 0 | 4 | 0 | 4 | 0 | 314 | 0 |
| 20 | Food and kindred products | 1 | 12[b] | 8 | 21 | 41 | 2,171 | 2,204 |

**TABLE 4-1** *(Continued)*

| | | Number of Permits | | | | NSR Permitted Emissions (tons) | | |
|---|---|---|---|---|---|---|---|---|
| SIC | SIC Type | Greenfield | New at Existing Location | Modifica-tions | Number of Permits by SIC | Greenfield | New at Existing Location | Modifica-tions |
| | | | | PM *(Continued)* | | | | |
| 24 | Lumber and wood products | 1 | 7 | 11 | 19 | 9 | 834 | 1,101 |
| 25 | Furniture and fixtures | 0 | 1 | 0 | 1 | 0 | 11 | 0 |
| 26 | Paper and allied products | 1 | 12 | 10[b] | 24 | 46 | 2,121 | 3,047 |
| 27 | Printing and publishing | 1 | 0 | 0 | 1 | 14 | 0 | 0 |
| 28 | Chemicals and allied products | 1 | 18 | 12[b] | 31 | 14 | 1,002 | 3,402 |
| 29 | Petroleum and coal products | 0 | 4 | 7 | 11 | 0 | 264 | 454 |
| 30 | Rubber and misc. plastics products | 0 | 0 | 1 | 1 | 0 | 0 | 6 |
| 32 | Stone, clay, and glass products | 3 | 23 | 8 | 34 | 1,278 | 4,899 | 2,569 |
| 33 | Primary metal industries | 2 | 16 | 24[b] | 42 | 352 | 1,493 | 1,437 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 34 | Fabricated metal products | 0 | 0 | 1 | 1 | 0 | 0 | 7 |
| 37 | Transportation equipment | 0 | 0 | 2 | 2 | 0 | 0 | 17 |
| 49 | Electric, gas, and sanitary services | 95 | 67[b] | 30 | 192 | 17,548 | 9,659 | 2,580 |
| 51 | Educational services | 0 | 1 | 0 | 1 | 0 | 77 | 0 |
| 97 | National security and intl. affairs | 0 | 0 | 1 | 1 | 2 | 0 | 18 |
| Total tons | | 107 | 168 | 118 | 393 | 19,727 | 22,925 | 17,347 |
| | | | | $NO_x$ | | | | |
| 10 | Metal mining | 0 | 2 | 1 | 3 | 0 | 26,179 | 4,765 |
| 12 | Coal mining | 0 | 2 | 0 | 2 | 0 | 0 | 1,506 |
| 13 | Oil and gas extraction | 3 | 3 | 3 | 9 | 5,959 | 3,861 | 60 |
| 14 | Nonmetallic minerals except fuels | 0 | 4 | 0 | 4 | 0 | 1,136 | 0 |
| 20 | Food and kindred products | 1 | 9 | 7b | 14 | 75 | 6,706 | 2,028 |
| 24 | Lumber and wood products | 0 | 3 | 6 | 9 | 0 | 510 | 1,168 |
| 26 | Paper and allied products | 1 | 12 | 8 | 20 | 129 | 7,398 | 10,021 |

**TABLE 4-1** *(Continued)*

| SIC | SIC Type | Number of Permits |  |  | Number of Permits by SIC | NSR Premitted Emissions (tons) |  |  |
|---|---|---|---|---|---|---|---|---|
|  |  | Greenfield | New at Existing Location | Modifications |  | Greenfield | New at Existing Location | Modifications |
|  |  |  |  | NO$_x$ *(Continued)* |  |  |  |  |
| 27 | Printing and publishing | 0 | 0 | 1 | 1 | 90 | 0 | 0 |
| 28 | Chemicals and allied products | 1 | 17 | 7 | 26 | 186 | 3,841 | 1,776 |
| 29 | Petroleum and coal products | 0 | 7 | 6 | 13 | 0 | 2,381 | 2,989 |
| 30 | Rubber and misc. plastics products | 0 | 1 | 0 | 1 | 0 | 33 | 0 |
| 32 | Stone, clay, and glass products | 3 | 18 | 8 | 31 | 9,388 | 27,842 | 20,479 |
| 33 | Primary metal industries | 1 | 13 | 13[b] | 26 | 406 | 5,031 | 2,842 |
| 36 | Electronic and electric equipment | 0 | 1 | 0 | 1 | 0 | 18 | 0 |
| 37 | Transportation equipment | 1 | 2 | 0 | 3 | 2 | 1,080 | 0 |
| 46 | Pipelines except natural gas | 1 | 0 | 0 | 1 | 353 | 0 | 0 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 49 | Electric, gas, and sanitary services | 125 | 97[b] | 46 | 299 | 91,280 | 28,496 | 26,228 |
| 51 | Wholesale trade—nondurable goods | 0 | 1 | 0 | 1 | 0 | 434 | 0 |
| 82 | Educational services | 0 | 1 | 0 | 1 | 0 | 88 | 0 |
| 97 | National security and intl. affairs | 0 | 0 | 1 | 1 | 0 | 0 | 650 |
| Total (tons) | | 137 | 193 | 107 | 437 | 107,868 | 115,034 | 74,512 |
| | | | | $SO_2$ | | | | |
| 10 | Metal mining | 0 | 1 | 0 | 1 | 0 | 37 | 0 |
| 12 | Coal mining | 0 | 0 | 2 | 2 | 0 | 0 | 2,221 |
| 13 | Oil and gas extraction | 3 | 3 | 0 | 6 | 2,232 | 1,294 | 0 |
| 14 | Nonmetallic minerals except fuels | 0 | 2 | 0 | 2 | 0 | 640 | 0 |
| 20 | Food and kindred products | 2 | 8 | 6 | 16 | 80 | 26,272 | 5,494 |
| 24 | Lumber and wood products | 0 | 0 | 1 | 1 | 0 | 0 | 20 |
| 26 | Paper and allied products | 0 | 9 | 9 | 18 | 0 | 3,978 | 12,634 |
| 27 | Printing and publishing | 1 | 0 | 0 | 1 | 5 | 0 | 0 |

**TABLE 4-1** *(Continued)*

| SIC | SIC Type | Number of Permits |  |  | Number of Permits by SIC | NSR Permitted Emissions (tons) |  |  |
|---|---|---|---|---|---|---|---|---|
|  |  | Greenfield | New at Existing Location | Modifications |  | Greenfield | New at Existing Location | Modifications |
|  |  | $SO_2$ *(Continued)* |  |  |  |  |  |  |
| 28 | Chemicals and allied products | 0 | 9[b] | 6 | 15 | 0 | 12,299 | 22,206 |
| 29 | Petroleum and coal products | 0 | 3 | 3 | 6 | 0 | 928 | 2,368 |
| 32 | Stone, clay, and glass products | 3 | 17 | 7 | 27 | 3,155 | 8,104 | 20,290 |
| 33 | Primary metal industries | 0 | 8 | 8 | 16 | 791 | 3,580 | 1,224 |
| 37 | Transportation equipment | 0 | 1 | 0 | 1 | 0 | 40 | 0 |
| 49 | Electric, gas, and sanitary services | 57 | 47 | 19 | 123 | 29,116 | 4,012 | 24,541 |
| 51 | Wholesale trade—nondurable goods | 0 | 1 | 0 | 1 | 0 | 787 | 0 |
| 82 | Educational services | 0 | 1 | 0 | 1 | 0 | 37 | 122 |
| 97 | National security and intl. affairs | 0 | 0 | 1 | 1 | 0 | 0 | 0 |
| Total tons |  | 66 | 110 | 62 | 238 | 35,379 | 62,008 | 91,120 |

| VOC | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 10 | Metal mining | 0 | 2 | 0 | 2 | 0 | 1,354 | 0 |
| 12 | Coal mining | 0 | 0 | 2 | 2 | 0 | 0 | 1,160 |
| 13 | Oil and gas extraction | 1 | 1 | 2 | 4 | 1,216 | 95 | 37 |
| 14 | Nonmetallic minerals except fuels | 0 | 3 | 0 | 3 | 0 | 3,511 | 0 |
| 20 | Food and kindred products | 1 | 8 | 7 | 16 | 0 | 7,704 | 4,191 |
| 24 | Lumber and wood products | 0 | 13 | 13 | 26 | 0 | 2,222 | 3,052 |
| 25 | Furniture and fixtures | 0 | 2 | 0 | 2 | 0 | 971 | 0 |
| 26 | Paper and allied products | 1 | 17 | 10 | 28 | 637 | 4,158 | 6,640 |
| 27 | Printing and publishing | 1 | 6 | 0 | 7 | 88 | 517 | 0 |
| 28 | Chemicals and allied products | 1 | 10 | 10[b] | 21 | 12 | 1,023 | 2,577 |
| 29 | Petroleum and coal products | 0 | 3 | 2 | 5 | 0 | 161 | 24 |
| 30 | Rubber and misc. plastic products | 0 | 7 | 4 | 11 | 0 | 2,229 | 1,399 |

**TABLE 4-1** *(Continued)*

| | | Number of Permits | | | | NSR Permitted Emissions (tons) | | |
|---|---|---|---|---|---|---|---|---|
| SIC | SIC Type | Greenfield | New at Existing Location | Modifications | Number of Permits by SIC | Greenfield | New at Existing Location | Modifications |
| | | | | VOC *(Continued)* | | | | |
| 32 | Stone, clay, and glass products | 3 | 11 | 4 | 18 | 768 | 767 | 1,072 |
| 33 | Primary metal industries | 0 | 10 | 16 | 26 | 0 | 165 | 2,223 |
| 34 | Fabricated metal products | 0 | 1 | 1 | 2 | 0 | 44 | 142 |
| 36 | Electronic and electric equipment | 0 | 1 | 0 | 1 | 0 | 306 | 0 |
| 37 | Transportation equipment | 1 | 6 | 6 | 13 | 600 | 4,745 | 1,382 |
| 39 | Misc. manufacturing industries | 0 | 1 | 0 | 1 | 0 | 46 | 0 |
| 45 | Transportation by air | 0 | 1 | 0 | 1 | 0 | 201 | 0 |
| 49 | Electric, gas, and sanitary services | 90 | 65[b] | 30 | 185 | 10,886 | 4,954 | 1,026 |
| 82 | Educational services | 0 | 1 | 0 | 1 | 0 | 41 | 0 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 87 | National security and intl. affairs | 0 | 1 | 0 | 1 | 0 | 1,700 | 0 |
| Total tons | | 99 | 170 | 107 | 376 | 14,207 | 36,914 | 24,925 |

[a] Greenfield refers to a site where a new facility is built and no facility had existed previously.

[b] Numbers do not sum to total because some permits had both modifications and new units.

Source: EPA, unpublished data, August 2004.

industries), and 24 (lumber and wood products). The largest share of NSR permitted emissions for modifications was for SIC types 26 (paper and allied products, with a large contribution from coated and laminated paper), 20 (food and kindred products, with a large contribution from soybean oil mills), and 24 (lumber and wood products).

The summary above is subject to several key limitations. Complete permit data were not always available for every permit issued. The survey was for a specific time period (1997-1999); more-recent data were not available. Some sources accept limits on their emissions by state permits when modifications are made and thus are not included in the EPA database. There is some uncertainty with estimated NSR permitted emissions because emission rates are often reported on a short-term basis and had to be converted to an annualized estimate of emissions. Actual emissions are typically less than allowable levels. During the survey time period, there was a noticeable increase in the number of new natural-gas-fired turbines permitted, which would affect totals for greenfield sites and new facilities at existing locations. However, this probably does not significantly affect the frequency of permits issued for modifications. These data do not include situations in which NSR permits for major modifications were not issued, such as for facilities that considered but decided against making a modification, or for facilities that made modifications but did not get an NSR permit for a major modification, whether because of noncompliance or because the source agreed to reduce emissions and obtained a state permit. Despite the limitations of the preliminary data, they are the most comprehensive currently available.

The key inferences from the available data suggest that the following industries have significant NSR permitting activity for modifications, whether measured in terms of the number of permits or the permitted emissions: electric utilities; stone, clay, and glass products; paper and allied products; chemicals and allied products; and food and kindred products. The reported tons of permitted emissions for modifications composed 25-48% of the reported total of permitted emissions for all NSR permits, including greenfield, new facilities at existing locations, and modifications, depending on the pollutant.

Although the mix of industries appears to be widely different, the emission processes are often qualitatively similar across industries. For example, many industries use common unit operations, such as industrial furnaces, to generate steam for process use. Some industries, such as stone, clay, and glass products, use tunnel or rotary kilns, which are specialized combustion-based equipment for heating specific types of materials (EPA 1995b). Thus, although the specific design and duty cycle may differ, there are also similarities in terms of combustion principles and factors governing pollutant formation and control. For example, the $NO_x$ formation mechanisms and control strategies are similar for cement kilns, glass melting, and industrial boilers and include thermal and fuel $NO_x$ formation (if a nitrogen-bearing fuel is used), combustion-based controls, and postcombustion controls (EPA 1994b,c,d). Of course, not all the emission sources are combustion based. To provide a more thorough assessment of specific emissions technologies, later sections of this chapter feature a review of specific types of process facilities and their unit operations.

Several states provided summary information to the committee regarding NSR permitting. However, these summaries typically did not distinguish among permits for new sources and permits for modifications to existing sources. Thus, a direct inference regarding permitting activity for modifications is not readily inferable from the available state information. For example, in Louisiana, the largest share of all permits was issued for chemical manufacturing, power generation, refining, paper and allied products, and inorganic chemical industries. The industrial mix in Louisiana is somewhat unique because of the large industrial presence in areas such as those around the lower Mississippi River and Lake Charles and others. In New Jersey, permits have been issued for industries such as power generation, chemical and allied industries, petroleum refining, and others. The types of sources permitted in New Jersey have included combustion turbines, boilers, engines, and fluidized catalytic cracker units, among others. However, the industries identified in the Louisiana and New Jersey surveys as being of greatest importance with respect to permitting activity are qualitatively consistent with those identified in the EPA summary.

The use of data such as in Table 4-1 is one approach to identifying priorities among industries subject to NSR for modifications. However, another approach is to select industries that illustrate the complexity of the technology choices that are associated with decisions regarding common repairs and replacements. Furthermore, some industries are regionally important. For example, the petroleum-refining and pulp and paper industries provide useful case studies regarding the myriad of unit operations that are subject to repairs and replacement. Such industries also illustrate that many unit operations or processes are common to multiple industries. For example, industrial boilers are a common unit operation that are typically used to boil water to produce steam in many industries. In addition to industrial boilers, industrial process heaters are used to heat raw materials, such as crude oil or intermediate products for processing or distillation. Industrial heaters often exhibit emissions that are similar to those from industrial boilers. The fuel used for industrial heaters and boilers differs among industries. Natural gas is predominant in the chemical industry; fuel gas and natural gas in petroleum refining; and coal, tire chips, "bark" (waste wood such as stumps), and "black liquor" (lignin that has been separated from cellulose) in the pulp industry. Based on the review of available summaries of data on permits and the evaluation of other factors, such as representativeness of the complexity of technology characteristics and options, several industries and emission sources were identified as key priorities for characterization and evaluation. These include electric utilities, petroleum refining, and paper and allied products. Furthermore, because industrial boilers are common to many industries, they are also characterized.

## PROCESS TECHNOLOGIES OF EMISSION SOURCES: PROCESS DESCRIPTION, REPAIRS AND REPLACEMENT, AND POLLUTION PREVENTION AND CONTROL APPROACHES

The purpose of this section is to describe the major components of emission sources that are most relevant to NSR permitting decisions pertaining to repair and replacement. An understanding of the typical facilities in several key industries is needed to assess the impact of changes of NSR on emissions and energy use from these sectors. Thus, the focus is on those components that are most commonly subject to common repair as well as the potential for more substantial replacements. Furthermore, typical pollution prevention and control strategies are identified. Because the number of industries affected by NSR is potentially large, it was deemed infeasible to provide a comprehensive survey of all industries. However, a selected set of industries is reviewed here that either represent a high frequency of permitting activity or contain emissions processes typical of many industries. For example, electric utility power plants are among those source categories for which there is a relatively high frequency of NSR permits associated with modifications. Other industries, such as petroleum refining and paper, are important in selected regions of the country. However, these types of industries include emission processes, such as industrial furnaces, that are common to many industries. Thus, the review provided here is intended to furnish a technical foundation for identifying issues pertaining to typical repair and replacement and their implications for cost, emissions, and other impacts.

There are no standard ways across industries of reporting process design, repair and replacement practices, and performance and cost information. Classification schemes may differ across industries because of differences in feedstocks, process configurations, and constituent unit operations. Classification schemes also may differ because of industry-specific practices and metrics. Thus, in presenting information regarding specific industries in later sections of this chapter, we tend to adhere to terminology, flowsheets, repair and replacement practices, and technology options that are tailored to that industry. For each of the industries described here, there is a representative flow sheet of the process technologies and a narrative that highlights key NSR-relevant technological characteristics.

## Electric Utilities

According to 2002 national emissions estimates, electric utilities emit annually approximately 4.7 million tons of $NO_x$, 10.3 million tons of $SO_2$, 52,000 tons of VOCs, 499,000 tons of CO, and 582,000 tons of $PM_{2.5}$ (EPA 2004o). Most utility $NO_x$ emissions are from coal-fired plants, including bituminous and subbituminous coals, and natural-gas-fired plants. $SO_2$ emissions are primarily from bituminous coal-fired plants, with smaller contributions from other ranks of coal and from other fuels. VOC emissions from power plants tend to be low compared with other sources because of the high combustion efficiency relative to other types of energy conversion systems (e.g., internal combustion engines) and because evaporative emissions at other sources contribute significantly to national totals. Similarly, CO emissions from utility sources are a small fraction of national emissions and are associated mostly with coal and natural gas. Coal accounts for most of the estimated utility $PM_{2.5}$ emissions, which in turn represent less than 10% of the estimated national $PM_{2.5}$ emissions. These data are for primary emissions and do not include formation of secondary $PM_{2.5}$. Thus, the key pollutants of concern for utilities tend to be $NO_x$ and $SO_2$, although the $PM_{2.5}$ emissions can be significant in the context of local airsheds. Coal and natural gas are the fuels of greatest interest with respect to this mix of key pollutants. Therefore, this section focuses on identifying the characteristics of typical coal-fired and natural-gas-fired utility plants for purposes of identifying the typical repair and replacement issues for such facilities.

## Typical Electric Utility Power Plant Designs

There are many variations on power plant design for both coal- and natural-gas-fueled systems. For example, for coal-fired power plants, the choice of an appropriate furnace design, as well as the design of other plant components, often depends at least to some extent on the rank of the coal and the specific properties of the coal. The choice of furnace design can influence baseline emission rates. For example, tangentially fired furnaces promote the formation of a rotating fireball inside the furnace, leading to different $NO_x$ emissions than a wall-fired boiler. Operational practices, such as optimization of fuel and air ratios, also influence emissions. A well-tuned furnace can have substantially lower $NO_x$ emissions than one that is not well-tuned, for example.

Figure 4-1 illustrates a generic power plant burning pulverized coal that is equipped with postcombustion controls for $NO_x$, PM, and $SO_2$. The plant includes coal storage and handling facilities and pulverizer mills that typically deliver finely pulverized coal via a pneumatic transport system to the burners. The furnace, also often referred to as a boiler, is the structure where combustion of the coal takes place. The burner design and methods for staging combustion significantly affect the formation of $NO_x$.

The walls of the furnace structure typically are composed of steam tubes and thus most of the surfaces inside the furnace are actually heat exchangers. Therefore, the flue gas temperatures decrease as the fuel gases leave the flame zone and travel past the heat exchanger tubes. The topmost portion of the boiler is referred to as the “convective pass” and includes the heat exchangers for producing superheated steam. The temperature window in portions of the convective pass can be appropriate for selective noncatalytic reduction (SNCR), which is a $NO_x$-control technique involving injection of ammonia or urea to promote conversion of $NO_x$ in the flue gas to molecular nitrogen (e.g., EPA 2002e). After the convective pass, at which point the flue gas temperature has been reduced because of heat exchange, is the economizer, which is also a heat exchanger.

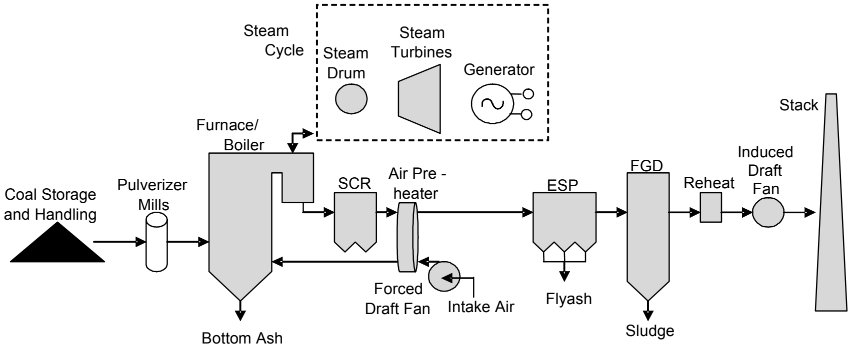

**FIGURE 4-1** Simplified flow sheet for a generic pulverized coal-fired electric utility power plant with postcombustion controls for $NO_x$, PM, and $SO_2$.

The flue gas leaving the economizer is typically at approximately 367°C, which is compatible with the desired temperature window for selective catalytic reduction (SCR) for postcombustion $NO_x$ control (e.g., EPA 2002e). Flue gases exiting the SCR, if present, or the economizer, if SCR is not present, flow through the air preheater, which is a heat exchanger. A typical air preheater design is a slowly rotating basket, portions of which are exposed to the hot flue gas and then the cooler inlet air. An intake air fan is typically used to force air into the furnace. In some power plant designs, an induced draft fan is located downstream to pull gases through the system.

The flue gas exiting the air preheater is typically at approximately 147°C, which is an appropriate temperature window for a "cold-side" electrostatic precipitator (ESP) or a fabric filter, either of which is used to capture a high percentage (typically 99% or more) of the fly ash entrained in the flue gas. If a power plant is equipped with a flue gas desulfurization (FGD) system, also commonly referred to as a "scrubber," the FGD system is typically located downstream of the fly ash collection device. A common design for FGD systems is a spray tower in which a slurry of limestone is sprayed into the flue gas, promoting contact of the gas with liquid droplets containing dissociated limestone (Cooper and Alley 1994; DeNevers 2000). There are numerous other FGD system designs, such as dry systems. FGD systems are also classified as throwaway (if there is a significant waste stream) or regenerative (if the sorbent is regenerated and reused in a continuous cycle). For illustrative purposes, we focus on wet limestone FGD because this is one of the more common designs. $SO_2$ is highly soluble in water. The spray tower thus promotes the absorption of $SO_2$ to facilitate aqueous-phase chemistry that produces calcium sulfite or calcium sulfate. A forced oxidation variation of the limestone-based FGD promotes a larger conversion toward calcium sulfate, which is a more desirable product in terms of handling abilities. If sufficiently purified and dewatered, the calcium sulfate from an FGD system can be used to make gypsum wallboard, although in many applications the sludge that includes calcium sulfate is ultimately disposed of in a settling pond or landfill. Because the spray tower also promotes some evaporation of water from the slurry when contacted with the warm flue gas, the temperature of the flue gas typically drops to approximately 47°C. To promote sufficient buoyancy of the flue gas for flow through the stack and some amount of plume rise, the relatively cool flue gas exiting the spray tower is reheated to a temperature of approximately 77°C or more. Reheat can be adjusted as needed by the plant operator in response to visual observation of plume buoyancy.

The other major components are part of the steam cycle. Some of the critical elements of the steam cycle include steam drums, steam turbines, generators, and associated pumps and piping. The plant will include a transmission system to deliver power to high-voltage power lines. The balance of the plant typically includes a myriad of auxiliary and support equipment and facilities, such as the control room, administrative and storage buildings, shops, roads, rail, and others.

A typical natural-gas-fired gas turbine combined cycle system is illustrated in Figure 4-2. The configuration shown is for a system with SCR for postcombustion $NO_x$ control. A gas turbine is composed of three major components: compressor, combustor, and turbine (also referred to as an expander). The compressor increases the pressure of ambient air for delivery into the combustor, where pressurized gaseous fuel (typically natural gas) or liquid fuel is introduced. The high-pressure, high-temperature combustion products enter the turbine via an inlet nozzle, and as the gases are expanded and cooled, energy is transferred to rotate a shaft. A significant portion of the shaft work is used to turn the compressor, while the balance is available for turning a generator. In some designs, a steam turbine is on the same shaft, with both the gas and steam turbines turning the same generator.

The gases exiting the expander of a typical heavy-duty gas turbine have a typical temperature of 597°C. Thus, additional thermal energy

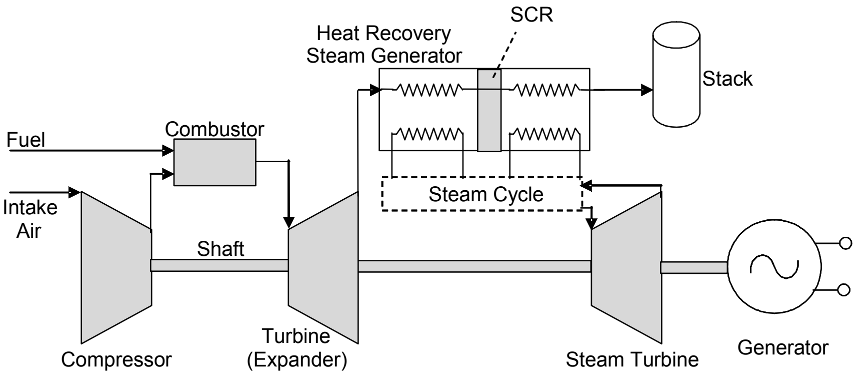

**FIGURE 4-2** Simplified schematic of a typical natural gas-fired gas turbine combined cycle system.

can be recovered from the exhaust gas via a heat recovery steam generator (HRSG). The HRSG is composed of multiple heat exchangers that serve tasks ranging from heating boiler feedwater to superheating steam. Steam typically is produced at two or three pressure levels to feed multiple stages of the steam turbine. Because SCR requires a specific temperature window, it is typically located within the HRSG so that the exhaust gas that passes through it is at an appropriate temperature during normal operations.

### Repair and Replacement Considerations at Electric Power Plants

This section reviews the typical repair and replacement considerations for electric power plants, with a primary focus on coal-based power plants and secondary consideration of natural-gas-fired combined cycle systems. The types of activities reviewed here are with respect to typical industry practice but are not evaluated here with respect to implications for NSR. A given repair or replacement activity may or may not trigger a requirement for an NSR permit depending on the specifics of each case.

Key elements of repair and replacement at a typical fossil-fuel-fired steam power plant include the following (Babcock and Wilcox 1978):

- Safety considerations: These often involve proper operation of various monitoring, observation, and detection systems, such as burner observation, flame failure, unburned combustibles, fuel/air ratios, water levels, feedwater and boiler conditions, pressures, and temperatures.
- Outages: These are scheduled outages for preventive maintenance (in the colloquial sense).

— Internal cleanliness and inspection (e.g., measure internal boiler tube deposits and chemical or acid cleaning of tube internals).

— External cleanliness and inspection (e.g., external fouling not removable by normal sootblowing, external signs of pending tube failure, such as blistering or warping, signs of erosion or corrosion, misalignments, deposits of ash or slag, condition of equipment, condition of exposed refractory).

— External cleaning (e.g., water washing of sulfur-bearing ash deposits).

— Identification of needed corrective actions (e.g., prevent recurrence of problems identified during inspection, such as start-up procedures that are too rapid and lead to overheating of superheater tubes).

- Cleaning of internal heating surfaces (e.g., chemical cleaning techniques)
- Repairs
- Care of idle equipment.

Specific areas of a typical coal-fired power plant that require repair and replacement can include the following (ERCC 2002):

- Boiler tube assemblies
- Air heaters
- Fans
- Mills/feeders
- Turbines and generators
- Condensers
- Control systems
- Coal and ash handling
- Feedwater heaters
- Sootblowers/water lances
- Burners
- Motors

- Electrical equipment
- Pumps
- Piping, ducts, and expansion joints
- Air compressors.

A summary of common repair and replacement activities for each of these specific areas is given in Appendix D in Table D-1.

Many of the common repair and replacement requirements at coal-fired power plants are attributable to exposure of key components to the erosive effects of ash or other solids during fuel handling or in the flue gas stream; the corrosive effects of acid gases in the flue gas stream; or impurities, such as in steam. Wear and tear on turbine blades, heat transfer surfaces, and other components can lead to a loss of system efficiency, reliability, capacity, or some combination of the three. Thus, common repair and replacement activities are often aimed at attempting to maintain the original efficiency, reliability, or capacity of the plant. Over time, new designs or materials may become available for replacement parts, such as turbine blades, leading to the potential for improved efficiency, reliability, or capacity compared with the original equipment used in the plant. It may be easier, more economical, or more energy efficient to use the more recently available replacement parts than to attempt to re-create the original parts. Many repair or replacement projects also can prevent more catastrophic failure of the plant. For example, replacing worn heat exchanger tubes potentially could prevent a catastrophic failure that could substantially damage the plant or injure personnel. Similarly, replacing worn turbine blades before they break and are "ingested" by other parts of the turbine can avoid a more massive failure of the turbine. Thus, there is clearly a role for preventive repair and replacement to maintain the safety of the plant as well as prudent timing of replacement of worn or damaged parts or components of the plant to maintain efficiency, reliability, and capacity of the plants.

The costs of repair and replacement projects typically are higher on a per-unit-capacity basis for smaller units than for larger units. Thus, the percentage of the total plant cost represented by a particular type of repair project typically may be larger for smaller units than for larger units.

Many of the common repair and replacement activities summarized in Appendix D occur at a large proportion of coal-fired furnace units and represent costs that are a relatively small fraction of the total initial plant cost. The appendix does not attempt to summarize less frequent major replacements at a plant, such as repowering with a new furnace using an existing steam cycle or replacing major components (e.g., turbine-generator) with an entirely new system.

## Typical Air Pollution Prevention and Control Approaches for Electric Power Plants

Air pollution prevention and control options for coal-fired power plants typically focus on emissions of PM, $NO_x$, and $SO_2$. For natural-gas-fired gas turbine-based systems, $NO_x$ emissions are usually of primary concern, whereas emissions of other pollutants, such as CO and VOCs, are of secondary concern. There is often a trade-off between $NO_x$ prevention using combustion-based approaches (e.g., wet injection, low $NO_x$ burners) and emissions of products of incomplete combustion, such as CO and VOCs. Changes to the combustion process that prevent a portion of $NO_x$ emissions, such as lower flame temperatures, can lead to reduced combustion efficiency. However, most of this section focuses on coal-based systems.

Typical control options for PM include cold-side ESPs or fabric filters. For $NO_x$, control options are typically classified as combustion-based or postcombustion. Combustion-based approaches typically include low $NO_x$ burners, overfire air, and other methods aimed at staging combustion to prevent at least some conversion of fuel-bound nitrogen to $NO_x$ while also preventing at least some creation of thermal $NO_x$ from nitrogen in the combustion air. Postcombustion approaches typically involve injecting a reactant such as ammonia to react with $NO_x$ in the flue gas, either without a catalyst (SNCR) or with a catalyst (SCR). To be effective, SNCR requires a specific temperature window, typically found in the convective pass of the boiler, as well as excellent mixing of ammonia (or other reagents, such as urea) with the flue gas. SCR operates at a lower temperature window, typically in a dedicated reactor downstream of the economizer heat exchanger. Detailed reviews of $NO_x$ control technology options are available elsewhere (EPA 1994b,c,d).

For $SO_2$, the typical control options are to switch to a lower-sulfur fuel or to use postcombustion control in the form of FGD. Switching to a low-sulfur fuel often requires changes elsewhere in the plant. For example, when switching from a bituminous to a lower-sulfur subbituminous coal, it is often necessary to modify the pulverizer mills. Furthermore, because the electrical resistivity of fly ash from subbituminous coal can differ from that of bituminous coal, retrofits to an ESP (if present) are often required. Thus, a fuel switch can entail some capital cost associated with changes within a plant.

For background information purposes, a budgetary cost analysis of typical $NO_x$ and $SO_2$ control technologies applied to generic types of new coal-fired power plants was conducted. The analysis of $NO_x$ control technology costs is predicated on generic types of coal-fired utility furnaces as summarized by EPA (1994e). Examples of generic types of furnaces include wall-fired, tangentially fired, wet-bottom wall-fired, cell, and cyclone types. For each type of furnace, a typical uncontrolled emission range and best estimate was reported by EPA depending on whether the furnace was built before new source performance standards (NSPS), under the Subpart D NSPS or under the Subpart Da NSPS. These estimates are summarized in Table 4-2. According to EPA (1994e), no boilers of the wet-bottom wall-fired, cell, or cyclone designs have been built since promulgation of applicable NSPS. Table 4-2 is useful in providing a baseline for uncontrolled emission rates that can be used to assess the overall effectiveness of pollution prevention and pollution control strategies that reduce emissions. In practice, the typical power plant has one or more methods for source reduction or control of $NO_x$ emissions and therefore will typically have lower emissions than the uncontrolled rates shown in Table 4-2.

As an illustrative analysis of the cost-effectiveness of $NO_x$ control, which is typically reported in units of dollars of levelized cost per ton of $NO_x$ emissions avoided, a sensitivity analysis was conducted using the EPA Acid Rain Division $NO_x$ Control Technology Cost Tool[3], which is a spreadsheet-based model (EPA 2002f). Levelized cost includes annualized cost recovery for capital cost plus annual fixed and operating costs and is in units of dollars per year. The annual emissions reductions is in units of tons per year. Therefore, cost effectiveness has units of dollars per ton of emissions reduction. To run this model, the user must specify the type of boiler (tangentially fired, wall-fired, etc.), the capacity of the boiler in megawatts (MW) of electricity generated, the capacity factor, and the uncontrolled $NO_x$ emission rate. The software provides results such as those summarized in Table 4-3 for two case studies based on a tangentially fired boiler with an uncontrolled emission rate of 0.7 pound (lb) of $NO_2/10^6$ British thermal units (Btu).

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[3] The algorithm was used mainly to illustrate the sensitivity of cost to various key factors; other cost estimates can be obtained by using another EPA costing algorithm (EPA 2004r) or the Integrated Environmental Control Model (Rubin et al. 1997).

**TABLE 4-2** Typical Uncontrolled $NO_x$ Emissions by Furnace Type for Coal-Fired Utility Plants in the United States

| | Typical Uncontrolled $NO_x$ Emissions (lb of $NO_2/10^6$ Btu) | | | | | |
|---|---|---|---|---|---|---|
| | Pre-NSPS | | Subpart D | | Subpart Da | |
| Type of Furnace | Typical Range | Best Estimate | Typical Range | Best Estimate | Typical Range | Best Estimate |
| Tangentially fired | 0.4-1.0 | 0.7 | 0.3-0.7 | 0.6 | 0.3-0.5 | 0.5 |
| Dry bottom wall-fired | 0.6-1.2 | 0.9 | 0.3-0.7 | 0.6 | 0.3-0.6 | 0.5 |
| Wet-bottom wall-fired | 0.8-1.6 | 1.2 | N/A | | | |
| Cell | 0.8-1.8 | 1.0 | | | | |
| Cyclone | 0.8-2.5 | 2.0 | | | | |

Abbreviation: Btu, British thermal unit; lb, pound; NSPS, New Source Performance Standard; N/A, not applicable.
Source: EPA 1994e.

**TABLE 4-3** Example of Cost-Effectiveness Estimates for Utility Boiler $NO_x$ Control for a Generic Tangentially Fired Furnace: Comparison of Cost Effectiveness for Different Sizes and Capacity Factors

| | | Cost Effectiveness, $/ton | |
|---|---|---|---|
| Control Option[a] | Emission Rate, lb of $NO_2/10^6$ Btu | 100 MW Boiler at 30% Capacity Factor | 600 MW Boiler at 75% Capacity Factor |
| Uncontrolled | 0.70 | — | — |
| LNC1 | 0.40 | 4,600 | 260 |
| LNC2 | 0.37 | 3,100 | 240 |
| LNC3 | 0.33 | 3,700 | 280 |
| SCR | 0.14 | 16,800 | 780 |
| LNC1+SNCR | 0.24 | 9,500 | 620 |
| LNC2+SNCR | 0.22 | 8,400 | 590 |
| LNC3+SNCR | 0.20 | 8,700 | 610 |
| LNC1+SCR | 0.12 | 17,200 | 810 |
| LNC2+SCR | 0.11 | 16,300 | 790 |
| LNC3+SCR | 0.10 | 16,560 | 820 |

[a] LNC1, LNC2, and LNC3 are various types of low-$NO_x$ burner designs.
Abbreviations: Btu, British thermal unit; lb, pound; MW, megawatt.

The two case studies were chosen to represent scenarios that would lead to high values of cost-effectiveness, such as for a smaller boiler used for peaking service, versus those that lead to lower values of cost-effectiveness, such as for a larger boiler used for baseload service. The purpose of the comparison is to demonstrate the wide range of variability in cost depending on boiler size and capacity factor. The choice of control options can include combinations of combustion-based and postcombustion options (e.g., LNC1 [low-$NO_x$ concentric burners, level 1], with selective catalytic reduction), as shown in the table. The cost-effectiveness varies by a factor of 3-5 when comparing control options, depending on the case study, with emission reductions varying from 43% to 86%.

The cost-effectiveness is sensitive to both the uncontrolled emission rate and to the capacity factor. For example, the estimated cost-effectiveness of $NO_x$ control for a 600-MW boiler with a 75% capacity factor ranges from $200 to $700 per ton (with corresponding control efficiencies of 43% to 86%) if uncontrolled emissions are 1.0 lb/$10^6$ Btu to $700 to $1,800 per ton if uncontrolled emissions are 0.4 lb/$10^6$ Btu. At an uncontrolled emission rate of 0.7 lb/$10^6$ Btu, but with a capacity factor of 0.5, the cost-effectiveness range, corresponding to the range of control options shown in Table 4-3, varies from $600 to more than $1,500 per ton.

For a wall-fired boiler, a similar set of case studies was conducted, assuming an uncontrolled emission rate of 0.9 lb of $NO_x$/$10^6$ Btu. For a 600-MW plant with a capacity factor of 75%, the estimated cost-effectiveness of $NO_x$ control ranged from $110 to $600 per ton over a range of control efficiencies from 51% to 89%. For a 100-MW plant with a capacity factor of 30%, the corresponding range of estimated cost-effectiveness was $1,400 to $13,000 per ton. Control options ranged from low-$NO_x$ burners (LNB) only to combinations of LNB, overfire air, and postcombustion methods of either SCR or SNCR.

Typical capital costs for selected pollution control equipment for coal-fired power plants are reported by EPA (2002e). For example, the capital cost of SCR is reported to be approximately $80/kilowatt (kW), whereas the capital cost of FGD systems for a typical 500- to 600-MW plant vary from approximately $160 to $210 per kW depending on the FGD system selected. A separate cost analysis performed using the Integrated Environmental Control Model (IECM) (Rubin et al. 1997), for a typical 600-MW wall-fired power plant burning bituminous coal produced capital estimates of approximately $25/kW for combustion-based

$NO_x$ control, $40/kW for SCR, $120/kW for FGD, and $45/kW for PM control, compared with a total plant cost (inclusive of all emission controls) of $1,280/kW versus a capital cost of $1,020/kW for the base plant excluding controls. The difference in the cost of the base plant versus the total plant includes the cost of controls plus additional costs associated with increased auxiliaries such as ash handling. Thus, the capital cost of installing all the air pollution controls collectively increases costs by 25% compared with the base plant. However, the costs for any of the controls individually vary from 2.5% to 12%. As an aside, the cost for SCR estimated by the IECM is at the low end of a typical range of reported SCR values for actual installations. However, the installed cost of SCR depends on site-specific factors and the cost of the catalyst, which can fluctuate, thereby leading to interplant variability in SCR cost.

All of the cost analyses reported in the preceding paragraphs pertain to a new plant. The costs to retrofit emission controls to existing plants can be considerably higher, depending on site accessibility and whether the retrofit can be accomplished during a scheduled outage without increasing outage time. Furthermore, the total impact of control technologies can include changes in overall plant efficiency as well as changes in fixed and variable operating costs. Thus, the cost analyses here typically represent a lower bound but nonetheless illustrate the sensitivity of cost to plant-specific conditions (uncontrolled emission rate, plant size, capacity factor, and others).

Costing algorithms for the capital, annual, and levelized costs of a variety of pollution control systems are available in EPA's *Air Pollution Control Cost Manual* (EPA 2002e) and other references, such as documentation of the IECM (Berkenpas et al. 1999). These algorithms as well as reported costs for various actual facilities can be used as a basis to evaluate the cost implications of various air pollution prevention and control options.

## Industrial Boilers

Industrial boilers and combustors represent a diverse collection of processes or devices that supply heat to a larger process or system or that act as thermal oxidizers of waste products. As is common when addressing emission sources for airborne pollutants, electric utility boilers are deliberately excluded from this category. Excluding electric utility generation, industrial boilers and combustors vary widely in their size and purpose. They play a role in a large number of different processes and systems that are geographically dispersed. As a result, the potential impact to humans of airborne emissions from industrial boilers and combustors is substantial because as they are widely dispersed geographically and equally present in urban and rural airsheds that may or may not be classified as nonattainment areas.

The diverse applications that use nonutility industrial boilers and combustors involve a variety of fuel types, which result in substantial variability in emission profiles. Relative to the six criteria pollutants, industrial boilers and combustors constitute significant sources of four ($NO_x$, PM, $SO_2$, and CO). The process that a particular unit serves determines, or strongly influences, the boiler or combustor fuel choice, which in turn greatly influences the emission profile. In a petroleum-refining process, flares used to oxidize sulfur in tail-gas streams, or combustion-driven process heaters fueled by crude oil with a high sulfur content, will produce high sulfur emissions. Pulp and paper processing can use biomass as a combustor fuel, resulting in high PM emissions. Because industrial boiler and combustor use is both widespread and tailored to specific applications, the potential to emit a particular criteria pollutant varies widely, depending on the fuel mix and installed emission controls. For example, because the $CO \rightarrow CO_2$ reaction is a principal reaction in combustion, both species are emitted in much higher concentrations than the other four gas-phase criteria pollutants. In addition, unlike the catalytic converters used to oxidize CO to $CO_2$ on mobile combustion sources, such controls are rare for large stationary combustion sources. As a result, nonutility industrial boilers and combustors represent a significant source of CO. Of the more than 1 million tons of CO emitted in 1999 (EPA 1999), the largest source categories by far were biomass-fired boilers and combustors (228,812 tons/year) and natural-gas-fueled reciprocating engines (206,647 tons/year), turbines (26,776 tons/year), and boilers (85,665 tons/year).

The diversity of applications in which industrial boilers and combustors are used makes them significant sources for four of the six criteria pollutants. After the phased elimination of leaded gasoline between 1975 and 1986, the primary source of lead emissions shifted from automobiles to metalworking (smelters) and battery-manufacturing processes, neither of which is considered in this section. Ozone is not directly produced by fossil fuel combustion, although $NO_x$ emissions and fugitive hydrocarbon emissions from fuel storage and supply components, among other sources, contribute to ozone formation (see Chapter

3). The remaining four criteria pollutants are emitted as a result of the combustion process, with different fuels and types of combustion resulting in different emissions, but the principal emissions vary depending on the type of combustion and the fuel used:

- $SO_2$: Source, combustion; abatement technologies, low-sulfur fuels (coal, oil).
- $NO_x$: Source, combustion; abatement, $NO_x$ reduction (primarily SNCR, also SCR), utilizing combustion best practices (e.g., lean combustion, air staging, flue gas recirculation, steam injection), low-$NO_x$ burners.
- CO: Source, combustion; abatement, none.
- PM: Source, combustion; abatement, electrostatic precipitators, fabric filters, cyclones, wet gas scrubbers.

Repair and replacement activities that are typical for industrial boilers and combustors are likely to be similar in many ways to those for utility boilers:

- Burner inspection and repair: For solid fuels and liquid fuels containing significant impurities, the fuel injection process can erode fuel injector parts over time, degrading burner performance. Periodic inspection and repair are required to monitor and address degraded burner operation.
- Repair/replacement of heat exchanger tubes: Heat is transferred from the hot-side combustion gases to the cold-side fluid (typically water) within large arrays of heat exchanger tubes. When fuels high in mineral impurities are burned, deposits condense on the outside of the tubes, reducing the rate of heat transfer over time and eventually requiring replacement or repair. Similarly, the thermal and mechanical stresses imposed on the tubes can cause rupture. Periodic inspections are required, which can lead to significant activities to repair degraded or damaged heat-exchanger tubes.

## Petroleum Refining

The domestic petroleum-refining industry consists of 152 facilities (down from 324 in 1981), geographically dispersed across 32 states. Fourteen of these facilities are small enough to avoid classification as "major sources" under Title V of the Clean Air Act (CAA). The remaining 138 facilities are located in both urban and rural areas, with concentrations of multiple facilities located along the coast of the Gulf of Mexico, along the Pacific coast of California, north-central Utah, and northwestern Washington State. Other refineries are located along the western Great Lakes and along the east coast from New York to Virginia. Some average-size inland refineries are located in Kansas, Oklahoma, Illinois, Tennessee, Kentucky, and Indiana. Petroleum refineries have a substantial impact on environmental quality of all sorts, not just air quality. For example, of all industries operating in California, petroleum refining is the largest source of hazardous wastes (CalEPA 2004). Of the petroleum refineries designated as major sources, slightly more than half (57%) are in nonattainment areas (Abt Associates Inc. 2003). The geographic distribution of refineries means that controlling air emissions from these facilities potentially affects tens of millions of people, both those living and working nearby in nonattainment areas as well as those downwind, in regions that may or may not be classified as nonattainment areas. Table 4-4 presents an inventory of emissions from typical petroleum-refining processes.

Petroleum refining is the process by which crude oil of various grades is converted into a wide variety of hydrocarbon products. Refineries range in processing capacity from 1,000 to 545,000 barrels/day (EIA 2003a). Fuels compose approximately 90% of the output of refineries, with the remaining percentage composed of lubricants and other hydrocarbon-based petrochemical products. Because each refinery constitutes a very large capital investment, and because the product lines of each refinery vary, actual refinery configurations vary from one facility to another.

It is illustrative to consider petroleum refining as consisting of a series of chemical reactors, each operating at a different temperature and pressure and handling different hydrocarbon feeds. Supporting these reactors is an array of devices that transport, blend, separate, pressurize, and heat the hydrocarbon feeds and catalysts to the conditions needed within each chemical reactor. With this framework, references to a specific refining process necessarily encompass ancillary devices such as pumps and heaters, which contribute substantially to the total emissions attributed to the process. Typical refining processes in order of decreasing processing volume are distillation (atmospheric and vacuum), cracking (catalytic and thermal), catalytic hydrotreating, catalytic re-

**TABLE 4-4** Natural Emissions Inventory (Tons/Year) for Typical Petroleum-Refining Processes

| Process (no. of facilities with process) | $NO_x$ | $PM_{10}$ | $PM_{2.5}$ | CO | $SO_2$ | VOCs | $NH_3$ |
|---|---|---|---|---|---|---|---|
| Vacuum distillation (34) | 24 | 8 | 7 | 45 | 135 | 1,763 | 1 |
| Catalytic cracking (78) | 22,946 | 12,002 | 9,267 | 80,008 | 105,499 | 6,800 | 1,286 |
| Fluid coking (13) | 43 | 153 | 111 | 4 | 3,712 | 484 | 1 |
| Oil and gas production (25) | 226 | 138 | 124 | 194 | 727 | 529 | 78 |
| Misc. petroleum production (34) | 2,036 | 489 | 398 | 1,926 | 7,534 | 3,588 | 64 |
| Chemical production (48) | 3,960 | 274 | 251 | 2,750 | 17,748 | 2,531 | 35 |
| Mineral production (6) | 18 | 17 | 10 | 27 | 103 | 146 | 3 |
| Misc. production (16) | 297 | 1,001 | 909 | 171 | 473 | 38 | 12 |
| Misc. petroleum processes (50) | 1,012 | 186 | 130 | 1,074 | 7,251 | 1,045 | 148 |
| Internal combustion (64) | 15,884 | 1,267 | 1,261 | 6,261 | 416 | 3,801 | 320 |
| External combustion (277) | 146,714 | 16,471 | 15,586 | 45,073 | 134,072 | 9,250 | 5,779 |
| Storage and transportation (178) | 1,752 | 108 | — | 190 | 2,635 | 33,585 | 196 |
| Water and waste treatment (194) | 1,253 | 2,449 | 2,243 | 979 | 6,336 | 11,239 | 344 |
| Fugitives (97) | 1,224 | 518 | 380 | 1,696 | 14,804 | 40,756 | 49 |

Source: Abt Associates 2003.

forming, and catalytic hydrocracking (see Figure 4-3). However, for any given facility and its instantaneous product mix, any combination of processes may be active, resulting in a variable “emissions fingerprint” for the facility as a whole. The national emissions inventory for petroleum refineries presented in Table 4-4 notably aggregates a number of the smaller-volume refining processes under several “miscellaneous” categories. Also notable in Table 4-4 is the predominance of combustion sources (internal and external) to overall emissions. Many of these com-

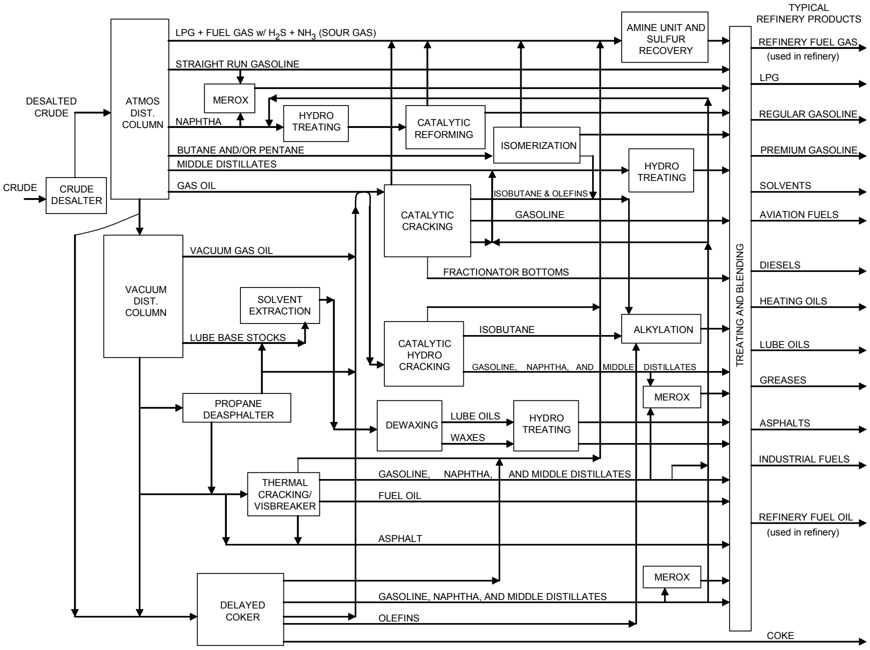

**FIGURE 4-3** Simplified process flow diagram for a typical petroleum refinery operation. Overall refining process proceeds from upper left (introduction of raw crude) to final dispensed products along right edge (fuel gases, gasoline, solvents, etc.). Not shown are ancillary devices (heaters, pumps, etc.) used to alter temperature and pressure of each feed (lines, arrows) as necessary before entering each individual process unit (boxes). Source: EPA 1995c, based on Garry and Handwerk 1994.

bustion sources are associated with the operation of one of the refining processes listed. To understand the air emissions attributed to each process, a basic understanding of each process is necessary:

## Distillation

Distillation is the process of coarsely separating the components of the petroleum feed by boiling-temperature differences. This is achieved by heating the liquid feed to progressively higher temperatures. The different components in the feed volatilize (change from liquid to gas) at different temperatures, based on molecular weight and mixture composition. Components that volitalize in the same temperature range are then collected, condensed, and sent for further purification. Distillation can take place under atmospheric or reduced pressure (vacuum) conditions. The latter is used to separate higher-molecular-weight components of the petroleum feed.

## Conditioning and Other Miscellaneous Processes

Conditioning and other miscellaneous processes involve manipulating the fluid and chemical characteristics of the petroleum feed to optimize the operation of subsequent, downstream processes. Hydrotreating removes impurities such as sulfur and nitrogen from hydrocarbon feeds that would poison catalysts used in downstream processes. Hydrotreating also converts olefins (alkenes) to paraffins (alkanes) to prevent the formation of gums in fuels. Hydrotreating involves reacting the petroleum feed with hydrogen under high pressure in the presence of a catalyst. Isomerization involves rearranging molecules (typically alkanes) without altering their molecular weight or composition to obtain-higher-value isomer species. The process takes place in the presence of a catalyst. By comparison, catalytic re-forming converts low-value species (e.g., naphthas) into high-value species of similar, but not necessarily identical, molecular weight (e.g., benzene). Catalytic re-forming also takes place in the presence of a catalyst. Dewaxing is a process that removes waxy contaminants (paraffins) from lubricating oils produced in a refining process. The dewaxing process can be either catalytic (paraffins in the lubricant are broken down in reactions over a catalyst) or filtration (paraffins are condensed and removed from the lubricant).

## Catalytic Cracking

The catalytic cracking process involves breaking down larger hydrocarbon molecules and re-forming the fragments into smaller hydrocarbon molecules. It occurs at high temperatures and involves vaporizing the hydrocarbon feed and introducing a granulated or powdered catalyst.

As a result, in addition to the ancillary processes associated with catalytic cracking that are needed to pressurize and heat the reactants and collect the lower-molecular-weight products, additional supporting processes exist to recover, regenerate, and reheat the granulated or powdered catalyst material. Note that regeneration of the catalyst material under reducing conditions is a primary source of CO.

## Sulfur Recovery

The sulfur-recovery process, also referred to as gas "sweetening," involves removing primarily hydrogen sulfide ($H_2S$) from process gases for conversion to elemental sulfur and eventual resale. The predominant sulfur-recovery method is a modified Claus process in which the gaseous $H_2S$ stream is partially oxidized to $SO_2$. The mixture of $SO_2$ and $H_2S$ then reacts over a catalyst to produce elemental sulfur. Because the modified Claus process is 94-97% efficient, additional steps are usually required to extract the remaining sulfur compounds in the "tail-gas." If the remaining sulfur in the tail gas is predominantly $H_2S$, the tail gas stream can be directed to a thermal oxidizer to convert $H_2S$ to $SO_2$ and then subjected to wet or caustic scrubbing. Alternatively, the Beaven process adsorbs $H_2S$ in a quinone solution, producing hydroquinone and elemental sulfur. This mixture is then centrifuged to remove the sulfur and oxidized to convert the hydroquinone back to quinone, which is then recycled in the process. If a variety of sulfur compounds exist in the modified Claus tail gas (e.g., $SO_2$, carbonyl sulfide, carbon disulfide), a SCOT (Shell Claus off-gas treating) process is used to catalytically reduce these compounds to $H_2S$ (cobalt-molybdenum catalyst), which are then adsorbed in a regenerable diisopropanolamine solution.

## Internal and External Combustion Devices

Boilers, incinerators, furnaces, and steam generators supply steam and electrical power to drive machinery and provide heat for various refining processes. Fuels fed into these devices include coal, fuel oil, natural gas, and facility off-gases. Air emissions from these devices are typical of hydrocarbon-fueled combustion devices.

### Fugitive Emissions

Fugitive emissions originate throughout the refining process as a result of leaks from seals associated with fittings connecting pipes, tanks, and process devices. Fugitive emissions also originate from the loading and unloading of raw materials (e.g., PM released during coal delivery) and from wastewater-treatment processes (e.g., aeration, holding ponds).

One way to envision refinery emissions is to consider petroleum refining as consisting of a series of chemical reactors, each operating at a different temperature and pressure and with a different hydrocarbon feed. Supporting these reactors is an array of devices that transport, blend, separate, pressurize, and heat the necessary hydrocarbon feeds and catalysts to reach the conditions needed for each chemical reactor. Air emissions from petroleum refining, and the technologies commonly used to abate them, can largely be categorized as below. The abatement technologies listed for each criteria pollutant reflect those technologies catalogued in a comprehensive review of EPA's RACT/BACT/LAER clearinghouse (more than 100 facilities and more than 350 processes reviewed, listed under "petroleum refining processes"):

- $SO_2$: Source, sulfur recovery, fugitives, internal combustion; abatement, gas scrubbing and adsorption (wet gas, caustic, Beaven, SCOT, Welman-Lord processes), fuel scrubbers, flares, incineration, fuel-sulfur content limits, and leak detection and prevention.
- $NO_x$: Source, internal and external combustion, sulfur-recovery unit; abatement, SCR, SNCR, utilizing combustion best practices (e.g., lean combustion, air staging, flue gas recirculation, steam injection), annual/daily limits on engine operation, and low $NO_x$ burners.
- VOCs: Source, distillation, catalytic cracking and re-forming, isomerization, waste treatment, materials loading, fugitives; abatement, flares, incineration, leak detection and prevention, and vapor recovery.
- CO: Source, catalyst regeneration; abatement, CO boiler/oxidizer.
- PM: Source, catalytic cracker, catalyst regeneration, internal combustion, materials loading; abatement, electrostatic precipitators, cy-

clones, baghouses, wet gas scrubbers, covered conveyers, telescoping chutes, partial and full enclosures, and watering.

The promulgated and subsequently stayed equipment replacement provision (ERP) exempts changes from triggering NSR activities that are considered "routine maintenance and repair." Thus, any assessment of the impacts of procedural changes to the NSR program must consider the type of repair and replacement activities typical of petroleum refineries. Table D-2 in Appendix D presents the aggregated responses to a National Petrochemical and Refiners Association member survey initiated in response to an information request from the committee.

## Pulp and Paper

The pulp and paper industry is a multifaceted industry, encompassing facilities that manufacture paper and paperboard products including linerboard, office paper, paper bags, paper towels, and napkins (among others). Because of the variety of final products, the mills that exist in the United States can be very different, and the process flow diagrams can vary. Typically, the manufacture of paper and paperboard products involves chemical pulping, mechanical pulping, or combined chemical and mechanical pulping. However, approximately 80% of the facilities that exist in the United States are mills that manufacture paper products by the kraft process (Springer 2000). This section on the pulp and paper industry focuses specifically on kraft mills because of the prevalence of these facilities in the United States as well as the numerous air pollution concerns associated with the chemical recovery processes of kraft mills.

A basic flow diagram for a mill operating with the kraft process is depicted in Figure 4-4. In addition to the major components in Figure 4-4, each mill also has a separate boiler for producing power. All the subprocesses depicted in Figure 4-4, as well as the power boiler, are critical to the overall production rate, and each has components that require repair and/or replacement to ensure proper operation. Thus, each section of a typical kraft mill is potentially affected by the NSR changes.

The process of generating paper in a kraft mill involves four primary processes: (1) preparing and digesting the raw materials, (2) processing the pulp, (3) drying and preparing the product, and (4) chemical recovery.

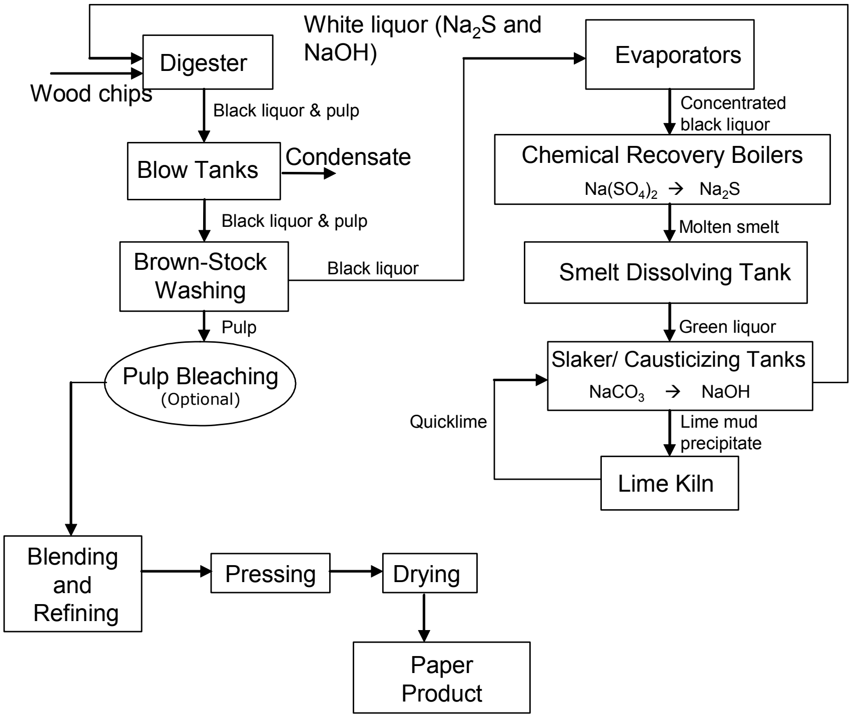

**FIGURE 4-4** Schematic of the major processes in a kraft mill.

## Preparing and Digesting Raw Materials

Hardwoods and softwoods are used in paper mills. The final product produced in the mill dictates the blend of hardwood and softwood material used. However, regardless of the nature of the wood, the primary step in a kraft milling process involves debarking the wood logs (by a mechanical procedure) and reducing the raw materials to chips. The chips are size segregated, and those deemed “too small” are transferred to the power boilers for use as fuel. Larger chips are mechanically processed further to achieve optimal chip size. Optimally sized chips are then fed into the digesters.

Digesters in a kraft mill are either batch or flow reactors that are used to convert raw wood chips to pulp. As noted in Figure 4-4, optimally sized wood chips are mixed with a white liquor that consists of sodium sulfide ($Na_2S$), sodium hydroxide (NaOH), and water. At high temperatures and pressures, the white liquor helps convert the wood chips to a soluble phase containing the lignin and an insoluble phase (the brown pulp) that is further processed into paper. The soluble and insoluble phases are separated in the blow tanks.

### Processing the Pulp

The pulp that emanates from the blow tanks is subjected to additional processing to remove spent digesting liquids (black liquor), improve the quality of the pulp, and, depending on the final product, bleach the pulp. The brownstock washers are used to remove spent digestion liquids from the pulp material. The diluted black liquor that exits the brownstock washers is collected for further chemical treatment. Washed pulp (brownstock) is also passed through screens to remove excessively large (partially undigested materials) or small pieces of the pulp. A proper pulp size is needed to ensure the strength and quality of the final product.

Certain kraft mills also use a bleaching process to convert the brown pulp to a white (bleached) pulp. This bleaching process involves using of a chlorinated compound such as chlorine dioxide to remove any residual lignin from the pulp, which results in a brightening or bleaching of the digested raw material. Pulp is introduced into a bleaching tower, bleached, and then washed to remove excess bleaching liquid.

### Drying and Preparing the Product

The washed (and perhaps bleached) pulp is processed into a final product through a series of blending and drying processes. Blending of softwoods and hardwoods changes the ultimate strength and characteristics (e.g., softness) of the final product. It is important to note that different wood types are processed in the digesters separately to ensure that proper digestion times as well as recovery techniques are used. (As an example, softwoods contain high concentrations of terpenes. Thus, after the digestion process, gases emanating from the digester and blow tanks used for softwood processing are condensed and recovered to form turpentine.) To achieve the desired final product characteristics, softwood pulp and hardwood pulp must be blended. Once the appropriate pulp blends are achieved, the pulp is sprayed onto large pressing and drying rollers where the paper product is formed.

## Chemical Recovery

A critical component of a kraft mill is the chemical recovery process. The black liquor generated in the digester is captured in the blowtanks and washer sections of a typical mill. This liquor is then passed through a recovery boiler to recover $Na_2S$. The molten smelt that is generated is further reacted to ultimately recover NaOH. The recovered $Na_2S$ and NaOH form the basis of the white liquor that is fed into the digesters as wood chips are processed.

## Typical Emissions and Control Equipment

The primary emissions from a kraft mill consist of VOCs, $SO_2$, $NO_x$, CO, and PM. Variations in the emission rates of each of the pollutants can exist based on the wood products used (softwood versus hardwood) as well as the final product that is produced by the mill (Someshwar 2003; Davis 2000). The National Council for Air and Stream Improvement as well as EPA have conducted studies to determine the typical emissions from specific mill processes (Someshwar 2003; NCASI, in press). Table 4-5 provides data on the types of compounds emanating from the major sections of a typical kraft mill as well as the typical air pollution control devices that are used to reduce emissions (Someshwar 2003; NCASI in press; Witkowski and Wyles 2004; Springer 2000; Davis 2000). It is important to note that the composition of emissions from the power boilers will vary depending on the type of fuel that is used. Typical fuels and the percentage of mills using the specified fuel in steam-generating power boilers are as follows: natural gas, approximately 33%; wood, approximately 33%; coal, approximately 26%; and oil/miscellaneous fuels, approximately 8% (NCASI in press). Although the use of waste bark may be an efficient use of resources, the combustion of bark typically generates excessively high levels of CO compared with the combustion of other fuels in a typical steam-generating power boiler (NCASI in press).

## Mill Repair and Replacement Activities

Numerous repair and replacement activities are periodically undertaken to ensure safe and optimal mill performance. For existing kraft mills, these types of activities have the potential to trigger NSR. There-

**TABLE 4-5** Typical Air Pollutant Compositions and Emission-Control Equipment Used in Each Subprocess in a Kraft Mill

| Subprocess | Typical Air Pollutants | Typical Emission Control |
|---|---|---|
| Digester | VOCs, sulfur compounds | Combustion |
| Blow tanks | VOCs, sulfur compounds | Combustion |
| Brown stock washing | VOCs, sulfur compounds | Combustion |
| Bleaching | Halogenated compounds (particularly chlorine dioxide and chloroform), CO | Alkaline scrubber |
| Chemical recovery boilers | PM | ESP |
| Smelt dissolving tanks | PM | Scrubbers |
| Slaker/causticizing tanks | PM | Scrubbers |
| Limn kiln | PM, sulfur compounds | Scrubber or ESP |
| Drying | VOCs, sulfur compounds | Combustion |

Source: Data from Witkowski and Wyles 2004.

fore, any effort to assess the impact on kraft mills of operational changes to the NSR program depends on the nature of these activities. Table D-3 in Appendix D lists repair and replacement and other activities specific to kraft mills that are periodically undertaken. The quality and variety of the fuel types used in the pulp and paper industry may result in repair or replacement activities for facility components that are different from those that occur in industrial sectors relying on one fuel type.

## TECHNOLOGICAL CHANGE

The stringency and form of environmental regulation can influence the nature and speed of technological change for pollution control equipment and have important implications for the cost and performance characteristics of that equipment. Technological advances can lead to lower costs of installing pollution control devices, lower costs of operating those devices, improved emission reduction performance, or some combination of those improvements. Understanding the relationship between regulation and technological change is important to accurately assess the costs and, in some cases, the benefits of environmental regulations into the future, including the changes to NSR rules being considered in this report.

Regulatory stringency and applicability have a direct relationship to the size of the potential market for a particular control technology and the incentive of a developer to improve that technology. Greater certainty about future regulatory requirements also provides for a more accurate assessment of the potential market for a particular technology and may increase incentives for improving that technology. The potential for being designated NSPS, BACT, or LAER, in theory, could provide an incentive for technology developers to devise a better technology for reducing or even preventing emissions, but there are no empirical studies of the effects of these regulations on new technology development. The form of environmental regulations—be they technology standards, emission rate standards, or cap-and-trade programs—will also affect incentives for different forms of innovation. In particular, emissions cap-and-trade regulations impose an opportunity cost in the form of the price of an emission allowance on every ton of pollutant emitted and thereby potentially create a stronger incentive to improve emission-control efficiencies of particular technologies than would exist with either technology standards or emission-rate standards (Keohane 2002).

To illustrate the relationship between environmental regulation and the development of emission-control technologies, two examples of such technologies are considered: FGD technology used to reduce emissions of $SO_2$ and SCR technology used to reduce $NO_x$ emissions from fossil-fuel-fired boilers used to generate electricity.

## Flue Gas Desulfurization

FGD technology is of particular interest because it must be installed for compliance with new source performance standards for $SO_2$ emission reduction at new pulverized coal electricity-generating units. The recent settlements of EPA NSR enforcement cases against several utilities (see Chapter 2) included agreements to install FGD scrubbers at one or more coal-fired units. FGD units were also an important part of utility compliance strategies with the $SO_2$ cap-and-trade provisions of Title IV of the 1990 Clean Air Act Amendments. Sixteen utilities installed retrofit FGD units in at least one of their existing coal-fired generators to comply with Phase I of Title IV (Swift 2001). Approximately eight scrubbers were installed after stricter caps were put in place under Phase II of the program, which took effect in 2000 (Burtraw and Palmer 2004).

Studies of the effect of NSPS and Title IV on innovation in scrubber technology suggest that both forms of regulation helped spur technological advances, but of different types. Taylor et al. (2003) found that patents relevant to $SO_2$ control technology grew dramatically in the early 1970s and have remained high through the mid-1990s relative to earlier time periods. Popp (2003) found that $SO_2$ removal patent counts peaked in the early 1980s, substantially above post-1990 levels. He suggested that this pattern indicates that stricter NSPS rules issued in the late 1970s contributed to increased patenting in the early 1980s. The subsequent decline in patenting activity could be due to a combination of factors, including lower-than-expected $SO_2$ allowance prices, the drop in construction of new coal-fired generators, and a declining propensity to patent in general.

Several authors find that the move toward a more flexible cap-and-trade approach to $SO_2$ regulation contributed to new forms of innovation. Burtraw (1996, 2000) found that the flexibility associated with permit trading allowed generators to make changes in institutional behavior that helped to lower costs and that by creating a form of competition with scrubbing helped to provide incentives to reduce scrubbing costs. Popp (2003) found that although capital and operating costs of scrubbers declined during the period since first implementation of NSPS, the move to cap-and-trade regulation for $SO_2$ in the late 1990s was accompanied by an improvement in the $SO_2$ removal efficiency of FGD units. This improvement is seen as a direct result of the stronger incentive to continually reduce emissions associated with a need to hold $SO_2$ allowances to cover all emissions. Keohane (2002) also found that FGD equipment costs did not decline during Phase I of Title IV but that the operating efficiency of scrubbers did increase and brought about large declines in operating costs per ton of $SO_2$ removed. Recent vintages of FGD units reduce potential stack emissions of $SO_2$ by 95% or more, whereas the median emission reduction before the revised NSPS for $SO_2$ in the late 1970s was closer to 80% (Popp 2003; Taylor et al. 2003). Today's systems are also much more reliable than were the FGD systems installed in the 1980s, and the increased reliability contributes to higher total $SO_2$ removal (Taylor et al. 2003).

Improvements in reliability and in the removal efficiency of FGDs are linked to some extent. As noted by de Nevers (2000), the electric utility industry endured problems associated with the early adoption of systems such as limestone scrubbers in the 1970s and early 1980s. Examples of problems encountered included higher than anticipated corrosion of metals; deposits of solids, as well as scaling and plugging, in the FGD system itself; entrainment of slurry droplets and downstream deposition of solids; underutilization of reagent; and problems with the separation of water from the waste products. Solutions to these problems have included better control of pH in the slurry, better control of the composition of the slurry to avoid scaling and plugging problems, improved design for key components such as entrainment separators, and increased slurry holding times and oxidation.

Learning by doing also has helped to bring down the costs of operating FGD units. Taylor (2001) showed that the operating costs of FGD units have fallen by 17% for every doubling of installed capacity. Capital costs of a wet limestone scrubber designed to reduce emissions of 3.5% sulfur coal by 90% at a 500-MW unit have fallen by roughly 50% over 20 years, and the bulk of those declines occurred before the beginning of the cap-and-trade program (Taylor et al. 2003, Figure 6).

### Selective Catalytic Reduction

SCR technology is of interest because it is a very effective means of reducing $NO_x$ emissions at utility boilers that has the potential to reduce emissions by between 70% and 90%. SCR generally is assumed to be necessary to meet NSPS requirements for $NO_x$ reductions at new pulverized-coal facilities. SCR is also the technology typically selected to control $NO_x$ in settlements of NSR enforcement cases brought against large electricity producers by EPA in recent years.

SCR is one of many ways to control $NO_x$ emissions, and it is a relatively capital-intensive and expensive method compared with other approaches (Swift 2001) that have proven sufficient to achieve compliance with recent $NO_x$ regulations. Before the 1990 CAA Amendments, many existing coal-fired generators faced no restrictions on emissions of $NO_x$. Title IV of the 1990 CAA Amendments imposed an annual average emission-rate cap on $NO_x$ emissions for coal-fired generators in the United States. The emission-rate limit was based on the use of low-$NO_x$ burners, and the standard varied by boiler type (Swift 2001). Most units complied with the regulation by installing low-$NO_x$ burners, although flexibility provisions in the law, such as emission-rate averaging across units at a plant, encouraged firms to reduce emissions through other means, such as changing air/fuel mixtures and adjusting boiler temperatures to reduce $NO_x$ emissions before investing in control technology (Swift 2001). The linking of these standards to the degree of reduction achievable with low-$NO_x$ burner technology provided limited incentive for U.S. coal-fired generators to adopt the more expensive SCR technology. However, in several states, such as California, SCR was applied starting in the 1980s on gas turbine combined cycle facilities.

Demand for SCR to reduce $NO_x$ emissions was expected to grow somewhat when the Ozone Transport Commission (OTC) program for capping summertime $NO_x$ emissions from electricity generators in nine northeastern states took effect in 1999. This cap began in Phase II of the OTC program, which ran from 1999 through 2002, mandating a 55% reduction in summertime $NO_x$ emissions from affected sources below 1990 levels. Despite the large reductions sought, most of the regulated units were able to achieve a large fraction of the required reductions in $NO_x$ emissions through operational changes, and thus the role for SCR was much smaller than expected (Swift 2001). Beginning in summer of 2003, this cap was tightened to roughly 70% below the 1990 level (Burtraw and Evans 2004). The geographically more expansive multistate $NO_x$ caps under EPA's $NO_x$ State Implementation Plan Call, which covers 19 states and the District of Columbia and took effect in the summer of 2004, greatly increased installations of SCR technology. Also, coal-fired power plants in a number of states have retrofitted combustion and postcombustion $NO_x$ controls (for example, low-$NO_x$ burners and SCR) in response to state implementation plan (SIP) requirements for attaining National Ambient Air Quality Standards.

The United States was a relatively late adopter of SCR. In Japan, it was used as early as the late 1970s but at much lower removal rates than are common today, typically at a rate of 60%. These lower removal rates meant that there was less of an issue with ammonia slip because utilization of ammonia is more complete under these conditions. German coal-fired boilers adopted SCR in the late 1980s and early 1990s in combination with environmental regulations. During the 1980s, improvements in catalyst formulation, as well as injection grids and control systems, enabled achievement of the 80-90% removal efficiencies with less ammonia slip for a wider variety of flue gas compositions.

One barrier, in addition to high costs and relatively low regulatory stringency, to adoption of SCR in the United States during the 1980s was the perception that SCR could not be used in U.S. coal plants because the alkali content of U.S. coal was higher than that from coal used in Japan (or Germany) and that this difference could be a potential cause of catalyst plugging or poisoning. However, experience has shown that, with appropriate catalyst formulation, different coal chemistry is not a problem. Other potential problems with the application of SCR, such as ammonium salt deposition on downstream equipment, are apparently reduced or eliminated by controlling ammonia slip and by selecting appropriate materials and surfaces for such equipment (e.g., an air preheater).

Ongoing work by Taylor (2004) finds that SCR emission removal efficiencies have improved dramatically coincident with the spread of regulations requiring or spurring their use from Japan in the late 1970s to early 1980s, to Germany in the late 1980s to early 1990s, and then to the United States more recently. Increased SCR use in the United States has come about only recently, largely in response to the regional summertime $NO_x$ emissions cap-and-trade programs in the northeastern states and to NSR requirements. Currently, removal efficiencies of 90% and beyond are feasible, and typically 90% removal is guaranteed by vendors (Culligan and Krolewski 2001). Operating costs of SCR units have also declined by 50% in 10 years (Taylor 2004).

### NSR Modifications and Incentives for Technological Change

Several economic researchers have raised the question as to whether NSR regulations inhibit technological change. Anecdotal evidence and a small amount of empirical evidence, discussed in Chapter 5, suggest that differentiated regulation of new sources slows capital turnover and that differentiated regulation of modified sources reduces investment in modifications and upgrades at existing plants. To the extent that these technological modifications would have promoted new technologies, the evidence of reduced investment at existing plants could be consistent with dampened diffusion of new technology and reduced technological change more broadly. However, no empirical studies have explored this relationship directly (Jaffe et al. 2003). .Not addressed here is the issue of the implications of tighter controls on new sources versus keeping older sources online longer.

The dearth of literature on NSR and technological change makes it difficult to offer much in the way of informed judgment about how the recent NSR rule changes are likely to affect innovation, let alone any direct evidence on the issue. To the extent that the regulation reduces applicability of NSPS, BACT, and LAER to existing sources, it could reduce demand for pollution control retrofits and thereby reduce innovation by technology developers. However, if the very endogeneity of the original rules (the fact that NSR applies only when major modifications actually take place) limited investment activity in the first place, then this effect is likely to be small.

An argument can be made that by expanding the use of flexibility measures such as plant-wide applicability limitations (PALs), the new rules could increase incentives for innovation and for adopting new technologies. PALs represent a form of intrafacility emissions trading, and emission trading has been shown to provide a stronger incentive for innovation than uniform emission standards. However, most of the research on this issue has focused on broader-scale interfacility emissions trading and the incentive effects of the more narrowly defined PALs program are likely to be smaller. Because the PAL applies for 10 years, firms typically emit below the PAL level in the earlier years to allow some headroom to accommodate anticipated demand growth over the 10-year period (EPA 2002a). The emissions cap created as a result of a PAL could provide an incentive to become more efficient in order to increase the firm's production of marketable goods. However, under a PAL, firms have little incentive to seek ways to reduce ultimate emission levels below the PAL. An exception would be if a particular pollutant were also covered by a broader cap-and-trade program such as the summer cap-and-trade program for $NO_x$ in the eastern states or the Title IV national cap-and-trade program for $SO_2$. In both of these cases, a firm has a direct incentive in the form of the emission allowance price to reduce emissions beyond the PAL. Most of the NSR modifications such as changes in methodology for estimating emissions effects and baseline emissions, PALs, exemptions for pollution control, and the expenditure threshold definition of routine maintenance limit the possibility that a particular investment or expenditure at an existing facility will trigger NSR. Those favoring the NSR rule changes have asserted that concerns over triggering NSR reduced investments at existing plants and, at the same time, reduced markets for new technologies (see Box 4-1). They also have asserted that limiting its applicability could increase the adoption of new technologies, which in turn could spur technological innovation. Whether this hypothesized effect would occur remains an open question.

## SUMMARY

The key conclusions of this chapter are as follows:

- There is significant NSR permitting activity pertaining to modifications. On the basis of preliminary data, which are subject to

**BOX 4-1 Example of an Emerging Technology: IGCC**

An example of an emerging technology is integrated gasification combined cycle (IGCC). IGCC features the gasification, rather than combustion, of fuels. For example, coal (or a wide variety of other fuels, including waste fuels) is partially combusted by using an oxidant (typically 95% pure oxygen from a dedicated air-separation plant), and steam or water is added. The partial combustion of the fuel supplies thermal energy for endothermic gasification reactions that lead to the formation of a synthesis gas containing CO, $H_2$, and other compounds. The bulk of noncombustible material in the fuel is removed via the bottom of the gasifier as a vitrified "slag" that typically is less leachable than the bottom ash of a conventional furnace. The "syngas" goes through gas cooling, scrubbing, and acid gas separation to remove particles, $H_2S$, and carbonyl sulfide (COS). The sulfur is recovered in elemental, solid form and can be used as a by-product. The synthesis gas can be used as a fuel in a gas-turbine combined cycle to generate power. Alternatively, the synthesis gas can be used as a feedstock for the production of chemicals, such as hydrogen, ammonia, and methanol. Gasification can be the cornerstone of a "polygeneration" system or "coal refinery" that creates a mix of multiple products. For power-generation applications, $NO_x$ emissions can be prevented or minimized via saturation of the syngas with moisture and/or injection of nitrogen from the air-separation plant. IGCC systems are generally more efficient than the combustion-based systems and have lower water usage, lower air pollutant emissions, and greater fuel flexibility. Although IGCC technology has been shown to be technically feasible in several large-scale demonstration plants, IGCC has not yet been cost competitive in the United States. However, American Electric Power has recently announced its intentions to construct the first commercial IGCC plant in the United States sometime in the next 5 to 6 years.

various limitations, the reported permits for modifications compose 25-48% of the reported total amount of permitted emissions among all NSR permits, depending on the pollutant.

- NSR permits for modifications have been issued for a wide variety of emission-source categories but primarily in the following industries, whether measured by number of permits or amounts of permitted emissions: electric utilities; stone, clay, and glass products; paper and allied products; chemicals and allied products; and food and kindred products.

- Although the mix of industries appears to be diverse, their emission processes are often similar. For example, many industries use common unit operations such as industrial furnaces to generate steam for process use, whereas others use combustion sources, such as tunnel or rotary kilns.
- A review of common repair and replacement practices for selected types of process facilities showed that such activities can vary considerably in frequency and cost[4]. Likewise, for a given emission source, such as a utility boiler, a wide range of pollution prevention and control options can vary in effectiveness and cost.
- Emission sources, pollution prevention techniques, and pollution control technology are expected to change over time, and regulations such as the ones considered here can be part of the motivating factors for such change. However, the effects of regulations can vary greatly, depending on the specifics of the programs.

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[4] The committee takes no position on whether these repair and replacement activities are “routine” within the meaning of EPA’s old or new regulations.

# 5

# Analytic Methods for Assessing Effects of New Source Review Rule Changes

## INTRODUCTION

In principle, numerous methods could be used to assess the effects of the U.S. Environmental Protection Agency's (EPA's) recent changes to the New Source Review (NSR) rules. Some methods focus on the response of individual firms or facilities; some focus on entire industrial sectors; and some attempt to assess the responses of multiple sectors or the entire economy. An assessment of all of the factors of interest requires an evaluation of how firms, industrial sectors, or the economy will alter their investments and operations (including pollution control and pollution prevention) in response to changes in the NSR rules and the resulting changes in efficiency and pollutant emissions. The assessment also involves an evaluation of how the emission changes might affect air quality and human exposures and the resulting health consequences of those exposures.

The methods used in evaluating responses to changed NSR rules begin with assumptions about how individual firms or industries respond to regulatory incentives and constraints. In some cases, these assumptions are based on empirical information involving interpretations of historical data, surveys, case studies, or anecdotal reports. In more formal analyses, the assumptions usually also incorporate theoretical constructs that have been developed in the field of economics. The usefulness of the alternative methods available and the selection of a particular one depends on the methods' accuracy in representing responses to regulatory incentives and constraints, their sensitivity to the particular regulatory changes being assessed, and their ability to accurately estimate the outcomes of interest in the assessment.

Different indicators can be used to assess magnitudes and trends in pollution prevention and control, energy efficiency, emissions, air quality, and health effects (e.g., NRC 1999; Esty 2001; Hayward 2004). Table 5-1 lists possible indicators for each. Many of these indicators vary over time and space or from plant to plant, and some degree of averaging or smoothing may need to be done before the data can be analyzed. In many cases, the data currently are not available from a single comprehensive source (or even distributed among many sources), and thus incomplete data would be used for drawing inferences. Furthermore, the list of measures in Table 5-1 includes factors that are quantitative and directly indicative of the targeted outcome, such as the emissions from individual plants, industries, and states, as well as other factors that are more qualitative and difficult to measure, such as the rate of innovation for pollution prevention and control technology.

Because many of the outcomes and indicators in Table 5-1 are affected by a number of factors beyond the realm of the NSR rules (or even pollution control laws in general), such as economic conditions, government investment in research and development (R&D), fuel supplies and prices, and meteorological conditions, these other factors and data should also be considered in analyses that attempt to assess the likely impact of NSR rule changes on the outcomes of interest. Thus, any assessment involves (explicitly or implicitly) comparing two different estimates: an estimate of what would have happened had the rule changes not occurred and an estimate of what will happen with the rule changes. Both are subject to substantial uncertainty, and, as discussed in Chapter 6, it will be necessary to consider a range of possible scenarios for the economic and environmental assumptions that are applied to estimate and compare outcomes of the revised NSR rules with outcomes of the NSR rules before the revisions.

The remainder of this chapter reviews the major approaches and methods that have been, or might be, used to assess the impacts of changes in the NSR rules on the outcomes in Table 5-1 at the level of the firm, the industrial sector, and the economy. The committee considered it important to review the full range of methods available for this purpose to determine the extent to which the different approaches could assist in responding to the committee's charge. This survey is deliberately broad

**TABLE 5-1** Possible Indicators for Assessing the Outcomes of Interest

| Outcome | Possible Indicators to Assess Outcome |
|---|---|
| Pollution control | • Innovation in new technologies<br>o Expenditures for research and development<br>o Inventions and patents<br>• Implementation of new technologies<br>o Adoption by industry and utilities<br>• Improvements in use ("learning by doing")<br>o Performance histories for selected technologies |
| Pollution prevention (source reduction) | • Innovation, implementation, and improvements in industrial processes to be less polluting<br>o Expenditures for research and development<br>o Adoption by industry and utilities<br>o Performance histories of selected technologies<br>o Trends in emissions generated per unit of product produced<br>• Life-cycle material-use impacts, considering economy-wide impacts through the supply chain and product delivery use, reuse, and disposal<br>o Number of products introduced into commerce with reduced hazardous properties<br>o Substitution of materials with less polluting substances |
| Energy efficiency | • Innovation, implementation, and improvement in use of new technologies that enable energy efficiency in electricity generation and industrial processes<br>• Energy efficiency of operating units and plants<br>• Industry sector-wide energy use<br>• Life-cycle energy-use impacts, considering economy-wide impacts through the supply chain and product delivery, use, reuse, and disposal |
| Emissions | • Trends in emissions for individual units, plants, industries, states, regions, and the nation as a whole<br>• Relationships between emissions and unit and plant operating costs and use<br>• Life-cycle emission impacts |
| Air quality | • Ambient concentrations of relevant emitted primary pollutants and pollutants formed in the atmosphere over various spatial and temporal scales. |
| Health effects | • Human exposure and dose<br>• Mortality and disease<br>o Population incidence<br>o Incidence for particular subpopulations (regional, socioeconomic)<br>o Risks to highly exposed individuals |

because different approaches are likely to be required for different industries, and because a final choice of methods has not been made. Furthermore, it is important to understand the general assumptions of each approach so that their practical and theoretical limitations are clear. Once the changes in emissions are estimated, other methods are used to estimate the resulting changes in ambient concentrations, exposures, dose, and human health and environmental risks. A preliminary assessment of the potential of these tools to be used in our evaluation of NSR rule changes is then provided. The assessment approaches discussed in this report will be relevant to the committee's final report. No assessment results are provided in this interim report.

## FRAMEWORKS FOR ASSESSING THE IMPACT OF REGULATION

In this section, we review the various approaches that can be used to estimate economic behavior in response to regulations at the level of the firm, the industrial sector, and the economy, as well as methods for evaluating the air-quality and public-health impacts of these responses. Where formal methods have been developed and applied, we identify the candidate models available, the types of variables that they estimate, the kinds of input data that they require, and their potential relevancy for evaluating the impacts of the recent changes in the NSR regulations on efficiency and emissions. In applying and interpreting these various models, important issues arise concerning the way statistical procedures are used and model uncertainty is interpreted. As such, we also briefly review key methods and issues for statistical estimation and uncertainty analysis.

### Assessments of Individual Firm Behavior

Decisions to undertake plant maintenance and alterations and/or decisions to implement new or different pollution control technologies are made at the level of the individual firm or facility. Their decisions reflect the constraints and incentives of environmental regulation as well as economic and financial conditions, available information, alternative investment possibilities that compete for the firm's resources, and individual firm preferences (including tolerance for risk).

Assessments of firm behavior in response to regulation can be based on anecdotal reports, directed case studies, surveys of multiple firms, and conceptual economic models. Anecdotal reports, case studies, and surveys have been done by EPA and specific state, environmental, and industry groups to address some of the issues concerning the likely impact of the NSR rules and rule changes. Although studies of this type have the potential to provide important information, they also are subject to bias depending on how issues are framed, survey participants are selected, and questions are asked (Yin 1994; Cox et al. 1995; Stake 1995). As part of our final report, we will evaluate the usefulness of a number of these studies for addressing the issues in our charge.

To the extent that their information is representative and pertinent, the insights from empirical studies of the type described above help to inform economic models that characterize and predict how firms will behave in response to different incentives. Economic models estimate behavior based on principles of rational choice and profit maximization (e.g., Tietenberg 2003; O'Sullivan and Sheffrin 2005). Process engineering models that estimate the performance (for example, efficiency), emissions, and cost, given alternative capital investments and operating decisions at individual facilities, can be included as a part of, or a precursor to, these models (e.g., Allen and Rosselot 1997; Lewin 2003).

Economic theory of firm behavior provides a useful window into how firms make choices and how they would likely alter their investment, input use, production, and emissions in response to changes in environmental regulations such as the NSR rule changes. Economists assume that firms exist to make profits and that their fundamental objective is to maximize profits by keeping costs low and revenues high. The effects of environmental regulation on firms' decisions will depend on the stringency and form of the regulation and on the incentives that the regulation provides for firms to adjust their behavior (Magat 1978; Milliman and Prince 1989; Helfand 1991; Montero 2002).

The economics paradigm can be at odds with how business leaders might describe what motivates their actions. Firm managers often deny that they are motivated solely by profits, arguing that firms have other goals, such as maximizing market share or even broader social goals that guide their decisions. Indeed, the long-term economic performance of a company can be affected by its commitment to environmental quality. For example, many firms now recognize that consumer confidence and allegiance can be influenced by environmental performance, and that employee health and productivity are likewise affected (Grabosky 1994;

Hamilton 1995; Curcio and Wolf 1996; Anton et al. 2004). Nonetheless, a firm's behavior is clearly disciplined by the realities of the market, and environmental commitments and controls can be costly. Firms that do not behave in ways that are consistent with profit maximization over the long term cannot succeed in a competitive market. The challenge for economic modeling is to characterize the firm's resources, risks, costs, and profit opportunities that are most relevant to how a profit-maximizing firm responds to regulations and incentives. Data limitations and a lack of understanding of a firm's constraints and opportunities can make the results of economic analyses highly uncertain, even if profit maximization is generally a good descriptor of firm behavior.

The profit-maximizing paradigm described below can inform many different methods of assessing how firms would be likely to respond to regulatory changes, including case studies, surveys of firms, and more formal econometric and simulation models. The key insight from this paradigm is that in understanding how firms will respond to regulation, it is important to understand the incentives created by different forms of regulation. This is particularly true when, as is the case with the NSR rules, the firm's actions determine whether it will ultimately be subject to the cost of complying with a regulation.

Figure 5-1 is a hypothetical illustration of the trade-offs between cost and emission reductions for a firm considering different possible plant maintenance or alteration activities. The figure is simplified in several respects to highlight key implications. First, it represents a continuous and smooth range of alternatives when in fact there may be only a handful of discrete alternatives. Installation of a particular emission-control device is usually an all-or-nothing decision, and the curve is thus more properly characterized by a sequence of discontinuous steps. Second, the curve is not necessarily "drawn to scale," exaggerating, in most cases, the costs of emission changes relative to the total cost of production. The graph identifies the emissions and costs associated with a set of possible plant maintenance and alteration decisions that a facility is assumed to be considering, while currently operating at location A, with relatively low total production costs but high emissions. The firm is considering a maintenance activity or alteration to the plant that would move it to nearby point $M_1$, allowing it to operate with both lower cost and lower emissions. The change might result in modest improvements in operating efficiency or reliability that yield both cost and pollution benefits—a win-win outcome for the firm and the environment (this is the type of activity that proponents of the recent NSR rule changes hope to

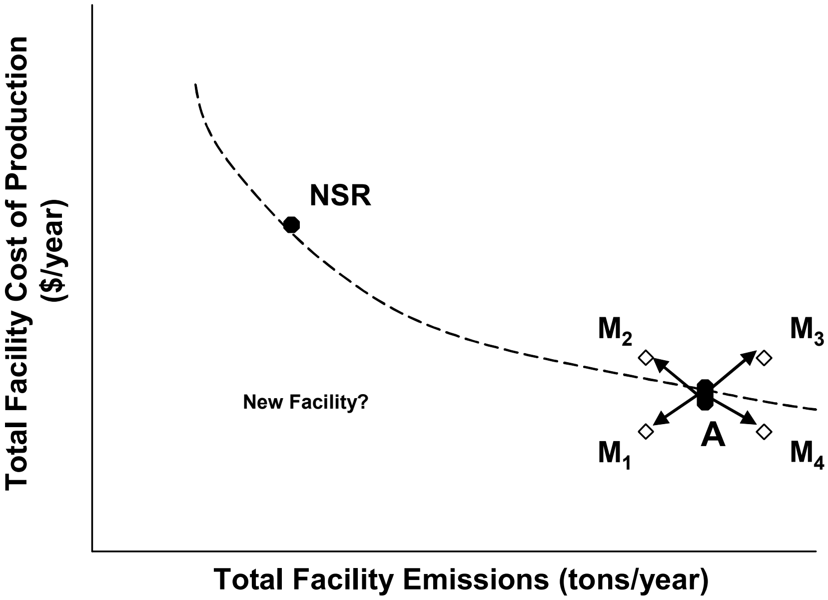

**FIGURE 5-1** A hypothetical illustration of options facing a firm operating with low costs/high emissions at point A, considering a maintenance activity that would result in a shift to $M_1$, $M_2$, $M_3$, or $M_4$ but that might also trigger an NSR that would require them to shift to the high-cost/low-emissions point labeled NSR. New facilities, with new technology, might be able to operate in the low-emissions/low-cost area denoted by "New Facility?"

encourage). However, if the firm fears that the proposed $M_1$ change will trigger NSR, forcing it to move to the "NSR" location in the figure with much higher costs (and much lower emissions), it may elect to forego the $M_1$ maintenance or alteration, thereby losing the opportunity to achieve the lower costs and the associated modest emission reductions.[1]

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[1] Although NSR rules are intended to apply only to the case in which emissions of regulated pollutants are significantly increased, an activity of the type denoted by $M^1$ still might trigger NSR—for example, with a system of linked producers, such as utility generators. In particular, consider a single boiler that could be improved so that it generates more and increases its emissions, but with a decrease in the overall emissions from the utility system because the modified plant is more efficient than the one that it replaced. Similarly, a multiplant firm

Other maintenance and alteration activities shown on the figure are also possible—opponents of the NSR rule changes fear that they would encourage more of the changes denoted as $M_3$ and $M_4$, resulting in higher emissions (regardless of whether they yield cost savings to the firm, although presumably, the cost-saving maintenance and alteration activities in $M_4$ are more likely than those in $M_3$). Even when the modest emission reductions achieved by $M_1$ and $M_2$ are lost in some cases, proponents of stricter criteria for triggering NSR argue that these criteria yield an overall net reduction in emissions. This happens because stricter rules encourage a number of these high-emitting plants either to make the major changes necessary to reach the low-emission levels of the NSR point on the curve (because they cannot continue to operate at the current point A without implementing the activity that now triggers NSR) or to be replaced by new facilities that do. Because of new, advanced technologies, these new facilities might even be able to achieve the lower emissions with much lower total costs, operating in the region denoted on the graph as "New Facility?". Hart (2004) discusses how different regulatory policies can provide incentives for industry to adopt new vintages that lead to both reduced pollution and production growth.

In the next section, we discuss in more detail the formulation of conceptual models of profit-maximizing behavior that underlie the trade-off between reductions in costs and emissions illustrated in Figure 5-1.

## Conceptual Models

Conceptual models provide a formal mathematical representation of how firms make choices to maximize profits. The most common assumption in these models is that firms operate in competitive markets where they take the prices of the products that they produce and of the inputs that they use as given. The profit-maximization problem involves finding the amount of inputs to use that maximizes total profits, given a production function that relates inputs to outputs. Emissions of pollution and the capital equipment used to reduce emissions can also be repre-

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might have a least-cost strategy for decreasing emissions using modifications that rebalance production so that there is an increase in emissions at some plants, despite the net reduction in total emissions.

sented. A simple model of firms' behavior typically has the following structure:

- *Decision variablse*: quantities of inputs to production that are used, including fuel, labor, capital, and pollution control equipment.
- *Parameters*: input and output prices.
- *Constraints*: what values of the decision variables are feasible or allowable. In an environmental assessment, the major constraints are as follows:
    - —A production function that defines how inputs are transformed into output.
    - —An emissions equation that calculates the amount of emissions resulting from using different combinations and amounts of inputs and relates these emission levels to emission limitations the facility must satisfy.
    - —Other environmental constraints such as restrictions on fuel input use or the use of specific pollution abatement equipment that the facility must satisfy.
- *Objective function*—a function that identifies the combination of decision variables that will maximize profits (revenues minus costs).

This model typically leads firms to produce output up to the point where the marginal cost of increasing production by a single unit is equal to the price at which the firm can sell its product. When the level of the firm's output is known, the decision becomes one of selecting the mix of inputs that minimizes the firm's cost of production given its production function. The solution to the cost-minimization problem, for a given level of production, can be used to determine a relationship between emissions and the total cost of production, such as the one shown by the dashed line in Figure 5-1.

Firms face environmental constraints that can take a variety of forms. An operating permit affecting a facility's behavior typically imposes a cap on emissions from an operating unit within the facility. Often this cap is based on a desired maximum emission rate per unit of heat input and an assumption about maximum levels of fuel use. Environmental constraints can also take the form of requirements to install control equipment (including specific classes of control devices when technology-based rules are in place) that achieves required emission limits or requirements to use lower-polluting fuels, such as lower-sulfur coals in the generation of electricity. In some cases, firms can participate in a national or regional cap-and-trade program for emissions when the constraint takes the form of a requirement that firms hold sufficient allowances to cover their annual or seasonal emissions of a particular pollutant. All these requirements impose costs on the firms that will influence the trade-offs that they make when determining how to produce their product and how much pollution to emit.

## Regulated Markets

When, as was traditionally the case for electricity generation, the price of the firm's output is determined by a regulator (e.g., a state Public Utility Commission) and not by the market, the firm's profit-maximizing problem includes an additional constraint, and the product price is no longer a parameter in the model. Typically, regulators set regulated price equal to average cost, which provides weak incentives to minimize costs. Recognizing the weak incentive properties of average cost pricing, market regulators increasingly are relying on other forms of regulation such as capping product prices to provide regulated firms with an incentive to reduce costs. In particular, as the electric-power industry in several states has been making its way through the transition from monopoly regulation to competition, prices for electric power have been capped, providing strong incentives to reduce costs.

How regulators treat pollution control costs and other costs associated with environmental regulation in setting prices can have very important incentive effects on a firm's choices over various options for complying with environmental regulation. Differences across state electric utility regulations in the treatment of emission allowances, costs of fuel switching, and costs of flue gas desulfurization (FGD) scrubbers had a definite role in shaping how electric utilities chose to comply with Title IV of the Clean Air Act (CAA) Amendments (Bohi and Burtraw 1992; Arimura 2002). Movement toward more competitive pricing of electricity generation will diminish the importance of these effects, but in certain regions of the country, such as the Southeast, deregulation of electricity-generation pricing is proceeding very slowly.

## Differentiated Regulation

In the models discussed above, a firm has no influence on whether it is subject to a particular environmental regulation. For regulatory programs, such as new source performance standards (NSPS) and NSR, a firm does not face the regulation until it takes a particular action. If a firm builds a new facility, then it knows that facility will be subject to NSR and possibly even stricter requirements (depending on where the facility is located). If a firm makes a major modification to an existing facility that is deemed to result in a "significant" increase in pollution, then it will be subject to NSR. The revisions to the NSR program that are the subject of this report affect the conditions under which NSR applies to an alteration at a facility.

To analyze such endogenously triggered regulation, a dynamic formulation of a firm's profit maximization problem becomes more appropriate. Because major alterations to facilities are capital investments, the problem should be extended to include multiple periods and the firm's objective should be restated as one of maximizing the present discounted value of future profits. Firms will compare discounted profits with and without the alteration and choose the course of action that appears to be the most profitable. Future costs with the alteration will include the costs of regulatory requirements triggered by NSR, and future costs without the alteration may include reduced levels of equipment reliability and other adverse outcomes. If the additional costs of complying with the NSR rule outweigh the benefits of the contemplated alteration, then the firm will not make the change. Being subject to the NSR rule may affect the payoff to the firm of different investment options and, in theory, could cause the firm to forego investments that would reduce emissions or improve energy efficiency at a facility, as illustrated in Figure 5-1.

The extent to which this has happened in practice is the subject of much debate. Firms and industries indicate instances when the potential to trigger NSR requirements made or might have made plant upgrades too costly to move forward. However, there is no way to independently corroborate such reports and rigorous statistical studies of this phenomenon do not exist, party because of lack of data and the difficulty of identifying the effects of NSR given all the varied influences on investment decisions. One recent empirical study that applied statistical methods analyzing possible effects of NSR rules, as distinct from NSR rule changes (List et al. 2004), is discussed later in this chapter. Several features of the NSR rule changes, including the change in the selection of test years for emission changes and the minimum expenditure threshold for major modifications, reduce the types of investments at existing plants that will trigger NSR. By removing certain types of expenditures from the category that triggers NSR, the rule might reduce the regulatory uncertainty facing the source and lowers the cost of many types of investments. At the same time, by lowering the costs of making modifications to existing plants, the rule change could encourage more firms to choose the modification option rather than invest in new, cleaner facilities.

The implications of different investment choices for plant-level emissions are impossible to anticipate with a conceptual economic model. A conceptual model can be used to illustrate conditions under which emissions increases might occur and when they will not. Then, given the necessary data, empirical analysis could be used to identify which conditions are relevant to a particular change. If a particular pollutant is capped nationwide (or within a region), then national (regional) emissions that are already at the level of the allowable cap will not rise with a relaxation of NSR applicability rules, although emissions could increase locally.

As stated above, conceptual economic models tend to be fairly simple representations of a firm's behavior and choices. The models are intended to yield general economic insights about how firms might be expected to behave under certain conditions and assumptions and about how firms make trade-offs. The models can be used to generate hypotheses that could be tested later by econometric or other statistical methods. Imposing specific functional forms on the production and emission functions make it possible to develop a model that could be used for simulation purposes. However, the conceptual models do not provide much detail on how specific processes function, although, if necessary to address a particular question, such process models could be obtained from engineers and incorporated into economic models of behavior, as discussed later in this section.

## Methods for Applying Conceptual Models

Econometric methods can be used to estimate the parameters of a profit function or cost function to test hypotheses generated by using conceptual models of a firm's behavior and to quantify the size of the effects of concern. For example, Carlson et al. (2000) used a panel of generating-unit-level data from coal-fired electricity generators to estimate a cost function. In this model, total annual costs including pollution control costs depend on input prices including prices of different types of coal, the level of electricity production, the level of sulfur dioxide ($SO_2$) emissions, a plant indicator variable, and a time trend to account for technological change. Input cost share equations and a model of $SO_2$

emissions levels are estimated jointly with the total cost function. From the estimated cost function, they derived an equation for the marginal costs of emission reduction and used it to identify the efficient level of emission reduction at each plant and to solve for the market price of $SO_2$ allowance prices under Title IV.

Estimating structural economic models can be quite data intensive, and often the requisite data on input prices, total costs, and economic profits for the relevant firm or plant are not readily available. In many cases, the best way to find the answer to an empirical question about how firms have responded to certain types of regulations or regulatory changes may not be by estimating a structural model. Instead, researchers use plant-level, firm-level, or, in some cases, more aggregate data to look at how environmental regulations and regulatory changes that were implemented in the past have affected economic activity and costs, productivity growth, and R&D and innovation.

### Effects of Differential Regulation over Space and Vintage of Source

Research has also examined how differential regulations affect firms' decisions about activities that could increase the stringency of the environmental regulations they face. One such decision is where to locate a new plant given differences in regulations across locations. Levinson (1996) used a conditional logit model and census facility-level data to study whether births of new manufacturing plants respond to differences in state environmental regulations and found that they do not. Using county-level information on ozone attainment status and plant-level information on facilities for four manufacturing sectors emitting high levels of volatile organic compounds (VOCs), Becker and Henderson (2000) studied the effects of differences in environmental regulations on where new plants choose to locate, sizes for new plants, and the timing of investments. They found that new plants are more likely to locate in attainment areas.

Only a few studies have used econometrics to look at the effect of differential regulation of sources due to vintage on economic decisions. An econometric study by Gruenspecht (1982) looked at the effects of corporate average fuel economy (CAFE) standards[2] on turnover of the automobile fleet and found that applying tighter standards to new cars reduces the rate of turnover of the existing automobile fleet. Nelson et al. (1993) studied the effect of NSPS and lowest achievable emission rate (LAER) standards on the age of installed capital of electricity generators and associated effects on emissions. They estimated an equation that relates the average age of the capital stock for a group of 45 electric utilities to measures of demand and input price growth and regulatory intensity. They found that differential regulations retard capital turnover but do not result in a significant increase in emissions.

A recent study by List et al. (2004) uses econometric models and nonparametric techniques to analyze the relationship between plant alteration and closure decisions and county attainment status as a proxy for stringency of NSR requirements.[3] This study uses data from the industrial migration file maintained by the New York State Department of Economic Development from 1980 through 1990. The authors find that NSR appears to retard the rate of alteration of existing plants, but they find little evidence that NSR affects the closure of existing plants. Their study does not consider the effects of NSR on emission levels.

## Process Engineering Models

Many of the modeling approaches described elsewhere in this chapter deal with multiple facilities and their interactions or use simplified characterizations of production technologies that merge multiple processes into a single-stage production function. However, such models often lack details about technology characteristics. For example, many life-cycle inventory and market analysis models use linear coefficients for the ratio of energy consumption to delivered units of a particular

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[2] CAFE standards, which were initiated by Congress in the Energy Policy and Conservation Act of 1975, established mandatory fuel efficiencies in the form of required miles-per-gallon goals for fleets of passenger cars and light-duty trucks.

[3] The study by List et al. (2004) focuses on NSR rules in effect before the recent changes that are the subject of this report.

product or for the ratio of emissions to a particular product. In reality, energy consumption and emissions at specific facilities can be a complex function of site conditions, feedstocks, process configurations, designs of each process area, operating practices, and maintenance, among others. Furthermore, when retrofit options are being evaluated, the availability of space at a site can severely constrain the location of new additions to a plant and thereby affect cost. Thus, there can be a need for a model or evaluation at the level of an individual plant, taking into account details of the plant's major components. Such models can enable "what-if" analysis of changes in design, feedstock composition, and operations on efficiency, emissions, and cost at the level of an individual plant.

There are numerous plant-level modeling approaches, ranging from empirical to theoretical. An empirical approach typically involves fitting a regression equation or system of equations to available data regarding the inputs and outputs of individual process areas and linking the process area models together to describe an entire plant. A theoretical approach involves developing mass and energy balances for each process area including detailed chemistry (e.g., chemical kinetics) and physics (e.g., fluid flow) for each unit operation. For example, the furnace of a power plant could be simulated by using computational fluid dynamics coupled with a chemical mechanism that describes the combustion of fuel and formation of pollutants during combustion. Such a simulation would make it possible to describe the temperature field in three dimensions within the combustor and also dynamically. Such models can be both data and computationally intensive. If the same approach is applied to all process areas of a complex plant, the resulting model can be large and difficult to use in practice. Thus, the choice of an appropriate modeling approach depends on the objectives of the model.

Commercially available software tools, such as the Aspen Plus steady-state chemical process simulator, can be used to develop and apply simulation models of a wide variety of process plants. The user specifies key parameters of each unit operation and of the inlet streams. Thermodynamic databases describe the key physical and chemical properties of each chemical "component," such as compounds. Aspen or Aspen Plus models have been developed for a variety of power-generation systems, including, for example, integrated gasification combined cycle systems (Frey and Rubin 1992). Cost models of process technologies can be developed by using built-in features of Aspen, or they can be developed separately and coupled with the performance model as subroutines. Aspen Plus simulation models require some software-specific expertise to develop and run. It has been shown that simplified reduced-form models can be developed based on Aspen models, which in turn facilitate more rapid analyses useful for policy purposes (Frey and Bharvirkar 1998).

To be of practical use, process-engineering models of plants should be executable in a reasonably short period of time by users who are not experts in the model. An example of this type of model is the Integrated Environmental Control Model (IECM), which runs in a Windows environment and has a graphic user interface (Rubin et al. 1997). In the past, EPA developed and maintained a somewhat similar model, known as the Integrated Air Pollution Control System (IAPCS) (Radian 1999). However, IECM and IAPCS typically had a somewhat different technology focus, and IECM includes a distinguishing probabilistic simulation capability for quantifying uncertainty in inputs and outputs.

A key goal of plant-level models intended for policy applications is to capture salient details and key interactions among process areas without becoming unwieldy. One approach, used in the IECM and similar models, is to start with basic mass and energy balances for major "process areas" of the plant to describe, with adequate accuracy, the major mass and energy flows in the plant. For example, the major process areas of a new coal-fired electric power plant typically include the boiler, economizer, air preheater, particulate matter (PM) control device (typically a cold-side electrostatic precipitator or fabric filter), nitrogen oxide ($NO_x$) control devices (typically a low-$NO_x$ burner and/or other combustion-based approaches and perhaps a postcombustion selective catalytic reduction system), an $SO_2$ control strategy (e.g., the use of a low-sulfur fuel and/or postcombustion FGD), a steam cycle (including heat exchangers, steam drums, steam turbines, and condensers), and any other special considerations (e.g., mercury control using carbon injection). For each major process area of the plant, a separate mass and energy balance model is developed. The process areas are interconnected by the flow of mass and energy between them.

Plant-level models can be incorporated into a larger simulation framework. This has been done in the past, such as for the Advanced Utility Simulation Model, to support system-wide planning applications that take into account some of the details of design and operation of individual plants as well as system-wide considerations (e.g., Badger and Ojalvo 1988). Also, as noted later in the section entitled "Estimating Effects Across Multiple Sectors of the Economy," process models for production facilities are often included as a part of a life-cycle environment assessment for a given product or industry.

## Assessment of Sector-Wide Response

### General Framework for Sectoral Assessments

The response of a full industrial sector to regulation can be estimated with generalizations of the tools used for individual firms, including anecdotal reports and representative case studies or surveys. In addition, economic models are available to estimate the behavior of multiple plants or facilities that may or may not interact in some way in response to common constraints and incentives. These models are most frequently applied to electric-power generation, including short-term dispatch as well as long-term capital investment and technology adoption in response to future demand, prices, and regulation.

The purpose of sectoral assessments is to project the possible response of an entire sector of U.S. industry to scenarios concerning government policies, technological change, and economic conditions. The major difference between sectoral assessments and the individual firm analyses of the previous subsection is that sectoral assessments aggregate the actions of all firms within an industry while imposing certain consistency conditions that must be met by the market as a whole. These conditions usually require that markets clear—that is, that prices adjust so that supply equals demand for the sector's inputs and outputs.[4]

In the case of outputs, an example of such a market clearing condition is that the quantity of electric power produced by a region's power plants equals the quantity consumed by that region's consumers, adjusted for net imports. By imposing such a condition, a sectoral analysis ensures that, for example, if one facility or set of facilities greatly increases their output (and emissions) in response to a change in NSR rules, then some other facilities will need to decrease their production (and possibly their emissions). A sectoral analysis can also account for price

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[4] Sector models are also limited in their ability to track or predict other aspects of firm-specific behavior, such as the performance improvements that occur over time as a result of site-specific process adjustments or learning-by-doing.

changes on demand so that, for instance, demand increases stimulated by lower prices could also consume and assimilate some of the increased production.

In the case of inputs, market clearing ensures that the aggregate demand by the sector for fuel or emissions allowances, for example, is consistent with the amount available. Continuing with the power industry example, a national cap on $SO_2$ emissions under Title IV of the 1990 CAA Amendments implies that, if the cap is binding, an increase in emissions from one group of facilities must be matched by a decrease somewhere else or, because of allowance banking provisions, at some other time in the future. Conversely, if emission allowances have a positive price, then if a regulatory action forces a power plant to reduce its emissions, and the plant is allowed to sell the resulting excess allowances rather than surrender them, the result will be an increase in emissions at another location and/or at another time. This outcome would not occur if, as part of the settlement agreement imposed by the regulatory action, the allowances are eliminated.[5] Because the supplies of some sectoral inputs, especially fuels, respond to price, increases in inputs demanded by one set of facilities can be met by a decrease in use by other facilities and by an increase in supply. Thus, for instance, if an emissions policy motivates a shift in fuel from coal to natural gas, prices for coal will fall, shrinking its supply, and prices for natural gas will increase, stimulating an increase in its supply. The resulting redistribution of fuel use (and emissions) among the nation's power plants will reflect a balancing of supply and demand for the fuels and allowances. The purpose of sectoral

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[5] In a statement regarding the surrendering of emission allowances as part of settlement agreements, a recent report of EPA's Inspector-General's office notes that (EPA 2004b)

> When controls are installed, excess allowances of $SO_2$ emissions are created, and it is vital that these allowances not be used. Consequently, all seven settlement agreements included an Emissions Trading Clause requiring the company not to use or sell any emission reductions. Also, all the settlement agreements required the surrender of allowances, except for Tampa Electric Power, which prohibited the selling and trading of $SO_2$ allowances. If a facility is able to use allowances elsewhere at a plant or sell them to another facility, there will be no environmental benefit achieved.

analyses is to project these shifts in a way consistent with the operation of the sector's input and output markets.

However, sectoral assessments do not attempt to trace the effects of a policy change throughout all sectors of the economy. For instance, changes in energy use and emissions by railroads due to a change in demand for low-sulfur western coal by the power industry might be significant but would not be considered in a power sector assessment. Such indirect changes, however, are the focus of multisectoral assessments, discussed later in this chapter.

Figure 5-2 presents a basic framework that might be used to interpret the outputs of a sectoral analysis. The two axes represent the economic cost to society, excluding environmental costs, of producing and using a good and the environmental effects resulting from that production. Economic cost might include only the cost of production, if consumption is fixed, or, more generally, it could be the change in the net benefits of consumption if demand is responsive to price. Commonly, the environmental axis is measured in terms of tons of emissions per year because they are more easily estimated than the ultimate health and other effects. The two axes represent the aggregate effects for the entire industry, as opposed to the effects of an individual company's or plant's decision shown in Figure 5-1. As an example, trade-offs between $SO_2$ emissions and power production costs for the entire U.S. electricity-generation system might be considered in this manner. Points on this plot might represent possible outcomes under different policies—for example, under different proposals for changes to the Title IV $SO_2$ emissions cap. Point A might represent the present level of emissions and cost, and point B might indicate aggregate emissions and cost if the cap were reduced by 50%. The dashed line indicates a "production-possibility frontier" for the industry, representing the most efficient possible combinations of emissions and cost, given present technology. Points to the southwest (e.g., point C) are not feasible, and points to the northeast (e.g., point D) are inefficient, having higher costs or emissions than necessary.

However, such a two-dimensional plot can hide as much as it reveals for three reasons. First, it does not disclose the distribution of effects among different societal groups. A point on or near the frontier, such as point B, might have lower total emissions than some other point to its northeast, such as point D, but the former point actually might have higher emissions and impacts in some particular location. Second, the

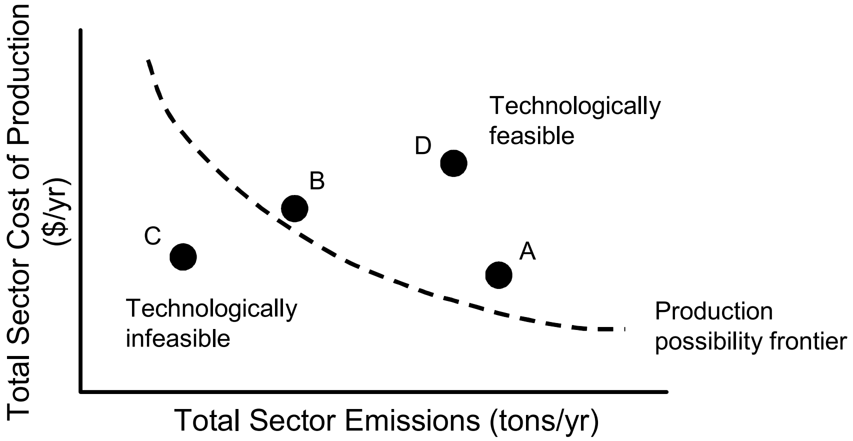

**FIGURE 5-2** Alternative sector-wide costs and emissions.

plot does not reflect the fact that environmental effects depend on the location and timing of emissions and not just the aggregate amount. Third, other potentially important policy objectives (not to mention other types of emissions) are not shown. Point D, for instance, might result in less disruption of coal-mining employment, which was a major policy driver in the 1978 revisions to power plant NSPS. In sum, there are many more than two dimensions to the impacts of policy scenarios, and these types of plots cannot tell the full story.

## Methods for Sectoral Assessments

Sector-wide analyses can use a variety of methods to project the location of alternative scenarios in plots such as Figure 5-2. Two basic approaches are surveys and microeconomic simulations. Surveys, at their least systematic, might simply be nonrandom collections of anecdotes that are argued to be more or less representative of conditions facing, or actions by, firms in an industry. More desirable are sampling schemes in which the reported data are auditable and statistically representative. Surveys may address past actions of firms, or they might ask respondents to state how they would react to hypothetical conditions. In the latter case, no attempt is made, however, to ensure that the aggregate future response of the sector is consistent with market clearing, and there are obvious dangers in the form of motivational and other biases.

There are two general sorts of sectoral simulation models (Andrews 1995). Top-down or econometric models are based on aggregate representations of sectoral responses that are estimated by statistical methods. For instance, the parameters for supply-and-demand curves for steel of a particular type might be estimated from historical data on prices, quantities produced and consumed, and input prices. Simulations are carried out by solving the resulting equations simultaneously under different input assumptions.

In contrast, bottom-up models (also called process-based or engineering economic models) instead represent the physical processes by which an industry converts inputs into outputs, and they usually include explicit variables describing investment and operating decisions of various types. As an example, a bottom-up model of steel production would explicitly account for the capacities of different types of steel production processes and the inputs they require (e.g., electric arc furnaces that use electricity to recycle steel scrap and integrated plants that make steel from iron ore, coal, and limestone using blast furnaces).

Bottom-up models compute market equilibria by assuming that companies operate and invest in production facilities to maximize profits, usually assuming conditions of perfect competition (such as perfect information and the absence of oligopolistic behavior). A well-known result is that a bottom-up model can simulate the result of a perfectly competitive market if it chooses the values of the operating and investment variables to maximize consumer benefits minus production costs. If demand does not respond to price, then production-cost minimization will also yield the competitive outcome.

The process detail of bottom-up models is what makes them useful for assessing the effect of environmental policy on production efficiency and emissions. First, efficiency and emission effects depend on the particular technology and inputs used to produce a product, which bottom-up models represent. Second, the health, ecosystem, and other effects of emissions depend on when and where the emissions take place, which bottom-up models can trace. Third, a regulation being studied may affect only particular operating or investment decisions for a subset of the processes or companies in an industry, a discrimination that can be represented in a bottom-up model.

On the other hand, bottom-up models have two weaknesses. The first is their detailed data needs. Largely because of federal reporting requirements and extensive state regulation, the necessary information on input costs, process efficiencies, and consumption patterns is available for the electric power industry.[6] However, this industry is an exception. For other industries that are less regulated and less concentrated and that produce a much more heterogeneous product, the data needed to build bottom-up models may be unavailable.

A second weakness can occur in the assumptions of rational profit-maximizing behavior and pure competition. Actual and modeled market behaviors can deviate significantly for several reasons: model simplifications, short-sighted decision making, non-economic objectives, market power, and inefficient market rules. Modelers have responded by developing approaches to sectoral modeling that recognize these market imperfections. Examples include agent-based models and oligopoly models. However, these approaches are not widely applied for policy making, in part because they often incorporate assumptions about how firms behave that are very difficult to verify.

Available data, relatively homogeneous outputs, and policy importance have made the agricultural and energy sectors the most common areas of application of bottom-up models. The use of bottom-up energy models by the federal government began with Project Independence in the 1970s, and both EPA and the U.S. Department of Energy have been enthusiastic consumers of such models since that time (Murphy and Shaw 1995). As an example of this type of model, electric power market simulation models generally have the following structure:

- *Decision variables:* locations, capacities, operating levels, inputs, and emissions of pollutants from generation and transmission facilities.
- *Objective function:* choose values of those variables to maximize consumer benefits minus investment and operation costs.

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[6] Recent transfers of existing generating assets from regulated utilities to unregulated firms has reduced the amount of detailed financial data that are being collected for the electricity-generation sector.

- *Constraints*: what values of the variables are feasible:
  —For each location and time period:
    - Generation plus net imports must equal quantity demanded.
    - Generation and transmission quantities must be equal to or less than capacities.
    - Kirchhoff's voltage law, and other physical relationships that determine power flows must be satisfied.

  —Local constraints on emissions and facility siting:
    - Emission caps defined over relevant regions and time periods.
    - Other regulatory restrictions.

Models that are created for specific markets, such as the Pennsylvania-Jersey-Maryland Interconnection, and that simulate short periods of time, such as operation over the next year, can represent much more detail about the transmission grid and the operation of particular generation plants. However, because power markets are national (and to some extent international) in scope,[7] as is the $SO_2$-emissions market, and because investments in this sector can have lifetimes of several decades, national models with a multidecade time horizon most commonly are used to analyze national energy and environmental policies. These models often also include explicit representations of supply and demand in fuel markets, whereas detailed regional models tend to treat prices of coal, natural gas, and other inputs as being fixed. The price that national models pay for their comprehensiveness is a necessarily simplified representation of power system operations—for instance, aggregating supply, demand, and emissions to census regions, as in the National Energy Modeling System (NEMS). This scale is too aggregate for detailed assessment of the health and other impacts of emissions because pollutant transport and transformation models require particular locations and timings for emissions. Therefore, the scenarios created by such national models on occasion are disaggregated to a county or similar scale.

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[7] The U.S. power market is divided into three autonomous regions: the Eastern Interconnection, the West, and the Electric Reliability Council of Texas. These regions also have important connections to Mexico and Canada.

Examples of national models that have been used to assess possible effects of NSR rule changes include EPA's Integrated Planning Model (IPM) and NEMS of the U.S. Energy Information Agency. IPM is a large, bottom-up model of the U.S. electric power industry that EPA frequently relies on for analyzing the impact of present and proposed policies and regulations on that sector's emissions and costs (EPA 2004s). It considers investment and operations on a multidecade time scale (e.g., 2005-2030), and its geographic disaggregation corresponds approximately to the National Electric Reliability Council regions. Similar generation facilities within a region are aggregated to limit model size. IPM represents the economics of power plant retrofits and retirements, which occur automatically when the benefits of these actions exceed the cost. Although in the long-run electricity consumption is price elastic, the model represents demand as fixed. This facilitates computation by allowing use of a cost-minimization objective and linear, rather than nonlinear, programming. This fixed demand assumption means that intersector competition is not considered.

NEMS, in contrast, provides less detail on the power sector but represents intersector interactions, such as natural gas-electricity substitution for household heating. NEMS is an interconnected suite of models for various components of the U.S. energy sector as well as models of the remainder of the U.S. macroeconomy and world energy markets (EIA 2003b). The model searches for a set of prices and quantities supplied and demanded that represents an equilibrium among modules representing oil and natural gas supply, natural gas transmission, coal supply, renewable fuels supply, electricity generation, petroleum fuels processing, and energy demands by residential, commercial, transportation, and industrial customers. The modules can also be run in stand-alone fashion—for example, for just the electricity sector subject to fixed energy demands. NEMS breaks down the results by nine census divisions and provides projections through the year 2025.

Electric power models of this type generally assume rational and perfectly competitive behavior by generators and that there are no obstacles to trade other than the transmission capacity limits. If the only environmental constraint is a total cap on emissions, then by definition the model will yield the lowest-cost solution for that level of emissions, which will be a point on the production possibility frontier in Figure 5-2.

However, model solutions may not be on that frontier, because of other regulatory restrictions in the model, such as NSPS or local air-quality restrictions. Of course, actual market outcomes also will not be on the dashed frontier, because electricity markets are evolving at different rates across the United States, trade is not completely free, generator behavior may not be rational, and the model may be missing many actual constraints or it might misrepresent costs.

Future projections are necessarily highly uncertain because of unforeseen economic, legal, and technological changes. For example, model runs done by EPA to support development of the Title IV acid rain program projected higher $SO_2$ compliance costs, more scrubbing, and less fuel switching than actually occurred, partly because prices and transport costs for western low-sulfur coal fell more quickly than anticipated. Therefore, sectoral models are best used to identify a range of possible outcomes and to gain insight into general relationships rather than to create specific numerical forecasts that, with current knowledge and methods, cannot be accurate in their details.

### Costs, Productivity Growth, and Innovation

A number of econometric studies have looked at the effects of environmental regulation generally on costs, productivity growth, and innovation within specific industries and within the economy more broadly. Studies by Barbera and McConnell (1986) and Gray (1987) used industry-level data and found statistically significant negative impacts of regulation on productivity growth, but the effects are not necessarily large. Gollop and Roberts (1983, 1985) estimated firm-level cost functions and marginal abatement costs for coal-fired utilities to study the effect of $SO_2$ regulation on productivity growth in the electricity sector as well as the regional effects of these regulations on the industry.

More recent studies of manufacturing industries take advantage of more-detailed plant-level data for manufacturing firms collected by the U.S. Census Bureau. In recent decades, the U.S. Census Bureau has made available plant-level economic data on manufacturing facilities collected as part of the quintennial Census of Manufacturers and Annual Survey of Manufacturers, which applies to larger facilities, making it feasible to use these more disaggregate data to look at how regulation has affected costs and productivity. For example, Greenstone (2002) used the plant-level database extending from 1972 to 1987 to examine the relationship between nonattainment status and measures of economic activity, including employment, investment, and shipments for plants in polluting industries. He found that plants in nonattainment counties have lower employment, lower shipments, and lower total capital stock than analogous plants located in attainment areas, but the size of these effects is relatively small. Numerous other studies have used these data to study the effects of regulation on specific industries including pulp and paper (Gray and Shadebegian 2003) and oil refineries (Berman and Bui 2001).

Econometric methods have also been used to study the effects of environmental regulation on R&D and innovation; many of those studies are reviewed by Jaffe et al. (2003). The empirical studies present mixed results. Lanjouw and Mody (1996) found a significant positive relationship between pollution abatement expenditures and patenting activities. Jaffe and Palmer (1997) found a positive relationship between pollution abatement expenditures and R&D expenditures but no impact of the former on patenting. Taylor et al. (2003) determined that CAA regulations have had a significant impact on air-pollution-control innovation and patenting. Other studies looked at the effects of energy price changes and explicit efficiency standards on the nature of technological change in appliances, focusing particularly on the energy-savings character of the innovations (Newell et al. 1999).

Another modeling approach that can be used to explore the impact of regulation on environmental performance involves using "adaptive agents" to simulate the innovation and production activities of multiple firms competing in a product market. The decisions of the agents evolve over time in response to changing consumer preferences and demand and regulatory decisions affecting costs, prices, and profitability. These models have been used to explore the factors that affect the evolution of green products and processes (Teitelbaum 1998; Axtell et al. 2002; Bulla and Allada 2003). However, they are still in the early stages of research development, and none has yet been advanced to the point where detailed decisions on plant maintenance and replacement of the type that are important to NSR rule making can be evaluated.

### Estimating Effects Across Multiple Sectors of the Economy

The sectoral assessments described in the section "Assessment of Sector-Wide Response" are concerned only with the direct effects of a policy on an industry and its immediate inputs and outputs. When firms modify their production levels or product designs in response to regulation or other incentives, the effects of these decisions ripple through the economy and affect other industries, including those that provide their inputs, those that use their products, quantities shipped, and associated emissions. These indirect or ripple effects can be important.

One type of indirect effect results from substitution among sectors. For instance, a policy aimed at reducing emissions from a particular sector might result in increased prices for that sector's output, shifting demands to other goods and services in the economy whose emissions then might increase. Electricity, for example, competes with natural gas, fuel oil, wood, and other fuels for home and water heating in various geographic markets in the United States, and policies that affect the price of electricity will influence the mix of fuels the residential sector consume. Another type of indirect impact is the result of upstream and downstream effects. As an example, the consideration of emissions only from the combustion of fossil fuels in power plants disregards emissions from other stages of the fuel cycle, including fuel extraction, transportation, and waste disposal.

Tracing indirect effects throughout the entire economy is the focus of life-cycle analyses and macroeconomic models that compute a general equilibrium outcome for multiple sectors of the economy. Each of these methods is briefly reviewed.

Studies that attempt to quantify ripple effects on the economy and the environment (as well as the direct effects from product manufacture) are referred to as life-cycle assessments (LCAs). The ripple effects occur "upstream" of the particular company, as modified orders to suppliers, their suppliers, and so forth. They also occur "downstream" of the production process because modified products and production quantity can result in changes in the emissions that occur during product use, reuse, recycling, and disposal.

LCAs can be performed by one of two methods: the process modeling approach or the economic input-output approach. The process method is the underlying principle behind a variety of LCA tools, most of which have been developed in Europe (Fruhbrodt 2004): the Society of Environmental Toxicology and Chemistry (SETAC) endorses this approach (Hendrickson et al. 1997). The process modeling approach requires that each aspect of a particular product's life cycle be analyzed and documented. The models require extensive databases on materials and manufacturing and nonmanufacturing processes and use these to estimate a wide range of economic, technical, social, and environmental impacts. Environmental impacts include factors such as resource depletion, acidification, eutrophication, global warming, human toxicity, freshwater aquatic toxicity, marine aquatic ecotoxicity, terrestrial toxicity, ozone layer depletion, tropospheric ozone creation, and radiation. Technical impacts include nonrenewable and renewable energy consumption and energy efficiency.

The second approach, based on economic input-output models, considers the full set of economic transactions between different sectors in the national economy. The general framework of the economic input-output model was developed by Nobel-Prize-winning economist Wassily Leontief, and it requires that a nation's economy be divided into sectors (typically about 500). The inputs and outputs of these sectors are then defined by the 500 × 500 matrix that quantifies the economic transactions between each. The total transactions that ripple through the economy (all upstream flows) are computed for each unit of economic activity, and these can be adjusted linearly to produce estimates for various dollar amounts of output. With this framework, an economic input-output model is capable of determining the total economic activity and associated environmental impacts from any purchase amount of a particular product or service. Because of the comprehensive data provided by the U.S. Census Bureau, the economic input-output model is able to trace even seemingly unrelated and insignificant transactions such as office computer paper used at a manufacturing plant. The Bureau of Economic Analysis also develops work files that are used to extract specific data points from the large input-output matrix produced by the U.S. Census Bureau. A model that uses this approach is the Environmental Input-Output Life Cycle Assessment program (Green Design Initiative 2004).

Another method for looking at the broader economic effects of an environmental policy change is the use of macroeconomic analysis, implemented with a computable general equilibrium (CGE) model. In contrast to an input-output model, which assumes that inputs are used in fixed proportions, the CGE model allows firms to adjust their mix of inputs in response to changes in relative prices. If, for example, a change in environmental regulations increases the demand for a particular fuel, thereby increasing its price, the CGE model allows that effect to feed through to other sectors. Although this additional flexibility provides a better representation of how industries would respond to regulation-induced price changes, it comes at a cost in terms of sectoral detail. Most CGE models have only aggregate sectoral detail, dividing the entire economy into between 5 and 25 economic sectors. When augmented with information on emission rates, CGE models can be used to look at the effect of the regulatory changes on direct emissions from regulated sectors and indirect effects on other sectors. CGE models have been implemented primarily at the scale of national economies and have been applied most frequently in the realm of environmental evaluation to address issues related to carbon control for climate change assessment, although national assessments have also been conducted for elements of the CAA (Jorgenson and Wilcoxen 1990a,b, 1993a,b; Manne et al. 1995; Fossati and Wiegard 2002).

Some models go further than just looking at emissions by incorporating air transport models that estimate impacts on pollutant concentrations and dose-response functions that translate air-quality changes into effects on human health and the environment. These models, known as integrated assessment models, often also include economic estimates of the monetary value of various changes in human health and environmental endpoints. These models have been used to analyze the benefits and costs of different environmental regulations including Title IV of the 1990 CAA Amendments (EPA 1997). More information on the type of modeling used to translate emissions into environmental effects is provided in the following section of this chapter.

LCAs, CGE, and integrated assessment models can provide useful information to evaluate the ripple effects of changes in production and demand that result from environmental regulation. However, given the difficulty in determining even the *direct* effects of NSR rules and rule changes on the production and emissions of regulated plants and industries, the use of a tool that translates these direct effects into estimates of changes in *indirect* economic activity and environmental emissions is premature at this time. As better estimates for direct effects are obtained and LCA and CGE tools are improved to allow more location- and plant-specific calculations, the use of these methods to estimate ripple effects should be considered.

### Estimating Environmental and Public Health Impacts

Quantifying the influence of changes in emissions on public health and welfare is a complex, multistage process involving the integration of multiple data streams with physical, econometric, and behavioral theories using statistical models and expert opinion (NRC 2002). Models are needed to evaluate the causal pathways from the effects of NSR rule changes, beginning with the relationship between changing plant emissions and ambient air pollution, followed by personal exposure, and then human health effects. Engineering, econometric, chemical, atmospheric, biomedical, and sociological theories and data are needed to inform these relations, but available empirical information is generally insufficient to the task. In some cases, data are not available; in others, data are incomplete or observational rather than experimental so apparent relations need to be adjusted. For example, in addition to changes in NSR rules, medium- to long-term trends in ambient pollution are influenced by emissions from other sources not affected by NSR rule changes and possible trends in weather or climate.

Trends in health outcomes likewise are affected by a variety of factors in addition to ambient air pollution, and even pollution effects can be modified by personal behavior (e.g., susceptible individuals may alter their behavior on high-pollution days). Additional complications arise from the need to assess relations over time and at relatively fine geographic scales. Because of the complexity of the relations and the relative lack of direct information, simulation models and complex statistical analyses are necessary to help sort out this causal network. These formal approaches are necessary to document assumptions, define and organize inputs and outputs, and, as much as possible, isolate the effects of NSR changes in the set of other candidate causes. A properly conducted and reported formal approach identifies relevant uncertainties and ensures that their influences are embedded in the outputs. Typically, the process begins with an estimate of how much emissions will change as an input, then estimates how these changes will affect exposure, and then estimates how these changes in exposure will affect human health.

## Ambient Concentrations and Exposure Outcomes

Once changes in emissions have been estimated, atmospheric dispersion models are needed to relate emission changes to temporally and spatially indexed ambient concentrations and deposition. Pollutant fate and transport are affected by stack height and diameter, pollutant exit temperature and velocity, and other site characteristics, so differentiating among sources and source categories is important. Because relevant atmospheric conditions such as temperature, humidity, wind speed and direction, and background pollution levels vary both seasonally and spatially, it is important to estimate where and when emission changes occur as well as the seasonal variations in these changes.

Assessments of the effects of changes in the NSR rules depend on estimating impacts of emission changes on ambient concentrations of primarily emitted pollutants such as $SO_2$, carbon monoxide, and large or fine primary particles ($PM_{10}$ and $PM_{2.5}$, respectively) as well as secondarily formed fine PM ($PM_{2.5}$) and ozone. In previous regulatory impact analyses of policies involving these pollutants, EPA applied multiple models with various degrees of sophistication, spatial coverage, and spatial resolution. For example, when evaluating the benefits and costs of the CAA (EPA 1999), EPA used the Urban Airshed Model (UAM) to evaluate ozone and combined the Regional Acid Deposition Model/Regional Particulate Model with the Regulatory Modeling System for Aerosols and Acid Deposition (REMSAD) to evaluate impacts on $PM_{2.5}$, $PM_{10}$, acid deposition, and visibility. Only a few historic episode dates were simulated and the geographic resolution was fairly coarse (56 × 56 kilometer grid spacing or greater over much of the country). More recently, EPA has used the Comprehensive Air Quality Model with Extensions (CAMx) for assessing ozone and is in the process of applying the Community Multi-scale Air Quality (CMAQ) model for its updated analyses of the Clean Air Interstate Rule.

A significant contributor to uncertainty in atmospheric modeling involves the formation and subsequent fate and transport of secondary pollutants (such as sulfate particles, nitrate particles, and ozone). The UAM captures many critical factors influencing ozone formation, including the spatial distribution of emissions of $NO_x$ and VOCs (including compositional information), spatially and temporally varying wind fields, diurnal variations of solar insolation and temperature, wet and dry deposition, and the Carbon Bond IV subroutine for chemical reactions among important species (EPA 1999).

But UAM has been shown to underestimate diurnal variability and has been recommended more for average patterns over longer time periods than for site-specific short-term estimates (Hogrefe et al. 2001). Similarly, REMSAD and related models contain modules for formation of secondary sulfates and nitrates, which depend on the relative ambient concentrations of sulfate, nitrate, and ammonium, solar insolation and temperature, wet and dry deposition processes, and other factors. Given the nonlinear and regionally varying relationship between changes in precursor emissions and changes in $PM_{2.5}$ concentrations (West et al.

1999), uncertainty beyond that of primary pollutant fate and transport should be anticipated.

Many uncertainties have been addressed in recent modeling efforts. Improved emission inventories, detailed gas-phase constituents, and hundreds of reactions have been incorporated in air-pollution models. Models with explicit microphysics and chemical thermodynamics have been developed that provide mechanistic descriptions of the partitioning of gas-phase pollutants to the particle phase. These provide a more accurate description of particle evolution (Seigneur et al. 1999). Basic aspects of secondary aerosol formation prompted by ozone photochemistry vary substantially among models, with few reproducing the observed afternoon maximum in particle growth (Pun et al. 2002). This critical feature of aerosol growth is common in many regions of the country, yet many widely used models do not adequately address it.

A fate-and-transport model with outputs used in a health benefits analysis does not have to accurately estimate at overly fine spatiotemporal scales. However, models are expected to perform well in estimating over long time frames and at relevant spatial scales. Local transport is insufficient, because studies have shown that a substantial portion of the health impacts of a source with an elevated stack can occur hundreds of kilometers from the stack (Levy et al. 2003). For secondary PM and ozone, such estimations are challenging, because detailed meteorologic and pollution data are required. Also, the models should be able to capture the time resolution that matches the evidence used to develop concentration-response functions. If 1-hour maximum ozone concentrations are associated with health outcomes, a model that lacks hourly concentration estimates will be deficient.

Estimation of spatiotemporal exposure gradients have relied on coupling physical models with data available from ambient monitoring stations coupled with statistical interpolation and smoothing models. The best of these provide space-time point estimates and relevant uncertainties using formal Bayesian models (Christakos et al. 2001).

Of course, personal exposures to pollutants can differ substantially from ambient concentrations. Efforts are being made to study the relationship between the two, but most epidemiologic, health effects studies have been based on data from monitors of ambient concentrations. Even though the locations of these monitors are not ideal for estimating population exposures (many were located to assess regulatory compliance), most health effects studies have relied on these data (NRC 2002). Many uncertainties in exposure relationships remain. For example, because people generally spend most of their time indoors, many individual factors will influence the relationship between personal exposure and ambient concentrations. However, to understand the impacts of changes in NSR, we are concerned with personal exposures to air pollutants of ambient origin. For pollutants such as PM, personal exposure to air pollutants of ambient origin is highly correlated with ambient concentrations (EPA 2003b). However, there is some evidence that ambient levels of gaseous criteria pollutants may be more strongly correlated with personal $PM_{2.5}$ exposures than with personal exposures to the gases themselves (Sarnat et al. 2001). In an exposure-health assessment, these and similar uncertainties should be documented and, to the extent possible, incorporated into the analysis.

### Relating Ambient Concentrations and Exposure to Health Outcomes

To evaluate health impacts of concentration changes, concentration-response functions are developed for key health outcomes—ranging from mild morbidity effects to premature mortality. For most health outcomes, epidemiologic studies are used to develop the concentration-response functions, with animal studies and human experimental studies providing corroborating evidence for causality (NRC 2002). Many studies are available that employ a variety of approaches. Integrating findings across multiple published studies (research synthesis; meta-analysis) is generally preferred to selecting single "representative" studies. The synthesis should be based on an underlying model or models, including multistage models that incorporate site or study characteristics if heterogeneity in effects is present (Levy et al. 2000; Dominici et al. 2003). To the extent possible, it is important to evaluate the independent effects of the pollutant in question, usually by regression adjustment for co-pollutants. Proper treatment of these issues often requires advanced statistical methods.

A critical component in this stage of the analysis is the evaluation of whether thresholds for the health effect are anticipated, or, more generally, whether the concentration-response function deviates from linearity. Most key epidemiologic evidence to date has not detected thresholds or statistically significant deviations from linearity (Daniels et al. 2000; Pope et al. 2002), although these studies (and most studies) have low statistical power to address these issues. The approach by EPA generally has involved computing a baseline estimate assuming no threshold and conducting sensitivity analyses for selected plausible thresholds. This has been considered a reasonable approach but is only one of many candidate options (NRC 2002).

Though some laboratory-controlled exposure studies of the short-term effects of air pollution are available, and there are a few "natural experiments" (Pope 1989; Friedman et al. 2001; Clancy et al. 2002; Marufu et al. 2004), most of the evidence on the health effects of ambient and indoor air pollution comes from observational studies that relate changes in health indicators to changes in exposure to air pollution. Estimates of acute exposure effects come from time-series studies. These studies relate short-term, within-location changes in air pollution to relative changes in death rates or other health outcomes. Because mortality rates is also associated with season, temperature, day of the week, and other pollutants, sophisticated statistical models using covariate adjustment and semiparametric regression are needed to adjust for long- and medium-term temporal variations and for other potential confounders. Estimates of long-term effects come from cohort studies. These studies follow individuals and use between-location variations in air pollution as the basis for estimating health effects. Both types of studies have their advantages and drawbacks, and research continues on reconciling estimates of effects (the cohort studies produce higher effects).

### Fitting Models and Characterizing Their Uncertainty

As identified above, simulation-based and statistical models are needed to sort out key relationships in the chain from emissions to health effects. Sophisticated simulation approaches have been applied by EPA and in a wide variety of other contexts. Sophisticated statistical models are needed to integrate information from a variety of sources, gathered over different spatial and temporal scales, and with different degrees of measurement error, biasing and confounding influences (Rothman and Greenland 1998; Robins 1999; Robins et al. 1999; Mugglin et al. 2000; Pearl 2000; Zeger et al. 2000). Sensitivity analyses are especially important to quantify the robustness or fragility of conclusions to changes in model (or simulation system) form and inputs.

There are a variety of methods for quantifying uncertainty in model inputs and outputs and for dealing with structural uncertainties in models and scenarios. Morgan and Henrion (1990) and Cullen and Frey (1999) provide an overview of such methods. Typically, uncertainties in the inputs to models can be quantified based upon statistical analysis of empirical data, the encoding of expert judgment in the form of probability distributions, or a combination of both. As an example, Bayesian methods provide an effective way to document assumptions; link information and expert opinion; guide analyses of complex, multilevel, nonlinear systems; ensure that all relevant uncertainties are incorporated and reported; and structure sensitivity analyses. Armitage et al. (2002) provide an excellent introduction; Carlin and Louis (2000) provide a more advanced treatment.

In any modeling or simulation exercise, two kinds of uncertainty operate: inherent stochastic (also called sampling uncertainty) and modeling uncertainty (also called nonsampling uncertainty) (see Morgan and Henrion 1990). The boundary between the two is fuzzy (some nonsampling uncertainties can be embedded in an overarching model), but a distinction can be made. Modeling uncertainties tend to dominate an assessment but generally are underexplored and underreported.

Although advanced statistical methods of the type described above are unlikely to be feasible for our evaluation (given both data and time limitations), we will attempt to highlight, at least qualitatively, key conceptual uncertainties in the modeling approaches that we use. Furthermore, EPA and others charged with addressing this issue over the long term should develop the capability for implementing these tools, as appropriate, in future assessments.

## SUMMARY EVALUATION OF APPLICABILITY OF ANALYSIS METHODS FOR ESTIMATING IMPACTS OF CHANGES IN NSR RULES

Whether the formal methods described in this chapter will have sufficient sensitivity to the NSR rule changes under investigation to be able to estimate their effects accurately remains to be determined. Nonetheless, insights into the behavior of individual firms might help in estimating how individual facilities could respond to the incentives created by the rule changes. If recent historical evidence supports these behavioral models, this might then allow an assessment of at least the direction of the impacts of these changes on the outputs of concern (e.g., whether emissions are likely to increase or decrease) and possibly an estimate of the magnitude of the impact for typical facilities in different industrial sectors. Some models of the electricity-generating sector appear to be sufficiently detailed and sensitive to allow conclusions about the responses of individual facilities to be aggregated to the entire industrial sector. Long-term simulations with these models could allow a first assessment of how changes in NSR rules might affect technology adoption and emission trends. However, such a model would have to be subjected to thorough sensitivity analysis to see how much the conclusions change with different input assumptions and scenarios—for example, concerning the rate of innovation, the stringency of regional or national caps on pollutant emissions, surrenders of emissions allowances under NSR settlements, and the cost of alternative electricity-generation and pollution control technologies. Furthermore, models with the capacity for representing alternative technologies in a long-term simulation are not available for other sectors, and the time and resources available to the committee are not sufficient to support the construction of sector models for this purpose. For these other sectors, therefore, any generalization from the estimates of facility-level responses to estimates of industrial-sector responses will have to be undertaken more informally.

For the most part, the multisector models are even less able to represent the types of changes we are assessing than the sector models. Modifying the available models so that they can reflect these changes is substantially beyond the committee's capacity or resources. Therefore, any intersector impacts will also have to be assessed informally, and any estimates of their direction or magnitude are likely to be highly uncertain.

The most appropriate way of assessing the impacts on health and other outcomes of any emission changes estimated on the basis of the above assessments will depend substantially on the amount and quality of information resulting from these assessments. In many cases, the human health impacts, for instance, are likely to depend on which specific facilities change their emissions in response to the rule changes, who is exposed to the emissions from these facilities, and the ambient air quality in the vicinity of these facilities before the alterations occur. It is unlikely that we will be able, at least in most cases, to make estimations with such specificity. Where we cannot, attempting to undertake sophisticated modeling of human health impacts would have little validity, and we probably will be able to do little more than indicate the likely direction and possibly the rough magnitude of these impacts, if any.

As discussed in Chapter 6, it will be necessary to consider a range of possible scenarios for the economic and environmental assumptions that are applied to estimate and compare outcomes from the revised NSR rules with outcomes from the NSR rules before to the revisions.

# 6

# A General Approach to Assessing Impacts of NSR Rule Changes

## INTRODUCTION

In this section, a general approach to considering the impacts of New Source Review (NSR) rule changes on emissions, energy efficiency, innovation regarding pollution prevention and pollution control, and public health is outlined. A key feature of this approach is recognition that future developments in other air-pollution laws and regulations can profoundly influence those impacts and that those impacts can vary from one industry to another. Therefore, the committee plans to assess impacts under alternative scenarios concerning those developments using appropriate methods discussed in Chapter 5 to the extent practicable. This scenario approach is described in the next section. Within each scenario, the effects of the rule changes are addressed by describing possible pathways by which each of the rule changes could affect industry decisions, followed by a screening of those pathways for plausibility and significance of impacts and identification of possible interactions among the rules. Both steps are described briefly in this chapter to present important features of our pending analyses, and both will be developed in greater detail in the committee's final report. Although our general approach should be considered preliminary, we emphasize two of the most important dimensions needed in a prospective assessment of NSR rule changes: assessing impacts under alternative regulatory scenarios and systematically determining the plausibility and significance of pathways by which rule changes could affect industry decisions.

## SCENARIOS OF REGULATORY BACKDROPS AND NSR RULES

As discussed in Chapter 2, NSR is not the only Clean Air Act program that affects air emissions by industry. For instance, in the case of sulfur dioxide ($SO_2$) emissions by electric power generators, the Title IV emissions trading system and state implementation plans (SIPs) both impose their own constraints. The incremental effect of NSR rule changes on a particular facility and industry will depend at least in part on how tight these other regulations are. Future developments in those regulations are a major uncertainty in assessing the impact of NSR.[1]

Another uncertainty is what the effect of the old NSR rules would be if left in place. It is unknown whether the courts would ultimately sanction a stringent interpretation of those NSR rules. Conflicting federal district court decisions, summarized in Chapter 2, mean that the ability of the EPA to use the old NSR rules to force substantial investments in pollution control, at least on the power industry, is unknown at the time of this writing.

It is not possible to state with any confidence what would happen with other regulations or with NSR interpretation if the old rules were to remain in place. Because the net impacts of the changes made to the NSR rules of 2002 and 2003 can depend strongly on the scenario, it is important to assess those impacts under each possibility. Furthermore,

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[1] Continuing with the $SO_2$ example, we point out in Chapter 5 that a reduction in the national $SO_2$ emissions cap for power generators would cause total national emissions to decrease and emissions allowances to have a relatively high price. When allowances have value, power plants that reduce emissions in response to NSR will sell those allowances, if they are permitted to so, to other power plants. In that scenario, the incremental effect of NSR enforcement would then be reduced. Then the health impacts that may result will depend on how those national emissions are rearranged in time and space, perhaps improving or perhaps worsening. On the other hand, if stringent interpretation of the old NSR rules would result in surrenders of allowances in some cases, as has occurred (see Chapter 2), then the national cap (e.g., the present Title IV cap of 8.95 million tons/year) is effectively tightened, and national emissions would fall as a result of NSR enforcement. Whether those surrenders would remain in effect should the Title IV cap be reduced further by Congressional or U.S. Environmental Protection Agency (EPA) action is relevant to an assessment of emissions and health impacts of the new NSR rules. Also, stringent NSR interpretation that yields significant amounts of scrubber installation or coal plant retirements could cause total emissions to fall below the cap.

because the effect of other regulations varies across types of sources, these assessments should be done separately for different industries. Table 6-1 outlines the general scenarios that will be considered for each major industry and pollutant.[2]

The precise scenarios concerning other regulations or NSR interpretation might depend on the pollutant and the industry. For some industries, there may be no relevant non-NSR regulatory changes that have been proposed that would affect their emissions, in which case only Scenarios 1a and 1b would be considered. For other industries, especially the power industry, the strictness and scope of emission caps might be the relevant non-NSR regulation to be considered, whereas, for still other industries, other regulations might be most relevant to consider. For all regulatory scenarios, we will consider the time horizon of the regulation and any secondary effects associated with implementation of the regulation, such as the delayed or accelerated implementation of other air-quality regulations.

## ASSESSING IMPACTS OF INDIVIDUAL SCENARIOS

Given this scenario analysis framework, a formalized approach is needed to articulate and address the significant primary and secondary impacts of the NSR rule changes. Because many of the rule changes provide some incentives that theoretically could increase emissions and others that might decrease them, it is important to systematically determine which incentives will dominate under various policy scenarios.

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[2] For the case of power-sector nitrogen oxide ($NO_x$) emissions, as an example, the "no-change" scenario would be the present "SIP-call" cap on summer emissions in 19 eastern and midwestern states. A "stricter" scenario might be, for instance, the EPA Clean Air Interstate Rule proposal for a year-round cap in a larger 28-state region, which likely would force additional reductions, or one of the legislative alternatives considered in the 2003-2004 Congress. An intermediate case could be a proposal of intermediate strictness. Meanwhile, the "aggressive enforcement" scenario for old NSR rules could involve assumptions about substantial retrofits of, for instance, selective catalytic reduction or other $NO_x$-control investments as a result of NSR enforcement actions, accompanied by surrenders of allowances, so that total regional emissions fall. On the other hand, less aggressive enforcement might imply few such retrofits. Specification of the scenarios should reasonably consider possible outcomes of court decisions or legislative action.

**TABLE 6-1** Scenarios to Compare with Revised NSR Rules[a]

| | Other Regulations Applied to NSR-Affected Facilities | | |
|---|---|---|---|
| Old NSR Rules | 1. No Change | 2. Intermediate | 3. Stricter |
| a. Stringent interpretation | Scenario 1a | Scenario 2a | Scenario 3a |
| b. Less stringent interpretation | Scenario 1b | Scenario 2b | Scenario 3b |

[a]Revised NSR rules will be compared with each scenario about old-rule stringency under a given set of other air-quality regulations.

Although the committee does not develop this approach in full in this interim report, we briefly discuss key elements that might be helpful in ultimately determining the net impacts of the rule changes.

The amount of quantitative information available varies across sectors. Especially for rule changes that largely affect non-electricity-generation sources, the committee may be limited in its ability to quantify emissions or energy efficiency changes and therefore initially may need a more qualitative approach. If the committee cannot simulate the net impacts on plant or industry behavior via models such as the Integrated Planning Model (IPM) or National Energy Modeling System (see Chapter 5), a logical first step involves articulating all the theoretically possible effects the rule change could have on plant and industry behaviors. These behaviors include maintenance, production, and retirement decisions concerning existing facilities as well as investment in new facilities. Many of these effects would be identified from previous analyses and from knowledge about how similar regulatory programs have operated previously. It is important to consider secondary impacts of the rule changes—for example, if a rule change influences retirement decisions and thus the life expectancy of a subset of facilities, which in turn will affect the market for new facilities (and therefore emissions from the entire industry sector). At this stage, the committee will be as comprehensive as possible, including pathways for which evidence has been only anecdotal or where the impacts are hypothetical, given no prior experience. The purpose of this analytical step would be to ensure that no significant pathways are omitted, with the strength of the evidence to be analyzed subsequently.

Then, the committee will evaluate each pathway to determine both its plausibility and the likely direction and magnitude of the emission changes. For the electricity-generation sector, the committee will propose a set of analyses using sector-wide models such as IPM, encompassing a wider range of possible regulatory and technological developments than considered previously.[3] For data-limited industries, the committee proposes a qualitative assessment—not likely, possible, and likely accompanied by small, medium, and large emission increases and decreases. Empirical data, to the extent that they are available and pertinent, will be used. These assessments will depend in part on the regulatory landscape outside of NSR, so the committee will consider whether either the emissions change or the likelihood of the pathway varies across the matrix in Table 6-1.

Based on this assessment, the committee will focus on those rule changes, industries, and pathways that appear likely to contribute substantially to changes in emissions, pollution prevention, pollution control, and changes in energy efficiency. We will conduct this analysis on a pollutant-by-pollutant basis, evaluating factors such as geographic location, stack height, and proximity to population centers that might, for example, cause an industry sector with lower emissions to have more significant public health impacts. Evaluation of dominant pollutants and source characteristics will help further determine the most significant contributors to emissions, population exposure, and human health impacts and will help the committee focus on data sources that may support additional quantitative analyses.

Within this analytical framework, the committee also must consider interactions between the pathways. It is possible that the influence of two simultaneous rule changes will not be equivalent to the sum of the effects of the rule changes taken independently, because the rule changes represent a package that firms and industries will consider when making emission-control decisions. As mentioned previously, the committee will consider the potential for synergy and antagonism across a matrix of regulatory landscapes.

Implementing this analytical approach will be complex. Data are limited and the "scenario space" is large; there are numerous uncertain-

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[3] Additional policy and technology scenarios that could be undertaken include stringent interpretation of the old NSR rules, resulting in reduction of emissions below applicable caps; significant surrender of allowances under NSR settlements; and possible technology and economic developments that could result in a high penetration of renewable generation sources. Moreover, changes in electric power market designs, tax policy, or the relative prices of various technologies could influence the response of the electric utility sector to regulatory policy shifts.

ties. However, the committee has concluded that this enumerative approach will help to uncover high-leverage rule changes and the pathways by which they may influence emissions and energy efficiency. This identification will help to structure and scope a more formal analysis.

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# Terms and Abbreviations

| | |
|---|---|
| BACT: | best available control technology (This is the level of control required to obtain a PSD permit.) |
| Btu: | British thermal unit |
| CAA: | Clean Air Act, codified at 42 U.S.C. § 7401 et. seq. |
| CAFE: | corporate average fuel economy |
| CASAC: | Clean Air Scientific Advisory Committee |
| CEM: | continuous emission monitoring |
| CGE: | computable general equilibrium |
| Criteria pollutant: | The Clean Air Act requires EPA to set National Ambient Air Quality Standards (NAAQS) for certain pollutants known to be hazardous to human health and the public welfare (for example, damage to forests and degradation of atmospheric visibility). In addition, these pollutants should be ones whose presence in ambient air results from numerous or diverse mobile or stationary sources. EPA has identified and set standards to protect human health and welfare for six pollutants: ozone, carbon monoxide, particulate matter ($PM_{10}$ and $PM_{2.5}$), sulfur dioxide, lead, and nitrogen oxide. The term criteria pollutants derives from the requirement that EPA must describe the characteristics and potential health and welfare effects of these pollutants. It is on the basis of such criteria that NAAQS are set or revised. |
| EIA: | U.S. Energy Information Administration |

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|---|---|
| EPA: | U.S. Environmental Protection Agency, the agency that implements the Clean Air Act. |
| ERP: | equipment replacement provision |
| ESP: | electrostatic precipitator |
| FCCU: | fluid catalytic cracking unit |
| FGD: | flue gas desulfurization |
| HAP: | hazardous air pollutant |
| HRSG: | heat recovery steam generator |
| $HNO_3$: | nitric acid |
| $H_2S$: | hydrogen sulfide |
| IECM: | Integrated Environmental Control Model |
| IGCC: | integrated gasification combined cycle |
| IPM: | Integrated Planning Model |
| LAER: | lowest achievable emission rate (This is the level of control required to obtain a Part D NSR permit.) |
| LCA: | life-cycle assessment |
| LNB: | low-$NO_x$ burners |
| MACT: | maximum available control technology |
| NAAQS: | National Ambient Air Quality Standards (Many of the mechanisms of the Clean Air Act are aimed at attaining and maintaining compliance with these standards.) |
| NaOH: | sodium hydroxide |
| $Na_2S$: | sodium sulfide |
| NEI: | National Emissions Inventory |
| NEMS: | National Energy Modeling System |
| NERC: | National Electric Reliability Council |
| $N_2O$: | nitrous oxide |
| $N_2O_4$: | dinitrogen tetroxide |
| $N_2O_5$: | dinitrogen pentoxide |
| NO: | nitric oxide |
| $NO_2$: | nitrogen dioxide |
| $NO_3$: | nitrogen trioxide |
| $NO_x$: | nitrogen oxides |
| $NO_y$: | sum of $NO_x$ and other oxidized compounds |
| NPRA: | National Petrochemical and Refiners Association |
| NRC: | National Research Council |
| NSPS: | new source performance standard |

| | |
|---|---|
| NSR: | New Source Review (The collective name for the Part D NSR and PSD programs.) |
| ODS: | ozone-depleting substance |
| OTC: | Ozone Transport Commission |
| PAL: | plant-wide applicability limitation (A PAL limits emissions from a source or facility as a whole.) |
| Part D NSR: | This is the NSR program that applies to sources seeking permits in areas whose air quality violate the NAAQS. |
| PCP: | pollution control project |
| PM: | particulate matter |
| $PM_{2.5}$: | particles less than 2.5 µm in aerodynamic diameter, called fine particles |
| $PM_{10}$: | particles less than 10 µm in aerodynamic diameter |
| ppm: | parts per million |
| PSD: | prevention of significant deterioration (This is the NSR program that applies to sources seeking permits in areas whose air quality complies with the NAAQS.) |
| R&D: | research and development |
| REMSAD: | Regulatory Modeling System for Aerosols and Acid Deposition |
| SCR: | selective catalytic reduction |
| SIC: | Standard Industrial Classification |
| SIP: | state implementation plan (Every state must prepare a plan to show how it will attain and maintain the NAAQS.) |
| SNCR: | selective noncatalytic reduction |
| $SO_2$: | sulfur dioxide |
| TVA: | Tennessee Valley Authority |
| UAM: | Urban Airshed Model |
| VOC: | volatile organic compound |

# Appendix A

## BIOGRAPHICAL INFORMATION OF COMMITTEE

**Charles F. Stevens** (Chair) is a Howard Hughes Medical Institute Investigator and the Vincent J. Coates Professor of Molecular Neurobiology at the Salk Institute for Biological Studies in La Jolla, CA. Previously, he was professor and Chair of the Section of Molecular Neurobiology at the Yale University School of Medicine. Dr. Stevens's research centers on mechanisms responsible for synaptic transmission in the central nervous system, using a combination of molecular biological, electrophysiological, anatomical, and theoretical methods. He is a member of the National Academy of Sciences and the American Academy of Arts and Sciences. Dr. Stevens served on a number of NRC committees and as chair of the Committee on Possible Effects of Electromagnetic Fields on Biological Systems. In addition to his publications in the field of neurobiology, he authored a book on the core theories of modern physics. Dr. Stevens serves as an advisor to a telecommunications firm on the possible health effects of cell phone use. He received his M.D. from Yale University School of Medicine and his Ph.D. from Rockefeller University.

**Jean M. Andino** is an associate professor in the Department of Environmental Engineering Sciences at the University of Florida. She is also affiliated with the university's School of Natural Resources and the Environment and serves as the Technical Leader for Air Revitalization in the NASA-Johnson Space Center-sponsored Environmental Systems Commercial Space Technology Center. Her research focuses on air pollution, specifically the chemical kinetics and mechanisms pertinent to air pollutant formation and control. From 1997 to 2002, Dr. Andino was a National Science Foundation CAREER award recipient. She earned her Ph.D. in chemical engineering from the California Institute of Technology.

**Lyle R. Chinkin** is the senior vice president for Emissions, Policy, and Geographic Information Systems Services at Sonoma Technology, Inc. (STI). He also serves as STI's corporate General Manager. Those business areas encompass the preparation and assessment of stationary and mobile source emission inventories for use in air quality analyses and control strategy development. Mr. Chinkin has expertise in emission inventory preparation and assessment and air quality analyses. He has performed numerous emission inventory and air quality studies primarily for government agencies. He also has directed analyses for industrial associations. His work involves emission inventory field measurements, surveys, development, improvement, preparation, and evaluation. Mr. Chinkin earned an M.S. in atmospheric science from the University of California, Davis.

**Herek L. Clack** is an assistant professor of mechanical and aerospace engineering at the Illinois Institute of Technology in Chicago. His research interests include transport processes within multiphase flows, and design and development of advanced thermofluid processes with application toward combustion and combustion emissions. Currently, his primary research involves developing methods to control mercury emissions from coal-fired electric power plants. In January, 2004, Dr. Clack was awarded a National Science Foundation Faculty Early Development CAREER award. He received his Ph.D. in mechanical engineering from the University of California, Berkeley.

**Edwin H. Clark, II** is president of Clean Sites Inc. in Alexandria, VA. He is a former secretary of Natural Resources and Environmental Control for the State of Delaware, vice president of the Conservation Foundation, vice president of the World Wildlife Fund, and associate assistant administrator for pesticides and toxic substances in EPA. He has served as a member of the National Research Council's Board on Environmental Studies and Toxicology and on several committees, including the Committee on Risk-Based Criteria for Non-RCRA Hazardous Waste and the Committee to Review EPA's Research Grants Program. He holds a Ph.D. in applied economics from Princeton University.

**John C. Crittenden** is the Richard Snell Presidential Chair in the Department of Civil and Environmental Engineering at the Arizona State University (ASU). His research expertise includes sustainability, pollution prevention, physical-chemical treatment processes in air and wastewater, and modeling of fixed-bed reactors and adsorbers. Dr. Crittenden is the codirector of the Sustainable Technologies Program at ASU and directed the National Center for Clean and Industrial and Treatment Technologies (CenCITT) for 10 years. CenCITT conducted research on environmentally responsible manufacturing and involved 60 faculty from 16 academic units and over 200 graduate students. Dr. Crittenden is a member of the National Academy of Engineering. He is an associate editor of the journal *Environmental Science and Technology*. Dr. Crittenden received a Ph.D. in civil and environmental engineering from the University of Michigan.

**H. Christopher Frey** is a professor in the Department of Civil, Construction, and Environmental Engineering at the North Carolina State University. Dr. Frey's research is in the areas of environmental control, energy utilization, and modeling methods applicable to exposure assessment. He is involved in a number of different projects, including assessment of advanced technology for controlling sulfur dioxide and nitrogen oxide emissions from coal-fired power plants, advanced electric power generation and end-use technologies for transfer to developing countries, and optimal design capability for coal gasification systems. Dr. Frey's research and consulting work has been funded by a number of sources, including EPA, DOE, NSF, consulting firms, industry, universities, and nonprofit organizations. Dr. Frey has contributed to assessments and guidance documents particularly pertaining to uncertainties in emissions characterization, exposure assessment, and risk assessment for organizations such as the Intergovernmental Panel on Climate Change (IPCC), NARSTO, and the World Health Organization and Food and Agriculture Organization (WHO/FAO). He serves on EPA’s Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) Scientific Advisory Panel and is president-elect of the Society for Risk Analysis. He earned a Ph.D. in engineering and public policy from Carnegie Mellon University.

**Benjamin F. Hobbs** is a professor in the Department of Geography and Environmental Engineering and the Department of Applied Mathematics and Statistics (joint) at Johns Hopkins University. Dr. Hobbs’s research activities involve the development and application of systems analysis and economic methods to analyze energy, water, and environmental problems. He currently has research projects investigating regulatory and economic influences on the electric power sector. Dr. Hobbs has received funding for research and consulting from various sources including EPA, U.S. Geological Survey, National Science Foundation, and industry, such as the Baltimore Gas & Electric Corporation and the Electric Power Research Institute. He is a member of the California Independent System Operator Market Surveillance Committee. His Ph.D. is in environmental systems engineering from Cornell University.

**Jonathan I. Levy** is an assistant professor of environmental health and risk assessment in the Departments of Environmental Health and Health Policy and Management at the Harvard School of Public Health. Dr. Levy's research centers on developing models to quantitatively assess the environmental and health impacts of air pollution on local, regional, and national scales, the focus being on urban environments. This work involves the evaluation of exposure using a combination of atmospheric dispersion modeling, predictive statistical models, and field measurements. Dr. Levy has published several papers that model emissions from power plants. He earned a Sc.D. from the Harvard School of Public Health.

**Thomas A. Louis** is professor of biostatistics at the Johns Hopkins Bloomberg School of Public Health. He earned a Ph.D. in mathematical statistics from Columbia University. His research interests include risk assessment, environmental health and public policy, and development of related statistical approaches. Current applications include assessing the health effects of airborne particulate matter, assessing the cardiopulmonary complications of AIDS therapy, and clinical quality improvement. He is a fellow of the American Statistical Association and of the American Association for the Advancement of Science. He serves on the Health Review Committee of the Health Effects Institute and on the EPA's Science Advisory Board Drinking Water Committee. Dr. Louis's previous National Academies service includes the Committee on National Statistics, the Board of the Institute of Medicine (IOM) Medical Follow-up Agency, the IOM Panel to Assess the Health Consequences of Service in the Persian Gulf War, the Panel on Estimates of Poverty for Small Geographic Areas, and the Committee on the Use of Third Party Toxicity Research with Human Research Participants. He also chaired the Panel on Formula Allocation of Federal and State Program Funds.

**Brian F. Mannix** is a senior research fellow in the Regulatory Studies Program of the Mercatus Center at George Mason University. Previously, he served in a variety of positions, including deputy secretary of natural resources under Virginia Governors George Allen and Jim Gilmore and director of science and technology studies for the Manufacturers Alliance for Productivity and Innovation. In addition, he has worked within numerous federal government agencies, including the EPA, the Department of Energy, the Office of Management and Budget, and the Council on Wage and Price Stability. Mr. Mannix received an A.M. in chemistry from Harvard University and an M.P.P. in public policy from the Kennedy School of Government.

**Joe L. Mauderly** is vice president of the Lovelace Respiratory Research Institute; president of its subsidiary, the Lovelace Biomedical and Environmental Research Institute; director of one of its research programs, the National Environmental Respiratory Center; and former director of the Inhalation Toxicology Research Institute. Dr. Mauderly received his D.V.M. degree from Kansas State University, and after brief periods in clinical practice and the U.S. Air force, specialized in research on comparative respiratory physiology, comparative pulmonary responses to inhaled toxicants, and the adverse effects of materials inhaled in the workplace and environment. During the past decade, his research has focused on the health effects of complex mixtures of air contaminants, including engine emissions. He is an adjunct professor of medicine at the University of New Mexico and on the editorial board of *Inhalation Toxicology*. He is a member of the Particulate Matter Panel of EPA's Clean Air Scientific Advisory Committee (CASAC) and member or chairman of several research center advisory committees. His past appointments include chairman of the CASAC of the EPA Science Advisory Board, chair and member of several National Research Council committees, chairman of the Environmental and Occupational Health Assembly of the American Thoracic Society, president of the Inhalation Specialty Section of the Society of Toxicology, member of the Research Committee of the Health Effects Institute, chairman of the Air Pollution Health Advisory Committee of the Electric Power Research Institute, associate editor of *Fundamental and Applied Toxicology*, and editorial board member of *Experimental Lung Research*.

**Craig N. Oren** is a professor at the Rutgers School of Law. Mr. Oren has written extensively on the Clean Air Act, including the New Source Review provisions of the Act. He received his A.B. and J.D. degrees from the University of California, Berkeley. From 1979 to 1983, Mr. Oren served as assistant counsel to the Subcommittee on Health and the Environment of the House Energy and Commerce Committee. He served on the Committee on Risk Assessment of Hazardous Air Pollutants and the Committee on Haze in National Parks and Wilderness Areas.

**Karen L. Palmer** is a senior fellow at Resources for the Future in the Quality of the Environment Division. She served as an economist with the Federal Energy Regulatory Commission, Office of Economic Policy. Her research interests include the environmental and economic consequences of electricity restructuring and of new environmental policy proposals targeted at the electricity sector; the regulation of solid waste and recycling; and the cost-effectiveness of environmental regulation. Dr. Palmer also is studying the costs and environmental benefits of the product stewardship movement, which among other things encourages industry to play a more active role in dealing with the environmental consequences of products at the end of their useful lives. She received a Ph.D. in economics from Boston College.

**Lynn M. Russell** is an associate professor in the Center for Atmospheric Sciences, Scripps Institution of Oceanography, University of California, San Diego. Her research is in the area of aerosol particle chemistry, including the behavior of particles under pristine and anthropogenically influenced conditions. Her research interests span experimental and modeling approaches to aerosol evolution in the atmosphere, incorporating chemical and physical mechanisms in aerosol-cloud interactions, organic aerosols, and their radiative effects. She has served on several NRC committees, including the Panel on Aerosol Radiative Forcing and Climate Change, the Committee to Review NARSTO's Scientific Assessment of Airborne Particulate Matter, and the Panel on Atmospheric Effects of Aviation. She holds a Ph.D. in chemical engineering from the California Institute of Technology.

**Mitchell J. Small** is the H. John Heinz III Professor of Environmental Engineering in the Departments of Civil and Environmental Engineering and Engineering and Public Policy at Carnegie Mellon University. He earned his Ph.D. in environmental and water resources engineering from the University of Michigan. Dr. Small's research focuses on mathematical modeling of environmental quality, including statistical methods and uncertainty analysis, human exposure modeling, indoor air pollution, human risk perception and decision making, and integrated assessment models for acid deposition and global climate change. Dr. Small has served on EPA's Office of Research and Development's Board of Scientific Counselors and is currently a member of EPA's Science Advisory Board. He has served on several NRC committees, including the Committee on Remediation Priorities for Hazardous Waste Sites and the Committee on Environmental Remediation at Naval Facilities. Dr. Small is an associate editor for the journal *Environmental Science & Technology*.

**Ira B. Tager** is professor of epidemiology in the Division of Public Health, Biology, and Epidemiology at the University of California, Berkeley, and is codirector and principal investigator for the Center for Family and Community Health. He holds an M.D. from the University of Rochester School of Medicine and an M.P.H from the Harvard School of Public Health. Dr. Tager's research interests include the development of exposure assessment instruments for studies of health effects of chronic ambient ozone exposure in childhood and adolescence, the effects of ozone exposure on pulmonary function, and the effects of oxidant and particulate air pollution on cardiorespiratory morbidity and mortality as well as morbidity from asthma in children. Dr. Tager was a member of the NRC Committee on Air Quality in Passenger Cabins of Commercial Aircraft. He currently serves as a member of the Research Committee for the Health Effects Institute.

**John G. Watson** is a research professor in the Division of Atmospheric Sciences at the Desert Research Institute in Reno, Nevada. His research includes the development and evaluation of measurement processes, receptor models for source apportionment, and the effects of measurement uncertainty on model results. Dr. Watson is the primary author of a chemical mass balance receptor model and its application and validation protocol. Dr. Watson is currently principal investigator for the California regional particulate and air quality study, the Fresno Supersite, the southern Nevada air quality study, and for a Department of Defense program to quantify emissions from nonroad diesel engines. He recently completed the 2002 Air and Waste Management Association's critical review of *Visibility: Science and Regulation* that examined evolution and scientific justification for EPA's Regional Haze Rule. He earned a Ph.D. in environmental science from the Oregon Graduate Institute.

# Appendix B

## CONGRESSIONAL MANDATE[1]

As soon as practicable after the date of enactment of this Act, the Administrator of the Environmental Protection Agency shall enter into a cooperative agreement with the National Academy of Sciences to evaluate the impact of the final rule relating to prevention of significant deterioration and nonattainment new source review, published at 67 Fed. Reg. 80186 (December 31, 2002). The study shall include

1) increases or decreases in emissions of pollutants regulated under the New Source Review program;
2) impacts on human health;
3) pollution control and prevention technologies installed after the effective date of the rule at facilities covered under the rulemaking;
4) increases or decreases in efficiency of operations, including energy efficiency, at covered facilities; and
5) other relevant data.

The National Academy of Sciences shall submit an interim report to

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[1] Conference Report on H.J. RES. 2, Consolidated Appropriations Resolution, 2003.

Congress no later than March 3, 2004, and shall submit a final report on implementation of the rules.

In 2004, following EPA's promulgation of the equipment replacement rule, published in 68 Fed. Reg. 61248 (October 27, 2003), Congress amended the provision shown above to include an identical study of the equipment replacement rule. The National Academy of Sciences was required to issue an interim report by January 1, 2005. This report responds to that charge.

# Appendix C

## STATEMENT OF TASK

An NRC committee will evaluate potential air quality, public health, and other impacts of EPA's final rules of December 31, 2002, and October 27, 2003, relating to "prevention of significant deterioration" in areas currently meeting air quality standards and "new source review" in areas that do not currently meet air quality standards. The programs are collectively referred to as NSR. Taking into account the relatively short time that will have elapsed since the promulgation of the rule and the economic conditions that have prevailed in the interim, the committee will consider the data and methods necessary to assess specific effects of the NSR rules expected to occur in the coming years. To the extent possible, the committee will utilize such approaches to estimate and evaluate the following:

- Resulting increases or decreases in emissions of pollutants regulated under the NSR program;
- Resulting impacts on human health;
- Pollution control and prevention technologies to be installed after the effective dates of the rules at facilities covered under the NSR rulemaking;
- Increases or decreases in efficiency of facility operations, including energy efficiency, at new and existing facilities covered by the NSR rule;
- Other relevant data; and

- The amount of uncertainty associated with estimates of the effects mentioned above.

Having reviewed and evaluated the available data, the committee would be expected to identify and recommend additional data collection that would be necessary in the future years going forward to assess impacts.

In addition to a final report, the committee will provide an interim report containing all conclusions and recommendations the committee determines to be feasible and appropriate at that stage in its study.

Sponsor: U.S. Environmental Protection Agency.

# Appendix D

## REPAIR AND REPLACEMENT ACTIVITIES IN SELECTED INDUSTRIES

A summary of common repair and replacement activities for specific areas of a typical coal-fired power plant is given Table D-1. The table does not attempt to summarize less frequent major replacements at a plant, such as repowering with a new furnace using an existing steam cycle or replacing major components (e.g., turbine generator) with an entirely new system.

Table D-2 presents the aggregated responses to a National Petrochemical and Refiners Association (NPRA) member survey, initiated in response to an information request from the committee. Sixty-four petroleum refineries responded to the survey, constituting half (8,808,122 barrels/day) of the total U.S. petroleum refining capacity (16,894,314 barrels/day) (EIA 2004c). Table D-2 presents approximately 60 activities that typically are undertaken as repair and replacement at petroleum refineries. Each activity is listed along with an estimate of how frequently it occurs and its cost. The cost of each activity is presented as a percentage of the total replacement cost of the major process unit with which the activity is associated. For example, replacing or repairing the fluidized catalytic cracking unit (FCCU) regenerator cyclones is estimated to occur at intervals of 3-5 years or longer. The cost of this activity is estimated to be up to 10% of the replacement cost of the FCCU. Because not all refineries are of the same size and configuration, there are likely to be variations in the replacement cost percentages. The results presented in this survey, though not exhaustive, illustrate the diverse nature of repair and replacement activities typically undertaken at petroleum refineries.

Table D-3 lists repair and replacement and other activities specific to kraft mills that are periodically undertaken. Both the structure of Table D-3 and its contents were provided by representatives of International Paper, Inc., in response to an information request from the committee. Table D-3 lists approximately 90 repair and replacement activities that are periodically undertaken in a kraft mill. For each activity, the table provides an estimate of how frequently the activity occurs, an estimate of how likely the activity is to occur within the specified time interval, and the relative cost of the activity. The relative cost of the activity is presented as a percentage of the replacement cost of the major process component with which the activity is associated. For example, repairing or replacing the boiler safety relief valves (Table D-3) is estimated with near certainty to be an annual activity at a kraft mill, with an estimated cost that is less than 5% of the replacement cost of the entire boiler. Although the list of activities in Table D-3 is not certified as exhaustive, it serves to illustrate a variety of repair and replacement activities that may be undertaken in pulp and paper manufacturing facilities.

The repair and replacement activities presented here are expected to have different frequencies and costs across various industrial sectors, production facilities, and types of process units because many factors, such as equipment design and operating conditions, affect the frequency and cost of those activities (R. Bessette, Council of Industrial Boiler Owners, November 10, 2004, letter to committee).

**TABLE D-1** Summary of Common Repair and Replacement Activities, Frequencies, and Cost for Coal-Fired Electric Utility Power Plants

| Category | Description | Repair or Replacement Needs | Frequency | Cost |
|---|---|---|---|---|
| Boiler tube assemblies | Rows or bundles of heat exchanger tubes | Wear and periodic failure attributable to erosion, corrosion, and temperature/pressure-related stresses, leading to outcomes such as leaks, forced outages, loss of reliability, and potential for substantial boiler failure | Considered to be common; entire tube assemblies replaced at nearly every boiler, as early as 5 years after commercial operation | Up to $40/kW to replace tube assemblies on a large boiler and potentially more on a smaller boiler |
| Fans | Forced draft fans push combustion air into the furnace; induced draft fans pull flue gas from the furnace; a balanced draft system has both; other typical fans include primary air fans for pneumatic transport of pulverized coal and flue gas recirculation fans for $NO_x$ control | Erosion and cyclic fatigue; fans exposed to flue gases often subject to higher temperatures as well as erosive ash and corrosive acid gases. Reduced effectiveness of fan reduces plant output; failure leads to shutdown | Fans have been substantially replaced in over 70% of units | Replacement of a large fan can cost up to $20/kW; retrofitting a balanced draft system in place of a forced draft system can cost $70/kW |

| | | | | |
|---|---|---|---|---|
| Mills/ feeders | System for feeding and pulverizing coal into a fine powder | Abrasion due to hard minerals in coal, and erosion where solids/powder strikes interior surfaces, including deterioration of rollers, tables, balls, classifiers, bearings, seals, motors, belts, flow control devices, and piping | Pulverizer mills have been replaced or substantially repaired in over 50% of units | Replacing wear parts in a pulverizer mill can cost $2/kW and mill replacement can cost up to $5/kW |
| Turbines and generators | Steam turbines are composed of a shell, blades, nozzles, diaphragms, and rotors; generators are composed of rotors and stators, including windings and insulation | Turbine blades experience wear due to impurities in steam, requiring replacement of blades (usually with better designed shapes and more recently available alloys); generator insulation can deteriorate due to exposure to heat or contaminants | Turbine blades or rotors have been replaced in more than 90% of units | Turbine blade and rotor replacement can cost up to $20/kW; replacement of the shell of the turbine can cost up to $60/kW |
| Condensers | Typically, a shell and tube heat exchanger in which river water flows on the tube side and low-temperature steam and low pressure (at a vacuum compared to ambient) are on the shell side | Flow on either side can lead to erosion; impurities in steam or water can lead to corrosion; biological fouling on the water side is also possible; partial or full pluggage of tubes reduces heat transfer, and tube failure leads to contamination of the steam cycle | More than 60% of units have replaced condenser tubes | Tube bundle replacement can cost up to $10/kW |

**TABLE D-1** *(Continued)*

| Category | Description | Repair or Replacement Needs | Frequency | Cost |
|---|---|---|---|---|
| Control systems | Control and monitoring of boiler, turbine, and balance of plant management | Control systems affect combustion efficiency and other operations of the plant; when systems fail and require replacement, replacement parts for the original design may no longer be available | Replacement of pneumatic controls with solid-state, computerized, or automated controls has occurred in "most" units | Replacement projects can cost up to $10/kW on larger units and $40/kW on smaller units |
| Coal and ash handling | Unloading, storage, and conveying coal; key subsystems include bulldozers (to manage the coal pile), conveyor belts, and bunkers (or silos) | Wear of conveyor belts, motors, and other equipment; corrosion | Replacement of components such as conveyor belts, motors, barge and rail unloaders, and others is reported to be "common" | Replacement of key components of coal handling can cost up to $4/kW; replacement of key components of ash-handling systems can cost up to $14/kW |
| Feedwater heaters | Heat exchangers, treatment system, and pumps to deliver, heat, and process water from the condenser to the economizer | Leaking tubes lead to reduced efficiency; plugged tubes lead to loss of capacity | More than 80% of units have replaced feedwater heaters or major tube bundles therein | Replacement of a feedwater heater can cost up to $5/kW |

| | | | | |
|---|---|---|---|---|
| Sootblowers and water lances | System for delivery of steam or compressor air to remove soot, ash, and slag from surfaces of equipment such as heat exchanger tubes | Deterioration of soot-blowers reduces effectiveness, which in turn leads to less efficient cleaning of surfaces; the latter can lead to losses or damage; for example, uncontrolled buildup of slag on boiler surfaces can lead to failure if large amounts of slag fall and damage boiler internals | Sootblowers have been replaced at “most” units | Replacement projects can cost up to $9/kW |
| Burners | Burner systems include tubes and, in some cases, annuli via, which pulverized coal and staged air are introduced; dampers, vanes, nozzles, windbox, flame scanners, and lighters are other typical components | High temperatures, ash, and corrosive gases can lead to corrosion, erosion, and temperature-related stresses | Replacements have occurred “one or more times at most units” | Replacement costs up to $30/kW |
| Motors | Motors are used throughout a plant to drive pumps, belts, pulverizers, and other equipment; motors can vary greatly in size | Motor failures typically attributable to failure of insulation, which causes overheating and potential short-outs | Rewind or replacement of motors is “common” | Replacements can cost up to $5/kW per motor |

**TABLE D-1** *(Continued)*

| Catergory | Description | Repair and Replacement Needs | Frequency | Cost |
|---|---|---|---|---|
| Electrical equipment | Equipment used to convert and transmit electricity in a form useful for internal plant end uses, such as motors, fans, lighting, etc. | Exposure to coal dust, temperatures in the plant, and other aspects of the plant environment can lead to shorts and overloads | Replacement of switchgear and other equipment is "very common" | Replacement projects cost up to $9/kW |
| Pumps | Pumps are used throughout the plant for feedwater, cooling water, and slurries (e.g., ash sluice); pumps can be exposed to corrosive materials, erosive materials, and extremes of temperature and pressure | Failure typically due to corrosion, erosion, and other demanding service conditions (e.g., high temperature, pressure) | Nearly 100% of units have overhauled or replaced boiler feedpumps | Replacement projects can cost $10/kW |
| Piping/ ducts/ expansion joints | Pipes carry fluids or slurries; ducts carry gases; expansion joints are flexible connections between pipes or between ducts | Leaks can occur due to high-pressure, high-temperature environments, or because of erosion or corrosion; expansion joints can crack or separate | Replacements of pipes, ducts, and expansion joints is "common"; repair and replacement can cost up to $23/kW | |

| | | | | |
|---|---|---|---|---|
| Air compressors | Compressed air is used for pneumatic drives, system controls, some sootblowers, and some power tools | Moving parts are subject to typical wear; reduced effectiveness of the compressor or failure can lead to reduced effectiveness or failure of other components (e.g., sootblowers, surfaces not adequately cleaned by failed sootblowers) | Replacement is a typical choice, but frequency is not reported | Replacement projects can cost up to $2/kW |

Source: ERCC 2002. Reprinted with permission; copyright 2002.

**TABLE D-2** Petroleum Refinery Industry: Projected Repair and Replacement Frequencies and Relative Costs

| | | Estimated Frequency (years) | | | | Replacement Cost (% per Unit) | | | |
|---|---|---|---|---|---|---|---|---|---|
| Activity | Unit | 1 | 3-5 | >5 | <5 | 5 | 5-10 | 10-20 | <20 |
| | | | | Pumps | | | | | |
| Replace pump seals | All | x | x | x | | x | x | | |
| Repair pumps | All | x | | | | x | | | |
| Replace pumps | All | | | | x | x | x | | x |
| | | | | Valves | | | | | |
| Replace valve packing | All | x | x | x | x | x | | | |
| Replace valves | All | | | | x | x | | | |
| | | | | Catalysts | | | | | |
| Regenerate catalysts | Reformer | x | | | | x | | | |
| Replace catalysts | Hydrotreaters | | x | | | x | | | |
| Replace catalysts | Sulfur recovery unit (SRU) | | | x | | x | | | |
| Replace catalysts | not specific | x | x | x | | x | x | | |
| | | | | Columns Reactors | | | | | |
| Repair or replace trays and hardware | All | | x | | | | x | | |
| Repair or replace reactor internals | All | | x | | | x | | | |
| Replace weld overlays inside of columns, vessels, and reactors | All | | | | x | x | x | | |
| | | | | Pressure Safeties | | | | | |
| Repair, replace, test PSVs | All | | x | | | x | | | |
| | | | | Exchangers | | | | | |
| Repair or replace exchanger | All | | | | x | | | | x |

**TABLE D-2** *(Continued)*

| Activity | Unit | Estimated Frequency (years) | | | | Replacement Cost (% per Unit) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 3-5 | >5 | <5 | 5 | 5-10 | 10-20 | <20 |
| Exchangers *(Continued)* | | | | | | | | | |
| Repair or replace bundle | All | | x | | | | x | x | |
| Clean tubes | All | | x | | | x | | | |
| Crude Unit | | | | | | | | | |
| Crude unit turnaround | Crude | | x | x | | | x | | |
| Fluidized Catalytic Cracking Unit (FCCU) | | | | | | | | | |
| FCCU turnaround | FCCU | | x | x | | | x | x | x |
| FCCU turnaround with cylcone replacement | FCCU | | | | x | | | | x |
| Replace or repair spent catalyst deflectors in an FCCU | FCCU | | x | | x | x | | | |
| Replace or repair slide valves (orifice plates and tongues) | FCCU | | x | | | x | | | |
| Replace or repair spent catalyst slide valve actuators | FCCU | | x | x | x | x | x | | |
| Replace or repair FCCU regenerator cyclones | FCCU | | x | | x | x | x | | |
| Replace or repair FCC reactor cyclones | FCCU | | x | | x | x | x | | |
| Replace or repair fractionation tower internals | FCCU | | x | | x | x | | x | |
| Repair fractionation tower internals | FCCU | | x | x | x | x | | x | |

*(Continued)*

**TABLE D-2** *(Continued)*

| | | Estimated Frequency (years) | | | | Replacement (% per Unit) | | | |
|---|---|---|---|---|---|---|---|---|---|
| Activity | Unit | 1 | 3-5 | >5 | <5 | 5 | 5-10 | 10-20 | <20 |
| Fluidized Catalytic Cracking Unit (FCCU) *(Continued)* | | | | | | | | | |
| Replace or repair wet gas compressor | FCCU | | x | | x | x | | | |
| Turnaround | Reformer | | x | | | | | x | |
| Alkylation Unit | | | | | | | | | |
| Turnaround | Alkylation | | x | | | | x | | |
| Hydrocracker | | | | | | | | | |
| Turnaround | Hydrocracker | | x | | | | x | | |
| MTBE Unit | | | | | | | | | |
| Turnaround | Methyl bert-butyl ether (MTBE) | | x | | | | | x | |
| Diesel Desulfurization | | | | | | | | | |
| Turnaround with catalyst change | Hydrotreatment (HDT) unit | x | | | x | | | | |
| Coker | | | | | | | | | |
| Coke drum replacement | Coker | | | | x | | | x | x |
| Crude/coker turnaround | Coker | | | x | | x | | | |
| Sulfur Plant | | | | | | | | | |
| SRU thermal reactor repair | SRU | | x | | | x | | | |
| SRU thermal reactor replacement | SRU | | | | x | | | x | |
| Turnaround | SRU | | x | | | | | x | |

**TABLE D-2** *(Continued)*

**TABLE D-2** *(Continued)*

| | | Estimated Frequency (years) | | | | Replacement (% per Unit) | | | |
|---|---|---|---|---|---|---|---|---|---|
| Activity | Unit | 1 | 3-5 | >5 | <5 | 5 | 5-10 | 10-20 | <20 |
| **Flare** | | | | | | | | | |
| Flare tip replacement | Flare | | | | x | | x | | |
| Flare knockout drum replacement | Flare | | | | x | | | | x |
| Replace flare | Flare | | | | x | | | x | |
| **Piping** | | | | | | | | | |
| Repair piping re-corrosion | All | | x | | x | x | x | | |
| Replace piping re-corrosion | All | | x | x | x | x | | x | |
| **Heaters/Boilers** | | | | | | | | | |
| Replace or repair heater tubes | All | | | x | x | x | x | | |
| Replace or repair boiler tubes | Boilers | | | x | x | x | x | x | |
| Replace burners | All | | | | x | x | x | | |
| **Steam Turbine** | | | | | | | | | |
| Steam turbine repairs | Turbine | | x | | | x | | | |
| Steam turbine replacement | Turbine | | | | x | | x | | |
| **Storage Tanks** | | | | | | | | | |
| Repair storage tanks | Tank farm | | | x | x | x | | x | |
| Replace storage tanks | Tank farm | | | | x | x | | x | |
| Replace floating roofs in tanks | Tank farm | | | | x | x | | | x |
| Replace floor in tanks | Tank farm | | | | x | | | x | |
| **Wastewater Systems** | | | | | | | | | |
| General maintenance | Waste-water | x | | | | x | | | |

*(Continued)*

**TABLE D-2** *(Continued)*

| Activity | Unit | Estimated Frequency (years) | | | | Replacement Cost (% per Unit) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 3-5 | 5 | >5 | <5 | 5-10 | 10-20 | >20 |
| | | | | | **Metallurgical Changes** | | | | |
| Metallurgical changes to accommodate feedstock quality changes | | | | | x | | | | x |
| | | | | | **Instrumentation** | | | | |
| Replace CEMS | | | | | x | | | x | |
| Repair CEMS | | | | x | | | | x | |
| General instrumentation | | x | | | | x | | | |
| Replace instrumentation | | | | | x | | | x | |
| | | | | | **Electrical Substations** | | | | |
| Replace substations | | | | | x | | | x | |
| Repair substations | | | x | | | x | | | |
| Replace transmission lines | | | | | x | | | x | |

Abbreviations: CEMS, continuous emission monitoring system.
Source: National Petrochemical and Refiners Association, unpublished material, 2004.

**TABLE D-3** Pulp and Paper Industry: Repair and Replacement Activities

| Activities | Category | Estimated Frequency (years) | | | | Percent Replacement Cost | | |
|---|---|---|---|---|---|---|---|---|
| | | 1 | 5 | 10 | 20 | <5 | 5-10 | 10-20 |
| | | | | | **Boiler Used to Generate Power** | | | |
| Repair superheater tie lugs | 4 | x | x | | | x | | |
| Repair superheater steam-cooled spacers | 4 | | x | x | | x | | |
| Replace superheater loops | 4 | | x | x | | x | | |

**TABLE D-3** *(Continued)*

| Activities | Category | Estimated Frequency (years) | | | | Percent Replacement Cost | | |
|---|---|---|---|---|---|---|---|---|
| | | 1 | 5 | 10 | 20 | <5 | 5-10 | 10-20 |
| Boiler Used to Generate Power *(Continued)* | | | | | | | | |
| Replace superheater assemblies | 4,7 | | | x | x | | x | |
| Replace desuperheater liner assembly | 4 | | | | x | x | | |
| Replace economizer assemblies | 4,7 | | | | x | | x | |
| Replace generating bank tubes | 4,6,7 | | | x | x | | x | |
| Replace lower wall tube sections | 4,6,7 | | | x | x | x | | |
| Replace lower wall tube panels | 4,6,7 | | | | x | x | | |
| Replace lower furnace | 4,6,7 | | | | x | | | x |
| Repair tubular air heaters | 4,5 | x | x | x | x | x | | |
| Replace tubular air heaters | 4 | | | x | x | x | | |
| Repair refractory | 4 | x | | | | x | | |
| Repair/replace cyclone burners | 4,6 | x | x | | | | x | |
| Clean and scaffold fire side | 1,2,4 | x | | | | x | | |
| Auxiliary Equipment for Power Boiler | | | | | | | | |
| Repair/rebuild coal pulverizers | 4 | x | | | | x | | |
| Repair/rebuild traveling grates | 4 | x | | x | | x | | |
| Repair/rebuild ash-handling system | 4 | x | x | x | | x | | |
| Repair/rebuild coal-feeder systems | 4 | x | | | | x | | |
| Repair/rebuild boiler safety relief valves | 1,2 | x | | | | x | | |

*(Continued)*

**TABLE D-3** *(Continued)*

| Activity | Cate-gory | Estimated Frequency (years) | | | | Percent Replacement Cost | | |
|---|---|---|---|---|---|---|---|---|
| | | 1 | 5 | 10 | 20 | <5 | 5-10 | 10-20 |
| Auxiliary Equipment for Power Boiler *(Continued)* | | | | | | | | |
| Remove, calibrate, and simulate boiler protective interlock devices | 1,2 | x | | | | x | | |
| Replace, calibrate, and simulate boiler protective interlock devices | 1,3,4 | | | x | | x | | |
| Repair/rebuild burner assemblies | 4 | x | | | | x | | |
| Repair/rebuild sootblowers | 4 | x | | | | x | | |
| Repair/rebuild dust collectors | 4 | x | | | | x | | |
| Repair/rebuild precipitators | 4 | x | | | | x | | |
| Repair/rebuild turbine drives | 1,2,4 | | x | | | x | | |
| Repair/rebuild ED and ID fans | 4 | | x | | | x | | |
| Upgrade safety systems to revised standards | 1,2,3 | | | x | | x | | |
| Replace unsupported control hardware | 3,4 | | | x | x | | x | |
| Inspect/repair stack | 2,4 | | x | | | x | | |
| Repair/rebuild ducts and flues | 4 | | x | x | | x | | |
| Building structural repair | 4 | | | x | x | x | | |
| Chemical Recovery Furnace | | | | | | | | |
| Replace smelt spout tube openings | 1,2,3,4,5 | | x | x | | x | | |
| Replace lower wall tube sections | 1,2,3,4 | | x | x | | x | | |

**TABLE D-3** *(Continued)*

| Activity | Cate-gory | Estimated Frequency (years) | | | | Percent Replacement Cost | | |
|---|---|---|---|---|---|---|---|---|
| | | 1 | 5 | 10 | 20 | <5 | 5-10 | 10-20 |
| Chemical Recovery Furnace *(Continued)* | | | | | | | | |
| Replace lower wall tube panels | 1,2,3,4 | | | x | x | x | | |
| Replace lower furnace | 1,2,3,4 | | | x | x | | x | |
| Repair superheater tie lugs | 1,2,4 | x | x | | | x | | |
| Repair superheater steam-cooled spacers | 1,2,4 | | x | x | | x | | |
| Replace superheater loops | 1,2,4 | | x | x | | x | | |
| Replace superheater assemblies | 1,2,4 | | | x | x | | x | |
| Replace desuperheater liner assembly | 2,4 | | | x | x | x | | |
| Replace economizer assemblies | 1,2,4 | | | x | x | | x | |
| Replace generating bank tubes | 1,2,4 | | x | x | x | | x | |
| Complete NDE | 1,2,3,4 | x | | | | x | | |
| Repair refractory | 2,4 | x | | | | x | | |
| Clean and scaffold fire side | 1,2,4 | x | | | | x | | |
| Chemical Recovery Furnace Auxiliaries | | | | | | | | |
| Repair/rebuild ash handling system | 4 | x | x | | | x | | |
| Repair/rebuild green liquor system | 4 | x | x | | | x | | |
| Repair/rebuild dissolving tank scrubber system | 4 | x | x | | | x | | |
| Repair/rebuild dissolving tank | 3,4 | x | x | | | x | | |
| Repair/rebuild black liquor system | 4 | x | x | | | x | | |

*(Continued)*

**TABLE D-3** *(Continued)*

| Activity | Cate-groy | Estimated Frequency (years) | | | | Percent Replacement Cost | | |
|---|---|---|---|---|---|---|---|---|
| | | 1 | 5 | 10 | 20 | <5 | 5-10 | 10-20 |
| Chemical Recovery Furnace Auxiliaries *(Continued)* | | | | | | | | |
| Repair/rebuild boiler safety relief valves | 1,2,3 | x | | | | x | | |
| Remove, calibrate, and simulate boiler protective interlock devices | 1,2,3 | x | | | | x | | |
| Repair/rebuild burner assemblies | 4 | x | | | | x | | |
| Repair/rebuild sootblowers | 4 | x | | | | x | | |
| Repair/rebuild direct contact evaporators | 4 | x | x | | | x | | |
| Rebuild direct contact evaporators | 4 | | x | x | | x | | |
| Repair steam coil air heaters | 4 | x | x | | | x | | |
| Replace steam coil air heaters | | | x | x | | x | | |
| Repair/rebuild precipitators | 4 | x | | x | | | x | |
| Repair/rebuild turbine drives | 4 | | x | | | x | | |
| Repair/rebuild forced-draft (FD) and induced-draft (ID) fans | 4 | | x | | | x | | |
| Upgrade safety systems to revised standards | 1,2,3 | | x | x | | x | | |
| Replace unsupported control hardware | 4 | | | x | x | | x | |
| Inspect/repair stack | 4 | | x | | | x | | |
| Repair/rebuild ducts and flues | 4 | | x | | | x | | |
| Building structural repair | 4 | | | | x | x | | |

**TABLE D-3** *(Continued)*

| Activity | Categroy | Estimated Frequency (years) | | | | Percent Replacement Cost | | |
|---|---|---|---|---|---|---|---|---|
| | | 1 | 5 | 10 | 20 | <5 | 5-10 | 10-20 |
| Power Plant Auxiliary Devices | | | | | | | | |
| Repair/rebuild deaerator | 1,3 | | x | x | x | x | | |
| Repair/rebuild demineralizers | 4 | | x | x | | x | | |
| Repair/rebuild boiler feedwater pumps | 4 | x | x | | | x | | |
| Repair/rebuild air compressors | 4 | x | x | | | x | | |
| Repair/rebuild air dryers | 4 | x | x | | | x | | |
| Repair/rebuild demineralized water transfer pumps | 4 | x | x | | | x | | |
| Repair/rebuild condensate transfer pumps | 4 | x | x | | | x | | |
| Repair/rebuild condensate polishers | 4 | | x | x | | x | | |
| Repair/rebuild condensate magnetic filters | 4 | | x | x | | x | | |
| Repair/rebuild water softeners | 4 | | x | x | | x | | |
| Repair/rebuild sand filters | 4 | | x | x | | x | | |
| Repair/rebuild water clarifiers | 4 | | x | x | | x | | |
| Repair/rebuild drive turbines | 4 | x | x | | | x | | |
| Repair/rebuild uniterrupted power supply (UPS) | 4 | x | x | | | x | | |
| Repair/rebuild station batteries | 4 | x | x | | | x | | |

*(Continued)*

**TABLE D-3** *(Continued)*

| Activity | Cate-groy | Estimated Frequency (years) | | | | Percent Replacement Cost | | |
|---|---|---|---|---|---|---|---|---|
| | | 1 | 5 | 10 | 20 | <5 | 5-10 | 10-20 |
| Power Plant Auxiliary Devices *(Continued)* | | | | | | | | |
| Repair/rebuild steam pressure relief valves (PRV) and desuperheaters | 4 | x | x | | | x | | |
| Repair/rebuild oil storage tanks | 1,4 | | x | x | | x | | |
| Repair/rebuild woodwaste receiving equipment | 4 | x | x | | | x | | |
| Inspect/repair woodwaste storage equipment | 4 | x | x | | | x | | |
| Repair/rebuild coal receiving equipment | 4 | x | x | | | x | | |
| Repair/rebuild coal storage equipment | 4 | x | x | | | x | | |
| Repair/rebuild natural gas piping | 1,4 | | x | x | | x | | |
| Repair/rebuild water storage tanks | 4 | | | x | x | x | | |

Category:
1. Required by state regulatory agency or insurance carrier
2. Required by company or industry standards
3. Required to maintain safe operation
4. Required to maintain reliable operation
5. Required due to design deficiencies
6. Required due to unforeseen operational problems
7. Required due to unforeseen mechanical damage

Source: Council of Industrial Boiler Owners, unpublished material, 2004.