State of California

California Environmental Protection Agency

AIR RESOURCES BOARD

Strategic Plan for Research 2001 to 2010

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EXECUTIVE SUMMARY

This report presents the Air Resources Board's (ARB's) Strategic Plan for Research (Plan) and will serve as the ARB's roadmap for research funding from 2001 to 2010. Specifically, the purpose of the Plan is to lay out the research needs of the ARB's regulatory programs and to identify key research activities the ARB expects to pursue over the next ten years. The Plan is intended to inform the public, provide stakeholders and research funding organizations with targets for possible collaboration with the ARB, and inform university researchers and private consultants about the ARB's research needs.

The focus of the plan is to identify broad areas where research is needed, rather than present developed research projects. The Plan is intended to aid the ARB in its regulatory decision-making, advance efforts to meet State Implementation Plans (SIPs) and other commitments, and facilitate coordination with other research organizations. Because it takes three to five years to plan and complete new research projects, we evaluated the ARB's future regulatory commitments over that same time horizon. We drew from a broad spectrum of resources, including the Research Screening Committee (RSC) – the ARB's external scientific advisory body – as well as experts within the ARB and those affiliated with other regulatory and research organizations. Knowledge gaps were identified, prompting a more focused investigation to determine whether the ARB needed to initiate additional study or if sufficient work was being done by other organizations to fill the gaps.

Because the nature of environmental protection is complex and involves many disciplines, we realize that the Plan must be flexible enough to adapt to changes in regulatory priorities, advances in scientific information, and new environmental concerns. It is our intention to adjust research activities as new or more accurate information becomes available. Therefore, the Plan will be updated at least every five years, but, if necessary, as frequently as every two.

Through this Plan, we also intend to improve the annual research planning process. This Plan will help us to directly support the ARB's strategic goals and objectives and meet its regulatory obligations on an annual basis. It will be used to ensure future research meets the ARB's ongoing responsibilities, to clarify priorities, and to explore opportunities for cooperation among other research organizations. This will allow the annual process to be more focused and effective.

The Plan also combines the ARB's current vision and strategies for reducing air pollutants into an integrated program to support and refine its actions. As such, it will enhance the ARB's relationships with stakeholders, leveraging and enhancing the use of available resources and encouraging the formation of partnerships and strategic alliances. Further, the Plan will help to ensure that the ARB continues its tradition of environmental leadership by conducting relevant research of the highest scientific quality that serves as the foundation for effective regulatory decisions.

As a result of our investigations, three broad regulatory priorities were identified that will be the primary focus of research support over the next several years. These regulatory priorities are to: 1) reduce emissions of and exposure to particulate matter (PM); 2) characterize and reduce community exposure to air pollutants; and 3) promote continued advancement and acceptance of zero and near-zero emission technologies. These priorities are the basis for this Plan, and from them we have developed focused research needs.

This Plan organizes research needs into four major categories: 1) ***Health and Welfare Effects***; 2) ***Exposure Assessment***; 3) ***Technology Advancement and Pollution Prevention***; and 4) ***Global Air Pollution***. These categories were selected because they represent the scope of research that is anticipated over the next decade. Furthermore, they define the natural progression of research, from identifying the impacts associated with air pollution (i.e., *Health and Welfare Effects*) and characterizing exposures (i.e., *Exposure Assessment*), to facilitating the application of

effective exposure reduction strategies (i.e., *Technology Advancement and Pollution Prevention*). Since *Global Air Pollution* concerns encompass all three of these categories, but contain elements that extend well beyond their individual components, a separate category was created. A brief description of the scope of future research needs for each of these categories is offered below.

- Health and Welfare Effects

A major research priority for the ARB is to establish clean air targets that are protective of sensitive ecosystems and the health of all Californians, including sensitive individuals, and those living in disadvantaged communities. The knowledge gained from our health effects research supports many programs, including the establishment of ambient air quality standards, the assessment of community health, the development of effective public health intervention programs, and the assessment of the consequences of long-term exposure to air pollution. Additional research concerns efforts to better characterize and address the impact adverse air quality has on ecological resources, including Lake Tahoe and other sensitive ecosystems. Additionally, while the primary goal of air pollution control is to protect public health, the public recognizes air pollution by its associated haze and judges the success of pollution control programs by the perceived reduction of that haze. New federal regulations recognize this public expectation and considerable new research will be needed to prepare a Regional Haze SIP to meet federal requirements. Continued research to develop better tools for characterizing the benefits, as well as the costs, of air pollution control efforts will play an increasingly important role in the ARB's efforts to develop the most effective control strategies. These research activities will help address several informational needs for our regulatory priorities to reduce emissions and exposure to PM and to characterize and reduce community exposure to air pollutants.

- Exposure Assessment

Another major research priority concerns efforts to advance our understanding of exposures to air pollution. This includes characterizing personal exposure to pollutants from both indoor and outdoor sources. Improved understanding of exposures helps assure that our regulatory activities focus on reducing exposures that represent the greatest health concerns. Efforts to further improve emission inventories for manmade and natural sources, increase our understanding of the atmospheric processes that impact the behavior of pollutants, and advance our knowledge of the impacts that air pollutants have on other media such as water bodies and soils are important aspects of this research. These research activities will help address two key regulatory priorities – to reduce emissions and exposure to PM and characterize and reduce community exposure to air pollutants.

- Technology Advancement and Pollution Prevention

The ARB will continue to engage in activities designed to advance the development, demonstration, and commercialization of technologies associated with zero or near-zero emissions. Furthermore, the ARB will also take steps to enhance emission monitoring and measurement methods and the development of pollution prevention alternatives. Given the growth in the use of distributed electricity generation anticipated over the next several years, the ARB has an extraordinary opportunity to partner with interested stakeholders to promote the development and commercialization of technologies with low emissions. These research activities will help address our regulatory priority to promote continued advancement and acceptance of zero and near-zero emission technologies in order to reduce emissions and exposure to PM and to reduce community exposure to air pollutants.

- Global Air Pollution

Changes in the global climate, due to increases in carbon dioxide and other greenhouse gases, are expected to create regional changes in temperature, humidity, and precipitation. Research is needed to determine

the impact of these changes on regional air quality and, in turn, on existing and future control strategies. Further, an understanding of the sources of global climate change is needed before effective mitigation methods can be determined and assessed. Another aspect of global air pollution concerns the transport of pollutants far beyond their point of origin. Dust and other pollutants have, on occasion, been transported from Asia and the Sahara Desert to the western United States, contributing to an increase in regional background levels for PM and ozone within California. Investigations are needed to determine the impacts of global transport on statewide air pollution distribution and the contribution it, as well as increasing industrialization and desertification, has on PM and ozone control needs in California.

I. INTRODUCTION

The ARB's Plan will serve as the ARB's roadmap for research funding from 2001 to 2010. This section discusses the purpose of the Plan, the annual process for selecting and funding research projects, and the history of the ARB's research program. It also summarizes the relevance of research to the ARB's mission.

Purpose of the Plan

Because of the complex nature of California's air pollution problems and solutions, research is a vital part of the ARB's mission to protect California's public health, welfare, and ecological resources. However, research into problems of this complexity typically requires a number of years to produce answers. Thus, the ARB's needs would best be met if research could be undertaken with a view to the Board's future priorities. A Strategic Plan for Research, based on the ARB's regulatory priorities for the next decade, will provide direction for the ARB's research programs and allow the information needed by the Board to be available in a timely fashion.

While the Board's research program is unique in its focus on California's air pollution problems, the ARB's research interests are shared by many other governmental, industrial, and public funding organizations. Thus, the Plan will help these organizations to identify research areas of mutual interest and potential co-funding opportunities. Implementing the Plan will help ensure that limited resources are used efficiently and that the resulting research efforts will effectively serve the needs of the ARB and others.

To make effective decisions about air pollution research requires a comprehensive look at the interrelationships among air pollution issues. The ARB recognizes that pollution problems are not exclusive. Rather, the interaction of impacts on individuals, community health, and the environment must be understood, to the greatest extent possible, to assess the feasibility and effectiveness of air pollution regulations. The research needs identified throughout this document focus on obtaining the information and developing the expertise and tools necessary to achieve one or more of the following objectives.

- Reduce emissions and exposure to PM.
- Characterize and reduce community exposure to air pollutants.
- Promote continued advancement and acceptance of zero and near-zero emission technologies.

However, although the Plan has identified four main areas of research concentration, the ARB's regulatory priorities are woven throughout this document and are reflected in all areas of research. These include investigations supporting the reduction of levels of ozone, toxic air contaminants, and regional haze. The Plan addresses each of these areas in more detail. For ease of use, this Plan is organized according to the following headings: **Health and Welfare Effects, Exposure Assessment, Technology Advancement and Pollution Prevention, and Global Air Pollution.** We believe these areas encompass the comprehensive mission of ARB's air pollution research.

Annual Research Planning Process

The ARB's annual research budget totals a little more than $8 million. To administer this budget, the Research Division establishes an Annual Plan, which details specific research projects. Each year, ideas are solicited from the ARB staff, the public, university researchers, and research contractors. Staff, internal research teams, and an Executive Research Review Committee evaluate the ideas and recommend those to be funded. The Board approves the final plan, which normally contains 15-25 projects. Contracts are initiated with universities, private entities, and governmental agencies, whose scientists carry out most of the projects. Contracts are implemented through either interagency agreements or public solicitations. The annual plan serves as a short-term road map for the upcoming fiscal year. Independent of our research program, we also manage a technol-

ogy development grant program. All grant awards are made annually on a competitive basis.

The ARB's Research Screening Committee (RSC), a nine-member body established by the California Legislature in 1975 (Health and Safety Code §39705), provides technical expertise and external review for individual research projects, as well as the Annual Plan. The RSC also provides critical technical evaluations and makes appropriate funding recommendations to the Board. The committee is comprised of experts in various air pollution disciplines and assists the Board in managing a technically sound research program.

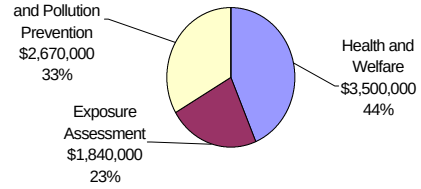
Identifying the Board's long-term needs and goals will aid in integrating individual projects and annual priorities. With the implementation of this Plan, we hope to make the annual process more focused and effective.

History of the ARB's Research Program

The ARB's research program was established by the Legislature in 1971 (Health and Safety Code §39700) as an integral part of a broad-based statewide effort to combat air pollution and protect and enhance the ambient air quality of California. The program was mandated to coordinate and collect the research data needed to develop a better understanding of the aspects of air pollution. In recent years, several legislative mandates have expanded and further defined the scope of the program. Annual funds are allocated based on the ARB's immediate priorities. The distribution of the 2000/01 budget is represented in Figure 1. It is expected that this Plan will improve the ARB's ability to project fiscal requirements and adequately adjust budgets to incorporate inflation and long-term project requirements.

Since its inception, under the leadership of Dr. John R. Holmes, the ARB's research program has been an international leader in the fight against air pollution. The breadth of the program has spanned health effects, ecosystem impacts, emission inventory, atmospheric chemistry, transport and deposition,

Figure 1
2000/01 Budget Allocations
$8,000,000



personal exposure, indoor air pollution, control technology, and economic assessment. It has produced over 600 research reports, thousands of peer-reviewed publications, and has had countless contributions to California's air pollution control policies. The sound scientific results produced by the ARB's research program have been crucial in enabling the Board to make effective decisions to implement policies that adequately protect public health. Some historic accomplishments during Dr. Holmes' tenure that have made significant contributions to air pollution community are highlighted below.

- To protect public health, California has set standards that are, in some cases, more protective than (i.e., ozone and PM), or apply to pollutants not covered by, federal standards (i.e., hydrogen sulfide and sulfates). The ARB research program conducted the health studies necessary to provide recommendations on the appropriate levels for the standards and to support the Board's decisions to implement those levels.
- The Children's Health Study is a ten-year epidemiological study of the effects of multi-pollutant exposures on the respiratory health and lung growth of nearly 5,200 children from 12 communities in southern California. It continues to be the only study of its kind in the world and has established links between long-term air pollution exposures and retarded lung function growth (Gauderman, 2000), exacerbation of asthma symptoms (McConnell, 1999), and school absenteeism. This study is particularly innovative in that it is continually updated to include state-of-the-science technologies addressing new

concerns that surface as a result of the project. For example, the ARB research program recently established the only long-term monitoring network of ultrafine (PM<0.1μm) particle number in the world to address project issues concerning traffic-related pollutants.

- The California Acid Deposition Monitoring Program investigated the effects and causes of acidic deposition in California (Takemoto et al., 1995). It focused on California's motor vehicle-influenced nitrogen-containing acidic deposition problem, and complemented the National Acidic Precipitation Assessment Program's emphasis on sulfur-containing acid chemistry and effects. This program was one of the first multi-year efforts to investigate the potential for nitrogen-containing acids to cause long-term human health and ecological impacts.
- The ARB research program supported the control of nitrogen oxides (NO_X) as the means to reduce California's ozone and PM pollution (Finlayson-Pitts and Pitts Science Paper). Three decades ago, the ARB was the first agency in the world to implement stringent NO_X control for motor vehicles and stationary sources. In the last decade, the effectiveness of this strategy was recognized by the National Research Council (NRC, 1991), and has been implemented by the United States Environmental Protection Agency (U.S. EPA) and air pollution control agencies worldwide.
- The Innovative Clean Air Technologies Program (ICAT) provides $1 million annually to assist in the development, demonstration, and commercialization of broad-based technologies designed to reduce air pollution within the state, as well as create jobs within the related industries. Twenty-two companies have received co-funding for pilot-scale studies, development of prototypes, or application demonstrations. Some of these projects have moved into commercial sales, thereby benefiting the private sector by providing jobs in California, helping California businesses with new technologies that reduce or prevent air pollution, and improving California's air quality. In a recent survey, ten companies that benefited from this program estimated that technologies developed with ICAT monies will generate between $200 to $600 million in annual sales for their companies and create between 675 to 1060 jobs over the next five to seven years.

Teaming up with other research organizations has provided the pathway for some historical accomplishments that have made significant contributions to the understanding and control of air pollution, as shown in the following examples.

- The ARB research program was the first in the world to conduct field studies of air pollution formation and transport for the development and testing of air quality simulation models. The 1972-73 Aerosol Characterization Experiment (Appel et al., 1980), the 1987 Southern California Air Quality Study (Lawson et al., 1995), and the 1997 Southern California Ozone Study-NARSTO (Motallebi et al., 1998) were all cooperative air quality studies that enhanced our understanding of the relationships between emissions and the spatial and temporal distributions of pollutants. Key participants included the South Coast Air Quality Management District, other local air pollution agencies, the U.S. EPA, and the Coordinating Research Council. These studies helped to ensure that California's air quality management strategies were based on the best possible science.
- In collaboration with the U.S. EPA, the ARB's Indoor and Personal Exposure Assessment Program determined that Californians spend most of their time indoors and are, therefore, at risk from exposure to residential indoor levels of particles and air toxics that are much greater than outdoor levels. These increased levels are due, primarily, to emissions from indoor building materials, carpets, and consumer products. The world's first comprehensive

study of exposures to particles showed that daytime personal exposures exceeded indoor and outdoor levels by up to 50 percent. Recent research indicates that this is likely due to people's close proximity to sources and activities that generate airborne particles – such as tobacco smoking, cooking, wood-burning, and house cleaning – as they go about their normal activities. The innovative research of this program continues with the world's first comprehensive studies of children's exposures to air pollutants in portable classrooms and school buses, currently in progress.

Summary

It is crucial for a research program to provide sound scientific results. This enables the Board to make credible decisions and implement policies that adequately protect public health. The ARB research program has a history of providing timely, state-of-the-science information in support of the Board's regulatory needs and other concerns. By developing this Plan, and basing it on California's highest priority air pollution issues, the ARB can allocate resources appropriately. We intend to share the plan and investigative results with other research organizations to prevent duplication of effort, and encourage collaboration to better leverage California's air pollution research dollars.

II. ANTICIPATED NEEDS OF THE ARB'S REGULATORY PROGRAMS FOR 2001 TO 2010

The ARB's mission is to promote and protect public health, welfare, and ecological resources through the effective and efficient reduction of air pollutants, while recognizing and considering the effects of these regulatory actions on the economy of the state. The Research Division supports this mission by providing the highest quality scientific information to assist the Board in its actions. Developing a world-class air quality program means achieving and surpassing federally imposed air pollution goals and standards, while ensuring that the ARB's regulatory decisions protect and enhance our communities and the natural environment. Air quality is often taken for granted and its impact on our quality of life is often overlooked. As a result, a significant portion of our daily activities has unintended adverse impacts on the air we breathe. This reality has imposed tremendous responsibilities on the ARB.

The ARB's research program enhances the Board's understanding of the effects of air pollution on human health and the environment. It assists the Board in developing scientific tools for predicting and assessing the impacts of air pollution and provides the Board with the information needed to develop and implement essential regulations. It also assists Cal/EPA boards, offices, and departments in assessing the business impact of proposed regulations. The Board's projected regulations are the fundamental motivation for the development of this Plan, and the standards and plans that define those regulatory goals drive our research priorities. These standards and plans are described below.

Ambient Air Quality Standards

The federal Clean Air Act (CAA) requires the U.S. EPA to set national ambient air quality standards, but it permits states to adopt additional or more protective air quality standards, if desired. The ARB is the state agency that establishes California's ambient air quality standards. These standards are set at levels intended to protect public health, including the health of "sensitive" populations, such as asthmatics, children, and the elderly. Under the requirements of the Children's Environmental Health Protection Act (Senate Bill [SB] 25, Escutia, 1999), the ARB and the Office of Environmental Health Hazard Assessment (OEHHA) are investigating whether current California standards adequately protect the public's health, with special emphasis on protecting the health of infants and children. The Board set priorities for more extensive review and possible revision of those standards not considered sufficiently protective. One standard will be reviewed each calendar year and may be subject to additional reviews in later years. Below is a schedule of the upcoming standard reviews.

Standard	Dates for Review
Particulate Matter	2002 and 2007
Ozone	2003 and 2008
Nitrogen Dioxide	2004 and 2009

2001 Clean Air Plan

The ARB's 2001 Clean Air Plan: Strategies for a Healthy Future, which is currently being developed, will present the ARB's long-range vision for ensuring that all individuals in California, especially children and the elderly, can live, work, and play in a healthful environment – free from harmful exposure to air pollution. A comprehensive assessment of emission reduction opportunities will be conducted for all sources under state and federal jurisdiction, including motor vehicles, off-road vehicles and equipment, fuels, the refueling process, and consumer products. The resulting Clean Air Plan will define the ARB's air pollution control strategy for the next 20 years. Some of the longer-term measures in the plan will rely on advanced technologies to achieve emission reductions. Research to support development of these technologies will be critical to the ultimate success of the plan. Adopting the measures outlined in the plan will be a major focus of the ARB's regulatory calendar in the upcoming years. Selected measures and goals in the approved plan will

then form the basis for new state commitments in upcoming revisions to SIPs for the South Coast (2001) and San Joaquin Valley (2002). In addition, we expect to use these projections as the starting point for future plans to meet the more health-protective State ozone standard, and federal eight-hour ozone and PM2.5 standards.

The overview afforded by the ARB's Clean Air Plan will help integrate efforts to attain the health-based standards for criteria pollutants and initiatives to reduce the public health risk from air toxics. By considering the broad emission reduction needs and opportunities for each source category, we hope to consolidate new control requirements and encourage cost-effective approaches that benefit the public health by achieving multiple air quality goals. A draft of the Clean Air Plan is expected in the summer of 2001 and should be presented to the Board the following September.

State Implementation Plans (SIPs)

The federal (CAA) establishes planning requirements for those areas where ozone levels routinely exceed the National Ambient Air Quality Standards (NAAQS). The CAA requires these “non-attainment” areas to adopt and implement SIPs that demonstrate how each area will attain the standards by specified dates. SIPs must also establish rate-of-progress milestones and demonstrate how the attainment strategy meets those interim year targets. The plans are subject to review and approval by the U.S. EPA. The provisions and commitments in a U.S. EPA-approved SIP are federally enforceable. The CAA also allows interested parties to sue the U.S. EPA, the state, or local agencies to compel implementation of an approved SIP. The ARB envisions several SIP planning cycles over the next decade, including the following.

- South Coast SIP for ozone (one-hour standard), PM10, and CO by the end of 2001.
- San Joaquin Valley SIP for 1-hour ozone standard by Spring 2002.
- SIPs for 8-hour ozone standard in 2003-2005 (exact date will not be certain until legal challenges to the standard are fully resolved).
- SIPs for PM2.5 and Regional Haze standards in 2006-2008 (exact date will not be certain until legal challenges to the standards are fully resolved).

Diesel Risk Reduction Plan

The Diesel Risk Reduction Plan is a comprehensive strategy for significantly reducing diesel PM emissions. The Plan will require the use of diesel fuel with very low sulfur content and all new diesel-fueled vehicles and engines will be required to use state-of-the-art catalyzed diesel particulate filters (DPFs). Furthermore, all existing vehicles and engines will be evaluated and retrofitted with DPFs.

Over the next several years, staff will develop the actual regulations envisioned by this plan and bring them to the Board for consideration and approval.

- Baseline measures are scheduled to be adopted starting December 2001.
- The anticipated final implementation of the measures will be in 2008.

III. HEALTH AND WELFARE EFFECTS

A major research priority for the ARB is to establish clean air targets that are protective of sensitive ecosystems and the health of all Californians, including sensitive individuals, and those living in disadvantaged communities. The knowledge gained from our health effects research supports many programs, including the establishment of ambient air quality standards, the assessment of community health, the development of effective public health intervention programs, and the assessment of the consequences of long-term exposure to air pollution. Additional research concerns efforts to better characterize and address the impact adverse air quality has on ecological resources, including Lake Tahoe and other sensitive ecosystems. Additionally, while the primary goal of air pollution control is to protect public health, the public recognizes air pollution by its associated haze and judges the success of pollution control programs by the perceived reduction of that haze. New federal regulations recognize this public expectation and considerable new research will be needed to prepare a Regional Haze SIP to meet federal requirements. Continued research to develop better tools for characterizing the benefits, as well as the costs, of air pollution control efforts will play an increasingly important role in the ARB's efforts to develop the most effective control strategies. These research activities will help address several informational needs for our regulatory priorities to reduce emissions and exposure to PM and characterize and reduce community exposure to air pollutants.

Human Health Effects

Introduction: Airborne pollutants contribute to many health effects in humans, including death, cancer, chronic bronchitis, asthma attacks, coughing and other respiratory problems, and eye irritation. After several decades of concentrated study, the human health effects for short duration exposures to ozone, carbon monoxide, nitrogen dioxide, sulfur dioxide, and other gaseous pollutants are now well established, and emission control programs have successfully reduced these air pollutants to safe or substantially reduced levels in California. However, the health effects of PM components and the consequences of long-term exposure to air pollution are still not well understood.

Background: The ARB is mandated to protect public health and, therefore, one of its major research priorities is to determine the health effects caused by exposure to air pollution. The information gathered from our health and air quality research supports the ARB's adoption of ambient air quality standards in consideration of the public health, safety, and welfare (Health and Safety Code, Section 39606[a][2]). The ARB is required to regularly review all existing health-based ambient air quality standards to determine whether, based on public health, scientific literature, and exposure pattern data, the standards adequately protect the health of the public, including infants, children, and sensitive individuals, with an adequate margin of safety.

The health effects research program also generates information useful in informing the public about air pollution effects. This information is used in the ARB's Community Health Program, one of the Board's newest and highest priorities. The goal of this Program is to ensure that all individuals in California, especially children and the elderly, can live, work, go to school, and play in a healthful environment. Activities under the Program seek to address air pollution impacts on a community, rather than a regional, scale. A vital part of the Community Health Program is the effort to address environmental justice issues. Environmental justice relates to those communities that are disproportionately impacted by air pollution sources due, primarily, to socioeconomic factors. The Board has emphasized that all its programs, both existing and new, must address environmental justice concerns.

A concern to many local air districts each summer is fire smoke and its associated health impacts. Research on health effects from varying levels of intense exposures to

fire smoke and suggested interventions to reduce exposures addresses a critical need.

Ongoing Research: The ARB is currently sponsoring several laboratory-based research projects to investigate the short-term health impacts of air pollution. Much of this research is addressing the acute health effects of PM inhalation and mechanisms of PM's short-term toxicity on the respiratory system. The ARB is also supporting two long-term focused population studies and several smaller population studies.

The major long-term population study is the *USC/ARB Children's Health Study*, a ten-year epidemiological study of the effects of multi-pollutant exposures on the respiratory health and lung growth of nearly 5,200 children, from 12 communities in south-central and southern California. The study was originally designed to define the effects of PM10 and PM2.5, ozone, nitrogen dioxide, carbon, and acid. Assessment of ultrafine particles (PM<0.1 μm), elemental components of PM, and issues related to roadway-associated exposures have been added.

A second long-term, focused study is the *Fresno Asthmatic Children's Environment Study (FACES)*. This study, which began recruiting children in November 2000, is the first to be sponsored under the auspices of the Vulnerable Populations Research Program. The purpose of FACES is to determine the effects of the Fresno environment on children with asthma. The study will focus on how various environmental factors influence the way a child's asthma progresses over time. Air pollutants are a major focus, especially components of PM, including PM10 and PM2.5 mass, particle number distributions over size ranges less than 2.5 microns, and PM chemical constituents. The influence of other air pollutants, including ozone, nitrogen dioxide, nitrogen monoxide, and sulfur dioxide, as well as airborne molds and pollens, will also be considered.

ARB Research Needs: Several key questions and issues regarding the health effects of air pollution are being or will be addressed in our programs. These include the following

WHAT ARE THE KEY COMPONENTS OR CHARACTERISTICS OF PM THAT CONTRIBUTE TO ADVERSE HEALTH EFFECTS?

Unlike ozone and other gases, PM is not a single chemical pollutant, but rather a complex mix of pure elements (such as carbon, lead, nickel, and iron), compounds (such as nitrates, sulfates, and polycyclic aromatic hydrocarbons), and mixtures (such as diesel exhaust and soil). Particles are both directly emitted and formed in the atmosphere through physical and chemical processes. Inhalable particles that penetrate into the lung range in diameter from 0.002 to 10 μm. It is not known which components of PM are responsible for the many health effects (e.g., death, chronic bronchitis, asthma attacks) observed in hundreds of epidemiological studies (U.S. EPA, 1997). Therefore, to more effectively target PM control programs, we need to investigate the deleterious effects from specific PM components or characteristics (i.e., size, shape). The research should target those components and characteristics that are hypothesized to cause health effects, but have received little study, such as acids and ultrafine particles. These PM components should also be studied in combination with other constituents of PM, as their combined effect can be much greater than the sum of their individual impacts. For example, diesel particles greatly enhance the allergic response to ragweed. Prior ARB-sponsored research has produced state-of-the-science tools to characterize (e.g., single particle analyzers), collect (e.g., PM concentrator), and introduce (e.g., exposure facilities) ambient particles to cell cultures, and animal and human subjects.

WHAT ARE THE EFFECTS OF SHORT-TERM (LESS THAN 24-HOUR) EXPOSURES TO PM?

Some studies have shown stronger symptom effects from 1-hour and 8-hour average PM10 exposures than from the 24-hour PM10 average, but more evidence is needed in order to set a short-term ambient air quality standard. There is also a need to better elucidate the impacts of high PM exposures during excep-

tional events. This information will help local air pollution control officials deal with smoke management issues, whether due to wildfires or controlled burns. Other related areas of research should cover what are appropriate interventions that individuals and communities can take to lower exposures to fire smoke.

WHAT ARE THE HEALTH EFFECTS OF LONG-TERM EXPOSURES?

Over a period of months or years, an individual may experience repeated acute responses to short-term, high-level exposures. They may also experience constant subtle biological responses from longer-term exposures to lower levels of pollutants. These two types of exposure-response relationships, either independently or combined, may result in "long-term exposure" effects that are not reversible. Little research had been conducted and almost no information was available on these types of air pollution health effects until the ARB initiated the Children's Health Study in 1991. Since then, the ARB has also initiated the Cardiovascular Health Study – Air Pollution Ancillary Study (CHS-APAS) and FACES, both of which are investigating long-term exposure effects.

We need to research whether long-term exposures to PM, in the presence of other pollutants, have a greater effect in children and infants, especially considering the long developmental processes occurring as children mature from infants to young adults. We also need to investigate long-term effects in the elderly, who may be more susceptible to PM-related health impacts. Studies should use both experimental and epidemiological methods to investigate these effects. Much more work is needed to refine how long-term exposures diminish the health of the citizens of California.

DOES AIR POLLUTION INFLUENCE THE DEVELOPMENT AND PROGRESSION OF DISEASE?

Many of the known biological responses associated with air pollution exposures could potentially alter an individual's risk of getting a disease or influence the way an existing disease progresses. For example, even though there is scant evidence that air pollution causes asthma, it is known to induce asthmatic episodes in people with the disease. Repeated episodes of asthma may damage or alter the respiratory tract of asthmatics, leading to worsening of the disease and a poorer quality of life. FACES and CHS-APAS are beginning to examine some of the questions surrounding asthma and cardiovascular disease progression, but much work is yet to be done to understand the relationships between air pollution and disease. Clinical and animal toxicological studies, in addition to epidemiological studies, are needed to resolve these issues. Children and other individuals at high risk should be included in such efforts.

CAN THE HEALTH EFFECTS OF INDIVIDUAL POLLUTANTS BE MEASURED UNDER CONDITIONS OF MULTI-POLLUTANT EXPOSURES?

It is well recognized that, under real-life conditions, people are often exposed to more than one pollutant at a time. Thus, it is important to know the ways a biological response to simultaneous exposures to multiple pollutants differs from a response that would occur as the result of exposure to a single pollutant. For regulatory purposes, it is also important to know the effects of each pollutant, independent of the other pollutants. There are many challenges to studying multi-pollutant exposure effects. Most arise because ambient levels of many air pollutants closely track one another; that is, they are high [or low] at the same time and/or the same place, which makes separating their effects difficult. These challenges can be met by intensive exposure assessment components in epidemiological studies; advances in statistical methods; and carefully conducted, controlled exposure human and animal studies examining single and multi-pollutant exposure effects.

WHAT ARE THE HEALTH EFFECTS FROM SECONDARY POLLUTANTS, POLLUTANT INTERACTIONS, AND SYNERGIES BETWEEN POLLUTANTS?

We need to look more closely at the chemical interactions among gases, and between parti-

cles and gases, that occur on particle surfaces. The secondary products formed on particle surfaces may be more toxicologically active than the primary materials and could then be more readily carried to sensitive sites deeper in the lung. We need to determine whether synergism occurs as secondary chemical compounds are produced (e.g., sulfuric acid on the surface of the particles), especially under conditions of elevated relative humidity, as found in the human lung. We also need to investigate particle-allergen interactions and their effects on respiratory disease and health effects.

The lung is a very complex organ. The picture shows a cast of a human lung that is made with a plastic material. The right side has been pruned to show the airway structure.

IS PUBLIC HEALTH ADEQUATELY PROTECTED BY THE NITROGEN DIOXIDE (NO_2) STANDARD?

Epidemiological studies have reported relationships between both outdoor and indoor NO_2 levels and a variety of adverse health outcomes, including decrements in lung function; increased risks of respiratory symptoms and illness; exacerbation of asthma, especially in children; and increased risks of daily mortality. Further research is needed to determine whether this is an independent effect of NO_2 or an effect of important cofactors (especially different measures of PM). Recent studies involving allergen challenge at NO_2 levels that occur indoors suggest that NO_2 may enhance both allergen sensitization and its associated inflammatory response, including the effects of allergens in asthmatics. Studies should be initiated to determine the impact of NO_2 exposure on vulnerable populations, especially the elderly. Few human clinical studies of NO_2 have included elderly subjects.

HOW RELIABLE ARE EXPOSURE ESTIMATION MODELS AND HOW CAN THEY BE IMPROVED FOR USE IN EPIDEMIOLOGICAL HEALTH STUDIES?

In recognition of the fact that community monitoring sites may not accurately reflect the exposures of individuals, and in the absence of readily available personal monitoring devices that could measure an individual's exposure, researchers have resorted to statistical approaches for estimating exposures. The accuracy of these estimations depends on the quality and quantity of data available on: 1) the levels of pollutants in the different environments where people might spend time, such as homes or schools, and 2) data on the many factors that influence a person's exposure, such as activity patterns and housing characteristics. Often, there is little data on which to base the models, bringing the accuracy of these models into question. Because these models are being used more and more in epidemiological studies designed to assess the health effects of air pollutants, there is clear need to improve the accuracy of models and the estimates they generate.

HOW CAN WE BETTER MONITOR COMMUNITY HEALTH IN IDENTIFIED AREAS OF CALIFORNIA?

The Community Health Program would benefit from new innovative techniques to "monitor" community health and exposure, especially in children. This might include the development of protocols that would send public health practitioners into communities to conduct surveys to determine the health concerns of local residents. Finally, research is needed to investigate non-traditional air pollution problems on a local scale. It is common for individuals to feel they are adversely impacted by activities within their own community. Examples of specific local sources include jet exhaust from local airports, dust emissions from construction or dumpsites, or toxic air contaminates from local factories.

Coordination with Other Research Organizations: Various other organizations have programs that fund research projects to evaluate the impacts of air pollution on the health of populations in general or on specific populations that may be at special risk. A common feature of almost all of the projects funded by these programs is an emphasis on PM.

Most prominent of these are the U.S. EPA STAR grants program and its PM Center and Supersites programs. Populations-related research funded under these programs includes a wide array of studies to collect health status data, often linked to expansion of dedicated air monitoring and community-focused sampling. Persons with existing cardiovascular and respiratory illness are included in many of these studies. The elderly and children (especially those with asthma) are the individuals most commonly studied because of known or suspected sensitivity to PM. The U.S. EPA staff are also very active in population studies of the health impacts of PM, its components, and other pollutants. Other, somewhat smaller populations studies programs are supported by the National Institute of Environmental Health Sciences.

The Health Effects Institute (HEI) has funded studies to reanalyze and extend the findings of the Harvard Six-Cities Study and the American Cancer Society studies; all are pivotal to the establishment of the most recent federal PM ambient air quality standards. HEI supported studies include the development of a unified methodology to evaluate the nature of health effects for many cities across the United States where available health outcomes are associated with calculated exposures to pollutants of concern. Other HEI-supported studies include investigations of the various size and chemical fractions of PM on the health and well being of individuals and populations.

The ARB has conducted cooperative projects with the U.S. EPA, HEI, and California air quality management districts, and will need to continue this coordination in the future. This may include performing health studies that are coordinated with extensive ongoing or newly planned air monitoring efforts. The FACES study, for example, was conceived to make use of massive regionally and federally funded PM monitoring. These monitoring programs have provided both data and infrastructure that greatly assists the health study. In the Children's Health Study, air monitoring needs have been met by a combined network of existing and supplementary air monitoring stations in the communities under study. Air districts have agreed to augment their existing stations and, in many cases, operate the augmented sites.

As part of its Community Health research activities, the ARB needs to work with outside organizations that have a stake in addressing community health and environmental justice concerns. The U.S. EPA has a large Community-Based Environmental Protection program. It is currently funding studies to access the quality of air, water, and land in definable geographic areas and has provided funding to local communities to look at health and air quality issues and concerns. Due to their unique regional role in controlling air pollution, the air quality management and air pollution control districts could be strong partners in funding collaborative efforts that address community health and environmental justice. This is especially applicable in the South Coast and Bay Area Air Quality Management Districts and the San Diego Air Pollution Control District.

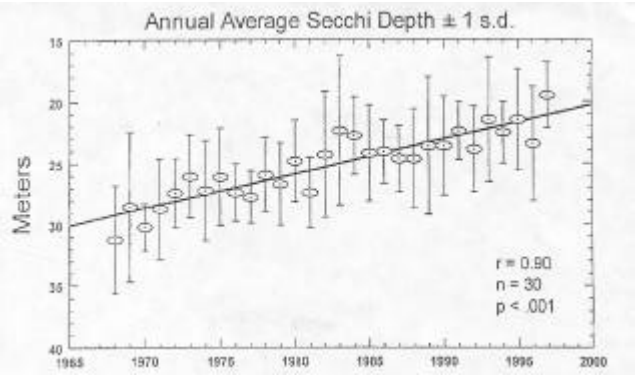
Lake Tahoe and Other Sensitive Ecosystems

Introduction: Air pollution contributes to a wide range of ecological problems in California, including water clarity deterioration in Lake Tahoe. Other significant environmental threats include photochemical air pollution damage to native pine forests surrounding the Los Angeles basin (Miller and McBride, 1999), ozone injury to crops throughout the state, and nitrogen saturation of soils in low-to-mid-elevation chaparral and conifer watersheds. Despite large decreases in ambient air pollution levels in southern California since the 1950s, ecological damage continues and

may increase with growth of population and vehicle use beyond 2010. Moreover, in central California over the past 20 years, increases in ambient levels of oxidants and nitrogenous pollutants have put mid-elevation forests and high-elevation aquatic systems at risk (Arbaugh, et al., 1998).

Background: In 1997, the Lake Tahoe Presidential Forum focused public attention on four environmental threats to the Lake Tahoe Basin (LTB): air quality, water quality, transportation, and forest health. The natural resources and associated economic productivity are integral to the public welfare; forestry and agriculture are multi-billion dollar industries in California and forested watersheds are critical to our water supplies. A striking example of ecological degradation due to air pollution is the decrease in the clarity of Lake Tahoe, from 100 feet during the late 1960s to only 70 feet 30 years later. The decline is largely due to changes in the nutrient balance of nitrogen and phosphorus in the lake and its effect on the growth of microscopic plant life (Reuter, et al., 2000). It appears that during the 1980s, Lake Tahoe became biologically saturated with nitrogen and is now phosphorus limited (rather than nitrogen limited), with respect to the undesirable growth of phytoplankton. Currently, it is estimated that half of the nitrogen loading of the Lake is due to deposition of air pollution. Understanding the forms and sources of the nitrogen and phosphorus input is necessary for effective control.

Marked increases in needle injury to pine trees, due to exposure to ambient ozone, have been observed in the LTB (Pedersen, 1989). Air pollution damage to pine forests are also present in southern California. First reported in the 1950s, the damage continues and remains significant, despite sizeable reductions in pollutant emissions. Controls implemented to lower regional air pollution have, in some instances, led to higher pollutant levels further downwind. From 1983-1993, the ARB investigated the causes and effects of acidic deposition in California; in particular, the effects of nitrogenous compounds on forests and aquatic ecosystems. Despite a stringent control program to reduce statewide emissions of nitrogen oxides, the potential for future adverse impacts to forests and aquatic systems remains high (Takemoto, et al., 1995; ARB, 2001b).



Source: Lake Tahoe Watershed Assessment 2000, Reuter and Miller

Ambient air quality in the mountain counties of the Sierra Nevada has not improved. Rapid population growth in rural areas of the state has brought associated increases in emissions of ozone precursors and PM that have largely offset emission reductions from advancements in control technologies (ARB, 2001a).

Ongoing Research: The creation of the multi-agency network in the LTB in 1998 focused on data coordination and monitoring support activities for the assessment of long-term trends in air quality. The multi-agency effort involves state (both California and Nevada), local, and federal agencies. Currently, the ARB staff operates monitoring stations at South Lake Tahoe and Echo Summit in California, and stations of the Nevada Department of Environmental Protection at Cave Rock and Incline Village. The Tahoe Regional Planning Agency (TRPA) operates sites at D. L. Bliss State Park, South Lake Tahoe, and Thunderbird Lodge.

In terms of forest effects outside of the LTB, two projects are expected to be completed in the summer of 2001. Researchers at the U.S. Department of Agriculture, Forest Service (USDA Forest Service) conducted field surveys along the western slope of the Sierra Nevada to characterize air quality and injury to native pines. As part of the study, geo-

graphic information system (GIS) techniques are being developed to estimate the extent of tree damage currently occurring. Complementary research to identify changes in wood biochemistry from exposure to ozone was conducted by scientists at the University of California, Davis, who collected samples at several of the sites surveyed by the USDA Forest Service.

To increase public awareness of the impacts ambient ozone has on agricultural crops, funding was provided to the University of California, Riverside, to establish a demonstration field project at the Kearney Agricultural Research Center in Parlier. The project will consist of eight field chambers used to grow crops typically cultivated in California's Central Valley. A measure of ozone's harmful effects will be provided by comparing the amount of damage to plants receiving ambient ozone versus that of plants receiving clean air.

ARB Research Needs: The impacts of air pollution on ecosystems are chronic, typically occurring over one or more decades. Thus, a key research priority is documenting changes in the air quality and determining the resultant effects to sensitive receptors, especially the long-term impacts of ozone and nitrogen-derived compounds on mid-elevation forests and watersheds and nitrogen deposition to high-elevation lakes, including the contribution of nitrogen and phosphorus deposition to the loss of clarity in Lake Tahoe. The overarching impacts of global climate change must also be seriously addressed.

The ARB's research into ecosystem effects should focus on monitoring impacts that have been found to develop over decade to multi-decade time-scales in natural systems and on characterizing yield losses in agricultural production areas. Primary questions in this area include the following.

IS DEPOSITION OF AIR POLLUTION THE PRIMARY FACTOR IN THE CONTINUING DECLINE IN THE CLARITY OF LAKE TAHOE?

The dramatic decline in the clarity of Lake Tahoe over the last 30 years may be the foremost ecological concern in the LTB. Key to any mitigation is understanding and quantifying the role of air quality in that degradation. Nutrients, nitrogen, and phosphorus are all necessary for the destructive growth of phytoplankton. In the recent past, the Lake was nitrogen limited; but it appears that, beginning in the 1980s, the balance shifted and the Lake became phosphorus limited. Atmospheric deposition has been identified as the primary input of nitrogen to the Lake. However, it is necessary to better quantify that conclusion and identify the nitrogen species and their sources before effective controls can be developed. Also, deposition has been hypothesized, but not confirmed, as an important input of phosphorus to the Lake. Testing of this hypothesis should be a priority. Currently controls on phosphorus input are focused on reduction of soil erosion. Thus, key research questions include the following.

- What is the mass input of nitrogen to the Lake from the atmosphere and how does that value compare with the total input of nitrogen from all sources?
- From what sources and in what form is nitrogen deposited from the atmosphere to the Lake?
- Is the atmosphere a significant source of phosphorus input to the Lake?
- What is an upper bound on the atmospheric deposition of phosphorus and is that significant in comparison with other phosphorus inputs?

TO WHAT EXTENT IS EXPOSURE TO OZONE IMPACTING THE HEALTH OF THE FORESTS OF THE LAKE TAHOE BASIN AND ELSEWHERE IN CALIFORNIA?

Evaluation of the spatial patterns and long-term trends is needed for air pollution levels in the LTB. This will require additional monitoring to adequately characterize the spatial complexity of the air basin. It is suggested that research focus on three broad efforts: 1) expanding and sustaining the multi-agency air monitoring program; 2) establishing a quality-assured database for those concerned

with stewardship of the LTB; and 3) implementing a research program focused on health and ecological effects in the LTB.

WHAT IS THE EXTENT OF INJURY TO PINES IN MID-ELEVATION FORESTS DUE TO OZONE EXPOSURE?

Due to the long-term nature of ozone impacts on native pines, periodic sampling and analyses of forest areas from the Modoc Plateau to the Tehachapi Mountains offers the most effective way to provide a record of air quality and tree injury responses over time. The work currently being done by the USDA Forest Service provides a baseline for future follow-up projects. Resurveying the same sites every 3-4 years would allow for any trends to be identified. The development of a flexible GIS platform would allow for more extensive analyses of air quality impacts in the forested regions of California. Focused questions include the following.

- What are the relative contributions from transport and specific local pollutant sources to ozone and the various PM species and size fractions in the LTB?
- What are the spatial patterns and trends in ozone levels and their effects on pine forests in the LTB?

WHAT ARE THE NITRATE LEVELS IN STREAMS AND THE RATE OF EMISSION OF NITROGEN SPECIES FROM SOILS IN NEAR-URBAN WATERSHEDS?

Although stringent control measures have been adopted to limit emissions of nitrogen oxides, streams draining forest and chaparral watersheds surrounding the Los Angeles basin exhibit high levels of nitrate. Moreover, studies have found soil nitrogen emission rates comparable to those in agricultural fields supplemented with nitrogen fertilizers. While the amount of nitrogen oxide emissions from urban areas is expected to decline through 2010, levels may rise post-2010 due to increases in population and vehicle use. The continued deposition of nitrogenous compounds poses a potential health risk to residents that secure drinking water from reservoirs that collect stream water from nitrogen-saturated watersheds.

WHAT ARE THE NITRATE LEVELS IN THE SIERRAN SNOW PACK?

The snowpack in the Sierra Nevada is a principal source of water to municipalities throughout California. While considerable effort is devoted to measuring the amount of snow deposited, little, if any, effort is dedicated to characterizing the chemical constituents in the snowpack. Population and motor vehicle use have risen substantially in the mountain counties of the Sierra Nevada, and levels of selected analytes should be measured and their trends analyzed to determine the potential for future ecological impacts on water supplies.

WHAT IS THE CURRENT BASELINE OF ECOLOGICAL CONDITIONS?

Global climate change serves as an overarching modifier of ecosystem response to ambient environmental stresses. Inventories of California's ecological capital would be a first step to understanding where impacts could occur and identifying areas that presently exhibit adverse impacts from air pollution. For example, an estimate of how much carbon is sequestered by California forests would be useful in future efforts to determine if credit should be given to entities that preserve natural carbon sinks in lieu of reducing anthropogenic carbon emissions.

Coordination with other Research Organizations: Federal land management agencies include the USDA Forest Service, the U.S. Department of the Interior, and the federal Bureau of Land Management. In addition, resource protection is also of concern to the U.S. EPA and the Resources Agency of the State of California. In future years, partnerships with other government agencies (e.g., USDA Forest Service) could be developed to co-sponsor research or monitoring efforts of mutual benefit. For example, air pollution research remains a priority concern for the Pacific Southwest Research Station of the USDA Forest Service. Over the next five years, the Forest Service plans to conduct research in several areas that parallel ARB

interests, including: 1) examining the effects of air pollution on biocomplexity in arid, coastal sage, and mixed conifer ecotones of southern California; 2) assessing the frequency, severity, and impacts of ozone and PM exceedances in Federal Class I areas in California; and 3) using passive monitoring systems to characterize multiple pollutant exposures to sensitive mid- and high-elevation ecosystems.

Other potential research partners include the regional and local water quality control boards. The ARB is currently cooperating with the local air districts and researchers from the Delta Group at University of California, Davis, and the Desert Research Institute at the University of Nevada, Reno. Monitoring and research in the LTB is occurring in partnership with the Tahoe Regional Planning Agency, and the Nevada Division of Environmental Protection.

Regional Haze

Introduction: "Haze" occurs because gases, particles, and water droplets in the atmosphere scatter light, adding "air light" to a scene and "washing out" the view. Particle pollution increases the amount of light scattered or absorbed by the air, producing visible "smog." California adopted State visibility standards in 1969 and federal law mandated visibility protection in National Parks and Wilderness Areas in 1977. Historically, regulators have relied on the loose correlation between "smog" and "haze" to avoid controlling visibility *per se*, assuming that health-based efforts to reduce pollution would bring commensurate visibility benefits. In recent years, it has become clear that achieving those standards may not provide all the visibility benefits required by law and public expectation. Moreover, new federal regulations require explicit treatment of visibility protection through a Regional Haze SIP. Considerable new research will be needed to provide the information to prepare this SIP.

Background: ARB began addressing visibility concerns in the late 1960s, with a compilation of airport visibility records. Since then the ARB has funded, led, or participated in several major visibility, aerosol, and related studies. The landmark report *Visibility in California* (1979) documented regional visibility patterns and tied them to major pollutant source types. The ARB cooperated with the U.S. DOD on its *Research on Operations Limiting Visual Extinction* (1984-86) to quantify effects on flight research activities in the Mojave Desert. The 1987 South Coast Air Quality Study (SCAQS) advanced the understanding of carbonaceous aerosols and secondary nitrates. The 1997 Southern California Ozone Study (SCOS97-NARSTO) provided a three-dimensional view of aerosol dynamics and chemical kinetics in the South Coast Air Basin. The ongoing 1999-2000 California Regional PM10/PM2.5 Study (CRPAQS) is addressing local and regional, episodic, and seasonal PM air quality in the San Joaquin Valley and neighboring air basins.

Regional haze occurs on localized, statewide, and continental scales. In 1992-93, the U.S. EPA, Southern California Edison, and the National Park Service (NPS) cooperated on Project Mojave, which studied the transport of haze-producing particles from southern California and southern Nevada toward Grand Canyon National Park. The Grand Canyon Visibility Transport Commission (GCVTC) (1995) assessed transport and controllability of haze from sources throughout the western U.S., Canada, and Mexico to 16 National Parks and Wilderness Areas in Arizona, Utah, New Mexico, and Colorado. The GCVTC found that improving emission control technology is currently driving total regional emissions downward, but population and emission growth in future decades, combined with new wildland fire management policies, may overwhelm these controls.

Ongoing Research: The ARB has a fairly good understanding of aerosols and visibility in the South Coast and San Joaquin Valley air basins. Research within California, led by other agencies, especially the U.S. DOD and TRPA, provide frameworks for understanding the aerosols in the western Mojave Desert and Lake Tahoe regions, respectively. Visibility conditions elsewhere in the state, however,

are not as well understood.

Current research is focused on completing the CRPAQS work, completing analysis of the SCOS97-NARSTO aerosol data, and continued development of mechanistic aerosol models. Additional projects include emission inventories for smoke in the Sierra Nevada and work on regional modeling methodologies, applicable to the South Coast and San Joaquin Valley air basins (in house). Long-term visibility research at the ARB is currently very limited.

Visibility work in the western U.S. is currently dominated by the efforts of the Western Regional Air Partnership (WRAP). This group is attempting to revisit the GCVTC analysis to confirm the predicted emission and visibility trends. However, the regional analyses of the GCVTC (and the anticipated WRAP work products) generally lack the specificity needed to develop SIPs for California's Federal Class I areas.

ARB Research Needs: Federal Regional Haze regulations impose planning requirements on the State that apply to more than thirty Class I areas located throughout California. In addition, the regulations require California to cooperate with neighboring states to address visibility impairment at Class I areas within those states that are affected by pollutants originating in California. Furthermore, international pollutant transport is known to impact California Class I areas, but the frequency and severity of these effects is unknown.

For each in-state site, California must determine the present degree of visibility impairment and develop a long-term strategy to reduce, and eventually eliminate, that impairment. Baseline aerosol monitoring for most of these sites is being provided by the Federal Interagency Monitoring of Protected Visual Environments (IMPROVE) Program, but these data alone will not provide all the information needed to prepare Regional Haze SIPs.

The research needed to support State and federal visibility programs falls into the following categories.

WHAT ORGANIZATIONAL CHANGES ARE NEEDED TO SUPPORT REGIONAL HAZE PROVISIONS?

The ARB must establish a dedicated visibility-aerosol data collection and analysis program. This requires both contract efforts to collect and analyze data and the creation, within the ARB, of a staff group with expertise in aerosol monitoring and multivariate data analysis. In addition, a modeling program is needed to develop California-specific analyses and to work with aerosol modelers in academic research groups, the U.S. EPA, and industry.

WHAT SUPPORT ACTIVITIVES ARE NEEDED TO PREPARE FOR REGIONAL HAZE MODELING NEEDS?

The ARB must develop advanced, high-resolution meteorological monitoring and modeling capabilities. High spatial and temporal resolution meteorological data are needed to assess long range transport from urban and agricultural areas through California's complex terrain to the state's Class I areas. Current capabilities are not reliable when applied in California's mountains and deserts.

WHAT SPECIALIZED FIELDWORK IS NEEDED TO SUPPORT A REGIONAL MODELING EFFORT?

The ARB needs to conduct specialized field studies to build the linkage between pollutant source areas in California and the Class I area monitoring data generated by the IMPROVE network. These studies will include sampling in known "clean" sites, along "clean air corridors", in populated source areas, and along transport corridors. It will also be necessary to conduct various special studies to properly interpret events that are not within the capacity of the IMPROVE protocol to properly resolve or characterize.

HOW CAN THE ARB ADDRESS THE "BACKGROUND" PROBLEM?

The ARB must conduct specialized field studies to document natural "background" aerosol levels. Natural aerosols include biomass smoke, soil dust, sea salt, oceanic sulfate, volcanic dust, and biogenic organic aerosols, all of which exhibit large spatial and temporal variations. Correctly distinguishing

the contributions of "natural" sources from those contributed by anthropogenic sources is essential to determining what visibility goals are appropriate under the Federal Regional Haze rules. This issue is especially pressing for biomass smoke, since present conditions represent significant suppression of "natural" burning and land managers are seeking to greatly increase the use of prescribed burns.

WHAT POLLUTION AT CLASS I AREAS IS BEYOND THE ARB'S REGULATORY REACH?

The ARB must conduct specialized field studies to document transborder aerosol transport. Recent data (Project MOHAVE, border area monitoring by ARB, etc.) demonstrate that there are at least two pathways that deliver a persistent flux of sulfate and other aerosols into California. Pollutants arriving from Mexico and the tropical Pacific are both assumed to originate in Mexico, but U.S. Gulf Coast oil and chemical industries may also contribute. Correct allocation is necessary to avoid asking California sources to reduce emissions in an effort to control pollutants dominated by upwind sources, and to facilitate interstate or international cooperation to address them.

Coordination with Other Research Organizations: Visibility research in urban and agricultural areas should be linked to the larger program of regional aerosol assessment being funded in support of PM SIP development, and thus should generally be pursued as a cost-effective adjunct to regional PM research. Conversely, long-range transport work will generally need to be addressed separately. Modeling regional haze associated with interstate transport is being addressed through the WRAP, but its funds are committed to modeling and thus not available for research projects.

Intrastate transport study cooperation should be sought from federal land managers and other national agencies, such as the U.S. DOE, NOAA, NPS, USFS, and the U.S. DOD. No significant Federal research is ongoing at this time. Other California agencies with interests in these problems include the California Department of Forestry, State Parks, and the Department of Water Resources. With these agencies, the ARB will probably need to take the lead. Some cooperation regarding emission and activity documentation is already in place through the Interagency Fire and Smoke working group, but these agencies should be encouraged to participate in meteorological monitoring and smoke impact studies as well.

Finally, international transport is being minimally addressed by the U.S. EPA and the State Department through the North American Free Trade Agreement and the National Science Foundation (NSF). The NSF's research activities, in particular, may present avenues of cooperation that ought to be explored.

Benefits and Costs of Air Pollution Control

Introduction: The primary role of the ARB is to protect public health by improving air quality in California. The benefits of improved air quality are reduced mortality and morbidity in populations sensitive to air pollutants, enhanced public welfare, and increased ecological protection. The ARB has extensive information on air quality and emission levels, but less information on the health and welfare impacts of improved air quality, such as reduced death, disease, improved visibility, and greater crop yields.

Background: The main goal of the ARB's benefits program is to provide decision-makers with estimates of the dollar value of the physical impacts of improved air quality. These benefits have been monetarily evaluated in the past by the South Coast Air Quality Management District (Jane Hall, et al., 1992). The Congress required the U.S. EPA to prepare a retrospective and a prospective estimate of the benefits of air pollution reduction from implementation of the federal Clean Air Acts (U.S. EPA, 1999). The U.S. EPA plans to continue improving the benefit estimations. These studies and others have helped decision-makers compare, in common terms, the positive impacts of an action with the costs of that action.

Exposure to Diesel Exhaust Causes Premature Deaths in California at a Cost of $18 Billion per Year

Premature deaths due to diesel PM exposure serves as an example of benefit estimation. Using concentration-response relationships, exposure levels, and economic value, the mortality effects of diesel exposure are estimated at 3,500 premature deaths. These premature deaths translate into $18 billion of benefits if the exposure to diesel is eliminated. The $18 billion benefit is an underestimation because the morbidity effects are not included.

	Annual Mortality In 2000 (Deaths)
Direct PM	**2400**
Indirect PM	**1100**
Total	**3500**

Statewide average exposure to direct PM was 1.8 ug/m^3 and 0.81 ug/m^3 to indirect PM from NO_X emissions (Lloyd and Cackette, 2001)

Economic analyses of air pollution's effects on public health and the environment are complex. Such analyses investigate the impacts that air pollutants have on the human body and the environment, and develop "damage functions" to estimate those effects at different levels of air pollution. These effects are economically evaluated to estimate the total mortality and morbidity costs of air pollution, which can be viewed as benefits when air pollution is reduced. In the early 1980s, the ARB conducted research evaluating public health, agricultural, and material damages of the state's polluted air. The damages were translated to dollar values. For example, statewide benefits of achieving different air quality improvements and reducing damages to the agriculture sector ranged from $50 million to $333 million per year. Such results and additional data are used to respond to concerns and questions from the Board. For example, the last three SIPs approved by the Board considered the benefits of air pollution control, using the valuation studies and data collected by the staff.

The economic impacts of clean air regulations on the state's economy, businesses, and individuals have also been studied. In 1983, the Legislature passed several bills requiring air quality regulations to be evaluated for their economic impact on business, including competitiveness, business expansion, and the creation (or elimination) of jobs. Methodologies such as 1) productivity analysis, 2) financial ratio analysis, 3) supply and demand analysis, and 4) model simulation have been used to evaluate costs and impacts of regulations. In the early 1990s, the cost of environmental regulations was considered by some to be a cause of the difficulties faced by California businesses. The ARB, concerned about its regulatory impacts, undertook several research projects to improve the efficiency of its regulations. One research project studied benefit/cost and socioeconomic impact methodologies; another studied the impacts of regulation on business relocations; and a third studied the economic impacts of the proposed 1994 SIP on the California economy. Continued research in benefit and cost estimation will help the ARB to achieve its primary goal of protecting the public health and welfare.

Ongoing Research: The ARB's current benefits research focuses on estimating the cost of illnesses caused by air pollution. Earlier studies have estimated the correlation between air pollution and cardiopulmonary diseases, using hospitalization data in the South Coast Air Basin. Hospitalization costs are indicators of how much air quality degradation is costing Californians. Another project will estimate people's willingness to pay to keep the air clean to avoid hopitalization.

Another current project examines jobs and incomes generated from air pollution control expenditures. Many air quality regulations require expenditures in new equipment, operation, and maintenance. These expenditures create jobs and incomes that can be viewed as a benefit to the economy to be weighted against the costs of control. The expenditures to clean California's air have spawned industries or extended segments of other industries that export equipment, know-how, and services to other states and the rest of the world. The jobs and income created by the business expansion are a part of the benefits.

ARB Research Needs: The public health benefits of improved air quality need to be

further researched and evaluated. The ARB should focus on expanding the benefits estimation to include all direct and indirect benefits of improving air quality. Research is needed to determine the following.

WHAT ARE THE ESTIMATED BENEFITS OF AIR POLLUTION CONTROL IN THE LAST 20 YEARS?

Future projects should continue investigating ways to evaluate the public health effects of small changes in emission levels and improve our ability to estimate the health cost imposed on the public because of delaying regulations. These projects could include updating an earlier ARB study that compared the benefits of air quality control to a scenario of no controls, as well as studies that evaluate the economic benefits of improved visibility, increased protection of the ecosystem, and the impact of air pollution on plants and animals.

WHAT ARE THE BENEFITS OF REDUCING ASTHMA BY REDUCING AIR POLLUTION?

The costs of air pollution-related health effects, such as hospital, medication, and doctor's costs associated with asthma, would have to be determined in order to estimate the value of reducing asthma in the sensitive population. . However, implementing informational programs on protecting children from the effects of allergens that exacerbate asthma could be of enormous value to parents concerned with improving their children's health.

WHAT IS THE PUBLIC'S WILLINGNESS TO PAY TO AVOID THE HEALTH EFFECTS OF AIR POLLUTION?

The ARB needs to determine how much the public values reductions in health effects because of air pollution. Current estimates are based on the economy of a decade ago. As the economy prospers, people value health higher by increasing their willingness to pay. By updating the valuation of all health effects, including children's lung function losses, cancer, mortality, and morbidity, the value dollar of benefits estimates should increase, compared with estimates done a decade ago. These updated values should maintain the benefit estimates above the increasing cost of control.

WHAT ARE THE RELATIVE HEALTH BENEFITS OF INCREMENTAL AIR QUALITY IMPROVEMENTS IN SOUTHERN CALIFORNIA USING OBSERVED AIR QUALITY AND HEALTH DATA?

Ambient air quality has improved in southern California, as evidenced by a decrease of 50 percent in ozone, 47 percent in PM10, and 30 percent in toxic air pollutants in the past twenty years. Although the effects of these pollutants on human morbidity and mortality have been documented, no effort has been made to validate the estimated health benefits resulting from this air quality improvement. The accuracy of past benefit estimates has been in question because of: 1) the inability to validate benefit estimates with observed air quality and health data; 2) wide variations in the range of estimates, presumably due to the assumptions made, selection of models, and model specifications; and 3) uncertainties in statistical approaches which may inappropriately force, or by default accept, a linear dose-response relationship between pollutant levels and effects. A comprehensive study is needed of the health benefits of ozone, PM10, and air toxic reductions in California.

Coordination with other Research Organizations: The ARB has used the benefits model developed under U.S. EPA funding, and further collaborations would be useful to both agencies. The Health Effects Institute (HEI) plans to develop an issue paper and solicit projects on the relative health benefits of incremental air quality improvements. Co-funding opportunities will be explored with HEI and other institutions interested in the work proposed here.

IV. EXPOSURE ASSESSMENT

Another major research priority concerns efforts to advance our understanding of exposures to air pollution. This includes characterizing personal exposure to pollutants from both indoor and outdoor sources. Improved understanding of exposures helps assure that our regulatory activities focus on reducing exposures that represent the greatest health concerns. Efforts to further improve emission inventories for manmade and natural sources, increase our understanding of the atmospheric processes that impact the behavior of pollutants, and advance our knowledge of the impacts that air pollutants have on other media such as water bodies and soils are important aspects of this research. These research activities will help address two key regulatory priorities – to reduce emissions and exposure to PM and characterize and to reduce community exposure to air pollutants.

Personal and Indoor Exposure

Introduction: The Personal and Indoor Exposure Assessment Research Program seeks to provide risk managers and policymakers with the best estimates of Californians' actual exposures to air pollution and to identify the primary sources of those exposures. Personal exposure is measured by sampling air in an individual's breathing zone as they move about throughout the day. Because people spend about 90 percent of their time in enclosed environments, personal and indoor measurements provide the best estimate of actual pollutant exposures and consequent health risk. The ARB uses personal and indoor exposure assessments to identify the primary sources of the pollutants actually inhaled and to identify more effective strategies for reducing harmful exposures. Specific uses of exposure assessment information include estimating Californians' exposures to TACs;

"A typical pollutant release indoors is 1000 times as effective in causing human exposure as the same release to urban outdoor air."

Source: Smith (1988)

developing school and office building specifications and building material emission guidelines; developing indoor air quality guidelines for the public; and supporting actions to reduce emissions from consumer products and sources of TACs.

Background: California Health and Safety Code Section 39660.5 requires the ARB to estimate Californians' indoor exposures to TACs and to assess the relative contribution that indoor exposures make to total exposure. In 1986, when the Board's Indoor Air Quality and Personal Exposure Assessment Program (Indoor Program) began, there was little information available in this area. The ARB has funded several large studies of indoor and personal exposures to toxic VOCs and particulate pollutants. Some of these studies were co-funded by the U.S. EPA. These studies have shown that both personal and indoor levels of VOCs are typically much higher than outdoor levels and that daytime personal PM exposures usually exceed indoor and outdoor levels by up to 50 percent. Additionally, in-vehicle gaseous and diesel exhaust particle exposures are especially high. Other field studies have examined indoor radon, PAH exposures, phthalates, metals, and other pollutants. The ARB's early studies also included population-based activity pattern studies and a breathing study, which have been used widely in exposure assessment, such as the U.S. EPA's *Exposure Assessment Handbook* and OEHHA's stochastic exposure guidelines for the Air Toxics Hotspots Program (Assembly Bill 2588) Risk Assessment Guidelines.

Studies of building materials and consumer products have shown that they are major contributors to indoor air pollution; for example, pressed wood products continue to be major sources of formaldehyde. These studies also have pointed to a need for further investigation into indoor chemistry, based on apparent "sink" effects involving absorption and re-emission of VOCs.

The ARB has also funded the development of important tools to help more accurately measure and assess indoor and personal ex-

posures to pollutants. The California Population Indoor Exposure Model was developed to improve estimates of Californians' indoor and total exposures to TACs. The first portable, real-time NO_2 and ozone monitors were also developed under ARB funding. The NO_2 monitor fills an especially critical need in light of the recent finding of an association between brief, high-level indoor exposures to NO_2 and the exacerbation of asthma.

Ongoing Research: Current ARB indoor and exposure studies are focused in two primary areas: children's exposures and exposures to particles. Studies of children's exposure are being conducted in portable and traditional classrooms, during school bus commutes (typically in diesel-fueled buses), and as part of the Children's Environmental Health Protection Program (SB 25) monitoring effort. Two major particle exposure studies (co-funded with the U.S. EPA) to examine the personal and residential exposures of pulmonary disease patients and healthy individuals to PM10, PM2.5, and associated pollutants are currently being conducted in Los Angeles. These studies are focused on improving our understanding of the relationships among outdoor, indoor, and personal PM exposures and quantifying the contributions of different indoor and outdoor sources to personal exposure. This has been a major area of controversy in the epidemiological studies used as the basis for setting federal and State PM standards.

Research coordinated by others includes a recent National Human Exposure Assessment Survey sponsored by U.S. EPA, which examined indoor and personal air, water, food, and dermal exposures of several populations to a variety of pollutants. Analyses are still underway. Other recent U.S. EPA studies have focused on all aspects of PM and on children's exposures to pesticides, in response to the Food Quality Protection Act. Lawrence Berkeley National Laboratory has undertaken a study of indoor-outdoor PM relationships using test homes and has recently begun examining portable classroom ventilation and improvement options. The Mickey Leland National Urban Air Toxics Research Center has sponsored a variety of personal and indoor studies; most recently, studies focused on assessing children's exposures in schools.

ARB Research Needs: Future indoor and personal exposure research needs to focus on several questions raised by recent study results and policymakers.

WHAT IS THE IMPACT OF AIR POLLUTION ON CHILDREN'S EXPOSURES, AND HOW DOES IT DIFFER FROM THAT ON ADULTS?

Children spend a majority of their time in much different environments than adults. We need to better characterize children's exposure to air pollutants, especially to TACs, and the contribution of various sources to those exposures in homes, schools, vehicles, and other environments.

HOW DO INDOOR AND OUTDOOR SOURCES OF AIR POLLUTION AFFECT INDOOR AND PERSONAL EXPOSURES?

A variety of studies is needed to adequately answer this question. Studies are needed for the following.

- Improved understanding of the contributions of indoor and outdoor sources of PM to personal exposure through personal monitoring and exposure apportionment studies, so that the most effective exposure reduction strategies can be determined.
- Better understanding of the chemistry and transport of indoor pollutants. Track-in, infiltration, and indoor re-suspension of PM components have been identified as major sources of personal exposure, but have been poorly characterized. Also, indoor ozone and hydrocarbons are known to react to produce high levels of indoor aldehydes and PM, so the indoor chemistry of these reactions needs to be better understood.
- More complete indoor and personal exposure data for the many TACs. Also, some previously studied TACs may need reassessment to determine the effective-

ness of risk reduction measures.

- Investigations into the usefulness of biomarkers as a measure of exposure and dose, and more frequent use of appropriate biomarkers to better understand the relationships between personal exposures, actual target organ doses, and health effects.

HOW EFFECTIVE ARE IMPROVEMENTS AND NEW FORMULATIONS OF CONSUMER AND BUILDING PRODUCTS IN REDUCING INDOOR EXPOSURES?

Many consumer and building products have been improved and reformulated to reduce emissions of air pollutants and air pollution precursors. It is important to determine the impacts of these improved products and new formulations on indoor air quality, especially for "green building" materials and practices which have not been tested for their effectiveness in reducing indoor exposures.

HOW DO SHORT BUT ELEVATED EXPOSURES TO SMOKE FROM FIRES IMPACT INDOOR AIR QUALITY AND EXPOSURES?

Exposures to smoke from agricultural burning, forest fires, and residential wood burning have not been well estimated, but appear to be increasing. Better characterization of exposures from these sources is needed. The effectiveness of various exposure reduction methods has not been well examined.

ARE PEOPLE AT THE LOWER END OF THE SOCIOECONOMIC SCALE EXPOSED TO HIGHER LEVELS OF POLLUTANTS?

Analyses to identify disproportionately high exposures of persons of different socioeconomic and ethnic backgrounds needs to be integrated, whenever possible, into all exposure studies. Tools such as GIS should be used to assist with such analyses. Molds and biological material exposures are also a key area of importance, but the Department of Health Services has the lead role in addressing these exposures.

Coordination with Other Research Organizations: Several current ARB projects are jointly funded or conducted with the Department of Health Services and the U.S. EPA. These projects meet mutual goals for assessing and improving children's environmental health. They also help to better quantify and understand the relationships among outdoor, indoor, and personal exposure levels of PM and its effects on sensitive subgroups of the population. Our projects and planned research will complement other organizations' research programs and goals, including the U.S. EPA's Government Programs and Results Act goals for children's health and PM and their community exposure studies; the National Academy of Science PM research plan; studies on children's indoor and personal pollutant exposures and community toxics, sponsored by the Mickey Leland National Urban Air Toxics Research Program; HEI's diesel exhaust exposure studies; LBL's portable classrooms studies and indoor-outdoor PM studies; planned Integrated Waste Management Board/Department of Health Services school and office building material emission studies; OEHHA's projects to develop guidelines for children's exposure and risk assessment in classrooms; and the California Energy Commission's Public Interest Energy Research (PIER) Program studies on portable classrooms, commercial buildings, and indoor air quality. All of these organizations are potential co-funders or collaborators for future ARB indoor and personal exposure projects.

Emission Inventory

Introduction: The emission inventory, a collection of measured and estimated pollution discharge rates from sources associated with society's activities, is a key component of SIPs and community exposure assessments. Any bias in the emission inventory results in similar errors in predicted air quality and can lead to the design of less-than-optimal emission control programs. After a concentrated effort over the past decade, emission inventories have improved for CO, VOCs, NO_X, and sulfur oxides (SO_X) for major source categories in California. However, other inventories, such as those for PM, many TACs, and chlorine, are still in their relative infancy.

Background: California law mandates the

ARB to inventory and project emissions of air pollution within each air basin. Senate Bill 2174, passed in 1996, requires triennial updates (beginning in 1997) of emission estimates from all source categories, including on-road mobile, non-road mobile, stationary, area, and biogenic sources. The legislation further requires verification of the emission inventory, using direct observations of pollutants in the atmosphere, and explanation of any inconsistencies. Congress has also taken an interest in the accuracy and reliability of the emission inventory and commissioned recently completed studies by both the National Research Council (NRC, 2000) and the General Accounting Office of the U.S. EPA's and the ARB's mobile source emission modeling efforts.

The emission inventory identifies the pollutant-specific contributions of each emission source category within an air basin for a specific year. In general, emission estimates are the product of emission factors (e.g., mass of pollution per mile for a car) and activity rates (e.g., number of miles driven per car). Using the results from a variety of emission factors and activity studies, emission inventory experts estimate base year emissions and project emissions to past and future years, using factors that account for growth and control. They re-allocate emissions to season, hour of day, grids of surface area (i.e., 2 x 2 or 5 x 5 km), and specific VOC and NO_X chemical species, using the results from a variety of activity and chemical speciation studies. Air quality simulation models use hourly, gridded emission inventories to generate estimates of past and future pollution levels. The ARB and others employ air quality simulation models to estimate current air pollution exposures and project the effect of proposed emission reductions for State Implementation Plans and community exposure assessments.

Ongoing Research: The ARB dedicates about 60 people to the development and maintenance of emission inventories in California. Their major focus is on on-road and non-road mobile source emission modeling (i.e., EMFAC2000 and OFFROAD models), transportation activity modeling (i.e., DTIM model), area sources, point sources, and biogenic sources (described in a later section) for CO, VOC, NO_X, SO_X, PM, and TACs. In addition, the ARB staff develops gridded emission inventories for air quality simulation models, project future year inventories, develop chemical speciation profiles, and have recently conducted micro-scale inventories for community health assessments. The ARB's extramural research program currently funds studies of heavy-duty diesel emissions of NO_X and PM, off-road sources of VOC and NO_X, weekend activity, and emissions of dust, ammonia, chlorine, and biogenic hydrocarbons. The level of support for the past five years reached at least $1,000,000 per year from various parts of the organization.

Other organizations sponsor research directed at emission inventory improvement. The U.S. EPA, the ARB, state and local government agencies, and other organizations participate in the Emission Inventory Improvement Program to update, improve, and document emission estimation methodologies through coordination of experts in developing recommended "best practices." A recent NRC report identified over 50 ongoing research studies of PM emission sources in the United States (NRC, 2001). The CRC, representing the auto and oil industries, organizes a consortium of sponsors (including the ARB, the South Coast Air Quality Management District, the U.S. DOE's National Renewable Energy Laboratory, and the U.S. EPA for development of nationally accepted heavy-duty diesel test procedures. The CRC-organized consortium recently established a test program of PM and NO_X emissions from 75 trucks; this effort will more than double the existing database for heavy-duty diesel trucks.

ARB Research Needs: Recent critical reviews by the National Research Council (NRC, 2000; 2001) and the NARSTO (2000) highlight the need for continued emission inventory research in the areas of PM, mobile sources, and ozone precursors (VOC and NO_X). The focus of the ARB's emission inventory both overlaps and, in some cases, is independent of national emission inventory needs. The ARB's research needs, with re-

spect to the emission inventory, range from knowing what compounds are being emitted into the atmosphere to what control measures on emission sources will best protect public health and welfare. Specifically, scientists and ultimately decision-makers need to: 1) know the types and amounts of compounds being emitted, directly or indirectly, into the air; 2) develop and improve the emission inventory by knowing how these emissions vary in time (including operational mode) and space (as the location of emissions is a critical factor in the fraction that is inhaled); 3) know the uncertainties in the inventory, and the confidence users can have in the accuracy of the inventory; and 4) know what control measures will likely lead to the greatest benefits. Questions that future research activities must address to meet emission inventory needs include the following.

WHAT ARE THE EMISSIONS OF BIOLOGICALLY RELEVANT SPECIES OF PM?

Chemical speciation profiles provide estimates of the weight fractions of individual chemicals or elements making up the PM emissions reported for source categories in the emission inventory. These chemical and elemental compositions of PM emissions are needed to better understand health effects and for PM control development. Throughout this decade the districts, the ARB, and U.S. EPA must develop and adopt plans to attain the PM standards in California. Improved PM speciation data is crucial in developing an inventory that is the most useful for the development of the needed PM control plans. As we gain more knowledge from our PM health studies concerning the most health-relevant PM species, it will be important that these species be accurately represented in the inventory so that the most health protective control strategies are implemented. Additionally, some components of PM (e.g., hexavalent chromium, due to its extreme toxicity) are especially important in ARB's community health program, and this highlights the need for better speciation profiles for the program's microscale inventories.

WHAT IS THE MAGNITUDE OF AMMONIA EMISSIONS FROM ANIMAL HUSBANDRY, MOBILE SOURCES, AND SOILS?

Ammonia contributes to the formation of PM, specifically PM2.5. In order to prepare the required PM2.5 SIPs, a comprehensive ammonia emission inventory is required. Preliminary estimates show that livestock, fertilizers, soils, and catalyst-equipped cars and trucks may produce significant ammonia emissions. To support ammonia inventory development and preparation of PM2.5 SIPs, research must be performed to understand the emissions from these and other sources. This research will include source testing, activity data collection, and development of spatially and temporally resolved emission estimation models. Ammonia emission models will take into account environmental parameters such as temperature, humidity, soil pH, and other relevant conditions. With the availability of better ammonia emission estimates, we can more accurately evaluate how much ammonia is contributing to regional PM2.5 levels and if source controls are warranted.

WHAT ARE PM AND AIR TOXIC EMISSIONS AT THE COMMUNITY LEVEL, ESPECIALLY IN URBAN AND RURAL ENVIRONMENTAL JUSTICE COMMUNITIES?

As part of its environmental justice initiative, the ARB is developing technical guidelines to assess the cumulative impact of air pollution at the neighborhood scale. An accurate emission inventory can be a useful tool in these assessments; however, the emission inventories maintained by the ARB were developed for regional estimations and are of limited value for microscale assessments. Microscale inventory tools and methods to estimate emissions from stationary, area, and mobile sources are needed. The needs for neighborhood scale inventories are far more specific than the traditional regional inventory. The exact location of all sources, stationary and mobile, as well as their activities and emissions need to be accurately portrayed to ensure that the community scale analysis is adequate. This is a daunting and resource intensive task even in a relatively small community. Tools and methods that automate the data collection, or reduce the resources nec-

essary to compile such a detailed inventory are needed. In addition more temporally refined (hourly) inventories are needed so that acute health effects can be accurately quantified, and tools and methods are needed to develop these inventories.

WHAT ARE WEEKEND EMISSIONS OF VOC, NO_X, AND BLACK CARBON?

More refined temporal and spatial inventories are needed to understand the ozone weekend effect. While maximum ozone values have decreased at all sites in the South Coast Air Basin over the years, the rate of decrease varies greatly among sites when comparing weekends to weekdays. While studies are beginning that will address the weekend/weekday phenomenon, much other data continues to be lacking, causing confusion among regulators, the regulated community and the public on the future direction of the ARB's programs to clean the air.

Work has begun to better spatially and temporally resolve emission data in the South Coast Air Basin, which is a start to resolving the weekend/weekday issue. However, other inventory data are needed. For example, continuous emission monitoring (CEM) of VOCs from stationary sources does not occur on a widespread basis and could better represent the weekend and weekday differences in emissions from these sources. Uncertainties associated with estimating VOC emissions, especially from evaporative sources, are much higher than uncertainties associated with estimating emissions of NO_X and methods are needed to improve this portion of the inventory. There are also atmospheric interactions that may affect the amount of emissions from sources. An example of this may be the impact of residual "black carbon," or diesel particulate emissions, on atmospheric opacity, which affects ambient air temperature and may therefore affect emissions, as well as the ultraviolet radiation that drives smog formation. Knowing the amount and density of ambient black carbon emissions on a daily basis in the atmosphere may lead to a way of determining its impact on emissions.

WHAT ARE VOC AND NO_X EMISSIONS FROM NATURAL SOURCES?

Because biogenic VOC and NO_X emissions from California landscapes play significant roles in the formation of ozone, PM2.5, and regional haze, the ARB will need to continue to invest in scientific and technological advances in the inventory, monitoring and modeling of these emissions. This will necessitate continued ARB collaboration with and support for researchers and developers in natural resource agencies and academic faculties, to identify and quantify emissions of relevant chemical species from biogenic and landscape processes, to develop critical spatially and temporally-resolved landcover and model input databases, and to develop science-based, emission process models.

WHAT ARE THE MAJOR SOURCES OF CHLORINE RADICALS?

Chlorine radicals in the troposphere enhance ozone formation, but no chlorine inventory exists today. Future research efforts will also investigate the significance of secondary by-products of emitted compounds. An obstacle to understanding the relative significance of these reactions is the lack of chlorine emission data. A recent, ARB-funded project focuses on chemical reactions involving sea salt spray as a source of chlorine radicals. Swimming pools and water treatment facilities are well-known chlorine sources. Chlorine emission estimates for these sources should be refined and additional sources should be investigated. Furthermore, the atmospheric processes that could generate the chlorine radicals from these sources need to be identified and their reaction efficiencies quantified, so that an assessment can be made of the anthropogenic influence relative to natural sources.

HOW CAN EMISSION INVENTORY ESTIMATES BE INDEPENDENTLY EVALUATED?

For an emission inventory to be useful, its data and methods of computation must be continually verified and updated. In general, improvements in apportionment methods are needed to refine the accuracy of the inventory process. Initially, motor vehicle emissions

were and continue to be the portion of the inventory most easily verified. However, better methods to verify the gasoline and diesel PM inventory are needed. Also for community scale inventories needed for ARB's community health program, better verification methods for stationary sources are needed. To date no satisfactory verification method exists for stationary sources. Overall, improvement in ambient monitoring, source profile information, and source activity, as well as increased testing, is needed to develop better source apportionment techniques and methodologies for all inventory categories.

WHAT ARE BETTER WAYS TO FORECAST FUTURE EMISSIONS?

Air pollution programs have always depended on predictive models for gaining a better understanding of the magnitude of future emissions. The results of these forecasting models assist in the development of air quality plans; determine how and where air pollution can be reduced most efficiently; track progress toward meeting the requirements of air pollution control mandates; and are used to construct emission trends. Existing forecasting models are designed to predict emissions of criteria pollutants at the county level. However, in the future, these models will also need to be able to forecast emissions of toxic air contaminants at regional, as well as community, scales. Research is therefore needed to improve the methodologies used in forecasting models, as well as the inputs, including but not limited to the speciation profiles, growth factors, and control factors.

Other Funding Organizations: As part of its emission inventory research program, the ARB will continue to seek out co-funding/coordination opportunities for emission inventory research, to ensure that related efforts are complementary rather than duplicative. For example, NARSTO prepared strategic research plans for both ozone and PM. The plans focus on atmospheric processes, including emission inventories, and NARSTO member organizations intend to use them as blueprints for their research programs. There are significant overlaps between the ARB and NARSTO research objectives, and the NARSTO annual and special topic meetings provide an opportunity to seek co-sponsorships of projects.

The ARB has a 15-year history of research coordination with the CRC and continued co-sponsorship of heavy-duty diesel research with the CRC, the SCAQMD, the U.S. DOE, the U.S. EPA and others will reduce one of the largest uncertainties in mobile source emission modeling. Opportunities with the CRC may exist in other areas, such as PM, VOC, and nitrogen species emissions from gasoline-fueled vehicles. The Texas Natural Resources Conservation Commission (TNRCC) and the ARB share mutual interests in understanding the emissions from Mexican vehicles that visit the U.S., and TNRCC is being encouraged to participate in the CRC-coordinated effort.

Although co-funding of research projects with the U.S. EPA does occur, coordination tends to be ad hoc. A more formalized and coordinated planning process with the U.S. EPA should increase the opportunity for leveraging of funds and synergy of the research product. An important opportunity currently exists for PM-related emission inventory research, as the U.S. EPA is using the NRC PM research priorities series of reports (NRC 2000, 2001) as a roadmap for its research program.

Atmospheric Processes

Introduction: The physical and chemical processes that occur in the atmosphere play a critical role in determining exposure to pollutants. The sequence of events leading to exposure to a pollutant starts with the release of a substance to the atmosphere. In the atmosphere, the substance undergoes physical processes, such as dispersion, transport, deposition, and, often, chemical transformations, before it reaches the receptor. Thus, to accurately assess exposure, it is vital to understand the physical and chemical processes that create, transform and transport the pollutants of concern. This information is used to improve atmospheric models that simulate the gaseous and particle pollutants in the at-

mosphere. Changes in climate can impact anthropogenic emissions of pollutants and changes in emissions can impact the climate. Therefore, a major area for further research is investigating the chemical and physical properties of aerosols that influence not only health and visibility, but also the weather/climate, through the differential effects on solar radiation and condensation nuclei.

Background: Air quality models are the tools used by regulatory and academic organizations for simulating atmospheric processes. The models are based on the current scientific understanding of physical and chemical processes occurring in the atmosphere. However, the complexity of the model and the size of the modeling domain push the limits of even supercomputers and simplifying assumptions must be made. The models are used in the development of SIPs, because the models predict how different control strategies will effect pollutant levels and, thus, human exposure. Changes in ambient level, in response to changes in emissions, can be very nonlinear and even counter-intuitive because, in addition to the mass or rate of emissions, the timing and location of the emissions, and meteorological transport, mixing, and removal processes influence the final result (Finlayson-Pitts, 2000; Seinfeld, 1998). Air quality models are constantly evolving as our scientific knowledge of the atmosphere improves and as increases in computing power allow more of the actual atmospheric processes to be included in the models. Thus, research in this area is needed so that the ARB has the best tools possible for this critical task.

Traditionally, control strategies for different pollutants have been developed independently. While this has been successful in the past, particularly with primary pollutants, the increasing emphasis on secondary pollutants, such as ozone and fine PM, will require that control strategies be evaluated in a more unified manner. For example, initial studies suggest that control measures, which reduce the total mass of PM from diesel engines, may result in significantly higher numbers of fine particles. It is also possible that VOC controls, designed to decrease ozone levels by substitution of less volatile compounds, could inadvertently increase the formation of secondary organic aerosols, thus worsening fine PM levels. Therefore, control strategies need to be evaluated in terms of the full suite of atmospheric chemistry and processes, so that the full consequences of all pollutants, not just the target pollutants, are understood.

Ongoing Research: Major field studies are regularly conducted in California to collect the routine and specialized data necessary for modeling atmospheric processes and quantifying the effects of emission control measures. Major field studies in recent years include the 2000 Central California Ozone Study, the 1999/2000 California Regional Particulate Air Quality Study, and the 1997 Southern California Ozone Study. Refinements are routinely being made to meteorological and chemistry modules in air quality (both gaseous and aerosol) models. In addition to physical processes, air quality models also model the chemical processes that occur in the atmosphere. Most emissions of interest are chemically reactive, so the models must also simulate the chemical reactions that determine how the intermediate reaction products and their levels vary in time and location. The chemistry occurring in the atmosphere involves thousands of reactions of organic compounds; oxides of carbon, nitrogen, and sulfur; acids; inorganic compounds; and other substances. These reactions need to be understood to estimate exposure and design effective control strategies. The NSF is very much aware of the importance of a healthy environment and is committed to environmental research and has supported research to: 1) measure and model the levels and distributions of gases and aerosols in the lower atmosphere; 2) identify chemical reactions among atmospheric species, and their sources and sinks; 3) better understand heterogeneous and aqueous-phase atmospheric chemistry and the transport of gases and aerosols throughout the atmosphere; and 4) develop improved methods of measuring levels of trace species and their flux into and out of the atmosphere.

ARB Research Needs: To understand the effect of an emitted compound on air quality and human health and welfare, it is necessary to have knowledge of not only the parent compound, but also its first- and later-generation products and how they interact with the environment to cause additional ancillary effects. Because of the complex nature of both the emissions and the series of reactions that many organic chemicals undergo in the atmosphere before reaching their final products, current knowledge of the chemistry that occurs in the atmosphere is far from complete. For example, some common classes of compounds, such as aromatics, still have significant uncertainties associated with their mechanisms, and the chemical mechanisms that form secondary organic aerosols are almost totally unknown. In addition, the effects of pollutant emissions on the radiative balance of the earth, and other planetary interactions, can have far-reaching implications. Thus, ongoing research into atmospheric chemistry needs to be supported.

Decision-makers rely on results from air quality models to provide predictions of ambient levels that will result from the implementation of various emission control strategies. This information is used to prepare SIPs and estimate human exposure. Continued development of scientific information for incorporation into air quality models is vital, so the Board has the best tools possible available to determine the most cost-effective way to achieve health-based air quality standards and reduce public exposure to adverse environmental effects.

A summary of questions that future research activities must address in the area of atmospheric processes include the following.

HOW ARE EMISSIONS DISPERSED AND TRANSPORTED IN THE ATMOSPHERE? HOW CAN THE TRANSPORT OF POLLUTANTS BE QUANTIFIED AND RESPONSIBILITY FOR EMISSION REDUCTIONS BE ASSIGNED?

Once in the atmosphere, pollutants begin being dispersed and winds transport them from their source to downwind receptors where the impact can be negligible or major. Although the theoretical mechanisms are known quite well, successful modeling and forecasting of specific transport conditions are limited. In particular, more research is needed about transport aloft and in regions of complex terrain (e.g., coastal environments, mountain valleys). Because of transport and the reactivity of many effluents, the impact of emissions from one area on air quality in another area can be difficult to quantify. Given the high cost of many pollution control strategies, the equitable assignment of responsibility is a difficult but very important task.

HOW ARE EMISSIONS TRANSFORMED IN THE ATMOSPHERE AND HOW DO THESE REACTION PRODUCTS IMPACT ATMOSPHERIC PROCESSES?

Once in the atmosphere, effluents are not only influenced by physical processes but can also react or be transformed to make other harmful or benign products. In many cases, these reactions are non-linear and it is even possible for a decrease in one pollutant to cause an increase in another pollutant. In other cases, the pollutants may be transformed into other compounds that influence atmospheric processes. For example, gaseous emissions can result in the formation of aerosols or PM that, in return, can absorb or scatter sunlight, thus changing the photochemical environment and affecting the formation of other compounds. Once again, knowledge in this area is limited, and understanding the processes is essential to the development of effective controls.

HOW CAN TRACE COMPOUNDS AND SHORT-LIVED SPECIES BE ACCURATELY MEASURED TO IMPROVE OUR UNDERSTANDING OF ATMOSPHERIC PROCESSES?

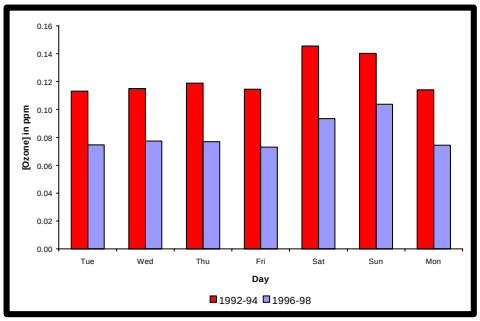
Many compounds occurring at levels too low to detect with current monitoring/sampling methodologies, are short-lived, or may be influenced by the monitoring technique. Even if a technology exists to detect these compounds, the technique may be too expensive to use on a routine basis. Furthermore, the increasing interest in conditions above ground level and their impact on ground-level (or mountain-side) levels has created an increasingly larger niche for remote sensing

applications. Of even greater interest is the simultaneous measurement of air quality and meteorological parameters that enable better interpretation and understanding of the atmospheric processes at work in any given situation. In aerosol modeling, additional research is needed on heterogeneous reactions and their products.

WHAT ARE THE BUDGETS FOR THE VARIOUS RADICALS AND ARE THE PHOTOLYSIS RATES OF SPECIES LEADING TO THE PRODUCTION OF RADICALS SUFFICIENTLY ACCURATE?

Radicals play a very critical role in photochemical processes but are difficult to measure. Various hydrogenous, nitrogenous, and organic radicals are known to play critical roles in photochemical processes. For example, ozone levels in many urban areas exhibit the so-called "Weekend Effect", where ozone levels tend to be higher on weekends (and particularly Sundays) than on weekdays, and

Mean Peak Ozone Concentration at Azusa by Day of the Week



In the last 1990s, Sunday became the day of the week with highest ozone levels in Los Angeles.

higher morning radical levels on weekends are postulated to promote ozone formation. Clearly, more information is needed about the sources and sinks of radicals.

HOW HAVE AND HOW MIGHT AMBIENT POLLUTION LEVELS CHANGE IN RESPONSE TO SPECIFIC TYPES OF EMISSION REDUCTIONS?

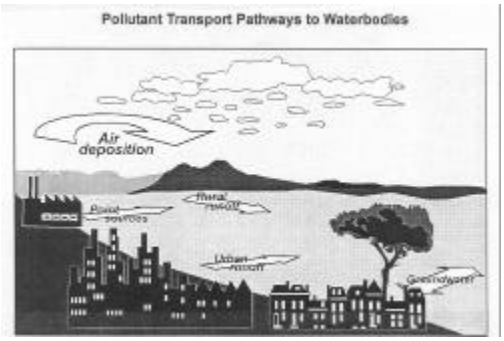
Oxides of nitrogen emissions have a plethora of environmental effects. The emission of nitric oxide (NO) can result in either increased or decreased peak ozone levels, depending on the environmental conditions. A better understanding is needed of historical conditions and new research into low-NO_X conditions are needed to better anticipate the impact of future environmental changes. Because additional control measures are increasingly expensive, it is imperative that the control plans are based upon the best available scientific information. Similarly, a better understanding of the limiting precursors are needed for control plans for secondary pollutants such as ozone and aerosols.

Coordination with Other Research Organizations: The NSF and the NCAR, as well as the U.S. EPA, have previously funded research in atmospheric processes and might be expected to co-fund some future atmospheric chemistry projects. The ARB will continue to seek out co-funding/coordination opportunities for atmospheric processes research to ensure that related efforts are complementary rather than duplicative. For example, NARSTO prepared strategic research plans for both ozone and PM. The plans focus on atmospheric processes and NARSTO member organizations plan to use them as blueprints for their research programs. There are significant overlaps between the ARB and NARSTO research objectives, and the NARSTO annual and special topic meetings provide an opportunity to seek co-sponsorships of projects. Other potential collaborators in research on atmospheric processes include NOAA and NASA.

Multimedia Effects

Introduction: Once released to the environment, many chemicals can infiltrate multiple environmental media (i.e., air, water, land, and biological resources). Identifying how, when, where, and for how long these chemicals and their derivatives impact receptors is critical to understanding the full implications for health and welfare effects. To accurately assess a chemical's effect on California's population and ecology, a multimedia approach is necessary. It is important that the approach include both the physical movement among and within different media, as well as chemical transformations and ultimate fate in

the environment. A recent study on the multimedia fate of methyl tertiary butyl ether (MTBE) in gasoline stressed the need for more comprehensive environmental assessments when considering changes to fuel (Keller et al., 1998). Given the increasing recognition of the importance of the multimedia effects of pollutants, the ARB needs to promote the research and development of multimedia impacts of air pollutants.



Background: Pollutants that are released to the air can be deposited to land areas, tributaries, or directly to the waterbodies by wet or dry deposition. The deposited pollutants can also be carried into a body of water by other routes, such as stormwater runoff or inflow from tributaries. In addition, contaminants in soil and water can enter the atmosphere via evaporation, surface disturbance, and air stripping. The importance of transport from the atmosphere to water can be seen in several analyses of the role of atmospheric deposition of nitrogen to the health of water bodies, such as Lake Tahoe, San Francisco Bay, and Chesapeake Bay. Conversely, ignoring multimedia effects can result in a substantial underestimation of the actual emissions into the air. In short, it has been documented that transport to and from the atmosphere from other media can play a significant role in inventory reconciliation.

To study and deal with multimedia environmental issues, cross-program teams and partnerships should continue to be established. One example of such a team was formed in 1999 to conduct a multimedia health and environmental assessment of the use of ethanol as a fuel oxygenate. Members of the team included the ARB, OEHHA, and the Water Resources Control Board.

Ongoing Research: Because of the importance of multimedia effects, a multimedia fate and transport assessment of chemicals released to the air should play an important role in regulatory/policymaking decisions. Examples include the Great Waters program, Lake Tahoe program (see Lake Tahoe Section), and the San Francisco Estuary regional monitoring program. The ARB is currently involved with two task groups that are investigating multimedia issues, the San Francisco Estuary Institute and the Reactivity Research Working Group. The San Francisco Estuary Institute (SFEI, 1999) is undertaking a monitoring program to provide the Regional Water Quality Board with scientific information in support of environmental decisions regarding pollution prevention and abatement for the San Francisco Bay. As part of a multi-year program to assess the sources of metals and organic compounds in the Bay, SFEI began a limited pilot study in 1999 to determine the magnitude of direct deposition of air pollutants to the surface of the Bay. The pilot study is intended to determine whether aerial deposition may be disregarded or eliminated from consideration as a potentially significant source of contaminant loading to the Bay or if it must be more rigorously quantified, along with other sources. The Reactivity Research Working Group (RRWG), established by the U.S. EPA, is also interested in multimedia research, and recently published two request for proposals (RFPs); one to investigate the effect of multimedia partitioning on VOCs and the other to combine a multimedia model with a simple air quality model to investigate the multimedia effects on ozone formation.

The Great Waters program (U.S. EPA, 2000), one of several large-scale studies promoting multimedia effects research, is a coordinated federal effort involving the U.S. EPA and the Departments of Agriculture, Defense, Interior, and Commerce. Recent results indicate that the welfare of ecosystems is affected significantly by changes in the atmospheric levels of certain compounds, which in turn, is affected by changes in atmospheric emissions of

those pollutants.

ARB Research Needs: Additional research is needed to develop better tools for determining multimedia effects and total exposure to deleterious compounds, whether directly emitted or derivative products. These efforts must consider contaminant exchange in both directions between air and other media. These research efforts must also consider the varied media (e.g., air, water, soil) and environments when people are exposed, (e.g., home, work, portable classrooms, and outdoors).

HOW IS THE ATMOSPHERIC DEPOSITION TO OTHER MEDIA QUANTIFIED?

Dry and wet deposition from the atmosphere continues to be a significant contributor of toxic substances to water, land, and biological resources. A plausible link exists between emissions into the air of certain pollutants, the atmospheric deposition of these pollutants (and their transformation products), and the levels of these pollutants found in water, sediments and biota, especially aquatic and plant species. Refinement of current multimedia fate and transport models is needed to allow better quantification of the effect of deposition.

WHAT IS THE INTERACTION OF INDOOR AND OUTDOOR ENVIRONMENTS?

The interaction of indoor and outdoor environments is an aspect of exposure that is not usually addressed by current multimedia models. Indoor environments have a high surface to volume ratio and many of the surfaces can act as sinks, absorbing and then re-emitting chemicals. Additionally, indoor environments provide many exposure routes. While some models, such as CalTOX, provide estimates of exposure to additional pathways, such as dermal and ingestion, additional research is needed to measure actual exposure.

HOW CAN THE SECONDARY POLLUTANTS BE CONTROLLED IN A MORE COMPREHENSIVE MANNER?

Another area that is only beginning to be explored is the transformation of compounds through chemical reactions. Traditionally, control strategies have been developed independently for each pollutant. While this has been successful in the past, particularly with primary pollutants, the increasing emphasis on secondary pollutants, such as ozone and fine PM, will require that control strategies be evaluated for total impact in a more comprehensive and unified manner.

Coordination with Other Research Organizations: The U.S. EPA has already funded some projects investigating multimedia effects and will continue to explore ways to integrate the authorities within single media statutes and their programs (i.e., CAA, CWA). The California EPA is also committed to supporting multimedia strategies to reduce pollutants of concern to human health and the environment. It is likely that many agencies and organizations, such as the U.S. EPA (i.e., Office of Air and Radiation, Office of Water, Office of Research and Development), Cal/EPA, the ACC, and the NSF would be willing to support additional multimedia effects research in the future.

V. TECHNOLOGY ADVANCEMENT AND POLLUTION PREVENTION

The ARB will continue to engage in activities designed to advance the development, demonstration, and commercialization of technologies associated with zero or near-zero emissions. Furthermore, the ARB will also take steps to enhance emission monitoring and measurement methods and the development of pollution prevention alternatives. Given the growth in the use of distributed electricity generation anticipated over the next several years, the ARB has an extraordinary opportunity to partner with interested stakeholders to promote the development and commercialization of technologies with low emissions. These research activities will help address our regulatory priority to promote continued advancement and acceptance of zero and near-zero emission technologies in order to reduce emissions and exposure to PM and to reduce community exposure to air pollutants.

Clean Air Technologies

Introduction: This element of the Plan addresses the further advancement of emission monitoring, emission characterization, and emission control technology, including the development of zero and near-zero emission control technologies. Commitments contained in the SIP for attaining the NAAQS and the need to address existing and potential issues related to the use of advanced control technologies provide much of the impetus for this advancement. For example, long-term measures identify the need for zero or near-zero technologies for certain coatings and consumer product categories, and such commitments require that we address product efficiency as well as product viability.

Background: The 1990 amendments to the federal Clean Air Act set new deadlines for attaining NAAQS standards, based on the severity of the pollution problem. This focused attention on the need for advanced emission control technologies and launched a comprehensive planning process for attainment. The promulgation of new federal PM2.5 and eight-hour ozone standards in 1997 resulted in additional statewide air quality planning efforts. Additionally, new federal regulations will require future SIPs to address ways to improve visibility in national parks and wilderness areas.

To address new standards and timetables, the ARB, local air districts, and transportation agencies have developed SIPs that reflect the need to implement controls that are not yet available. However, regulations requiring such controls, cannot be adopted unless a demonstration is made to show that the controls are technically feasible and cost-effective. The successful implementation of the SIP will require that air quality programs are more efficient and optimized to use the least-cost approach. Over the next three to five years, SIPs will be developed for meeting the federal PM2.5 and eight-hour ozone standards. In addition, triennial updates to the California Clean Air Act plan for meeting the state ozone standard will be prepared. The next triennial plan revision is scheduled for 2003. We are also developing the 2001 Clean Air Plan, which is the ARB's vision of how we can continue progress towards cleaner air through a combination of established and new air quality programs over the next 20 years.

To attain both the federal and California ambient air quality standards, effective near-zero emission control technology will need to be used for many sources of emissions. For example, development of clean diesel engines, fuel cells for vehicles and stationary sources, and zero-VOC solvent technologies for coatings and other applications may be among the advanced technologies that will be used to attain the standards. Also, as technologies advance, we will need to update information on the relationships between activities and emissions for both mobile and stationary sources.

Ongoing Research: As part of the ARB's ongoing research efforts, the goal of the Innovative Clean Air Technologies Program (ICAT) is to support development of more accurate measurement and evaluation techniques, as well as the development of advanced control

technologies capable of providing solutions to air pollution problems. Some of the projects in this program are intended to address short-range objectives and focus on technology needed to meet regulations currently in place. However, the development, demonstration, and commercialization of broad-based technologies designed to reduce air pollution (i.e., the ICAT program) have also been funded to address longer-term anticipated needs and potential issues. Additionally, the ARB has supported development of both instrumentation and data analysis methodologies, such as single particle measurement by Aerosol Time of Flight Mass Spectrometry (ATOFMS). Research conducted using prototype instruments has already resulted in significant new understanding of aerosol dynamics (chemistry, growth processes, etc.) in ambient air and specialized experiments.

The development of new clean air technologies is also the focus of research outside the ARB. The U.S. EPA sponsors research on cutting edge technologies through its Office of Research and Development (ORD). In the ORD's Year 2001 Strategic Plan (U.S. EPA, 2000), the U.S. EPA indicated that, as part of its strategy, it will be focusing on non-traditional approaches that address new issues, such as global climate change, non-point source pollution, and the risks associated with emerging technologies. New technologies identified in its strategic plan focus on miniaturization, energy generation, transportation, and remote sensing.

The South Coast Air Quality Management District (SCAQMD), through its Technology Advancement Office (TAO), provides assistance to the private sector to accelerate the development of low- and zero-emission technologies. Since its inception, the SCAQMD has co-funded more than 250 projects, involving a wide array of low-emission technologies and clean-fuel applications (SCAQMD 2001).

The California Energy Commission operates a research and development program, referred to as PIER. This program includes a full range of research, development, and demonstration activities that focus on advancing science and technology not adequately provided by competitive and regulated markets (CEC, 1997). Alternative generation technologies have been funded under this program, including fuel cells and other clean sources of distributed power.

ARB Research Needs: Several key questions and issues remain to be addressed beyond the ongoing studies. Due to the major role of mobile sources in the emission inventory and the special challenges represented by increased use of both on- and off-road vehicles, motor vehicle research will continue to be important for meeting our goals and objectives. Although most of the largest stationary sources have been controlled, there are numerous categories of stationary source emissions that have been particularly problematic. While these sources may individually represent a relatively small portion of the emission inventory, they continue to represent a significant portion of the emission inventory when combined with other similar sources of emissions.

HOW CAN WE PROVIDE BETTER MONITORING METHODS AND INCREASE THE ACCURACY OF OUR MEASUREMENTS AND INTERPRETATION OF DATA?

More and better air quality data are needed to optimize air pollution control strategies. However, improvements in the database will require significant advances in our monitoring methods, including faster and more accurate measurement techniques and better data interpretation. For example, new aerosol measurement methods address major shortcomings of "conventional" filter methods by providing greater specificity, better chemical speciation, better size resolution, and enhanced source specificity. Conventional filter- or impactor-based methods combine particles into bulk samples that mask the diversity of particles and limit the amount of information that can be retrieved from a sample. Future development of Atmospheric Time of Flight Mass Spectrometry (ATOFMS) will focus on advanced source characterization and source apportionment, new data management and

analysis methods, and technical improvements to make the instruments more portable and less costly. Additionally, conventional analysis methods only report physical and chemical composition data. Biological methods exploiting recent advances in biotechnology offer new dimensions of analytical capabilities. The ARB is working with researchers to demonstrate applications of biological tracers for source-identification, using both biotracers and genetic tracers. Another improvement in our characterization of the existing air quality problems is the development of better measurement methods and interpretation of data using small portable instruments, such as the direct measurement of mass emission rates of hydrocarbon leaks. Pushing newer technologies, such as the Electronic Nose (ENOSE), currently under development at the Jet Propulsion Laboratory and the California Institute of Technology, will also improve our ability to quickly and accurately obtain air quality data. This technology uses polymeric films impregnated with an electrically conducting material to monitor gaseous environments. Using this technology will also enhance our enforcement efforts.

HOW CAN WE IMPROVE/OPTIMIZE EXISTING CONTROL STRATEGIES, USING THE LEAST COST APPROACH, TO MAKE AIR QUALITY PROGRAMS MORE EFFICIENT?

Addressing the previous questions for improving our database will set the stage for the improvement and optimization of control strategies. This, in turn, should provide the most cost effective avenue to address the issues. For example, a major effort is needed to obtain technical information on vehicle systems, fuel and fueling infrastructure, and fuel cell engine systems. This will help us to more effectively implement the ZEV program and develop advanced electric, hybrid, and fuel cell vehicles for commercial application. An additional challenge will be to determine the impacts of changes in diesel technology, especially from ultra-fine emissions, and ways diesel PM changes as the exhaust plume disperses. Another example of the need for more accurate fleet information is the fuels program. The emission data that support current fuel regulations were generated in the late 1980s. This data was used for the ARB's gasoline and diesel fuel regulations and for the "predictive model" which is used to comply with the California Cleaner-Burning Gasoline regulations. Accurate information for the current on-road vehicle fleet is essential for updating the predictive model.

Fuel Cell Unit from H Power Corporation

The accuracy of VOC emissions from valves and flanges at facilities that process petroleum and natural gas are also cause for concern. The methods used to quantify these emissions do not address the VOC mass emission rates and are impractical to use for the hundreds of thousands of leaking components. Advanced measurement techniques that would provide mass emission rates would avoid the need for time-consuming and expensive bagging and GC analysis methods.

In the toxic air contaminants arena, two toxic air contaminants, dioxins and PAHs, are emitted from most combustion processes, and have complex chemistries. The source of much of our ambient dioxin is unknown. We need to develop less expensive, more effective and less timely sampling methods for dioxins and other pollutants. Many of these efforts rely on data collected by the ARB, however, significant resources will be needed for the Board's laboratories for cutting edge technology to ensure that good reliable monitoring and measurement data are collected and analyzed.

IN WHAT AREAS DO WE NEED TO SUPPORT THE

DEVELOPMENT OF NEW AND INNOVATIVE TECHNOLOGIES?

Advanced engine technologies, in addition to aftertreatment, are needed to significantly reduce PM emissions from motor vehicles. Further development of advanced engines, such as lean burn Otto-cycle engines and variations to the diesel cycle, will lead to greater fuel economies and reduced emissions, compared to existing natural gas- and diesel-fueled engines. Another important question is whether reformulation of diesel fuel could reduce exposure to carcinogenic PAHs. PAH emissions become more toxic as they are transported downwind, and a significant health threat exists from multi-media exposure to carcinogenic PAHs derived from airborne emissions (which are largely derived from unburned PAHs found in diesel fuel). All of these strategies can be enhanced through better diagnostics and improved vehicle emission control systems. An important element of emission quantification is the development of integrated systems for on-board emission measurements coupled with technology for the diagnosis of engine operating conditions. Investigation of methods of improving the durability of computer system sensors will extend the life of newer emission control systems.

A high priority will be to promote pollution prevention through the development of more environmentally compatible technologies. With the recent shortages in electricity generation supplies, technologies that are most competitive in economic terms also tend to be the highest polluting, including some that create significant ozone-forming air emissions, as well as toxic air contaminants. The development and commercialization of cleaner technologies, such as fuel cells, offer a means to reduce or eliminate air pollutants and greenhouse gas emissions, increase energy efficiency, and promote energy diversity and independence.

Emissions from consumer products and coatings can be significantly reduced through a shift to low/non-VOC coatings. Because some low or non-VOC solvents, used for applications such as degreasing and cleaning, pose problems relating to global warming and toxicity, water-based cleaners should also be investigated.

Coordination with Other Research Organizations: A number of other agencies sponsor research to develop emission control technology, such as the CRC, SCAQMD, and the CEC. The SCAQMD, through its TAO, co-sponsors research projects with private companies, research institutes, other government agencies, and universities. Historically, it has leveraged $4 in co-funding for every $1 provided by AQMDs. Other such organizations include the U.S. EPA, the California Fuel Cell Collaborative, and the Los Angeles Department of Water and Power. There are a number of organizations that are keenly interested in the development and advancement of efficient and cost-effective fuel cells and other alternative energy sources. Organizations, including the University of California, Irvine National Fuel Cell Research Center (NFCRC), promote and support the genesis of a fuel cell industry through research, development, and demonstration. The NFCRC has developed alliances with fuel suppliers and manufacturers of fuel cells to support the development of a market with fuel-efficient, environmentally friendly energy sources for transportation, distributed power generation, and power station applications.

We will continue to work with all of these organizations to develop alliances, as well as investigate co-funding opportunities for zero and near-zero emission research. These cooperative efforts will also help to ensure that research is complementary rather than duplicative.

Distributed Electricity Generation

Introduction: Distributed generation (DG), defined as electricity generation near the place of use, is expected to play an increasingly important role as one of the options for customers to meet part of their electricity needs. Depending on the technology deployed, distributed generators can range from zero emission sources to high emitting

sources, with respect to both criteria and toxic pollutants. Given the anticipated growth in the use of DG over the next several years, the ARB has an extraordinary opportunity to partner with interested stakeholders to promote the development and commercialization of zero and near-zero emission DG technologies.

Background: Before the recent shortages in electricity generation supplies, it was already expected that deregulation would create additional opportunities for DG. The forecasts on DG market penetration vary wildly (e.g., some forecasts suggest that DG could meet as much as 20 percent of California's total electricity demand). Although the coordinated efforts currently underway are anticipated to address the recent shortages, DG is expected to play an increasingly important role in the suite of energy choices available to customers in the not-too-distant future.

Distributed generators are typically smaller than five megawatts. Further, distributed generators are not limited to a single technology. Instead, DG can employ numerous technologies, including reciprocating engines (diesel and natural gas), microturbines, small gas turbines, fuel cells, solar panels, wind turbines, and batteries. However, some DG technologies create significant sources of ozone-forming air emissions, as well as toxic pollutants. For example, certain DG technologies (e.g., use of diesel generators) lead to NO_x emissions over 100 times greater than from new natural gas-fired central station power plants. In addition, these distributed technologies can be exempt from the permitting requirements of air districts.

With respect to regulatory activities, the ARB recently presented its Board with a plan for reducing emissions of diesel particles from a broad spectrum of both new and existing mobile, as well as stationary sources. As a result of the Board's approval, the ARB is developing a series of regulations that are expected to dramatically reduce diesel particle emissions from sources that include certain distributed generators (e.g., diesel generators). In addition, SB 1298, passed in 2000, addresses potential concerns about the increased deployment of high- emitting distributed generators. In short, the bill requires the creation of a streamlined regulatory program that ensures each new distributed generator operated in California is either certified by the ARB to meet uniform emission standards or is subject to the permitting authority of a local air district.

Ongoing Research: The potential increased use of DG was evaluated as part of an ARB-sponsored research effort, which determined that, on economic terms, certain DG technologies could capture a significant fraction of the increased demand for electricity over the next decade. The study also indicated that the technologies that were most competitive also tended to be the highest polluting. It should be noted that the study relied on a series of assumptions that are not consistent with the recent developments in the deregulated market.

The U.S. DOE is currently supporting studies to promote the commercialization of efficient clean air DG technologies. For example, the DOE's September 2000 Strategic Plan for Distributed Energy Resources (U.S. DOE, 2000) identifies its plans for distributed resources research over the next five years. The research priorities focus on technology development, systems architecture and integration, and systems implementation and outreach. The requested funding for the program in FY 2001 is approximately $250 million. In addition, the CEC has supported research that included developing recommendations for a DG technology certification program. The CEC's PIER program (CEC, 2001) identified DG research as one of its major research priorities. In addition, the CEC is developing its long-range plan for DG research. Specifically, the plan, which is being developed in coordination with the ARB, is expected to include the improvement of tools to characterize emissions from DG, emission reduction technologies, and energy efficiency advancements. Other organizations involved in DG-related research include the National Renewable Energy Laboratory, Gas Technology Institute, Electric Power Research Institute,

technology manufacturers, and universities.

ARB Research Needs: The ARB should focus DG research on advancing the development and commercialization of the cleanest, most efficient sources. The ARB should also take steps to better characterize the potential human exposure and health impacts associated with the increased use of DG. The primary research questions concerning DG include the following.

WHAT CAN BE DONE TO FACILITATE THE DEVELOPMENT AND DEPLOYMENT OF ZERO AND NEAR-ZERO EMISSION DG TECHNOLOGIES?

Research into technologies that produce electricity while minimizing emissions and exposure (and other adverse environmental impacts) will continue to be a high priority. For example, the most common forms of DG technologies today are predicated on the combustion of fossil fuels. Further, for DG, it is typically not cost-effective to use the cleanest control strategies associated with larger electricity generating sources (e.g., selective catalytic reduction). Finally, few control options effectively address all of the pollutants emitted (e.g., NO_x, PM, hydrocarbons, toxics, CO, and CO_2). Working in partnership with key stakeholders, it is recommended that the ARB support research activities that advance the development and demonstration of zero and near-zero emission DG technologies. It is anticipated that efforts to advance the development of fuel cells for stationary applications will play a prominent role in ensuring that the increased deployment of DG does not adversely impact public health.

HOW WILL THE USE OF DG IMPACT PUBLIC EXPOSURE AND HEALTH?

The ARB should take steps to better characterize the emissions, air quality impacts, and exposure and health consequences associated with DG. For example, because small distributed generators are typically not subject to air permits, the information on the number of units in use, as well as the associated emissions and near-source exposures, have not been well characterized. Further, because distributed generators are typically not subject to best available control technology requirements or emission offset requirements, the impact of certain DG technologies on air quality and exposure, particularly near-source exposure, may be significant.

Improved information on the net air quality impacts of DG will be an important part of future revisions to the SIP. For example, certain distributed generators typically have higher emissions than new central station power plants, but because they are near the source of use, they do not experience the line losses associated with the distribution of electricity over transmission lines. Therefore, the ARB expects to better characterize the net emission impacts associated with the increased use of DG. These research activities will require that we have reliable forecasts on the market penetration of DG. As such, the ARB will consider building on the economic study previously discussed.

Coordination with Other Research Organizations: As part of its DG research activities, the ARB will continue to build strategic alliances with outside organizations to leverage research funds. For example, there are a number of organizations keenly interested in the advancement of efficient, cost-effective fuel cells. These organizations include the CEC, local air districts, the U.S. DOE, the U.S. EPA, the National Renewable Energy Laboratory, the California Stationary Fuel Cell Collaborative, the National Fuel Cell Research Center, the California Fuel Cell Partnership, and others. As indicated above, there are long-range research plans being developed by the U.S. DOE and the CEC that identify low emission DG technologies as a priority. These related activities provide exceptional options for establishing or strengthening partnerships. As such, the ARB will seek out co-funding/coordination opportunities for zero and near-zero emission research to ensure that related efforts are complementary rather than duplicative.

VI. GLOBAL AIR POLLUTION

Changes in the global climate, due to increases in carbon dioxide and other greenhouse gases, are expected to create regional changes in temperature, humidity, and precipitation. Research is needed to determine the impact of these changes on regional air quality and, in turn, on existing and future control strategies. Further, an understanding of the sources of global climate change is needed before effective mitigation methods can be determined and assessed. Another aspect of global air pollution concerns the transport of pollutants far beyond their point of origin. Dust and other pollutants have, on occasion, been transported from Asia and the Sahara Desert to the western United States, contributing to an increase in regional background levels for PM and ozone within California. Investigations are needed to determine the impacts of global transport on statewide air pollution distribution and the contribution it, as well as increasing industrialization and desertification, has on PM and ozone control needs in California.

Background: Concerns about global warming must be taken very seriously. Emissions resulting from human activities are substantially increasing the atmospheric levels of the greenhouse gases; carbon dioxide, methane, chloro-fluorocarbons, and nitrous oxide (IPCC, 1996). Carbon dioxide (CO_2) emissions have increased 30 percent during the past century and fossil fuel combustion produces the largest amount of CO_2 emissions. In California, approximately 43 percent of the CO_2 emissions come from cars and trucks. Methane emissions have doubled in the past 100 years. Over the same period, nitrous oxide levels have risen about 15 percent. Agriculture is a major source of both methane and nitrous oxide, with additional methane coming primarily from landfills. Catalytic converters on automobiles also contribute to the levels of nitrous oxide. Nitrous oxide is a significant contributor to atmospheric warming because of its high global warming potential. Estimated U.S. anthropogenic nitrous oxide emissions totaled 1.0 million metric tons in 1997, about 47,000 metric tons above the 1990 levels.

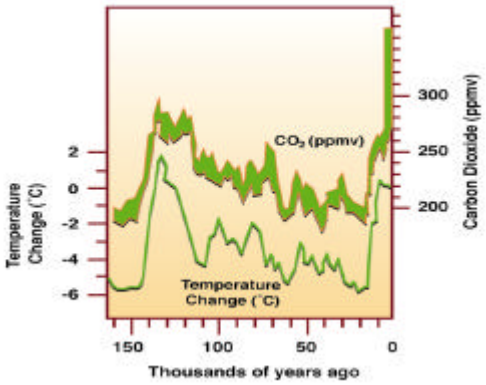
Both regional and global climate changes are occurring in response to intensified human activities. The possibility of significant climate change resulting from human activity is arguably the most challenging and complex environmental issue facing the world over the next century. Projected climate changes will impact California's air, public health, and environment by influencing the production of smog, distribution of pollutants, and amount of pollution that remains in the air. There are compelling reasons why action should be taken now. First, many greenhouse gases have lifetimes of decades or even centuries in the atmosphere, so the problem cannot be eliminated quickly by simply stopping emissions. Second, the eventual warming of the oceans expected from a given level of greenhouse gases occurs over many decades, so what we experience today does not accurately represent the full effect of current levels of greenhouse gases. Third, if improved scientific understanding confirms that we are on a rapid warming pathway, then significant action to lower total long-term greenhouse gas emissions will become necessary.

Ongoing Research: The ARB staff presently assess the impact of various motor vehicle regulations, which are intended to reduce HC, CO, NOx, CO_2, and other greenhouse gases emissions. The ARB's efforts to reduce greenhouse gas emissions include the promotion of low emission vehicles and reformulated gasoline, which offers the dual benefit of reducing criteria pollutants and carbon dioxide emissions. The ARB's Zero Emission Vehicle program has encouraged the development of both battery-powered and fuel cell powered vehicles.

Scientists have been investigating the impact of environmental changes on forest ecosystems through field observation, controlled experiments, historical records, and computer-based modeling. The results of these studies, conducted by ecologists of the University of California, Berkeley, indicate that climate change would affect various aspects of forest ecosystems. Temperature increase enhances

respiration of plants as well as the growth of microbes in the soil. Change in climate and ecosystem structure may also increase fire hazards and affect the conditions that cause pest and disease infestations (Linthurst, et.al., 2000).

Health scientists at the Centers for Disease Control and Prevention have identified several possible health effects that might increase worldwide with global climate change. These include heat stress, insect- and animal-borne diseases, respiratory diseases, allergic diseases related to environmental allergens, developmental effects (i.e., perinatal mortality and/or preterm birth), and health problems resulting from malnutrition and lack of water (Kalkstein and Greene, 1997).



Source: Adapted from Office of Science and Technology Policy. October 1997. Climate Change State of Knowledge

ARB Research Needs:
The purpose of the ARB's global climate research program is to assess the effects of greenhouse gas emissions, global climate change, and global transport of pollutants, especially as they impact the public health and environment of California. This comprehensive scientific research and assessment will help policymakers design the most appropriate control strategies to deal with these very complex issues. Important research questions concerning global air pollution and global climate change include the following.

HOW CAN THE GREENHOUSE GAS EMISSION INVENTORY BE IMPROVED?

Central to any study of climate change is the development of an emission inventory that identifies and quantifies the State's primary anthropogenic sources and sinks of greenhouse gas emissions. The ARB needs to compile emission estimates for both the criteria pollutants and greenhouse gases and identify the sources of greenhouse gases and the amount released into the atmosphere in California. Calculation of CO_2 emissions from fossil fuels is straightforward. Methane and N_2O emission estimates are much more uncertain, since they are generally inferred by extrapolating experiments conducted on a small number of samples across a large regional population. Thus, methodologies for estimating greenhouse gas emissions need to be refined. Compiled emission estimates for both the criteria pollutants and greenhouse gases are needed for evaluating the effects of global climate change on criteria pollutant levels. This information will also be useful in the analysis of regulations to consider their impacts on greenhouse gas emissions and global climate change.

WHAT IS THE TRUE CONTRIBUTION OF MOTOR VEHICLES TO NITROUS OXIDE (N_2O) EMISSIONS?

Recently, it has been found that the use of catalytic converters in cars significantly increases emissions of N_2O (Berges, 1993). Thus, N_2O emissions from motor vehicles need to be quantified and potential control measures identified. Attempts to quantify fleet emissions of nitrous oxide from motor vehicle exhausts have faced difficulty because nitrous oxide emissions are dependent on driving cycle variables, catalyst composition, catalyst age, catalyst exposure to variable levels of sulfur compounds and other poisons in the exhaust, and the fraction of the fleet equipped with catalyst converters. There is a serious need for additional data. Nitrous oxide emissions from in-use vehicles should be measured in as many testing programs as possible, and diesel vehicles of all weight classes should be tested. As new control technologies are developed, data will be needed on how those technologies affect nitrous oxide emissions. Clearly, further research is needed in this area before the role of road vehicles in global nitrous oxide emissions can be assessed with a satisfactory certainty and the most effective method of

reducing road vehicle nitrous oxide emissions identified.

HOW MIGHT GLOBAL CLIMATE CHANGES AFFECT THE STATE'S AIR QUALITY?

We need to assess the potential consequences of global change on tropospheric ozone and PM levels. The assessment should answer questions on climate variability, UV radiation, and which areas will experience the largest deterioration in air quality and subsequent failure to attain air quality standards. We also need to analyze the effects of climate changes and increasing temperature on biogenic hydrocarbon emissions.

Changes in weather patterns can influence the frequency of meteorological conditions conducive to the development of high pollutant levels. For example, during the 1997 El NiŽo year, there was only one Stage 1 smog alert in Los Angeles. The following year, climatic conditions spawned by La NiŽa resulted in 12 alerts, even though emission levels were lower. Such extreme weather conditions are expected to increase over the coming years. There is also a direct relationship between ambient air temperatures and the secondary production of ozone – weather conditions associated with warmer temperatures increase smog. High temperatures, strong sunlight, and a stable air mass tend to create the ideal conditions for ozone formation. Higher temperatures cause an increase in emissions: more fuel evaporates, engines work harder, and the demands on power plants increase. Air pollution is also made worse by increases in natural hydrocarbon emissions during hot weather. Additional research is needed on the impacts of changing or fluctuating meteorological/climatic conditions such as La Nina, global warming, sunspot cycles on both PM and ozone, and the subsequent health problems.

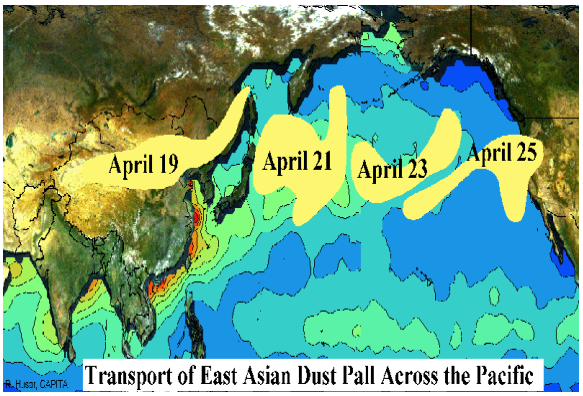
WHAT IS THE ROLE OF AEROSOLS IN CLIMATE CHANGE?

Past research on the direct effect of atmospheric aerosols has mainly focused on anthropogenic sulfate, in isolation from other aerosol chemical components (Jones et al., 1994). Sulfate aerosols are estimated to exert a global average cooling effect. However, absorption of light by carbon is expected to lead to heating of the atmosphere since the light energy is converted to thermal energy (Myhre et al., 1998). The magnitude of the direct radiative forcing from black carbon itself exceeds that due to methane, suggesting that black carbon may be the second most important component of global warming after carbon dioxide in terms of direct radiative forcing. To obtain the true effect on rising global temperatures of controls on black carbon, methane, and carbon dioxide, comparative time-dependent global model simulations of the response of climate to these pollutants are needed (Jacobsen, 2001).

WHAT CONTRIBUTION DOES GLOBAL TRANSPORT PLAY IN CALIFORNIA'S AIR QUAILITY?

The world's scientific community is engaged in many studies to better understand the generation, transport, and ultimate fate of pollutants on continental and global scales (Husay, 1997). Among the areas of concern are the timing and scope of smoke from biomass burning, the transport and deposition of sulfate and soot from fossil fuel combustion, and studies of the effects of gas and aerosol pollutants on atmospheric chemistry. With the advent of modern aerosol sampling, Saharan dust is now known to be that largest source of fine dust (PM2.5) in the air throughout the Caribbean and Gulf of Mexico, and occasional episodes of dust transport have been traced northward into the central and northeastern U.S. Recent research on global pollutant transport indicates a weak but persistent flux of aerosols across the North Pacific Ocean. These aerosols consist of a mixture of natural dust, agricultural dust and smoke, and industrial combustion products. The typical contribution of Asian sources to California rural aerosol levels is modest, but infrequent extreme events have approached the levels of State health-based standards. Additional questions need to be answered about the role of global transport on increasing background ozone levels and the transport of toxic air contaminants. Predicted future growth in Asian emissions make this a significant issue.

A clear understanding of Asian transport is needed to correctly recognize Asian pollution to avoid ascribing it to California sources and to properly explain rare extreme events.



Source: Dr. Rudolf Husar, Washington University, St. Louis

WHAT WILL BE THE EFFECTS OF GLOBAL CLIMATE CHANGE ON HUMAN HEALTH?

Since health is affected by a variety of social, economic, political, environmental, and technological factors, assessing the health impacts of global climate change is a complex challenge. As a result, health assessments will need to look beyond epidemiological and toxicological research to develop integrated health assessment frameworks that consider the effects of multiple stresses and their interactions. There should be research and assessment activities examining the consequences of global change on weather-related morbidity and waterborne diseases.

Current risk assessments of the likely regional health impacts of global climate change are hindered by two factors. First, dose-response relationships between weather parameters and many of the likely health effects have not been developed and, second, reliable estimates of future regional climates across the United States are still beyond the scope of current modeling efforts. Consequently, probabilistic risk estimates of most of the likely regional health impacts of global climate change have such a high degree of uncertainty that their usefulness to health officials dealing with regional issues is very limited. There should be research and assessment activities to fill the existing information gaps.

WHAT ARE CURRENT OR FUTURE TECHNOLOGIES THAT COULD PREVENT OR CONTROL GREENHOUSE GAS EMISSIONS?

The ARB needs to investigate/solicit technologies that provide better ways to prevent or control greenhouse gas emissions. For example, fuel cells are poised to make significant contributions to stationary power generation. Stationary power generated fuel cells can play an important role in reducing CO_2 emissions. A quantitative analysis should be conducted. We also need to identify potential measures/technologies to reduce in-state methane emissions and quantify the resultant air quality and greenhouse gas reduction benefits. Control measures should also the following.

- Encourage the benefits associated with mitigating urban heat islands with trees and more reflective roofs and streets.
- Identify low-emitting trees for CO_2 sequesterization programs. Because current U.S. climate change compliance methods relies on increased tree planting, it is critical to investigate which trees combine low biogenic emissions with other desirable traits.
- Encourage recycling of CO_2. Utilizing captured and recycled CO_2, instead of using CO_2 exclusively from natural reservoirs, to reduce greenhouse emissions to the atmosphere from enhanced oil recovery.
- Encourage voluntary technology certification. This program could provide some benefits to the early adopters of measures designed to reduce greenhouse gas emissions.

WHAT ARE THE POSSIBLE ECONOMIC IMPACTS OF GLOBAL CLIMATE CHANGE ON CALIFORNIA?

An analysis of the effects of increasing climate variability and its impacts on consumers, farmers, and industries is needed. Additionally, the program could examine how California could participate in and benefit from an emission trading program to lower the cost of compliance or increase emission reductions

that occur within the state.

Coordination with Other Research Organizations: Greenhouse gases and climate change issues are, by their very nature, interdisciplinary. Transportation, energy production and use, industrial processes, disposal and recycling of wastes, and agriculture all contribute to the release of greenhouse gases. Thus, evaluating climate change issues and developing a statewide control policy requires the coordinated input of many agencies.

There are a number of organizations actively interested in funding this line of research. These organizations include the CEC, local air districts, the U.S. DOE, the U.S. EPA, the California Stationary Fuel Cell Collaborative, the California Fuel Cell Partnership, and others. For example, climate change research can be coordinated with the U.S. EPA through the U.S. Global Change Research Program. Many federal departments and agencies are involved in climate change research activities through this program. U.S. EPA's research aims to address key scientific questions concerning factors affecting the ecological vulnerability of terrestrial ecosystems to climate change; to examine the human health risks associated with the ecological impacts of climate change; and to examine the socio-economic effects of climate change and adaptations to mitigate those effects. The ARB will seek out co-funding/coordination opportunities to ensure that related efforts are complementary rather than duplicative.

VII. IMPLEMENTATION OF THE PLAN

The Plan does not describe all of the ARB's extramurally funded programs. Some are more applied (i.e., technology demonstrations, test programs for fuels, routine vehicle testing) and funded under separate programs. It is our intention to adjust research activities as new or more accurate information manifests itself. Therefore, the Plan will be updated as necessary, at least every five years, but perhaps as frequently as every two years.

Building on the foundation of this Plan, we intend to explore opportunities for cooperation and build strong collaborative efforts with other research organizations. Major strategies for accomplishing this include the following.

- Sponsoring technical conferences to share information.
- Build a strong infrastructure of environmental organizations.
- Encourage open discussion of research programs and/or opportunities.

Through this Plan, we also intend to improve the Annual Research Planning Process. This plan will help us to directly support the agency's strategic goals and objectives and meet its regulatory obligations on an annual basis. This comprehensive process was used to ensure future research would help meet the agency's ongoing responsibilities, clarify priorities, and explore opportunities for cooperation among other research organizations. This Plan also allows our annual plan to be more focused and valuable.

Another facet of the Plan is to provide stakeholders and the public with an understanding of ARB's goals and programs. This is essential to the success of our programs. Cleaning up the air is a cooperative effort and requires the assistance and support of a broad spectrum of stakeholders. The ARB utilizes the World Wide Web to distribute its information to the widest possible audience by publishing research results (final project reports) and maintaining updates of major projects on the research home page, located at http://www.arb.ca.gov/research/research.htm.

The Research Division has also created list serves, which allows interested parties to register their email addresses and receive a notification when new items are added to the research webpage or when information becomes available in an area where they have expressed an interest. For more information about the research list serve, please visit the ARB's home page at http://www.arb.ca.gov.

Developing and disseminating information in support of the ARB's decision-making process achieves the best overall decisions and serves the public interest. Finding innovative ways to connect the public and the research community to our mission is important and we will continue to develop new methods to share that information.

VIII. REFERENCES

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IX. ACRONYMS

AAQS	Ambient air quality standards
APAS	Air Pollution Ancillary Study
ARB	California Air Resources Board
ATOFMS	Aerosol Time-of-Flight Mass Spectrometer
BEIGIS	Biogenic Emission Inventory through Geographic Information System
BEIS	Biogenic Emission Inventories Systems
BEMA	Biogenic Emissions in the Mediterranean Area
BWG	Biogenic Working Group
Cal/EPA	California Environmental Protection Agency
CAA	Clean Air Act
CEC	California Energy Commission
CHS	Children's Health Study
CHS-APAS	Children's Health Study – Air Pollution Ancillary Study
CO	Carbon monoxide
CRPAQS	California Regional PM10/PM2.5 Study
CRC	Coordinating Research Council
DG	Distributed generation
FACES	Fresno Asthmatic Children's Environment Study
GIS	Geographic Information System
GloBEIS	Global Biogenic Emission Inventories Systems
GPS	Global Positioning System
GCVTC	Grand Canyon Visibility Transport Commission
HEI	Health Effects Institute
HSC	Health and Safety Code
ICAT	Innovative Clean Air Technologies
IGBP	International Geo-sphere Biosphere Program
IMPROVE	Interagency Monitoring of Protected Visual Environments
LAI	leaf area index
LTB	Lake Tahoe Basin
MTBE	Methyl tertiary butyl ether
NAAQS	National ambient air quality standards
NASA	National Aeronautic and Space Administration
NCAR	National Center for Atmospheric Research
NPS	National Park Service
NRC	National Research Council
NO_2	Nitrogen dioxide
NO_x	Oxides of nitrogen
NOAA	National Ocean Atmospheric Administration
NSF	National Science Foundation
OEHHA	Office of Environmental Health Hazard Assessment
PAHs	Polycyclic aromatic hydrocarbons
PIER	Public Interest Energy Research
PM	Particulate matter
PM2.5	Particulate matter equal to or less than 2.5 microns aerodynamic diameter
PM10	Particulate matter equal to or less than 10 microns aerodynamic diameter
RSC	Research Screening Committee

ROG	Reactive organic gases
SB 25	SB 25 (Senator Martha Escutia, 1999), the Children's Environmental Health Initiative
SCAQS	1987 Southern California Air Quality Study
SCOS97-NARSTO	1997 Southern California Air Quality Study - North American Research Strategy for Tropospheric Ozone
SIP	State Implementation Plan
SoCAB	South Coast Air Basin
SO_2	Sulfur dioxide
SO_x	Oxides of sulfur
SWRCB	State Water Resources Control Board
TAC	Toxic Air Contaminants
TNRCC	Texas Natural Resources Conservation Commission
TRPA	Tahoe Regional Air Planning Agency
USDA	Unites States Department of Agriculture
U.S. DOE	United States Department of Energy
U.S. EPA	United States Environmental Protection Agency
USFS	United States Forest Service
VOC	Volatile organic compounds
WRAP	Western Regional Air Partnership
$\mu g/m^3$	Micrograms per cubic meter of air
μm	Micrometers