California Environmental Protection Agency

Air Resources Board

PLANNED AIR POLLUTION RESEARCH

Fiscal Year 2009-2010

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SUMMARY

This report presents the Air Resources Board's planned air pollution research for the fiscal year 2009-2010. Twenty-one projects that support the ARB's programs are recommended for funding. An additional fifteen projects are offered for consideration, should additional resources become available. This research portfolio is organized by key policy and regulatory drivers: Health Effects and Exposure, State Implementation Plan Support, and Climate Change. Issues related to agriculture and environmental justice are integrated into several of these primary categories.

This annual plan proposes research in the areas listed above, with a significant effort to further inform health impacts of air pollution, develop technologies and behavioral change strategies to reduce emissions of greenhouse gases, improve emission inventories, characterize and assess the behavior of pollutants in the atmosphere, and reduce emissions of conventional air pollutants and their precursors. The total budget for projects recommended for funding is approximately $5,340,500.

INTRODUCTION

The Air Resources Board (ARB) sponsors a comprehensive program of research addressing the causes, effects, and possible solutions to air pollution problems in California. This research program also provides support for establishing ambient air quality standards. The Board's research program was established by the Legislature in 1971 (Health and Safety Code Sections 39700 et seq.) to develop a better understanding of air pollution in California, including air pollution's effects on health and the environment, atmospheric chemistry and transport of pollutants, and inventory and control of emissions. Several legislative mandates have expanded and further defined the scope of the program in recent years. For example, ARB's growing research interest in climate change issues is reflected by Assembly Bill 2991 (Nuñez, 2008), which expanded membership of ARB's Research Screening Committee to include two experts on climate change.

The ARB's mission to protect California's public health, welfare, and ecological resources is supported by a Strategic Plan for Research covering the years 2001-2010. Based on current and anticipated regulatory priorities, the Strategic Plan provides direction for the ARB's research program. The Plan can be downloaded from: http://www.arb.ca.gov/research/apr/apr.htm.

This research plan is organized according to key policy and regulatory drivers that it supports: Health Effects and Exposure, State Implementation Plan (SIP) Support, and Climate Change, with issues related to agriculture and environmental justice integrated into several of these primary categories. Each key policy driver is accompanied by an overview that indicates links between the research area and ARB's mission, ongoing research efforts in the area, research and knowledge gaps that need to be addressed, and recommended research concepts. These contextual overviews are followed by the twenty-one projects recommended for funding and the fifteen projects recommended if additional funds become available.

ARB's research portfolio comprises intense, collaborative studies, some of which are long-term and build on unique data sets, others that address specific implementation or knowledge gaps as single modules. ARB funds niche projects that provide crucial input to California's air quality regulatory programs and may be unlikely to receive support from other funding agencies. In many cases, ARB technical staff play an active role in the research that extends far beyond contract management.

The proposed research projects are not intended to be exhaustive or exclusive. Unanticipated opportunities, unique or innovative study approaches, or urgency may lead to consideration of other projects.

Objective of the Research Program. The goal of the research program is to provide timely scientific and technical information that will allow the Board and local districts to make sound policy decisions and effectively implement air pollution control programs in California. Specifically, this plan supports ARB's missions to protect public health based

on the sound scientific understanding of health effects and exposures; develop and implement strategies to reduce greenhouse gas emissions in accord with the near-term (2020) goals of the California Global Warming Solutions Act (AB 32) as well as longer-term (2050) goals; develop effective strategies to safeguard health and welfare against adverse impacts of ambient air pollution; and support development of technologies and non-technological strategies that address multiple priorities related to environmental quality.

Process for Developing this Research Plan. The Board sends out a public solicitation inviting and encouraging the public to contribute ideas for project consideration. Members of the public, the academic community, and ARB staff submit research ideas. To aid in the evaluation, the Board's Executive Officer established interagency committees, led by ARB staff, to review research ideas. These interagency review teams comprised, in addition to ARB staff, experts from state agencies with related research priorities and responsibilities as well as experts from other state, air district, federal, and non-profit institutions with scientific research or regulatory authority in areas of policy relevance to ARB. In response to this year's solicitation, approximately 300 research ideas were submitted. Proposed projects were examined for relevance to regulatory questions facing the Board, scientific and technical merit, and opportunities to leverage State resources through co-funding. Proposals were modified as necessary. Reviewers then prioritized candidate projects in order of urgency and importance. The Board's scientific external review committee, the Research Screening Committee (RSC), which was established by Health and Safety Code Section 39705, reviewed these candidate projects. A list of projects recommended for funding, as well as projects to consider pending availability of resources, was compiled based on discussions between interagency review committees, feedback from ARB's divisions, and comments from the RSC as well as an agricultural stakeholder outreach working group. This list of recommended projects was submitted to the Executive Research Review Committee, whose members are the Executive Officer, his three deputies, and the Chief of the Research Division. The Executive Research Review Committee reviewed all of the proposed projects and modified the draft list of projects recommended for funding based on ARB's most pressing policy and regulatory needs. The RSC reviewed the selected projects and recommended the Plan to the Board.

Implementation of the Plan. The next step for research concepts approved in the plan will be their development into full research projects. The submission and selection of an idea does not guarantee a resulting contract for the submitter. Rather, the ARB is required to consider public California universities for expertise to execute these projects. If the universities do not possess the expertise, then a public solicitation is issued or a sole source contract is awarded. A list serve distributes updates on research activities. To subscribe to the list serve, visit http://www.arb.ca.gov/listserv/research.htm.

Research Budget. The twenty-one recommended projects total approximately $5.3 million. An additional fifteen projects totaling approximately $4.1 million are recommended if resources become available. Allocations for the twenty-one projects

recommended for funding are organized according to key policy or regulatory drivers as follows:

RESEARCH CATEGORY	BUDGET
Health Effects and Exposure	$1,630,000
State Implementation Plan (SIP) Support	$2,388,500
Climate Change	$1,322,000
TOTAL	**$5,340,500**

***Project Co-sponsorships*.** The Research Division is continually looking for co-funding opportunities and other ways to leverage the State's research dollars. This effort allows the ARB to be part of projects and studies that may otherwise lie beyond the state's fiscal reach. ARB has successfully worked with other research organizations and has participated in multimillion-dollar collaborations.

Summaries of Past Research. Projects completed since the beginning of 1989 are summarized in the Research Division's publication, Air Pollution Research, at www.arb.ca.gov/research/apr/past/past.htm. Research Division's final reports are available at the same web site.

OVERVIEWS OF RESEARCH AREAS

Health Effects and Exposure

Policy Drivers:

- The Children's Environmental Health Protection Act (SB 25, Escutia, 1999)
- Defining and Reviewing Ambient Air Quality Standards (Title 17 of the California Health & Safety Code, Section 39606)
- Diesel Risk Reduction Plan
- Exposure Assessment of Toxic Air Contaminants (California Health & Safety Code, Section 39660.5)
- Regulation of Ozone Emissions from Indoor Air Cleaning Devices (California Health & Safety Code, Sections 41985 *et seq.*)

Ongoing Efforts: The U.S. Environmental Protection Agency (U.S. EPA), as well as the National Institutes of Health (NIH) and the Health Effects Institute (HEI) are involved in extensive research efforts that inform health effects and air quality standards. Specifically, the U.S. EPA, as part of its Science to Achieve Results (STAR) program, will be funding national Clean Air Research Centers to support research on the health effects of exposure to particulate matter, ozone, and other air pollutants, both singly and in multipollutant atmospheres. Priority research areas include: explaining regional and temporal differences in air pollution risk; determining the origins and transformations of multipollutant atmospheres and their constituents; defining exposure/concentration-response relationships; assessing susceptibility; understanding PM effects in a multipollutant context; and developing greater understanding of PM and ozone health effects.

U.S. EPA's Clean Air Research Program also probes multipollutant exposures and has developed a research strategy to address multipollutant issues including:

- Laboratory studies to evaluate controlled source emissions and health effects.
- Laboratory studies of artificial mixtures that test hypothetical interactions that may be driving more generalized atmospheric exposure mixtures.
- Real-world studies in cities where emission, exposure, and health data can be collected or integrated on multipollutant exposures that may impact human health.

Areas of scientific investigation include: understanding the relationships between sources of air pollutants and atmospheric transformation to air pollutant products; understanding the health risks posed by mixtures of air pollutants; advancing atmospheric and exposure modeling of multipollutants; developing methods and controls for sources or air pollutants that impact health relevant emissions or products; and determining a hierarchy of sources and related emission components regarding relative health risks. As part of this effort, initial emphasis is directed to near-road exposures since mobile sources emit a complex mix of gases, vapors, and particles.

Ongoing research projects funded by HEI emphasize mixtures of air pollution with a focus on particulate matter and gaseous pollutants, diesel exhaust, and air toxics. HEI

funds theoretical, in vitro, animal, controlled human exposure, and epidemiologic studies. For example, HEI is supporting, among other topics, research on the toxicity of particles from new diesel engines and research on accountability (effectiveness of regulation for the improvement of air quality).

ARB has funded and conducted ongoing community exposure projects for a wide range of toxic air contaminants (TAC), as well as PM, CO, NO_2 and other pollutants in California, in various parts of the State, including southern coastal cities near ports. Previously ARB has funded several large personal and neighborhood exposure studies, as well as a study of exposures to diesel exhaust inside vehicles as they are driven on the roadway. U.S. EPA and HEI have previous or ongoing traffic and diesel exposure research projects and a pilot level port worker exposure project.

ARB has also funded and conducted ongoing indoor air quality and personal exposure projects for a wide range of toxic air contaminants, as well as PM, CO, NO_2 and other pollutants in California. Staff have previously conducted in-house research to measure ozone from portable air cleaners that emit ozone. U.S. EPA and the South Coast Air Quality Management District (SCAQMD) have a few ongoing indoor air quality research projects, including a pilot level project funded by SCAQMD to study the effectiveness of indoor air cleaning devices in removing outdoor-generated particles and VOCs in a small sample of classrooms.

Research/Knowledge Gaps: To support its mission to protect public health, the ARB must address a number of knowledge gaps regarding the harmful effects of air pollutants.

- While many epidemiologic studies report statistical associations between air pollutant exposure and a range of adverse health effects, research to date has not fully described biological mechanisms that could explain these associations.
- Differential toxicity of PM from various sources needs to be resolved. This information could lead to control measures targeted at sources that have the greatest impact on health. Of particular concern is the relative toxicity of ultrafine PM, which has been proposed to be highly toxic, but little published information is available to support this hypothesis.
- Air quality measurements at ambient monitoring stations routinely show consistent associations with important health endpoints. However, actual human exposures sometimes differ substantially in temporal and spatial distribution from those observed at monitoring stations. More focused monitoring and exposure assessment efforts are needed to better understand the impacts of diesel exhaust at the community level and those associated with port activities, so that control measures can be better targeted to reduce exposure.
- Exposure to diesel exhaust is estimated to be the largest contributor to Californians' cancer risk from ambient air pollution, as well as a notable contributor to the risk for the worsening of asthma and other harmful health effects. As regulations and policies are implemented to meet Board-approved diesel exhaust risk reduction goals for 2010 and 2020, near-source and personal exposure information is needed to determine time trends of actual health risks.
- For some pollutants, individuals' activities near key sources contribute to indoor and personal exposures that differ substantially from, and are often elevated relative to,

air quality measurements at ambient monitoring stations. More focused monitoring and exposure assessment efforts are needed to better understand individuals' exposures and impacts to TACs and criteria pollutants.

- Few measurements have been made of ozone emissions from in-duct air cleaning devices (air cleaners installed inside ventilation system ductwork), but some such devices appear to emit substantial amounts of ozone.
- There is growing interest in the use of air cleaning devices to help reduce asthma symptoms, but the data available to date do not document their effectiveness.
- Exposures to and health impacts of secondary pollutants from reactions of ozone with indoor air warrant investigation.
- Climate change regulations will affect fuel compositions, vehicle emissions, land use patterns, and other technological and behavioral factors with health implications. Tools need to be developed to delineate the benefits as well as potential adverse effects of climate change regulations on human health.
- Health effects of mixtures of pollutants require research to determine whether—and if so, how—some pollutants in ambient air interact with or modify the effects of particulate matter or other pollutants.
- Studies are needed to identify, quantify, and illuminate mechanisms of biological and genetic factors contributing to sensitivity to air pollution.
- As technologies evolve, an emerging concern is the impact of nanoparticles in products and materials on personal and indoor exposures, including exposure both to nanoparticles and to their toxic components (e.g., metals).
- In-vehicle exposures to VOC and semi-volatile organic chemical concentrations, as well as occupants' exposures from passenger cabin materials and products, need to be characterized because Californians spend a significant amount of time in vehicles, which constitute potentially high-exposure settings.

Recommended for Funding

Health Effects of Central Valley PM

PM2.5 has been associated with adverse human health outcomes; however, the specific biological mechanisms involved in causing these outcomes are poorly understood. The objective of this project is to elucidate the mechanisms linking inhalation of PM to pulmonary and cardiovascular responses using mice as an animal model. The results will facilitate assessment of PM-mediated health impacts, strengthen the scientific basis for the PM standards, and help provide evidence for the adequacy of the PM standards to protect the public. This project's cost-effectiveness is enhanced by its use of substantial resources available through the US EPA-funded PM Center at UC Davis. (p. 6)

Proposed funding level: $450,000

Genetic Control of PM-Induced Inflammation and Oxidative Stress in Subjects with Coronary Artery Disease This study will add new, useful information on how particles may induce or otherwise cause inflammation that may impact the progression of cardiovascular disease. It will examine the genetic component of air pollutant-related adverse health effects. The study will evaluate genetic expression in relation to the PM source, size and composition. In addition to addressing the biological mechanisms leading to adverse health outcomes in human populations, the results from this research may also help the Board evaluate the need to regulate PM on a particle basis

for the protection of public health. The proposed research is leveraged through data already collected in the parent research project funded by NIH. (p. 8)
Proposed funding level: $275,000

Using a Mobile Monitoring Platform to Investigate Spatial, Diurnal and Seasonal Pollution Gradients Near Freeways and Air Quality Improvements from New Regulations in the Port Area
Individual exposures to air pollutants depend strongly on place as well as time spent in microenvironments, and are not accurately resolved by regionally-averaged air pollution concentrations. This study will improve our understanding of how pollutants, particularly ultrafine particles, vary with location and time of day near freeways and arterial roads. This understanding is essential for improving health effects studies that depend on exposure assessment. Results of this research will also enable more accurate evaluation of the rate of improvement in air quality near the ports. (p. 11)
Proposed funding level: $280,000

On-Road Measurement of Emissions from Heavy-Duty Diesel Trucks: Impacts of Fleet Turnover and ARB's Truck and Bus Rule
As California proceeds with implementation of new emission controls on heavy-duty trucks, especially the truck and bus rule, over the next few years, major changes in fleet-average emissions, emission distributions, and relationships among various pollutant emissions are expected. This study will provide on-road confirmation of the emission impacts of the truck & bus rule, and will provide complementary information to a multi-year on-road assessment sponsored by the National Renewable Energy Laboratory that started in 2008 in southern California. (p. 14)
Proposed funding level: $300,000

In-duct Air Cleaning Devices: Ozone Emissions and Test Methodology
The objective of this project is to develop a robust and easy to use test method to measure ozone from "in-duct" air cleaning devices, and to measure emissions of ozone and ozone reaction by-products from a sample of in-duct air cleaners. ARB's current air cleaner regulation exempts in-duct air cleaners because there is little data on their emissions and there is no accepted test methodology for them, yet some of these devices intentionally emit ozone, and others have been shown to emit potentially harmful levels of ozone. This project would provide critically needed emissions information to determine whether regulation should be pursued, and a test method that could be adopted if regulation is warranted. (p. 16)
Proposed funding level: $325,000

<u>Recommended if Additional Funding Available</u>
Community Exposures to Traffic-Generated Pollutants
This research will refine what is known regarding concentrations of traffic-related air pollutants in community air and exposure levels experienced by people at elevated risk of adverse health impacts. Results will aid identification of sources as well as factors that mitigate exposures. This information will facilitate improved risk assessments and design of pollution control programs that are most likely to reduce these risks. (p. 18)
Proposed funding level: $800,000

Mitigation of Air Pollution Exposures from Land Use and Transportation Measures to Reduce Greenhouse Gases

This effort will provide a preliminary assessment of land use and building design measures that can mitigate potential increased exposures to air pollution associated with alternative land use and transportation approaches undertaken to reduce greenhouse gases. It will also provide study designs sufficient to develop accurate cost estimates for the research that is needed. Ultimately, research resulting from this and follow-on projects will provide a definitive assessment of mitigation effectiveness of the measures and a solid scientific basis for the selection of statewide exposure reduction measures. (p. 20)

Proposed funding level: $300,000

Port Workers' Exposure to Air Pollution

This project will characterize the exposure of port workers to selected air pollutants, including particulate matter. Analysis will also evaluate changes in human exposures with the implementation of the San Pedro Bay Ports Clean Air Action Plan. This study would provide exposure and microenvironmental concentration data at the ports and in the community and would enhance ARB's goods movement program. (p. 23)

Proposed funding level: $150,000

Evaluation of Secondary Pollutant Emissions from Portable "Air Cleaners"

Investigators propose to examine the creation of secondary reaction products (e.g., aldehydes, VOCs) indoors, which are produced by the operation of portable air cleaners that use new technologies. Since the adoption of ARB's air cleaner regulation, new alternate technologies have been developed, which may have unintended effects. There is concern that health risks from secondary indoor pollutants may exceed that of ozone associated with some portable "air cleaners" and could harm the health of those who use these air cleaners regularly. (p. 25)

Proposed funding level: $400,000

Comparative Effectiveness of Different Air Cleaning Technologies for Asthma Triggers in Homes and Offices

The objective of this concept is to measure the effectiveness of different types of portable air cleaning devices and ventilation system filters in removing particles and ozone from indoor air in a sample of homes and offices over a twelve-month period, and to provide a cost-benefit analysis which will provide guidance to asthma sufferers. This project would measure real-world effectiveness in typical California buildings and assess the effectiveness of the devices at removing both indoor-generated and outdoor-generated PM and ozone. Interest in, and the need for, filtration is increasing, especially for those with asthma and other respiratory disease. This project will provide information responsive to the public's interest, and subsequent outreach could supplement ARB's program in indoor air quality. (p. 28)

Proposed funding level: $200,000

Concepts Recommended for Funding

TITLE: Health Effects of Central Valley PM

PROBLEM: Numerous epidemiological studies demonstrate a correlation between ambient particulate matter (PM) concentrations and morbidity and mortality with lags of 1 to 3 days, yet the mechanistic and causal links between health effects and PM concentrations remain unclear. We previously found associations between health effects in mice exposed to concentrated ambient particles (CAPs) in Fresno, but there are no investigations into the time course for development of and recovery from particle-induced health effects. We propose to investigate the time course of pulmonary and systemic biological responses in mice exposed to Fresno PM using lag times after exposure that could help explain epidemiological results.

PREVIOUS WORK: Researchers at UC Davis have exposed animals to ambient PM in urban Fresno and the surrounding rural areas in both summer and winter. Results to date show significant changes in chemokine and cytokine levels, increased total inflammatory cell number, increased number and proportion of neutrophils, and evidence for systemic platelet activation in animals exposed to concentrated ambient particles. Measurements assessing adverse effects have typically been performed either immediately after exposure ends, or on the next day, although the optimal time for post-exposure measurements is unknown. It is possible that important indications of adverse changes are being missed due to lack of knowledge about the time courses of different endpoints (i.e., pulmonary, cardiovascular, inflammatory, platelet activation). Data from ozone-exposed human subjects indicates that different biomarkers of inflammation are elevated in the lungs at different times post-exposure. This reflects the time course of the inflammatory cascade mechanism, as well as the injury-repair cycle. There is no similar information in the literature for any category of endpoint for PM exposure.

OBJECTIVES: The proposed work will assess the toxicity of urban and background PM from the San Joaquin Valley on pulmonary and cardiovascular systems in a mouse model observed at different times post-exposure. Results will facilitate improved assessment and source attribution of PM-mediated health impacts and may illuminate mechanisms by which PM affects pulmonary and cardiovascular systems in humans.

DESCRIPTION: In the research proposed here, we will expand our research program by investigating the different pulmonary and cardiovascular indicators that are elicited at different times post- exposure. These experiments are motivated by epidemiologic studies that have shown health effects lagging by 1, 2 or 3 days post-exposure. It is likely that some health effects are elicited promptly while others take some time to be observed. Both pulmonary and cardiovascular endpoints will be assessed, and the composition of the PM will be analyzed chemically for source apportionment.

We propose to:

1. Expose mice to concentrated ambient particles in Fresno during winter and summer.
2. Employ a staggered set of post-exposure times to explore the temporal nature of different responses to concentrated ambient particles.
3. Assess markers of cardiovascular heath effects induced by this PM.
4. Assess markers of pulmonary health effects induced by this PM.
5. Source apportion the PM to correlate health effects with sources.

Animals will be exposed to CAPs at the East Shaw Avenue Monitoring Site in Fresno, California where we have performed exposures previously and observed health effects using the University of Southern California (USC) Versatile Aerosol Concentrator Exposure System (VACES) at the same time of year and for the same length of exposure proposed here. UC Davis is also developing an improved version of VACES under contract with ARB that can also be deployed for these studies. We will use HiVol samplers to collect coarse PM and PM2.5 for in vitro and in vivo laboratory exposures. Assuming that funding is established before the end of 2009, we will perform the exposures in the summer of 2010 and winter of 2011. June of 2010 is optimum for exposures because the CalNex and CARES field campaigns will be taking place so a greater range of ambient measurements will be available for our study. Due to the limited funding, chemical analysis and source apportionment will only be performed on PM2.5. If SAHERC funding is renewed, U.S. EPA funds will be used for chemical analysis and source apportionment of size-resolved PM samples as with previous SAHERC field studies.

There will be two experiments; one during summer 2010 and the other during winter 2011. In both experiments, mice will be exposed to CAPs for 10 days, 6 hours per day. There will be a group of 8 mice exposed to filtered air, and four groups of 8 mice that will be exposed simultaneously to CAPs. Two filtered air exposed animals and one group of 8 CAPs exposed mice will be sacrificed at each of the following post-exposure time points: 1, 2, 4 and 6 days post-exposure. All 40 animals will be acclimated to the Fresno site one week prior to exposure. At 16, 14, 12 and 11 days pre-necropsy, each group will begin exposure to the 10-day, 6-hr/day regimen. After the 16 day exposure protocol, the animals will be sacrificed and analyzed for a wide range of pulmonary and cardiovascular endpoints, as noted below.

BENEFITS: PM is the most serious air pollution problem in California. Air quality standards for PM are based on epidemiological studies that can not demonstrate causality, and current understanding of the biological basis for epidemiological associations is incomplete. This study is designed to clarify biological mechanisms and lags linking inhalation of PM to pulmonary and cardiovascular responses, which will strengthen the scientific basis for the PM standards, and enable ARB to be more confident that the standards adequately protect the public.

COST: $450,000

COFUNDING OPORTUNITIES: Pending renewal of the San Joaquin Valley Health Effects Research Center (SAHERC) funding, an $8M co-funding effort will be proposed to the U.S. EPA.

TITLE: Genetic Control of PM-Induced Inflammation and Oxidative Stress in Subjects with Coronary Artery Disease

PROBLEM: Findings in cohort and time series studies suggest that environmental exposure to particulate matter (PM) air pollution is associated with increases in cardiovascular hospitalization and mortality (1). Pathophysiological mechanisms underlying epidemiological findings as well as information regarding PM sources and chemical components responsible for these associations are beginning to emerge. There is evidence to support the hypothesis that ultrafine particles (UFP) and their organic components are capable of inducing the greatest amount of oxidative stress and inflammation per unit of PM mass (2-4). However, accurate exposure assessment methods (5) have generally been lacking in epidemiologic studies to date. Furthermore, there is little data on whether increased exposure to air pollution is associated with changes in mRNA expression reflecting biological processes linked to oxidative stress and inflammation. Most relevant gene expression data has come from *in vitro* studies or animal models. It is unclear whether these findings can be extrapolated to humans. The proposed study will address gaps in understanding mechanisms of PM-induced cardiovascular health effects in human populations.

PREVIOUS WORK: Associations of circulating biomarkers of inflammation as well as antioxidant enzymes with outdoor PM among people with coronary artery disease (CAD) have been demonstrated, in particular associations involving markers of primary combustion aerosols and quasi-UFP particles <0.25 μm (3,4). However, there is limited understanding of complex biological pathways by which PM exposure might trigger such systemic responses (6). An epidemiologic approach is to evaluate whether increased exposure to air pollution is associated with changes in mRNA expression reflecting key biological processes. *In vitro* data has shown that air pollutants can induce gene expression representing antioxidant response, inflammation, coagulation, endothelial function, and apoptosis in endothelial cells, epithelial cells, monocytes, and macrophages. There is some data showing gene expression changes in animals such as hypercholesterolemic mice exposed to urban UFP (7-8), but human data are limited to one small study of 15 welders (9) and another small cross-sectional study of 47 children in the Czech Republic (10). There are no data on whether gene expression in relevant biological pathways is associated with urban PM exposure in humans at increased cardiac risk from advanced age or CAD.

OBJECTIVE: *To assess whether key genes of inflammatory and oxidative stress responses are differentially expressed in peripheral blood of subjects with CAD in relation to air pollutant exposures measured at indoor and outdoor home sites.* We hypothesize that the expression level of genes involved in biological pathways relevant to cardiovascular acute responses and disease progression will be altered following higher PM exposures. We will evaluate within-subject differences in repeated gene expression in relation to particle size, PM composition and sources of exposure that have a major contribution to personal and indoor PM concentrations.

DESCRIPTION: This research to determine the expression levels of candidate gene transcripts in subjects from an ongoing funded panel study, and investigators will merge this data with available intensive exposure and health outcome assessments nearing

completion for an NIH, NIEHS-funded panel study (grant no. ES-012243; with supplemental funding through ARB contract no. 03-329 and US EPA grant no. RD83241301). Principal investigators collected repeated measures to evaluate acute cardiovascular health effects of exposure to PM, with a focus on ultrafine particles. Enrolled subjects with complete home exposure and health outcome data include 60 elderly nonsmokers living in retirement communities in areas of the Los Angeles air basin with high air pollution levels. Each subject has been followed over a 7-month period with up to 12 blood draws for whole blood total RNA at the same time blood samples were taken and already analyzed for biomarkers of inflammation and oxidative stress. The parent study scope of work did not include gene expression research. Subjects were followed weekly on site by research technicians. Diaries were used to monitor medication use, time-activity patterns, and exposure conditions. Extensive baseline and prospective cardiovascular clinical data are available.

BENEFITS: This project will contribute substantial new data to improve understanding of the air pollutant characteristics and sources that affect gene expression among elderly Californians at greatest risk of cardiovascular morbidity and mortality. Because subjects living in the LA Basin's most pollutant areas were followed at home for 12 weeks, results will provide clues to mechanisms not otherwise discoverable using experimental approaches. The greatest strength of this proposal is the use of a potentially powerful new tool in population studies to measure biological response to environmental stressors in what will be the largest study of its kind to date. Results of this study will establish a foundation for additional clinical research involving repeated measurements to yield information about exposure time-dependent gene expression.

COST: $275,000

COFUNDING/COLLABORATION OPPORTUNITIES: This project will leverage substantial resources in the form of data collected in the parent research project funded by NIH, NIEHS. Collaboration with an ARB-funded, additional major exposure assessment effort for the NIEHS project will enable principal investigators to evaluate effects from a broad range of particulate air pollutant sources and components. Ongoing EPA-funded research (Southern California Particle Center) is assessing oxidative stress biomarkers in the same subjects. Collaboration will make it possible to explore links between gene expression, protein expression, and oxidative stress.

REFERENCES:

1. Pope CA 3rd, Dockery DW. Health effects of fine particulate air pollution: lines that connect. J Air Waste Manag Assoc 2006;56:709-42.
2. Delfino RJ, Sioutas C, Malik S, Potential role of ultrafine particles in associations between airborne particle mass and cardiovascular health. Environ Health Perspect, 2005; 113:934-46.
3. Delfino RJ, Staimer N, Tjoa T, Polidori A, Arhami M, Gillen D, Kleinman MT, Vaziri N, Zaldivar F, Longhurst J, Sioutas C. Circulating biomarkers of inflammation, antioxidant activity, and platelet activation are associated with urban air pollution in elderly subjects with a history of coronary artery disease. Environ Health Perspect, 2008; 116:898–906.
4. Delfino RJ, Staimer N, Tjoa T, Gillen D, Polidori A, Arhami M, Kleinman MT, Vaziri N, Longhurst J, Sioutas C. Air pollution exposures and circulating biomarkers of effect in a

susceptible population: clues to potential causal component mixtures and mechanisms. Submitted.
5. Sioutas C, Delfino RJ, Singh M. Exposure assessment for atmospheric ultrafine particles (UFP) and implications in epidemiological research. Environ Health Perspect, 2005; 113:947-55.
6. Schulz H, Harder V, Ibald-Mulli A, Khandoga A, Koenig W, Krombach F, Radykewicz R, Stampfl A, Thorand B, Peters A. Cardiovascular effects of fine and ultrafine particles. J Aerosol Med 2005;18:1-22.
7. Araujo JA, Barajas B, Kleinman M, Wang X, Bennett BJ, Gong KW, Navab M, Harkema J, Sioutas C, Lusis AJ, Nel AE. Ambient particulate pollutants in the ultrafine range promote early atherosclerosis and systemic oxidative stress. Circ Res 2008;102:589-96.
8. Gong KW, Zhao W, Li N, Barajas B, Kleinman M, Sioutas C, Horvath S, Lusis AJ, Nel A, Araujo JA. Air-pollutant chemicals and oxidized lipids exhibit genome-wide synergistic effects on endothelial cells. Genome Biol. 2007 Jul 26;8(7):R149.
9. Wang Z, Neuburg D, Li C, Su L, Kim JY, Chen JC, Christiani DC. Global gene expression profiling in whole-blood samples from individuals exposed to metal fumes. Environ Health Perspect 2005; 113(2):233-241.
10. van Leeuwen DM, van Herwijnen MH, Pedersen M, Knudsen LE, Kirsch-Volders M, Sram RJ, Staal YC, Bajak E, van Delft JH, Kleinjans JC. Genome-wide differential gene expression in children exposed to air pollution in the Czech Republic. Mutat Res 2006;600:12-22.
11. Polidori A, Arhami M, Delfino RJ, Allen R, Sioutas C. Indoor-outdoor relationships, trends and carbonaceous content of fine particulate matter in retirement communities of the Los Angeles basin. J Air Waste Manage Assoc, 2007;57:366-379.
12. Ding C and Cantor CR. A high-throughput gene expression analysis technique using competitive PCR and matrix-assisted laser desorption ionization time-of-flight MS. Proc Natl Acad Sci USA 2003;100:3059-64.
13. Elvidge GP, Price TS, Glenny L and Ragoussis J. Development and evaluation of real competitive PCR for high-throughput quantitative applications. Anal Biochem 2005;339:231-41.

TITLE: Using a Mobile Monitoring Platform to Investigate Spatial, Diurnal and Seasonal Pollution Gradients Near Freeways and the Air Quality Improvements from New Regulations in the Port Area

PROBLEM: An understanding of the variability and extent of the steep pollution gradients in close proximity to combustion sources is emerging, but significant gaps remain, particularly concerning the diurnal variability and pollutant levels during calm conditions at night and in the early morning. Broad areas of highly elevated pollutant levels in the early morning likely play a disproportionate role in individual exposures to air pollution [1]. For the population of many urban areas, the most important, locally-variable source of pollution exposures are motor vehicles on freeways and major arterials. In earlier mobile platform (MP) studies we have shown this is particularly true for the port area of Los Angeles and Long Beach which have exceptionally high densities of mobile sources of pollution sources, especially heavy duty diesel trucks (HDDT). Since HDDT's are a target of regulations to protect human health by reducing diesel emissions it is critical to monitor the effectiveness of these regulations.

PREVIOUS WORK: The ARB-developed mobile platform (MP) continues to demonstrate the great versatility and power of using an instrumented electric vehicle to rapidly collect pollutant concentration data, with excellent spatial and temporal resolution, over a wide range of microenvironments [1-8]. Using the MP in 2008 in West Los Angeles, researchers showed that in the hours immediately preceding sunrise, average ultrafine particle concentrations exceed daytime downwind values by factors of 2 to 4 in the first 1000 meters downwind of the freeway, even though traffic flows are lower during the pre-sunrise period than daytime [1]. Further, concentrations of ultrafine particles and other traffic-related pollutants during stable conditions did not return to the background level until about 2500 meters downwind, thus affecting many times more people than during daytime, when pollutant levels return to background within about 300 m [9, 10]. It is suspected these extended high concentration gradients occur in all seasons, and can be generalized to other major roadways, but this needs to be confirmed with additional measurements.

Also of concern are the communities downwind of high densities of diesel truck and rail emissions in the port areas of Los Angeles, the target of many new and existing regulations aimed at reducing such emissions. Data are available from 2006 and 2007 characterizing areas around the 710 freeway as well as in Wilmington, Carson, and San Pedro. These data can be used to create a baseline for a long-term trend analysis of the effectiveness of the new regulations in reducing exposures to residents near the ports.

OBJECTIVE: Objectives are threefold: 1. Generalize the wide impact area of freeways under stable atmospheric conditions, particularly during the night and early morning, and better characterize the impact area phenomenon and its relationship with the time of day. 2. Investigate the diurnal variation of freeway and arterial road impacts due to heavy truck traffic in the port area, and 3. Provide on-going monitoring to track improvements in the air quality in the port area as new regulations aimed at reducing emissions come into force.

DESCRIPTION: This project seeks to continue to exploit the ability of the mobile platform (MP) to efficiently produce spatially- and temporally-resolved measurements. The MP is a self-pollution free electric RAV4 vehicle instrumented with fast instruments to monitor ultrafine particle number and size distribution, PM 2.5, black carbon and particle-bound PAH mass, CO, CO_2 and NO_X, wind speed, direction, temperature and relative humidity and records of traffic activity on video. To make a detailed assessment of pollutant buffers surrounding freeways, investigators will develop a sampling plan that will seek to monitor a range of atmospheric stability conditions, to characterize air pollution gradients under the range of diurnally variable mixed layer conditions typically found in California. Atmospheric stability data will be obtained from the network of vertical profilers managed by the South Coast Air Quality Management District, supplemented in the lowest few hundred meters above ground level with additional instrumentation if possible.

BENEFITS: Individual exposures to air pollutants depend strongly on place as well as times spent in microenvironments rather than on regional averaged air pollution levels. This study seeks to greatly improve our understanding of how pollutants, particularly ultrafine particles, vary with location and time of day, near freeways and arterial roads. These results are essential for more accurate exposure assessment. Results will also enable improved evaluation of the rate of improvement in air quality near the ports.

COST: $280,000

REFERENCES:

1. Hu, S., S. Fruin, K. Kozawa, S. Mara, S.E. Paulson, and A.M. Winer, (2009) A wide area of air pollutant impact downwind of a freeway during pre-sunrise hours. Atmos. Env. (*submitted*)
2. Westerdahl, D., S. Fruin, T. Sax, P.M. Fine, and C. Sioutas, (2005) Mobile platform measurements of ultrafine particles and associated pollutant concentrations on freeways and residential streets in Los Angeles. Atmos. Environ. **39** (20): p. 3597-3610.
3. Westerdahl, D., S.A. Fruin, P.L. Fine, and C. Sioutas, (2008) The Los Angeles International Airport as a source of ultrafine particles and other pollutants to nearby communities. Atmos. Environ. **42** (13): p. 3143-3155.
4. Fruin, S., D. Westerdahl, T. Sax, C. Sioutas, and P.M. Fine, (2008) Measurements and predictors of on-road ultrafine particle concentrations and associated pollutants in Los Angeles. Atmos. Environ. **42** (2): p. 207-219.
5. Hu, S., S. Fruin, K. Kozawa, S. Mara, S.E. Paulson, and A.M. Winer, (2009) Street level air pollution exposures: a comparison of neighborhoods. (*in preparation*)
6. Hu, S., S. Fruin, K. Kozawa, S. Mara, A.M. Winer, and S.E. Paulson, (2009) Characterization of aircraft emission impacts in a neighborhood adjacent to a local airport in Southern California. (*in preparation*)
7. Kozawa, K., S. Fruin, and A.M. Winer, (2009) Characterization of pollutants near heavily trafficked roadways in the communities near the Ports of Los Angeles and Long Beach. Atmos. Environ. (*submitted*)
8. Kozawa, K., S. Fruin, and A.M. Winer, (2009) Ultrafine particle size distributions near heavily trafficked roadways in communities adjacent to the ports of Los Angeles and Long Beach. (*in preparation*)
9. Zhu, Y., W.C. Hinds, S. Kim, S. Chen and C. Sioutas (2002) Study of ultrafine particles near a major highway with heavy duty diesel traffic. Atmos. Environ. **36** (27): p. 4323-4335.

10. Zhu, Y., T. Kuhn, P. Mayo and W.C. Hinds (2006) Comparison of daytime and nighttime concentration profiles and size distributions of ultrafine particles near a major highway Environ. Sci. and Tech. **40** (8): p. 2531-2536.
11. Houston, D., M. Krudysz, and A. M. Winer, 2008. “Diesel Truck Traffic in Port-Adjacent Low-Income and Minority Communities; Environmental Justice Implications of Near-Roadway Land Use Conflicts,” J. Transportation Research Board, No. 2076, 38-46.

TITLE: On-Road Measurement of Emissions from Heavy-Duty Diesel Trucks: Impacts of Fleet Turnover and ARB's Truck & Bus Rule

PROBLEM: New on-road heavy-duty (HD) diesel exhaust PM emission standards are effective for 2007 and newer model engines nation-wide. Furthermore, ARB recently adopted the Truck & Bus rule in December 2008; this rule will accelerate the deployment of control equipment such as diesel particle filters on older engines that are already in use. Some engines will be retired instead of undergoing retrofits. In either case, ARB's truck and bus rule will greatly accelerate penetration of the 2007 heavy-duty engine PM emission standards to the in-use truck fleet, completing a clean-up effort by ~2014 that would otherwise take another decade or longer to achieve. On-road emissions data will help to document and support the emission and air quality benefits of ARB's emission control program in this area.

PREVIOUS WORK: HD diesel truck exhaust PM emissions have been measured on-road at the Caldecott tunnel during summers 1997 and 2006 (Kirchstetter et al., *Atmos. Environ.* 1999; Ban-Weiss et al., *Atmos. Environ.* 2008; Ban-Weiss et al., *Environ. Sci. Technol.* 2009). The most recent study in 2006 for the first time provided data on particulate emission factors from over 200 individual diesel trucks (previous studies reported only fleet-average emissions data). The 2006 measurements described variability and inter-relationships affecting particulate matter emissions (specifically BC = black carbon, and PN = particle number) from individual heavy-duty trucks. There was minimal overlap between high BC and high PN emitters: when BC emissions were high, new PN formation via nucleation was inhibited due to condensation onto existing BC particle surfaces. Changes in emission factor distributions are expected as fleet-average emissions decrease over time: distributions are likely to become more skewed.

OBJECTIVE: Measure emission factor trends and distributions for heavy-duty diesel trucks driving through the Caldecott tunnel in 2010 and 2012.

DESCRIPTION: Pollutant concentrations will be measured in a mixed traffic bore of the Caldecott tunnel, in a ventilation duct above the traffic. Large diesel trucks with vertical exhaust pipes inject their exhaust emissions near the top of the tunnel where air sampling equipment inlets will be located. Measurements will be made for uphill traffic on a 4% grade (the uphill grade poses a significant load on truck engines). Previous work indicates that during midday hours on weekdays, diesel trucks pass by at a rate of about 1 per minute, and that pollutant concentrations (BC, PN, NO_X, and CO_2) increase well above tunnel background levels. Specific pollutants to be measured at 1 Hz:

* CO_2 (LICOR-820 already purchased & available)
* BC (Magee Scientific aethalometer – already purchased & available)
* PN (water and butanol CPCs – already purchased & available)
* Dustrak PM mass (TSI – available through LBNL)
* size distribution (FMPS to be borrowed from ARB – electrometer-based particle counting)
* Total NO_X (ECO Physics CLD 64, on order for delivery in summer 2009)

Investigators will measure at least 500 individual heavy-duty truck exhaust plumes in two separate field campaigns to take place in summer 2010 and 2012. Investigators will

calculate emission factors for all of the above pollutants via carbon balance methods (i.e., normalize pollutant of interest to total carbon – mainly CO_2 – concentration inside the tunnel). Investigators will analyze emission trends over time by comparing fleet-average emission factors and distributions measured at the same site with similar driving conditions.

BENEFITS: As California proceeds with implementation of new emission controls on heavy-duty trucks, especially the truck & bus rule, over the next few years, major changes in fleet-average emissions, emission distributions, and relationships among various pollutant emissions are expected. This study will provide on-road confirmation of the emission impacts of the truck & bus rule, and will provide complementary information to a multi-year on-road assessment sponsored by NREL that started in 2008 in southern California, and will continue for the next 4 years. The NREL study relies on remote sensing to measure HD vehicle emissions.

Information on the distribution of emission factors across a large on-road sample of heavy-duty trucks will complement chassis dynamometer testing programs that support the state's emission inventory and planning needs. Specifically, the emission factor distributions to be developed here will provide data on the prevalence and emission levels of high-emitting vehicles. Although their numbers can be relatively small, these high-emitting vehicles are very important in terms of the overall emissions budget from HD trucks. However, these high-emitting vehicles are difficult to account for in dynamometer-based test programs that are limited in terms of sample size due to budget constraints.

COST: $300,000

TITLE: In-duct Air Cleaning Devices: Ozone Emissions and Test Methodology

PROBLEM: In 2007, the ARB adopted a regulation that limits ozone emissions from indoor air cleaning devices. Air cleaners physically integrated within a central ventilation system, called "in-duct" air cleaners, were exempted from the requirements of ARB's regulation because no suitable test method was available for measuring ozone emissions from such devices, and few data were available on their ozone emissions to support regulation. However, there are a number of in-duct intentional ozone generators as well as in-duct electrostatic, ionizer, and ultraviolet air cleaners known to emit ozone that are marketed in California. There is reason to believe that some of these may generate significant amounts of ozone and/or ozone reaction byproducts such as formaldehyde. The presence of ozone in the indoor environment has known, serious health consequences, in addition to detrimental effects on building and household materials.

The current California regulation relies on the test method described in Section 37 of Underwriters Laboratory Standard 867 (UL 867) to certify compliance of portable indoor air cleaning devices with the 0.050 ppm emission concentration limit. However, while UL uses UL 867 to test in-duct air cleaners for their electrical safety, UL 867 does not include a suitable test method for measuring ozone emissions from in-duct devices.

PREVIOUS WORK: Measurements of ozone emissions from in-duct, intentional ozone generators are not generally available. However, Viner *et al*. (1992) measured air ozone emissions for three HVAC electrostatic air cleaners. Their findings suggest that some electrostatic air cleaners on the market generate more than 20 mg/hr of ozone, an amount considerably greater than most ion generators (1- 5 mg/hr, Mullen *et al*., 2005; Britigan *et al*., 2006; Waring *et al*., 2008) and less than most portable dedicated ozone generators (31 - 220 mg/hr, Mullen et al., 2005; Britigan *et al*., 2006). There have been changes in electrostatic air cleaner design since Viner *et al* conducted their study (i.e., the use of pin ionizers rather than coronas in some models) as well as newer information on the impact of dirty coronas, ozone reaction byproducts, and other factors than point to increased ozone emissions. In addition to the ozone emitted from the air cleaners, heterogeneous reactions of ozone with materials in a ducted system may produce unwanted aldehydes and other irritants. Research by Morrison *et al.* (1998, JAWMA) indicates that exposure of ducted materials to ozone increased the emission rates of aldehydes from a duct liner, duct sealing caulk, and neoprene gasket. Their results also indicated that, contrary to some claims, air ducts in ventilation systems are not likely to be a major sink for ozone, but this needs to be verified.

OBJECTIVE: The objectives of this project would be to: 1) develop a robust and easily applied method to measure ozone emissions from central system, in-duct air cleaners; 2) apply this method to test modern in-duct air cleaner designs in the laboratory; 3) measure ozone and byproduct emissions from in-duct air cleaners in homes and offices during actual use; 4) estimate the impact of these emissions on Californians' exposures to ozone and reaction byproducts; and 5) compare the ozone impacts to those from portable intentional and unintentional ozone-generating air cleaners. This study would develop a test method for in-duct air cleaners that could be adopted by UL and ARB; establish the relationship between tested ozone levels for in-duct ozone-generating air

cleaning devices and incremental increases in ozone and byproduct concentrations in buildings; and help identify the potential need for regulation of in-duct devices.

DESCRIPTION: The work would entail laboratory tests, field research, and modeling of potential ozone and reaction product concentrations within home and office environments. First, investigators would develop an ozone emission rate test methodology appropriate for in-duct air cleaners. The methodology would take into account the large airflows in typical HVAC systems, and variations in ozone emission rate due to factors such as temperature, relative humidity, upstream particle concentration, dust loading, flow rate, and voltage fluctuations. All of these factors are likely to vary significantly and have been shown to impact ozone emissions. They also would assess the potential for reaction of ozone on the air cleaner itself as well as on ducts and downstream HVAC components. These reactions can artificially reduce the measured ozone emission rates, and produce a variety of compounds that are odorous, irritating, and of serious health concern, such as formaldehyde.

Next, investigators would validate the test methodology in different test ducts at other facilities to assess repeatability and reliability as well as ease of use. These results would be used to improve the test method. Then, the ozone emission rates of 6 -10 in-duct air cleaning devices commercially available in California would be determined, using the methodology developed. Next, testing would be conducted in four homes and two office buildings to verify the relationship between laboratory-measured emissions and installed performance. Finally, using test data and modeling, investigators would estimate: 1) the incremental increase in ozone concentrations in residential buildings as a function of the measured emission rates from these units, 2) the anticipated total indoor ozone concentrations as a function of emission rates and a statistical analysis of California building characteristics and other relevant regional information, 3) the ozone and reaction product exposures for typical Californians in buildings with these devices, and 4) compare the measured impacts to those from portable intentional and unintentional ozone-generating air cleaners.

BENEFITS: This study would provide a test method and necessary data to support inclusion of in-duct air cleaners in ARB's air cleaner regulation, if warranted. Regulation of all significant contributors of ozone in an indoor setting is appropriate and should be further explored. If warranted, the resulting regulation would reduce Californians' exposures to ozone and the associated harmful effects of ozone and its byproducts.

COST: $325,000

Concepts Recommended if Funding Available

TITLE: Community Exposures to Traffic-Generated Pollutants

PROBLEM: Pollutants emitted by or formed from the emissions of motor vehicles have long been known to be harmful. Epidemiological studies have found that people living near roadways are more likely to suffer adverse health effects that include exacerbation of existing asthma, heart problems, low birth weights, and even excess mortality. Controlled animal, human and toxicological studies have reinforced these findings. Components that have been found to be related to health impacts include: particle-phase carbon, oxides of nitrogen, CO, organic vapors, PM2.5, ultrafine PM, PAHs, quinones, reactive oxygen species, and diesel exhaust particles. However uncertainties exist regarding which pollutant are causing these effects and what levels are encountered by people in the community. This is partially because epidemiological and biostatistical studies often use pollutant data that are quite limited, typically from routine air monitoring stations. These stations are intentionally sited to minimize the impacts of local sources, such as traffic and monitor a short list of pollutants. An added problem is that many of the pollutants are emitted by the same source. Thus, some reported associations with measured pollutants may act as surrogates, or stand-ins, for the actual harmful agent or agents.

The uncertainties regarding the specific potencies and level of exposure to the components of traffic-related air pollutants make it difficult to assess risk with confidence and to develop programs that efficiently control these risks. A key uncertainty remains to be resolved: what harmful pollutants are present in near traffic community air, including near roadways, in cars, in homes, schools, and workplaces?

PREVIOUS WORK: Studies have used differing approaches to assess the health impacts of traffic-related pollutants. Near roadway studies have shown that ultrafine PM and other primary pollutants diminish as they move from the roadway, but may be found at elevated levels for hundreds of meters. On-road exposure studies find that in-vehicle exposure is a major contributor to UFP exposures for commuters. Statistical studies which have used available data on health status or outcomes have found that estimated PM2.5, NO_2, CO or ozone exposures are associated with increased rates of asthma, low birth weights, mortality, heart problems and other outcomes. Other studies have found that distance from roadways, or to heavy duty truck traffic is linked to health impacts that include mortality rates and childhood respiratory illnesses. When more refined pollutant exposure data are available for individuals in a community, health outcomes such as reduced lung function development in children are seen to be associated with NO_2, PM2.5 and carbon. Cardiac function and blood markers of injury and inflammation have been related to personal and indoor exposures to outdoor traffic sources. Various approaches are employed to refine exposure/effects estimates for use in statistical studies of health outcomes. These include consideration of lifestyle and socioeconomic status determined from census data as well as limited air monitoring to refine local ambient air quality data. Land use has also been used to model community and population exposures. However, these methodologies and their reliance on the available, limited monitoring data may misrepresent the nature and risks of pollutant

exposures. One example is for NO_2 that has been found to be associated with a range of health outcomes by epidemiological and statistical studies. However, studies performed in controlled human and animal exposure studies have not shown NO_2 capable of causing such effects. A more probable explanation of the epidemiological results is that NO_2 is a stand-in for harmful pollutants emitted by vehicles, such as NO, UFP, or organics.

OBJECTIVE: The objective is to determine the nature of community and individual exposures to harmful traffic generated-pollutants.

DESCRIPTION: The study would incorporate intensive, time and spatially resolved air monitoring for pollutants of concern regarding the health impacts of traffic. Based on the findings of recent health studies these pollutants would include, as a minimum: ultrafine PM, PM2.5 mass, carbon (black, organic, and elemental), primary and secondary organic aerosols, CO, and, NO_X. In-vehicle, near roadway, community, and indoor air monitoring would be included to both provide spatially refined concentrations and to evaluate how the physical and chemical nature of these pollutants varies as they move from source to receptor.

The optimal deployment of this study would be to coordinate it with a health study (or studies) in order to improve the exposure data available for that study, as well as to document the nature of the pollutant across a community and indoors. UCI has two studies focused on traffic-related pollutants that are anticipated to begin in the fall or winter of 2009-2010 that would be candidates. The first would follow from successful observations of elderly people with health problems. In that NIESH/ARB/SCAQMD sponsored study performed by UCI, pollutants from outdoor origin, especially organic aerosols from traffic sources, were found to be associated with a range of health outcome measures. The second study is of asthmatic children whose respiratory health would be evaluated for changes due to community and indoor air pollution exposures. Extended air monitoring would provide both studies with an improved ability to evaluate how specific traffic related pollutants impact health.

BENEFITS: This research will refine what is known regarding concentrations of traffic-related air pollutants in community air and exposure levels experienced by people at elevated risk of adverse health impacts. Results will aid identification of sources as well as factors that mitigate exposures. This information will facilitate improved risk assessments and the design of pollution control programs that are most likely to reduce these risks.

COST: $800,000

TITLE: Mitigation of Air Pollution Exposures from Land Use and Transportation Measures to Reduce Greenhouse Gases

PROBLEM: As stated in SB 375 (Steinberg, 2008), additional measures beyond vehicle emission reductions, such as alternative land use patterns and transportation systems that will help reduce energy use, are needed in order to meet the greenhouse gas (GHG) emission reduction goals of AB 32 (Nunez, 2006). Measures such as increased housing density, closer proximity of buildings to public transit and roadways, and more walkable and bikable communities have been identified as additional means to achieve AB 32 goals. However, such broad measures can have unintended consequences, in addition to the expected environmental and social benefits. For example, greater proximity to busy freeways and arterial roadways can result in increased exposure of the community to air pollutant emissions from vehicles and traffic noise (Zhu et al., 2002, 2006; Baldauf et al., 2008; Hu et al., 2009). Also, increased building density and walkable/bikable community designs put commercial buildings in closer proximity to residential buildings, increasing exposures of residents to emissions and noise from establishments such as print shops, restaurants, and auto body shops. Measures to reduce such exposures are available, but have not been sufficiently studied to support their use on a statewide basis. Mitigation measures that have been used recently or are planned for use include set-back of buildings at a greater distance from major roadways; construction freeways and arterials below grade; the use of sound walls, raised landscape berms and dense foliage as pollutant interceptors or diverters and for noise attenuation; design of buildings with air intakes on the downwind side of the building away from major pollutant sources; the use of mechanical ventilation and high efficiency air filtration in homes; advanced building technologies to regulate outdoor air intake under high pollution conditions; and the use of reduced leakage and other “whole building” measures to achieve zero energy buildings. However, only very limited research has been conducted to date on most of these measures to confirm and quantify their actual effectiveness in mitigating exposures to air pollutants in the real world. The data are generally insufficient to support them as statewide mitigation measures or to allow quantification of the extent to which they would reduce the local population’s exposures to pollution from alternative land use patterns.

PREVIOUS WORK: Very little information is available on the effect of mitigation measures to reduce pollutant transport from roadways into homes. Sound walls can elevate the air pollutant plume from roadways and reduce downwind concentrations to 0-80% of roadway concentrations, while vegetation and buildings may reduce pollutant transport by increasing air turbulence and pollutant deposition (Bowker et al., 2007 and papers cited). However, local air flow patterns (e.g., during inversions) may also concentrate the polluted airstream flowing over the walls, resulting in increased exposures nearby. Hu et al. (2009) recently found that elevated pollutant levels occur at distances farther from busy roadways than previously measured, especially at night; thus, the current State policy of a 500 foot set-back of buildings from roadways may not be sufficiently protective, and warrants further research.

Homes with very tight building shells, mechanical ventilation and high efficiency air filtration can greatly (though not completely) reduce uncontrolled air leakage and pollutant infiltration from the outdoors. Such measures accompanied by no- or low-VOC

building materials and other measures comprise a “whole house” approach that is being used increasingly in Europe, and recently in the U.S., to reduce energy use and GHG emissions. However, the reduction of pollutant infiltration has not been assessed in such homes, nor have measures used in Europe been successfully demonstrated in California climates using local construction styles.

OBJECTIVE: The objectives of this project are to: 1) conduct a literature review of the land use and building design mitigation measures discussed above and other such mitigation measures to identify the type and extent of further research needed for each to be considered as a statewide mitigation measure; 2) for measures that are promising but require further research, develop study plans that would provide sufficient data to confirm and quantify their effectiveness in reducing exposures; 3) conduct pilot studies (or full studies if funds are available) for two of the most promising measures requiring further study; and 4) seek co-funding for the full field studies and the additional research needed.

DESCRIPTION: Within six months, investigators would conduct a comprehensive literature review of all relevant exposure reduction measures and prepare and deliver a draft report of their findings for review by ARB staff and others as determined by ARB. In consultation with ARB and appropriate scientists and stakeholders, measures warranting further study would be selected for development of study plans. Preliminary study plans would be delivered, and two measures would then be selected in consultation with ARB for immediate study. Pilot studies (or full field studies if sufficient funds are available) would be conducted for those two measures upon approval of a detailed study plan for each. Co-funding would be sought for the main studies of the first two measures and for the full studies for the remaining measures.

BENEFITS: This initial effort would provide a preliminary assessment of land use and building design measures that can mitigate the increased exposures to air pollution expected to occur from alternative land use and transportation approaches undertaken to reduce greenhouse gases. It also would provide study designs sufficient to develop accurate cost estimates for the research that is needed. This initial phase of work avoids allocating funds for full research and instead would pursue co-funding from other sources to help cover costs of the research. The ultimate research resulting from this project would provide a definitive assessment of mitigation effectiveness of the measures and a solid scientific basis for the selection of statewide exposure reduction measures.

COST: $300,000

REFERENCES:

(1) Baldauf et al., 2008. Traffic and meteorological impacts on near-road air quality; summary of methods and trends from the Raleigh near-road study. JAWMA 58: 865-878.

(2) Bowker GE, et al., 2007. The effects of roadside structures on the transport and dispersion of ultrafine particles from highways. Atmospheric Environment 41 (2007) 8128–8139.

(3) Hu et al., 2009. A wide area of air pollutant impact downwind of a freeway during pre-sunrise hours. Atmos. Envt. 43: 2541-2549.

(4) Zhu et al., 2002. Concentration and size distribution of ultrafine particles near a major highway. JAWMA 52: 1032-1043.

(5) Zhu et al., 2006. Comparison of daytime and nighttime concentration profiles and size distributions of ultrafine particles near a major highway. ES&T 40: 2531-2536.

TITLE: Port Workers' Exposure to Air Pollution

PROBLEM: The Ports of Los Angeles and Long Beach (Ports) and their terminal operators provide employment to thousands of workers in on-dock and transportation jobs. Current ARB and SCAQMD efforts to characterize air pollution levels in the surrounding communities do not address on-job air pollution exposure. As many of the workers live in the surrounding communities, assessing overall pollutant exposure of this sub-population requires knowledge of occupational exposure as well.

PREVIOUS WORK: A previous study funded by NIOSH and conducted by Cal-EPA measured the on-job pollution exposure of several occupation classes at the Ports. The study was limited and did not address many pollutants of concern such as diesel particulate matter. Other studies have assessed diesel exposure in other occupational settings.

OBJECTIVE: The objective is to characterize the exposure of Port terminal and transportation workers to air pollutants.

DESCRIPTION: In order to characterize exposure of Port workers, a combination of personal monitoring and area sampling will be conducted. A set of occupation types and settings will be selected after an initial scoping task to determine the jobs and areas where potential for high exposures exists. This will be accomplished via site visits and include input from occupational hygienists, the Ports, terminal operators, and the local dock workers union (ILWU #13). The exact number of samples, subjects, areas, and sampling durations will be determined based on the scoping exercise and available resources. Once the jobs and areas for sampling are identified, volunteers for personal monitoring and appropriate IRB approval will be sought.

Area sampling will include established methods for air monitoring of selected pollutants and air toxics. PM2.5 and PM10 filter samples will be collected and analyzed for mass, air toxic species, and elemental carbon as an indicator of diesel exhaust. Methods for measuring continuous PM mass will also be considered as resources allow. Ultrafine particle counters will also be considered. Eight-hour duration silanated canisters will collect organic gas air toxics for subsequent analysis.

Personal sampling may include some more recently developed active and passive methods. Many traditional occupational exposure monitors do not have the sensitivity to measure pollutants at ambient levels. Since the objective of the personal monitoring is to measure exposures that may be well below established occupational limits or guidelines and provide comparisons to fixed site monitors, the methods deployed for epidemiological exposure assessment are more appropriate. Methods that will be considered include personal, active PM samplers or impactors, passive and active gas samplers, and particle counters for ultrafine particles. Sampling analysis techniques will be as similar as possible to those used for the area sampling and the other ongoing monitoring studies in the surrounding areas.

Data analysis will include direct comparisons between on-job exposures, area concentrations, and community concentrations as measured by ongoing SCAQMD and

ARB monitoring studies. The specific source of the exposures will be assessed based on the chemical analysis of PM filters, gases, and estimated source profiles.

BENEFITS: Assessing the impact of goods movement includes the health effects costs associated with exposure to air pollution from goods movement activities. Given the large number of jobs associated with Port activities, and the proximity of these jobs to pollution sources, an impact assessment should include the potentially elevated exposures of this sub-population of residents. This study will help to identify these exposures and impacts and provide important information for decision-makers regarding Port operations and pollution mitigation measures.

COST: $150,000

COFUNDING/COLLABORATION OPPORTUNITIES: Potential cost matching by SCAQMD in the amount of $150,000.

TITLE: Evaluation of Secondary Pollutant Emissions from Portable "Air Cleaners"

PROBLEM: In a recent survey, 14% of California households reported ownership or use of portable air cleaner during the past five years *(1)*. A majority of portable air cleaners are electrostatic precipitators (ESPs), ionizers and ozone generators (OGs), all of which may negatively impact indoor air quality (IAQ) through emissions of O_3 *(2,3)*. Hence, nearly one million Californians may be exposed to potentially harmful pollutants emitted by poorly engineered air cleaning devices. Increasing public awareness of the deleterious effects of indoor ozone is likely driving consumers to seek alternative products available in a dynamic multi-million dollar market. Several new products combine new technology such as TiO_2 photocatalytic oxidation with established technologies in an integrated device. While ozone emissions remain a concern, formaldehyde and other partially oxidized VOCs may be generated as undesired byproducts of chemical processes taking place inside the air cleaner unit. These new integrated devices are capturing a growing market share, but research is needed to evaluate potential IAQ and public health impacts of these new generation devices.

PREVIOUS WORK: Characterization of ozone emissions by OGs, ESPs and ionizers has been carried out by ARB staff and other investigators *(2-4)*. Several other studies on portable air cleaners evaluated their effectiveness at removing aerosol particles *(5-8)*, microbes *(9)* and VOCs *(10,11)*. However, little attention has been paid to the generation of secondary organic pollutants formed during the operation of portable air cleaning devices. In recent work, we have investigated the performance of a prototype in-duct whole-building photocatalytic oxidation (PCO) air cleaner. We observed and quantified the formation of volatile aldehydes and carboxylic acids as partial oxidation byproducts upon challenging the device with realistic indoor VOC mixtures *(12,13)*. Our results suggest that PCO air cleaners, when operated under certain conditions and in the absence of secondary treatment, may constitute a significant source of harmful byproducts such as formaldehyde. Similar results have also been described by other authors *(14,15)*, further illustrating that the yield of secondary pollutants is highly dependent on experimental conditions, including the composition of the VOC mixture and the concentration of key constituents. In recent CARB-funded projects, our group has characterized secondary pollutants from ozone-initiated indoor chemistry *(16,17)* and emissions from office electronic equipment under idle and active cycles *(18)*, gaining valuable insight on the key physical-chemical phenomena involved and the experimental and analytical tools required to perform the proposed study.

OBJECTIVE: The objective is to evaluate the emission of indoor pollutants by devices commercialized as portable air cleaners in California, with emphasis on a new generation of equipment integrating several technologies that include photocatalytic oxidation (PCO). Emissions will be determined in realistic indoor conditions, to assess the risks associated with exposure to those secondary pollutants.

DESCRIPTION: Given the large number and the diverse nature of available portable air cleaners, ***Task 1*** of the project will involve performing a survey of equipment and technologies available in California through chain-store retailers with substantial market presence, as well as through online vendors. Additional information on leading

brand/models available in the US can be obtained through independent sources such as The Consumers Report magazine and from the results of ARB's ozone air cleaner survey performed by the U.C. Berkeley Survey Research Center *(1)*. This initial screening will allow us to identify devices with a likely significant presence in the State. A representative subset of those will be selected (in consultation with ARB staff) to perform the proposed experimental work. ***Task 2*** will involve the development of a test protocol for portable air cleaners. Devices will be operated inside the LBNL stainless steel 20-m^3 chamber operated at air exchange rates typical of buildings (in the range 0.2 – 1.5 h^{-1}), under a controlled atmosphere generated by continuous infusion of a challenge VOC mixture. Key parameters to be optimized include the composition of the chamber atmosphere and concentration of VOCs introduced in the chamber (with particular attention given to formaldehyde precursors such as alcohols and terpenes). Also, the study should be applicable to test equipment of different dimensions and different airflow throughput under comparable experimental conditions. ***Task 3*** will comprise the characterization of emissions of secondary pollutants by each of the air cleaners selected during Task 1, following the protocol developed under Task 2 for several air exchange conditions. This third task will be carried out with brand-new, out-of-the-box units, following manufacturers' operation procedures. At the completion of Task 3 tests, the air cleaners will be removed from the chamber and operated continuously in real indoor environments to age the test units. Subsequently, ***Task 4*** will involve a repetition of the tests performed under Task 3 using the aged equipment, to evaluate possible changes of emissions of secondary pollutants in used equipment. Finally, in ***Task 5*** the results determined under Tasks 3 and 4 will be used to estimate the expected IAQ impact of each of the studied devices using a mass balance model.

BENEFITS: Ineffective portable air cleaners may lead to poor IAQ and associated health effects for a significant number of Californians. The proposed research will help the State assist the public in making informed decisions when purchasing and using these devices. Information generated in this work would contribute to the broader effort that the ARB has been carrying out in this field over the past years.

COST: $400,000

REFERENCES:

(1) Piazza, T.; Lee, R. H.; Hayes, J. *Survey of the use of ozone-generating air cleaners by the California public.*; Final Report prepared for the California ARB and Cal EPA, Contract 05-301: www.arb.ca.gov/research/apr/past/05-301.pdf, 2006.

(2) Phillips, T.; Jakober, C. *Evaluation of ozone emissions from portable indoor "air cleaners" that intentionally generate ozone*; Staff Technical Report to the California ARB: www.arb.ca.gov/research/indoor/o3g-rpt.pdf, 2006.

(3) Jakober, C.; Phillips, T. *Evaluation of ozone emissions from portable indoor air cleaners: electrostatic precipitators and ionizers*; Staff Technical Report to the California ARB: www.arb.ca.gov/research/indoor/esp_report.pdf, 2008.

(4) Tung, T. C. W.; Niu, J. L.; Burnett, J.; Hung, K. Determination of ozone emission from a domestic air cleaner and decay parameters using environmental chamber tests *Indoor and Built Environ.* **2005**, *14*, 29-37.

(5) Ward, M.; Siegel, J. A.; Corsi, R. The effectiveness of stand alone air cleaners for shelter-in-place *Indoor Air* **2005**, *15*, 127-134.

(6) Shaugnessy, R. J.; Levetin, E.; Blocker, J.; Sublette, K. L. Effectiveness of portable indoor air cleaners: sensory testing results *Indoor Air* **1994**, *4*, 179-188.
(7) Shaugnessy, R. J.; Sextro, R. G. What is an effective portable air cleaning device? A review *J. Occup. Environ. Hyg.* **2006**, *3*, 169-181.
(8) Macintosh, D. L.; Myatt, T. A.; Ludwig, J. F.; Baker, B. J.; Suh, H. H.; Spengler, J. D. Whole house particle removal and clean air delivery rates for in-duct and portable ventilation systems *J. Air and Waste Manag. Assoc.* **2008**, *58*, 1474-1482.
(9) Cheng, Y. S.; Lu, J. C.; Chen, T. R. Efficiency of a portable indoor air cleaner in removing pollens and fungal spores *Aerosol Sci. and Technol.* **1998**, *29*, 92-101.
(10) Howard-Reed, C.; Nabinger, S. J.; Emmerich, S. J. Characterizing gaseous air cleaner performance in the field *Building and Environment* **2008**, *43*, 368-377.
(11) Howard-Reed, C.; Henzel, V.; Nabinger, S. J.; Persily, A. K. Development of a field test method to evaluate gaseous air clener performance in a multizone building *J. Air and Waste Manag. Assoc.* **2008**, *58*, 919-927.
(12) Hodgson, A. T.; Destaillats, H.; Sullivan, D.; Fisk, W. J. Performance of ultraviolet photocatalytic oxidation for indoor air cleaning applications *Indoor Air* **2007**, *17*, 305-316.
(13) Hodgson, A. T.; Destaillats, H.; Hotchi, T.; Fisk, W. J. Evaluation of a Combined Ultraviolet Photocatalytic Oxidation (UVPCO) / Chemisorbent Air Cleaner for Indoor Air Applications *Report prepared to the Building Technologies Program of the U.S. Department of Energy, Contract No. DE-AC02-05CH11231. [LBNL - 62202]* **2007**.
(14) Ginestet, A.; Pugnet, D.; Rowley, J.; Bull, K.; Yeomans, H. Development of a new photocatalytic oxidation air filter for aircraft cabin *Indoor Air* **2005**, *15*, 326-334.
(15) Sun, Y.; Fang, L.; Wyon, D. P.; Wisthaler, A.; Lagercrantz, L.; Strom-Tejsen, P. Experimental research on photocatalytic oxidation air purification technology applied to aircraft cabins *Building and Environment* **2008**, *43*, 258-268.
(16) Nazaroff, W. W.; Coleman, B. K.; Destaillats, H.; Hodgson, A. T.; Liu, D. L.; Lunden, M. M.; Singer, B. C.; Weschler, C. *Indoor air chemistry: cleaning agents, ozone and toxic air contaminants*; Final Report. Contract # 01-336 - California Air Resources Board: http://www.arb.ca.gov/research/abstracts/01-336.htm#Disclaimer, 2006.
(17) Destaillats, H.; Lunden, M. M.; Singer, B. C.; Coleman, B. K.; Hodgson, A. T.; Weschler, C. J.; Nazaroff, W. W. Indoor secondary pollutants from household product emissions in the presence of ozone. A bench scale study. *Submitted to Environ. Sci. Technol.* **2006**, Nov. 2005.
(18) Maddalena, R. L.; McKone, T. E.; Destaillats, H.; Russel, M. L.; Hodgson, A. T.; Perino, C. *Quantifying pollutant emissions from office equipment*; CEC/CARB Final Report, currently under review: University of California, Berkeley, 2009.

TITLE: Comparative Effectiveness of Different Air Cleaning Technologies for Asthma Triggers in Homes and Offices

PROBLEM: The research will investigate the comparative effectiveness of different air cleaning solutions to reducing the airborne concentrations of fine particulates and ozone in California homes and offices. It will address the lack of comparative data to assess the air quality impact of different filter designs and technologies on actual residential and office indoor environments.

PREVIOUS WORK: The applicant has completed an AQMD funded a pilot study at three elementary schools located near refineries, other industrial facilities and freeways in the Carson-Long Beach area. The project tested the effectiveness of various air filtration devices and filters at removing pollutants from indoor air. Preliminary results showed that the low cost high-efficiency HVAC filters are effective at removing particles from indoor air in classrooms.

OBJECTIVE: The specific aim of the research is to determine the effectiveness of different air cleaning solutions under typical and representative home and office conditions in California and to provide a cost-benefit analysis which will provide guidance to asthma sufferers.

DESCRIPTION: The proposed research will monitor the indoor and outdoor environments of 10 homes and 10 offices for the period of approx. 12 months for fine particulates and ozone. In this period, the effectiveness of six different filter designs and technologies on the reduction of fine particulates and ozone will be investigated. The study will include a wide selection of commercially available stand-alone room air purifiers and heating ventilation and air conditioning (HVAC) filters with a wide range of technologies and costs. The study will focus on home styles and office designs including HVAC designs common in California. The study will also yield a better understanding of how outdoor particle and ozone levels affect indoor air quality in residential and office buildings with different air cleaning technologies.

BENEFITS: The successful completion of this project will benefit Californians with asthma, their families and employers in providing much needed objective guidance as to which air cleaning devices provide the most effective reduction of the two most common asthma triggers: fine particulates and ozone.

COST: $ 395,000

State Implementation Plan (SIP) Support

Policy Drivers:

- Development and implementation of State Implementation Plans for ozone;
- Development and implementation of State Implementation Plans for PM.

Ongoing Efforts

Background: The federal Clean Air Act (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. The challenge of properly managing California's atmospheric resources is complex, because management strategies must simultaneously deal with two interrelated environmental concerns: air quality and climate change. Although separate programs are in place to research and manage air quality and climate change, these concerns are not separate and in fact are intimately connected. These connections arise because many of the atmospheric species of concern are the same, and in many cases the sources of the agents are the same or intimately connected. For example, surface ozone is both an air pollutant and a greenhouse gas. Aerosols, known in the air quality community as particulate matter (PM), not only have significant and complex climate impacts, but also are an important air pollutant that has significant human health impacts, degrades visibility and contributes to acidic deposition. In many cases, efforts to address one of these issues can be beneficial in addressing the other, but in other cases policies addressing one issue can have unintended detrimental impacts on the other.

ARB's research program for SIPs closely complements scientific work being conducted by other agencies. For example, the National Center for Atmospheric Research is involved in efforts to improve biogenics emission estimates, and ARB scientists are closely monitoring their work for its applicability to California. The U.S. EPA continues to fund and participate in the development of air quality modeling tools for use in SIP preparation, as well as providing guidance on the use and implementation of those tools. ARB scientists are heavily involved in the development, testing, and application of these tools and algorithms. The SCAQMD continues to fund important research into inventory improvements for their ozone and PM planning activities, and for improvements to meteorological fields used for SIP modeling. And ARB is a key player along with the National Oceanic and Atmospheric Administration (NOAA), the Caifornia Energy Commission (CEC), and others in planning and funding the 2010 CalNex study, which will collect valuable three-dimensional data to support the next round of SIPs and climate change planning activities.

Air quality modeling: Model depiction of atmospheric processes and precursor pollutant species, such as NO_X and speciated ROG, that participate in the formation of ozone and PM2.5 is critical to SIP support, as is field validation of models. A new version of the SAPRC chemical mechanism (SAPRC07) has recently been completed through ARB funded work at UC Riverside. ARB staff are currently working on implementing this mechanism into the CMAQ air quality model (a primary model used in SIP modeling efforts). U.S. EPA is also working on their own more condensed implementation of the

mechanism in parallel with ARB's efforts. A complete evaluation of the mechanism is a critical component of ARB's work.

Biogenic emission estimates: From a statewide perspective, field validation measurements of biogenic emissions have historically focused on relatively small geographic regions. While biogenic emissions measurements have been made at many locations around the globe, these emissions are a function of plant species and are strongly correlated to atmospheric conditions. Thus, measurements made outside of California do not offer a sound basis for evaluating the state's biogenic emissions inventory. During CalNex, NOAA will make airborne measurements of isoprene, which may provide some useful information about regional biogenic isoprene emissions. However, these measurements will not suffice to illuminate California's biogenic emissions inventory at the requisite resolution for improving the State Implementation Plans.

CalNex 2010: The goal of the CalNex 2010 program is to study critical issues at the nexus of the air quality and climate change problems, and to provide scientific information regarding the trade-offs faced by decision makers when addressing these two inter-related issues. Since ARB's earliest years, major field studies have expanded the science behind ARB's effort to improve air quality. This tradition continues as next year ARB will benefit from a $15 million effort on the part of NOAA focused on air quality and climate science issues. CalNex 2010 will benefit from an unprecedented level of support from NOAA, including multiple platforms and many scientists. The air quality and meteorological data collected during CalNex will improve ARB's emission inventories of greenhouse gases, traditional air pollutants and precursors. In addition the study will improve ARB's air quality models used in SIP development, our understanding of the atmospheric formation of ozone and PM, and the role of aerosols in radiative forcing over the State. NOAA's plan to deploy two aircraft in the state for four to six weeks will generate a dataset of unprecedented chemical completeness, spatial extent and temporal resolution. The presence of a research vessel off the coast will provide data about the emissions and impacts of shipping off California's coast. California has taken advantage of this opportunity to have questions of specific interest to ARB included in planning efforts and to leverage our research funds by coordinating work with NOAA.

Fertilizer air emissions: Measurements of NO emissions from cropland soils have been conducted in other states and countries, but the sensitivity of these emissions to crop type, fertilizer application, and environmental conditions preclude use of these measurements to characterize California. While extensive measurements of NO will be taken during CalNex, those measurements will not be crop-specific.

Research/Knowledge Gaps: Among the key knowledge gaps to be addressed to support the Board's decision-making are:

- Statewide validation of the biogenic emissions inventory is crucial, especially isoprene emission estimates, for California to augment field validation measurements that have been limited to smaller geographic scales;
- Characterization of emissions of NO from cropland soils in California to characterize the state's mix of crops, fertilization practices, and climate;

- Spatially resolved measurements of NO_2 to evaluate urban NO emissions inventory;
- Measurements of key species in atmospheric chemistry, such as formaldehyde (HCHO) and glyoxal (CHOCHO), coupled with modeling efforts;
- Clarification of sources and processes that contribute to PM2.5 in California;
- Lifecycle assessment of fuels-related emissions from fuel production, refining, transport, storage, and fueling, as well as vehicle emissions when driving;
- Investigation of discrepancies between current emission inventories and atmospheric measurements in urban areas of California for certain pollutants (e.g., whole gasoline VOCs, combustion nitrogen dioxide, particulate black carbon, mercury, manganese and other trace metals);
- Development of robust techniques for routine monitoring of ambient levels and trends of diesel PM;
- Improved understanding of the formation of secondary organic aerosols from gas to particle and from source to receptor, as well as improved simulation of the chemical-physical transformation and transport of primary carbonaceous PM and improved measurement methods for carbonaceous species in PM2.5 (e.g., organic fraction of aerosols);
- Monitoring, modeling, or data analysis research to quantify the current impacts of global-scale transport of pollutants on air quality in California and trends in global "backgrounds" for major criteria and GHG emissions, with particular interest in identifying sources of PM transported into California as well as effects of long-range transport on developing State Implementation Plans (SIPs) for ozone attainment.

Recommended for Funding

Improved Characterization of Primary and Secondary Carbonaceous Particles

Both sources and composition of carbonaceous PM are poorly understood, in part due to the contribution of atmospheric processes and transport to formation of secondary organic aerosol (SOA). This study will use spectroscopic techniques to delineate the various contributions to carbonaceous aerosols, which account for 20-90 percent of PM2.5 in urban and agricultural areas. Results will aid control strategies and help rectify discrepancies between emissions inventories and atmospheric measurements. (p. 34)
Proposed funding level: $255,000

Characterization of Emissions and Atmospheric Chemistry from Motor Vehicles

This project seeks to support recently suggested amendments to the widely used conceptual approach for treatment of organic aerosols in photochemical modeling. The amendments include a new accounting for gas-particle partitioning of POA and explicit representation of gas-phase oxidation of low volatility species in the SOA mechanism. Improvements to the proposed concept will come from the proposed measurement of gasoline and diesel vehicle emissions; with specific quantification of SOA production; followed by an update of emission inventories and SOA mechanisms used by chemical transport models. (p. 36)
Proposed funding level: $500,000

Determining Nitric Oxide Emissions from Soil in California Cropping Systems to Improve Ozone Modeling

Estimates of biogenic NO_X emissions and of NO_X from fertilizer applications have not yet been incorporated into the Emission Inventory Development and Reporting System

used for San Joaquin Valley, although NO_X plays a critical role in determining ozone concentrations that exceed state standards more than 120 days per year in the Valley. This research will determine baseline NO emissions from a range of cropping systems in California as well as characterize NO flux as a function of amount of nitrogen fertilizer and air temperature. (p. 38)
Proposed funding level: $83,500

Validation of ARB's statewide Biogenic Emissions Inventory
The accuracy of the biogenic emissions inventory is essential for realistically representing how anthropogenic emissions reductions will influence future PM and ozone levels throughout California. However, despite increasing importance of biogenic sources in the statewide hydrocarbon budget, a statewide comprehensive validation of the biogenic emissions inventory for California has not yet been conducted. This work will expand the spatial and temporal domain of the database used to evaluate ARB's biogenic emissions inventory on scales relevant to regional modeling tasks. (p. 41)
Proposed funding level: $400,000

AMAX-DOAS Column Observations from Research Aircraft Over California
The proposed research will use the recently developed Airborne Multi Axis DOAS (AMAX-DOAS) technique to measure various chemical species (i.e., NO_2, HCHO, CHOCHO) as well as aerosol optical depth over a large and vertically resolved spatial area, at a resolution consistent with ARB's regional models. (p. 43)
Proposed funding level: $550,000

Hourly In-situ Quantitation of Organic Aerosol Marker Compounds
Using a recently developed instrument that enables hourly, in situ measurements of organic marker compounds, this study will identify the relative contributions of diesel, spark ignition, biomass burning, and secondary aerosols to total PM2.5 aerosol over California's San Joaquin Valley. This work will complement a parallel data set for Los Angeles and allow for comparative understanding of the PM2.5 regulatory challenges in these two regions. (p. 45)
Proposed funding level: $400,000

Source Apportionment as a Function of Altitude of Atmospheric Aerosols in California
Because aerosols exert both health and climate impacts, PM2.5 control strategies can reduce the climate impacts of short-lived pollutants as well as protect public health. This study will help ARB design the most effective control strategies by clarifying California's primary sources of carbonaceous, sulfate-rich, and nitrate-rich aerosols, as well as spatial and temporal evolution of chemical and optical properties. (p. 47)
Proposed funding level: $350,000

<u>Recommended if Additional Funding Available</u>
Improved Estimates of VOC Emissions from Latex Paints in the South Coast Air Basin
Architectural coatings are one of the largest sources of VOC emissions in California and the South Coast Air Basin. Latex paints make up a large fraction of total architectural coating applications, and are an important source of volatile organic compound (VOC)

emissions in the South Coast Air Basin. This study will fill important knowledge gaps by measuring VOC emissions from latex paint in the field, ascertaining emission dynamics under various field conditions, and assessing whether the common assumption of complete mass emissions from paint is valid across all painted substrates. (p. 49)
Proposed funding level: $220,000

Concepts Recommended for Funding

TITLE: Improved Characterization of Primary and Secondary Carbonaceous Particles

PROBLEM: Carbonaceous compounds can constitute the largest fraction of particulate matter (PM) in many regions, but their composition is usually the least understood. Better understanding and characterization of carbonaceous aerosols through improved measurements are needed in order to identify their emission sources and their impacts on health and visibility. Because the organic fraction of carbonaceous aerosol has contributions from multiple sources, there is a need for improving the linkages between sources and this fraction of ambient PM concentrations. Since volatile organic carbon (VOC) emissions can produce organic PM by forming secondary organic aerosol (SOA), simultaneous measurements of VOCs and organic PM are needed to investigate the discrepancies between emission inventories and atmospheric measurements.

PREVIOUS WORK: Organic source apportionment of organic carbon (OC) and mass (OM) has been carried out using organic molecular markers to identify sources. An example is Minguillon et al. (2008), who used chemical mass balance (CMB) modeling to estimate 70-83% contributions to OC from vehicle traffic in Long Beach. At Riverside on the other end of the Los Angeles Basin, 45-90% of the OM was identified as SOA but was not attributed to specific sources. These recent findings illustrate the need to improve the chemical characterization of SOA in California so that its sources can be identified (as was done for Houston by Russell et al., 2009).

OBJECTIVE: The objective of this proposed study is to quantify the mass fraction of OM functional groups (including those formed as SOA) to emissions of combustion and other processes using trace metal and organic molecular signatures from VOCs. The organic aerosol sampling will be carried out as part of CARB-designated sampling locations, possibly in coordination with CalNex 2010 measurements in Los Angeles or the San Joaquin Valley.

DESCRIPTION: The proposed research to improve the characterization and quantification of organic particles will include measurements and factor analysis of OM by Aerosol Mass Spectroscopy (AMS) and Fourier Transform Infrared spectroscopy (FTIR) at designated ARB sites. Proposed Techniques: FTIR measurements (Russell et al., 2009; Gilardoni et al., 2007; Maria et al., 2003) collect ambient submicron particles on Teflon filters after an impactor, typically for sampling times of 4 to 12 hr. Filters are frozen, shipped back to our UCSD laboratory, and scanned with an infrared spectrometer in a humidity- and temperature-regulated clean room. Spectra (wavenumber range 4000-1500 cm-1) are baselined with a recently automated algorithm (Russell et al., 2009). The absorption spectra are integrated for calibrated absorption peaks of major organic functional groups of organic molecules. Quantified functional groups include alkanes, alcohols, amines, carbonyls, carboxylic acid, and organosulfates (alkenes and aromatics are also quantified if present above 1-3% OM). Ratios of oxygen to carbon (O/C) and OM-to-OC can be calculated from FTIR analysis,

revealing trends in oxidation and phase partitioning. In addition, the organic functional group composition can be broken down by factor analysis and correlated to trace metal analysis (by X-ray fluorescence) to identify particle source contributions (Russell et al., 2009). One surprising result of those measurements in the Houston and Mexico City metropolitan areas is that a significant fraction of OM and of oxygenated organic compounds is strongly correlated to trace metals associated with power plants and other fossil fuel combustion rather than biogenic or non-specific secondary particle sources (Russell et al., 2009; Liu et al., 2009), indicating that the SOA may be rapidly formed after emission. Simultaneous AMS measurements will provide complementary information with rapid in-situ quantification of aerosol mass fragments (Gilardoni et al., 2007; Russell et al., 2009). After size-resolved particles are collected, focused and ionized, the device uses electrical forces to separate ions according to their mass to charge ratios (m/z). The high time resolution of the AMS produces detailed time series of organic compound fragments, which can be associated with plumes and other short events that are not resolved by FTIR filter sampling for organic functional groups. AMS measurements simultaneously quantify size and corresponding composition, providing more detailed information about particle lifetimes, health effects, and chemical reactions.

Potential Tasks: As part of a CARB-designated sampling site, investigators propose to (1) collect and analyze AMS, FTIR, and XRF measurements, (2) use factor analysis to attribute the measured mass of OC functional groups to sources based on trace metal signatures, (3) compare these results to gas-phase organic tracers and oxidants, and (4) collect and analyze an additional set of FTIR and XRF measurements at an additional CARB-designated site. AMS measurements will be continuous during the study; FTIR and XRF will be coordinated with local meteorology and collocated sampling to collect 4-12 hr samples. Analysis will include broad dissemination of results as part of ARB reporting requirements and peer-reviewed publications.
(Note: Cited references are available at http://aerosol.ucsd.edu/publications.html.])

BENEFITS: Identifying the contributions of different types of combustion sources to SOA and other types of OC, will enable ARB to delineate which sources could be regulated in order to improve air quality efficiently. Better characterization of OC (which constitutes 20-90% of PM2.5 in urban and agricultural areas) will also improve our ability to identify potentially harmful organic functional groups in particles that reduce air quality and harm health.

COST: $255,000

TITLE: Characterization of Emissions and Atmospheric Chemistry from Motor Vehicles

PROBLEM: Many Californians live in nonattainment areas for fine particulate matter (PM). In all of these areas, organic material contributes a large fraction of the fine PM; however, the sources of these organics are not well understood. For example, chemical transport models systematically underpredict organic aerosol levels, especially during photochemically active periods. These problems hamper the development of effective State Implementation Plans (SIPs) for the State of California.

PREVIOUS WORK: Organic aerosols comprise primary organic aerosol (POA - particle mass directly emitted from sources such as motor vehicles) and secondary organic aerosol (SOA - particle mass formed in the atmosphere from oxidation of gas-phase precursors). Recent field measurements indicate SOA dominance, even in heavily urbanized areas; for example, the recent Study of Organic Aerosols at Riverside (SOAR-1) campaign estimated that around 75% of the organic PM in Riverside is SOA. However, state-of-the-art chemical transport models predict POA dominance.

Different researchers are using a variety of models to predict SOA formation including, empirical two-product (Odum), product specific, and volatility basis set (VBS) (Chen et al, Atmospheric Chemistry and Physics, 2009).

The VBS framework is a method that comprehensively treats all low volatility organics. The VBS lumps organics into a set of “volatility bins” that span a basis set of logarithmically spaced effective saturation concentrations. If this volatility distribution is known, one can calculate the organic aerosol mass from partitioning theory. A volatility operator is used to treat SOA production; this operator represents how the volatility distribution evolves with photochemical aging.

The VBS method is relatively new, and offers the ability to study relatively complex mixtures of aerosols and gases such as gasoline and diesel motor vehicle exhaust. Studies to date have generally involved relatively simple combustion sources such as small laboratory engines, but in-use vehicles have not been systematically tested.

OBJECTIVE: This research has three primary objectives:

1. Measure emissions of low volatility organics from in-use gasoline and diesel vehicles;
2. Quantify SOA production from in-use gasoline and diesel vehicle emissions; and
3. Update emission inventories and SOA mechanisms used by chemical transport models.

DESCRIPTION: The proposed research will develop techniques and knowledge required to measure and to simulate both gas-particle partitioning of primary emissions from motor vehicles and SOA production from these emissions. The focus is on low volatility organics, which we define as those less volatile than a C-12 n-alkane (vapor pressure of about 0.2 Torr). The gas-particle partitioning of this material changes as an emission plume dilutes; low-volatility vapors are important, but largely unrecognized, SOA precursors. Some of these emissions are currently in inventories and models,

albeit misclassified as non-volatile POA. However, there are unaccounted for or missing emissions, namely intermediate volatility compounds.

The research will characterize emissions from different classes of motor vehicle emissions (gasoline, diesel, smoker, low-emitter, etc). The vehicle testing will be performed at the ARB's Haagen-Smit and Heavy-Duty Vehicle Laboratories. The measurements will be made in collaboration with a research group to be determined.

Task 1. Source characterization. This task will measure mass emission factors and volatility distributions of low volatility organic emissions from different classes of gasoline and diesel powered vehicles. Specific objectives will be to quantify missing emissions and to appropriately classify POA emissions by volatility. The data will also be used to investigate how to efficiently update existing emission inventories and modeling. Dilution samplers and thermodenuders will be used to systematically investigate the gas-particle partitioning of the POA from near tail pipe to background conditions. Filter and sorbent based gas chromatography mass spectrometry will be used to characterize the low volatility vapor emissions. Instead of quantifying individual species, the chromatographic analysis will classify the total organic mass by elution time to provide an estimate of volatility.

Task 2. SOA production from mobile source emissions. The goal of this task will be to measure the SOA production from photo-oxidation of mobile source emissions. Briefly, combustion products (gases and particles) will be drawn into a smog chamber for aging. Photochemistry will be initiated using either sunlight or artificial UV lights. SOA production will be quantified and attributed to both traditional (e.g. light aromatics) and non-traditional (e.g. low volatility organics) precursors. Key research questions are quantifying relative contributions of different classes of vehicles (e.g. gasoline versus diesel or smoker versus non-smoker) to POA versus SOA and developing the next generation of SOA chemistry mechanisms. To aid the development of the SOA mechanism, aging experiments will also be conducted using smog chambers to quantify SOA production from photo-oxidation of emission surrogates such as mixtures of lubricating oil with either diesel fuel or gasoline.

BENEFITS: This project will provide important new knowledge and data to support emissions inventory development, air quality modeling, SIP development, and exposure and health effect assessments.

COST: $500,000

COFUNDING/COLLABORATION OPPORTUNITIES: Potential collaborators and co-funders include the Coordinating Research Council (CRC).

TITLE: Determining Nitric Oxide Emissions from Soil in California Cropping Systems to Improve Ozone Modeling

PROBLEM: Oxides of nitrogen (NO_X, which comprises nitric oxide [NO] and nitrogen dioxide [NO_2]) and volatile organic compounds (VOCs) are the two important precursors of ozone (O_3), a pollutant with negative implications on human health and crop productivity that routinely exceeds the State's standards. For example, the San Joaquin Valley exceeds State ozone standards on more than 120 days per year (California Emission Inventory Development and Reporting System, CEIDARS, 2004-2007). Either NO_X or VOCs can limit O_3 formation, and the influence of these precursors on O_3 production varies temporally and spatially across the landscape, depending on the ratio of NO_X to VOCs and the relative concentration (i.e. mixing ratio) of each precursor (Blanchard and Fairley, 2001). Therefore, quantifying all major NO_X sources is essential to predict the dynamics of O_3 levels and devise cost-effective control strategies. Agricultural soils are known to be sources of NO, which is rapidly oxidized to NO_2, but there are few definitive studies on NO emissions from soils especially in California, and this dearth of information restricts CARB's ability to develop accurate O_3 modeling. Estimates of biogenic (non-anthropogenic) NO_X emissions and of NO_X from fertilizer applications are conspicuously absent in CEIDARS.

PREVIOUS WORK: Of the world's annual 190 million tons of NO_X emissions, 80 million ton are biogenic, and 39% of the latter originate from microbial production in soils (Olivier et al., 1998). The range of NO flux from cultivated land reported in the literature is 0.1 to 23 kg NO-N ha-1 yr- 1, and on average, NO loss was higher in the tropics than in temperate zones (Davidson and Kingerlee, 1997). Assuming an average emission rate of 3.6 kg NO-N ha-1 yr-1 from agriculturalland based on a meta-analysis of the scientific literature (Davidson and Kingerlee, 1997), emissions of NO from all the land devoted to agriculture in California would amount to about 360 tons NO_X d-1, a quantity roughly equivalent to all stationary sources of NO_X in the State (CEIDARS 2006). Almost no data of NO flux in California's cropping systems exist. Mean NO fluxes during 50 days following N fertilizer (anhydrous ammonia) application in a tomato cropping system in western Sacramento county were 0.54 kg NO-N ha-1 d-1 (Venterea and Rolston, 2000a), comparable to NO emissions measured in intensively fertilized wheat fields in Mexico (Matson et al., 1998).

OBJECTIVE: The objectives of the proposed research are to determine baseline NO emissions in a range of cropping systems and to characterize NO flux in response to various amounts of N fertilizer and under several air temperature conditions.

DESCRIPTION: The NO flux will be measured in five cropping systems (tomato, alfalfa, corn, wheat and almond) in the Sacramento and San Joaquin Valley primarily in the summer when O_3 production is particularly problematic. The NO emissions will be measured in one season during several periods relating to fertilization and changing soil moisture status in each of the systems.

In soils, NO is produced by the microbial processes of nitrification and denitrification and via abiotic reactions (Firestone and Davidson, 1989). Soil nitrogen availability is positively correlated with NO emissions. Nitric oxide emissions are particularly

correlated with nitrite (NO_2-) concentrations in soil, especially when the soil pH is <5 (Davidson, 1991; Venterea and Rolston, 2000b), which can occur even in well buffered soils over the short term as a result of nitrification, for example after application of NH_3-based fertilizers (Frederick and Broadbent, 1965). To assess the effects of N fertilizer rates on NO_X flux, microplots will be set up in some of the systems in a randomized complete block design (at least 3 blocks, each with 5 microplots) and N fertilizer will be applied to microplots at several rates ranging from zero to a value that exceeds the highest rate reported for a particular crop. For example, tomato plots will be fertilized at 0, 75, 150, 225, and 300 kg N ha-1. Crop residue incorporation is another management event that will be followed with NO flux measurements. We will also conduct diurnal measurements of NO flux at each site as soil temperature is positively correlated with NO emissions (Matson et al., 1996) and because ambient air temperature is an important factor in O_3 modeling (Stohl et al., 1996).

The NO flux will be measured in the field by using dynamic chamber methods. Thin-wall stainless steel chambers (approx. 50 x 30 x 10cm), equipped with inlet and outlet ports that will be connected to a Thermo Scientific Trace Level NO-NO_2-NO_X analyzer (Model 42C, Thermo Fisher Scientific Inc.), will be attached onto pre-installed bases during the measurement periods. A pump in the NO-NO2-NO_X analyzer will continuously circulate chamber air that is scrubbed of NO_X before it reenters the chamber. The NO is converted to NO_2 as the analyzer detects NO_2. Ozone models use total NO_X as NO inputs (James Sweet, San Joaquin Valley Air Pollution Control District, personal communication), so the data that will be generated do not have to be converted to other N oxide species. Soil variables that will be analyzed regularly will be inorganic N, soil moisture, and pH in the top 15 cm of soil.

The deliverables of the project will be estimates of NO_X emissions from soil, including diurnal and daily variations of these emissions, in typical Central Valley cropping systems.

BENEFITS: This research will benefit state agencies ARB and the San Joaquin Valley Air Pollution Control District by providing baseline NO_X emissions estimates in typical Central Valley cropping systems. The NO_X emission data generated will improve the capability to predict O_3 production, which will allow the above agencies to better understand and regulate O_3 precursor sources.

COST: $ 83,500

COFUNDING/COLLABORATION OPPORTUNITIES: Most of the proposed research will be incorporated into existing studies that monitor nitrous oxide (N_2O) emissions and a complementary N_2O monitoring project, for which funding is currently requested to leverage the effort. Briefly, site selection will occur after on-site characterization of soil parameters; the management at the selected sites will reflect the “typical” practices for a given crop; some of the costs will be offset because we can take advantage of the already set up fertilizer trial plots of the N_2O projects, some of the travel to the monitoring sites and other logistics.

REFERENCES:

Blanchard, C.L., and D. Fairley. 2001. Spatial mapping of VOC and NO_x-limitation of ozone formation in central California. Atmos. Environ. 35:3861-3873.

Davidson, E.A. 1991. Fluxes of nitrous oxide and nitric oxide from terrestrial ecosystems, p.219-235. *In* J. E. Rogers and W. B. Whitman, eds. Microbial Production and Consumption of Greenhouse Gases: Methane, Nitrogen Oxide, and Halomethanes. American Society for Microbiology, Washington D.C.

Davidson, E.A., and W. Kingerlee. 1997. A global inventory of nitric oxide emissions from soils. Nutrient Cycling in Agroecosystems 48:37-50.

Firestone, M.K., and E.A. Davidson. 1989. Microbiological Basis of NO and N_2O Production and Consumption, p. 7-21, *In* M. O. Andreae and D. S. Schimel, eds. Exchange of Trace Gases between Terrestrial Ecosystems and the Atmosphere. Wiley, New York.

Frederick, L., and F. Broadbent. 1965. Biological interactions, p. 198-212, *In* M. H. McVickar, ed. Agricultural Anhydrous Ammonia Technology and Use. Agricultural Ammonia Institute, Memphis, TE.

Matson, P.A., R. Naylor, and I. Ortiz-Monasterio. 1998. Integration of environmental, agronomic, and economic aspects of fertilizer management. Science 280:112-115.

Matson, P.A., C.R. Billow, S. Hall, and J. Zachariassen. 1996. Fertilization practices and soil variations control nitrogen oxide emissions from tropical sugar cane. Journal of Geophys. Res. 101:18533-18545.

Olivier, J.G.J., A.F. Bouwman, K.W. Van Der Hoek, and J.J.M. Berdowski. 1998. Global air emission inventories for anthropogenic sources of NO_X, NH_3 and N_2O in 1990. Environ. Pollution 102:135-148.

Stohl, A., E. Williams, G. Wotawa, and H. KrompKolb. 1996. A European inventory of soil nitric oxide emissions and the effect of these emissions on the photochemical formation of ozone. Atmos. Environ. 30:3741-3755.

Venterea, R.T., and D.E. Rolston. 2000a. Nitric and nitrous oxide emissions following fertilizer application to agricultural soil: Biotic and abiotic mechanisms and kinetics. Journal of Geophys. Res.-Atmospheres 105:15117-15129.

Venterea, R.T., and D.E. Rolston. 2000b. Mechanisms and kinetics of nitric and nitrous oxide production during nitrification in agricultural soil. Global Change Biology 6:303-316.

TITLE: Validation of ARB's Statewide Biogenic Emissions Inventory

PROBLEM: State Implementation Plans require air quality modeling to be conducted as a means of demonstrating the effectiveness of control strategies to reach the ambient concentration levels prescribed by National Air Quality Standards. Estimates of anthropogenic and biogenic emissions are key inputs to air quality modeling and biogenic emissions play a key role in the production of both PM and ozone. It is estimated that the statewide tonnage of biogenic hydrocarbon emissions will surpass anthropogenic hydrocarbons by 2010 (ARB Almanac, 2008). The relative abundance of hydrocarbons emitted from biogenic sources over anthropogenic sources is expected to grow beyond 2010 as anthropogenic emissions are reduced and biogenic emissions grow in response to climate change. Despite the increasing importance of biogenic sources in the statewide hydrocarbon budget, a statewide comprehensive validation of the biogenic emissions inventory for California has not yet been conducted.

The accuracy of the biogenic inventory is essential for realistically representing how anthropogenic emissions reductions will influence future PM and ozone levels throughout California. Ideally, validating the biogenic emissions inventory would involve validation of the spatial distribution, as well as both short term (diurnal) and long term (seasonal) variability.

PREVIOUS WORK: Previous work supported by ARB, the SJVAPSA and the South Coast AQMD resulted in the essential databases and tools used in ARB's biogenic emissions model (BEIGIS). Previous ARB funded research conducted by UC-Bakersfield researchers used a ground-truth approach to validate the Leaf Mass, Leaf Area Index, and GAP land cover databases at six geographically diverse sites throughout Central California, while researchers from UC-Berkeley measured emission fluxes of biogenic hydrocarbons above a forest canopy at the Blodgett Forest Site. Using controlled laboratory experiments and tower-based flux measurements in the field, ARB funded researchers from UC-Berkeley are measuring emissions of a suite of biogenic hydrocarbons from major California crops (to be completed November 2009, but may be extended). Although previous and ongoing research related to biogenic hydrocarbon emissions in California have been useful in validating the databases used in BEIGIS and in expanding our understanding of emissions from specific plant species, the research is too specific in regards to location and corresponding ecosystem to be sufficient for validating the magnitude and spatial variability of ARB's statewide biogenic emissions inventory on scales relevant to regional air quality modeling.

OBJECTIVE: The objective of this proposal is to expand the spatial and temporal representation of the existing validation database that is used to evaluate ARB's biogenic emissions inventory on scales relevant to regional modeling applications. To date, the sole means of validating the inventory has been through comparison with emission flux measurements collected at a single site in the Blodgett Forest (Goldstein et al. 2001; ARB Award No. 98-328).

DESCRIPTION: Developing a more comprehensive database for evaluating California's biogenic emissions inventory requires emission flux measurements of biogenic hydrocarbons within a number of California's ecosystems. These

measurements could be accomplished in one of two ways. The first option involves deploying Relaxed Eddy Accumulation (REA) systems at roughly 10 existing flux towers for one year. There are currently 10 AmeriFlux towers operating in shrub lands and oak and conifer forests throughout California, which could be used for the REA measurements. It may also be necessary to set up additional low cost towers in select areas/ecosystems not currently accounted for in the AmeriFlux network. This option would result in a better understanding of the magnitude and seasonal variation of biogenic hydrocarbon emissions for representative ecosystems.

A second approach would be to conduct a one month airborne flux campaign, using PTRMS eddy covariance methods, covering key grasslands, croplands, shrublands, and forests throughout California. The airborne measurements would give a good characterization of a wide range of biogenic hydrocarbon emissions for many representative locations and many of the major California ecosystems and croplands on scales appropriate for regional air quality modeling (10-15 km). Alternatively, a combination of airborne flux and REA measurements, at two or three sites, could also be used.

BENEFITS: Successful completion of this project would allow staff to better validate the biogenic emissions inventory used in ARB's modeling studies and point to areas which need improvement. Since results from modeling studies are routinely used in policy decisions, an improved biogenic inventory will lead to better supporting science and ultimately more confidence in those decisions.

COST: $400,000

TITLE: AMAX-DOAS Column Observations from Research Aircraft Over California

PROBLEM: Past field campaigns in California provided little information about pollutant concentrations outside the boundary layer, and the vertical column integral over the boundary layer height. Further, while satellites, like SCIAMACHY or OMI, are now capable of providing column data useful for testing emission inventories of NO_X and to constrain the rate of hydrocarbon oxidation in photochemical hotspots of ozone and secondary organic aerosol (SOA) formation, satellites have significant limitations and such data must be carefully evaluated prior to using it in combination with atmospheric models for the management of air resources. For example, the sensitivity of the measurement varies over the height of the column, and depends significantly on ambient conditions, i.e., surface albedo, aerosol loading and optical properties.

PREVIOUS WORK: Airborne Multi Axis DOAS (AMAX-DOAS), a recent development of the well established MAX-DOAS technique, has successfully been used to validate solar straylight satellite retrievals of nitrogen dioxide NO_2, but never over California, where atmospheric models disagree as to the NO_2 abundance measured over urban areas. Recent work by the PI demonstrated that SCIAMACHY significantly underestimates the NO2 column observed by ground based MAX-DOAS in Mexico City, in part due to organic aerosols that absorb light much stronger than previously believed; similar effects likely also play a role over California urban areas. Glyoxal (CHOCHO) presents a novel indicator molecule to constrain the rate of hydrocarbon oxidation; it is also a relevant building block for SOA formation. The PI accomplished the first direct measurements of CHOCHO in the atmosphere and predicted the capability to measure it from space (regularly observed over Los Angeles from satellite); more recently he built a prototype AMAX-DOAS instrument and demonstrated first CHOCHO measurements (along with NO_2 and oxygen dimers, O_4, an aerosol indicator) from aboard NOAA's Twin Otter research aircraft (summer 2008). The PI has published numerous papers on urban Air Pollution, and conducted field work that integrates satellites with models in Mexico, China, Chile, and the Pacific Ocean. The CU AMAX-DOAS is a unique instrument in the US; capabilities to measure O_4 (aerosol optical depth) at 360, 477, 570 and 630nm, formaldehyde (HCHO) were recently added, and are unique in the world; further flights are planned in 2009.

OBJECTIVE: Deploy the CU AMAX-DOAS instrument on a research aircraft in California to measure pollutant concentrations outside the boundary layer, probe directly the horizontal and vertical distribution of NO_2, HCHO, CHOCHO and O_4 (aerosol optical depth) boundary layer columns, and use these measurements to test atmospheric models, validate satellites, and make improved models and validated satellite data available for the management of air resources.

DESCRIPTION: The CU AMAX-DOAS measures the same observables as SCIAMACHY and OMI with better spatial resolution and precision, and in addition places constraints on radiative transfer calculations that are not available to satellites. Specific tasks include (i) integration into the aircraft and science flights over point sources, urban areas, and photochemical hotspots, (ii) data analysis to extract vertical column densities (VCDs) of NO_2, HCHO, CHOCHO, surface albedo, and aerosol optical depth (AOD) by coupling with a radiative transfer model, (iii) assess vertical gradients

and concentrations outside the boundary layer, (iv) investigate synergies with SCIAMACHY to study NO_2 over point sources and urban areas (and OMI, where possible), (v) compare with UCD-CIT model predictions, (vi) assess the temporal and spatial variability in the rate of hydrocarbon oxidation over photochemical hotspots of ozone and SOA formation, and (vii) assess the potential and study limitations of the synergistic use of AMAX-DOAS, SCIAMACHY, and the UCD-CIT model to learn about the sources for ozone, and SOA. AMAX-DOAS, as these satellites, provide a column averaged measurement of trace gases. However, AMAX-DOAS is maximally sensitive to tropospheric absorbers, and has a greatly enhanced sensitivity at/near the instrument altitude. Vertical profiles can be obtained with few 100m vertical resolution by varying flight altitude. The horizontal resolution of AMAX-DOAS exceeds that of satellites and models (AMAX-DOAS: few 100m-1km; UCD-CIT model: 4x4km grid cell size; OMI: 14x14km, SCIAMACHY: 40x80km ground pixel size), which enables to visualize and track plumes, and to average data to closely resemble the resolution of models and satellites. The CU AMAX-DOAS measures four O4 bands and the ring effect at different wavelengths (300-620nm) simultaneously; independent sensors measure surface albedo. This enables to test assumptions in radiative transfer calculations that underlie satellite retrievals. AMAX column data enable novel means to test and improve the UCD-CIT model.

BENEFITS: AMAX-DOAS provides data about pollutant concentrations outside the boundary layer, and measures vertical column integrals of pollutant concentrations inside the boundary layer. These data place constraints on model emission inputs, enable to test and improve model predictions of pollution transport and photochemical transformations, and provide direct means to validate satellites. Good Air Quality is relevant for public health, and improving Air Quality models makes more reliable tools available for the management of air resources.

COST: $550,000.

TITLE: Hourly In-situ Quantitation of Organic Aerosol Marker Compounds During CalNex 2010

PROBLEM: Regulatory efforts to conform to PM2.5 standards require improvements in our knowledge of the factors controlling the concentration, size and chemical composition of PM2.5. While many advances have been made in measuring and modeling the inorganic ionic species that are found in PM2.5, much less is known about the organic fraction. Yet organic matter is a major constituent of airborne particles, comprising 20-50% of the PM2.5 mass in many regions. Quantitative, time-resolved knowledge of the composition of PM2.5 organic matter is key to tracing its sources, to understanding its formation and transformation processes, and to evaluating its role in global climate change.

PREVIOUS WORK: Our group has developed an instrument to provide hourly, in-situ measurements of organic marker compounds. Called a Thermal Desorption Aerosol Gas Chromatograph (TAG), our instrument uses an impactor collector, followed by thermal desorption onto a GC column, with subsequent GC/MS analysis to provide measurement of airborne particulate organics at the molecular level. The measurement system is automated, yielding around the clock speciation with hourly time resolution. While the identified compounds comprise only a fraction of the total organic mass, those that are quantified serve as valuable tracers for sources, and have been used to determine the relative contribution of various source types to primary ambient organic matter. This instrument has been used in several field campaigns, including a remote site in Nova Scotia, and at an urban location. Under previous ARB sponsorship it was deployed in two separate field campaigns in Riverside, California. As with traditional filter-based methods for organic compound, TAG provides identification of organic matter at the molecular level. However, the hourly time resolution afforded by our measurement provides a robust data set for receptor analysis, and valuable insight and guidance in our understanding of processes affecting airborne particulate organic matter.

OBJECTIVE: The objective is to identify the origins of organic matter in PM2.5 aerosol in California in support of the proposed 2010 field study to be conducted in the San Joaquin Valley of California. As in our prior work, we expect to identify and allocate the sources of primary constituents, and to improve our understanding of the formation pathways important to secondary components. Utilizing hourly, in-situ measurements of organic marker compounds provided by our Thermal Desorption Aerosol Gas Chromatograph, we will identify the relative contributions of diesel, spark-ignition, biomass burning and secondary aerosols to the total PM2.5 organic aerosol. We propose to use this instrument in conjunction with an organized field study to identify the origins of PM2.5 organic matter within a region in California that is currently out of compliance with PM2.5 air quality standards, and to investigate the implications of these aerosols related to aerosol radiative forcing. Similar measurements are planned for the Los Angeles CalNex 2010 ground site, so this proposal would provide equivalent measurements at the San Joaquin Valley site and allow for comparative understanding of the PM2.5 regulatory challenges in these two regions.

DESCRIPTION: In coordination with the proposed CalNex 2010 study, we will conduct measurements to determine PM2.5 organic composition at hourly intervals, building a database that be used for source receptor modeling. Measurements will be conducted at the San Joaquin Valley ground site, in a location determined in consultation with ARB. We expect to identify over 100 organic compounds at hourly intervals over the study period. These data will provide a rich and comprehensive basis for identification of primary sources through factor analysis. Through coordinated measurements of VOCs with similar time resolution, we expect to identify links between some of the secondary aerosol constituents and their likely primary precursors. These analyses will provide source attribution for primary organic compounds, and will elucidate transformation mechanisms for certain secondary species.

BENEFITS: This work addresses the critical need for on-line, time-resolved, quantitative measurement of atmospheric PM2.5 organics at the molecular level. Marker compounds unique to specific source types provide a means of determining the relative contribution of primary sources. Data at the compound level are also needed for understanding the chemical formation and transformation mechanisms leading to secondary organic aerosol formation. This research will provide useful new data of immediate value for air quality attainment strategies in California and the development of the State Implementation Plan, and for understanding the pathways leading to secondary organic aerosols that may be of importance in climate change.

COST: $250,000

COFUNDING/COLLABORATION OPPORTUNITIES: This project builds on our currently funded research through the DOE SBIR program for the refinement of our instrument package, thus making the ARB sponsored project possible at a highly subsidized cost. This project would be part of the planned CalNex 2010 study in collaboration with NOAA and other participating entities.

TITLE: Source Apportionment as a Function of Altitude of Atmospheric Aerosols in California

PROBLEM: Air pollution represents a growing environmental concern within California. As our climate warms, air pollution levels are increasing even higher. Aerosols represent a major component of air pollution and contribute to negative health and climate impacts. Our understanding of the sources and chemistry of aerosols is relatively poor. Given that aerosols have relatively short lifetimes with both warming and cooling effects on climate, it has been proposed by some scientists that certain control strategies involving aerosols could provide more rapid relief for California climate. However, in parallel to controlling greenhouse gases such as CO_2, we must establish a stronger understanding of short-lived aerosol sources, chemistry, and other properties such as cloud formation potential before enacting any major control strategies.

PREVIOUS WORK: Our group has performed extensive ground based studies focusing on determining the major sources of aerosols in California using a unique single particle mass spectrometer, aerosol time-of-flight mass spectrometry (ATOFMS), developed in our lab. Over the past decade, we have developed an extensive source library that can now be used to perform real-time source apportionment of aerosols in California. We have performed studies in Los Angeles, Riverside, Long Beach, Fullerton, Pasadena, Mt. Wilson, and San Diego. The major sources that have been characterized and apportioned in California include ships, diesel trucks, gasoline powered cars, biomass burning (i.e. wood smoke), and dust transported from Asia and other regions. Most recently, we constructed a smaller aircraft version of the instrument, an A-ATOFMS (Pratt, 2008). This instrument opens new doors for studying the spatial variability of the sources and chemistry of aerosols over the state of California.

OBJECTIVE: The major goal of the proposed research project involves using our A-ATOFMS to characterize atmospheric aerosols on the Twin Otter aircraft in collaboration with Prof. John Seinfeld (Caltech). The proposed study will address a number of questions including (1) What are the major sources of carbonaceous (OC and soot) aerosols in California? (2) How do the chemistry and optical properties of California aerosols evolve spatially and temporally? (3) How does aerosol mixing state influence hygroscopicity, CCN activity, and optical properties? (4) What are the major sources and levels of black carbon or soot in California aerosols? (5) How does the chemistry and associated optical properties of soot and other carbonaceous aerosols hange with age and altitude? (6) What are the major sources contributing to high levels of ulfate and nitrate in atmospheric aerosols?

DESCRIPTION: This proposed project will involve performing flights on the CIRPAS Twin Otter aircraft with Prof. John Seinfeld from Caltech. We will fly our newly developed single particle mass spectrometer (Pratt, 2008) along with other aerosol and gas phase measurements on board the aircraft over an 8 week period. This project will focus on making on-line single particle size, chemistry, and optical property measurements. We will study the evolution of the size and chemistry of aerosols as they travel from source regions to more inland urban sites. In addition to our single particle measurements, Prof. Seinfeld will have other complementary measurements on board including an aerosol mass spectrometer (AMS) and a PILS for measuring water-soluble

organic species. A major goal of the airborne measurements will be to acquire complementary data that can be used to obtain more accurate estimates of the impact of soot on climate in California. In addition to the ATOFMS single particle soot mixing state measurements, the Twin Otter payload will include a wide range of soot measurements including a Single-Particle Soot Photometer (SP2), three-wavelength Photoacoustic Aerosol Spectrometer (PASS-3), and a three-wavelength Particle Soot Absorption Photometer (PSAP). Aerosol properties measured during these flights will be used as inputs for a General Circulation Model (GCM) to assess the radiative forcing of aerosols over California.

BENEFITS: Knowledge of aerosol sources and how they vary as a function of altitude and time is critical to understanding the overall impact of aerosols on climate. A key facet of the proposed study involves developing a better understanding of how the chemistry and sources of soot and other aerosols vary with altitude. The overall climate-relevant properties of aerosols depend on their mixing state which can only be determined with single particle measurements such as the A-ATOFMS. The proposed combination of measurements will allow us to reduce the uncertainties associated with the role of aerosols on climate. Also, we will focus on better understanding the key sources contributing to the aerosols at different altitudes, addressing the important question of how much aerosol is globally transported into California from other regions of the world (Asia, Mexico) and other states.

Aerosols represent short-lived climate change pollutants and it is clear that they are affecting climate in California in a major yet poorly understood way. Aerosol-cloud interactions are hypothesized to affect regional weather patterns and lead to drought which ultimately means they could be impacting California's water supply. Developing a better understanding of the properties of aerosols and how they vary spatially, over time, and from different sources will allow one to eliminate the aerosols leading to the most deleterious climate and health effects.

COST: $350,000

COFUNDING/COLLABORATION OPPORTUNITIES: The cost of the aircraft will be covered by other sources. Since these flights will be conducted as part of CalNex, many opportunities will exist for collaborations with other researchers and sampling platforms (ship, ground, other aircraft) doing aerosol and gas phase measurements as part of Calnex in 2010.

Concepts Recommended if Funding Available

TITLE: Improved Estimates of VOC Emissions from Latex Paints in the South Coast Air Basin

PROBLEM: Architectural coatings are one of the largest sources of VOC emissions in California and the South Coast Air Basin.[1] Latex paints make up a large fraction of total architectural coating applications, and are an important source of volatile organic compound (VOC) emissions in the South Coast Air Basin. As such, this source may contribute significantly to the formation of ozone and secondary particulate matter in the basin. However, there have been no studies to actually measure VOC emissions from latex paint in the field, to ascertain emission dynamics under various field conditions, or to assess whether the common assumption of complete mass emissions from paint is valid across all painted substrates.

PREVIOUS WORK: The major VOCs found in latex paint are 2,2,4-trimethyl-1,3-pentanediol monoisobutyrate (TMPD-MIB or Texanol®) and ethylene glycol (EG). Laboratory studies at the University of Texas at Austin (UT) have shed light on the effects of different substrates on TMPD-MIB emission profiles, and also suggest that TMPD-MIB in painted gypsum board may be sequestered for months to years.[2] Ongoing studies at UT for which samples of well-characterized painted substrates, e.g., gypsum board removed from the USEPA test house in North Carolina, indicate that as much as 20 to 40% of TMPD-MIB mass remains sequestered in gypsum board after 15 to 20 years. Thus, an assumption of complete mass emissions of TMPD-MIB may be highly conservative over the useful lifetime of some substrates, e.g., if a substrate is removed to a landfill where the VOC in question may be effectively biodegraded.

OBJECTIVES: The objectives of this study will be to measure emissions of TMPD-MIB and EG from painted surfaces of actual buildings in the South Coast Air Basin, and to couple these findings with analysis of residual TMPD-MIB and EG in well characterized painted substrates removed from the basin. Emissions will be characterized per unit area of substrate for a wide range of previous paint applications and age, building materials, and environmental conditions, and will be useful for improved emission inventories. Emissions and chemical residuals will be used to estimate continued emissions from, and lifetime on/in, various substrates.

DESCRIPTION: The proposed study would include three major tasks. Task 1 would involve actual field measurements of TMPD-MIB and EG emissions from painted surfaces in the South Coast Air Basin. Task 2 would involve collection of previously painted substrates in the South Coast Air Basin for analysis of residual TMPD-MIB and EG from those substrates. Task 3 would involve an analysis of field and laboratory data to determine improved estimates of TMPD-MIB and EG emissions from, and lifetimes on, various painted substrates.

For Task 1, a Field and Laboratory Emission Cell (FLEC) would be used to collect samples from building surfaces in the field (South Coast Air Basin). Mass emissions would be determined for both the interior (e.g., painted gypsum board) and exterior (e.g., stucco) surfaces of buildings for which key information is available, such

as dates of last painting(s), types of paint and primer used (which would allow estimates of TMPD-MIB and EG content), etc. This would be possible by working with government agencies, e.g., SCAQMD, and local universities, as they should have records of painting dates and paint purchase requisitions for buildings in their facilities. The study design will account for different types and ages of paint, painted substrates, and environmental conditions. During each field event, ambient air and surface temperatures, barometric pressure and relative humidity will be measured and recorded. Samples would be collected on Tenax-TA and analyzed via thermal desorption and gas chromatography with mass spectroscopy (TD/GC/MS). The study design would include multiple field monitoring events over a two-year period with an estimate of over 100 field measurements and replicate analyses for the same materials.

For Task 2, the organizations described in Task 1 will be asked to provide small specimens ("legacy" samples) of the painted surfaces analyzed for Task 1. These would be analyzed by chemical extraction and GC/MS, allowing for estimation of the approximate amount of TMPD-MIB and EG that still remain on the painted materials over specified time periods. More than 20 legacy samples would be collected for this task.

Task 3 will involve analyses of data collected during Tasks 1 and 2. The nature and scope of this study would allow for new insights regarding the effects of various parameters on VOC emissions from latex paint, and potential for improvements in the existing emissions inventory. In addition, the findings of this study combined with previous and on-going research findings at UT would allow for a lifecycle analysis of TMPD-MIB and EG in latex paint.

BENEFITS: This effort would be the first of its kind to actually measure TMPD-MIB and EG emissions from painted materials in the field. The study would provide valuable information related to the extent of such emissions throughout the South Coast Air Basin. Corresponding improvements to the emissions inventory will allow for enhanced planning and policymaking related to air quality in the South Coast Air Basin.

COST: $220,000

REFERENCES:

1. Berry, N., http://www.epa.gov/region09/air/cecat-forum/stationary/Naveen-Berry.pdf
2. Lin, C.-C., and Corsi, R.L., *Atmospheric Environment*, **41**(15): 3225-3234 (2007).

Climate Change

Policy Drivers:

- California Climate Change Solutions Act of 2006 (AB 32)
- AB 32 Scoping Plan
- Executive Order S-3-05 establishing greenhouse gas emissions reductions targets
- SB 375

Based on the policy drivers above and ARB's other responsibilities, the major themes for the FY 2009-2010 climate change research portfolio are emissions and mitigation; long-range planning; behavioral change; the climate/air quality nexus; and public health co-benefits of climate change policy.

Ongoing Efforts: State-sponsored and -mandated research complements national and international efforts and has provided a scientific framework for informed climate change policy in California. At the national level, two interagency working groups coordinate climate change research: the Climate Change Science Program (CCSP) and the Climate Change Technology Program (CCTP). The Climate Change Science Program integrates research on climate and global change sponsored by 13 federal agencies. The program coordinates the scientific research of the participating agencies through a set of linked interdisciplinary research elements and cross-cutting activities that encompass a wide range of interconnected issues of climate and global change. Research elements and cross-cutting activities include atmospheric composition, climate variability and change, the global carbon and water cycles, ecosystems, land use and land cover change, decision-support resources, human contributions and response, monitoring of climate systems, international research cooperation, and communication.

The Climate Change Technology Program (CCTP) is a multi-agency research and development program. This program seeks to accelerate the development and deployment of technologies from the portfolios of more than a dozen participating agencies. Reduction, avoidance, and capture of GHG emissions are key priorities. Together, the CCSP and the CCTP represent the primary effort under the President's Climate Change Research Initiative for the United States.

California benefits from federal research funds for climate-related research. In addition to the participating agencies in CCSP and CCTP, there are approximately 40 national research laboratories based in California and programs such as the Integrated Earth Observation System and other networks, West CARB (administered by CEC), CALFED, a regional integrated sciences and assessment (RISA) center at Scripps Institution for Oceanography (UCSD), and other projects supported by NOAA, the U.S. Department of Interior, the U.S. Geological Survey, the National Park Service, the Fish and Wildlife Service, and the U.S. Department of Agriculture (USDA).

California's climate action programs are a collection of nearly 20 separate elements or functions that establish a comprehensive strategy for reducing GHG emissions. These elements include specific regulatory actions, programmatic functions of departments or boards, and statewide promotion of energy efficiency and conservation. The function of

coordination of state efforts on climate change for meeting the AB 32 GHG reduction targets resides with the Climate Action Team (CAT). As detailed in the 2008 CAT Report, many State agencies as well as private and public universities in California conduct, support, or direct research related to climate change, and there is increased coordination among agencies in this research. For example, the California Department of Food and Agriculture (CDFA), CEC), and ARB have joined forces to study N_2O emissions, primarily from agricultural activity in the State.

Research/Knowledge Gaps: To support the Board's decision-making and implement-tation of climate change policies, several key knowledge gaps must be addressed.

- Development of coherent strategies and tools for economic analysis to support sound and effective investments to reach near- and long-term State climate goals;
- Refinement and verification of emissions inventories and emissions reductions, with particular emphasis on large area sources, CH_4 emissions, and N_2O emissions;
- Further investigation of the climate impact of non-CO_2 GHG emissions not included in the international Kyoto Protocol (e.g., black carbon emissions);
- Investigation of the roles of human behaviors and decision-making in climate change emissions to support implementation, outreach, and social marketing;
- Identification of additional cost-effective climate change mitigation strategies (technology or non-technology based), with particular emphasis on sources of non-CO_2 GHGs;
- Development of methods for lifecycle analysis of proposed mitigation strategies;
- Development and application of GHG emission forecasting methods to project California climate change emission inventories into the future;
- Identification and characterization of emission reduction potential from strategies that provide consumers with information regarding the GHG footprint of personal choices;
- Development of protocols for quantifying and verifying emissions reduction associated with changing behavior (e.g., eco-driving, product labeling, carbon offsetting, etc.);
- Characterization of California-specific impacts of short-lived climate change pollutants (e.g., methane, black carbon, ozone precursors) and sensitivity of projections to such parameters as time horizon and emission levels to facilitate short-lived species' prioritization for mitigation via regulations, market-based approaches, or a combination of strategies;
- Costs and benefits of adaptation strategies suitable for application in California including heat emergency action plans or other responses;
- Characterization of economic and public health impacts of climate change on California.

Recommended for Funding

Determination of the Spatial Distribution of Greenhouse Gas and Ozone Precursor Concentrations and Emissions in the LA Basin

The proposed research would utilize novel instrumentation to measure spatial/temporal variations of greenhouse gas and air pollutant emissions in the South Coast Air Basin. The high time resolution (~1 hour) and large spatial coverage (with < 1 km resolution in

vertical and horizontal scales) proposed in this study would provide unique information on emission sources that is currently not available through other means. (p. 58)
Proposed funding level: $300,000

Pilot Study of Inverse Modeling to Verify California's Greenhouse Gas Emissions Inventory
To accurately quantify current emissions and verify future emission reductions—as mandated by AB 32—uncertainties in California's inventory estimates of CH_4 and other non-CO_2 GHG need to be reduced. ARB is now investing in instrumentation to measure CH_4 and other GHGs and needs to evaluate the measured data to effectively verify the CH_4 emission inventory. This project will use inverse modeling tools to evaluate and improve CH_4 emission inventory in California based on data that will be collected from ARB's CH_4 measurement network. Results will improve CH_4 emission inventory and verify future CH_4 emission reductions in California. (p. 60)
Proposed funding level: $275,000

Assessment of Baseline Nitrous Oxide Emissions in California's Dairy Systems
The study addresses N_2O emissions inventory and supports an AB 32 Early Action. The project objective is to measure N_2O emissions from forage croplands that receive liquid manure from dairy operations. The uncertainty regarding N_2O emissions from manure-amended fields has long been recognized and requires field investigation in California. The proposed research would leverage a number of ongoing efforts and would benefit from shared protocols and sampling/analysis equipment. (p. 62)
Proposed funding level: $82,000

Are There Any Counteracting Effects that Reduce the Global Warming Benefits Attributed to Diesel and Other Black Carbon Controls?
Black carbon, which is a major component of coal, diesel and other combustion-generated PM, may be the most important pollutant contributing to global warming after CO_2 and methane. Its short atmospheric lifetime (1-2 weeks) differentiates it from CO_2 and other globally well-mixed gases, which have lifetimes of decades to centuries. This property makes it attractive as a means to immediately reduce global warming impacts through directed controls of black carbon sources. Uncertainties regarding black carbon's indirect climate impacts associated with modification of cloud properties and abundance need to be clarified to support sound strategies for mitigating climate change through black carbon emissions controls. (p. 64)
Proposed funding level: $90,000

Quantifying the Effect of Local Government Actions on Vehicle Miles Travelled (VMT)
SB 375 requires California's regions to prepare Sustainable Community Strategies as part of their transportation planning, identifying a set of actions at the regional level that would bring transportation greenhouse gas emissions down to target levels. Given limited resources, it is critical to choose wisely which policies air implemented by local and regional governments to reduce VMT in their jurisdictions. Available policy tools include road and parking pricing, mixed use zoning, investments in alternative modes, and household travel planning programs. To help local/regional governments prioritize

actions, this research will estimate the likely impact of local government actions on VMT as a function of local/regional context variables. (p. 66)
Proposed funding level: $125,000

Develop Assessment Tool and Verify Emissions Reductions from Green Homes: GreenPoint Rated Climate Calculator Version II
California's Climate Change Scoping Plan states that further research is needed to quantify GHG emission reductions from green buildings. This project will expand the capabilities of a GreenPoint Rated Climate Calculator to include the latest green building methods and information. The climate calculator outputs can influence home buying and renovation decisions by quantifying a home's impact. This data will also help local governments to develop local climate action plans, and in particular, improve their existing housing stock. (p. 68)
Proposed funding level: $100,000

Evaluation of Models for Economic Analysis: ARB Regulations and Alternative Approaches to Reduce Greenhouse Gas Emissions
Major issues that arise in many of the proposed regulations or alternative approaches are economics based. Economic impacts of GHG reduction policies that materially change the energy markets, transportation alternatives, and land use are significant issues for the policy makers, the public, and the business communities. Economic models come in a variety of structures, sector focus, and completeness, which make the model selection and choice for a specific regulation or policy an important step. This project would assess and evaluate several models applicability to and usefulness for economic impacts analysis of ARB regulations and policies. (p. 70)
Proposed funding level: $120,000

Identify Factors that Support Low Residential Energy Consumption Observed in Some California Households
A large challenge facing ARB is facilitating behavior changes to achieve the GHG reduction milestones outlined in AB 32 and Executive Order S-3-05. The household profiles generated by this research can yield strategies, insights, and concrete examples of how Californians live with (much) less energy. This information could be used to help design more effective strategies and programs to promote household GHG reductions and achieve ARB's climate policy goals. (p. 72)
Proposed funding level: $95,000

Behavioral Strategies to Bridge the Gap Between Potential and Actual Energy Savings in Commercial Buildings
This study integrates social science with technical analysis to investigate the roles of building occupant, property manager, and operator behaviors on energy consumption. The study will identify barriers and opportunities to reduced energy use and enhanced occupant comfort. These important findings could dramatically enhance the State's ability to leverage professionals in and occupants of built environments to achieve GHG emissions reductions delineated by the Scoping Plan. (p. 74)
Proposed funding level: $135,000

Recommended if Additional Funding Available

Emission Reduction and Energy Efficiency Using Solid Oxide Fuel Cells Running on Anaerobic Digester Biogas from a Dairy Farm

This project will demonstrate the capability of solid oxide fuel cells in using biogas from a manure digester as the anode fuel, with an increase of the energy efficiency and a reduction of pollutant emissions. (p. 77)

Proposed funding level: $328,000

Carbon Life Cycle Impacts from Increased Biofuel Collection and Processing in California

California has a substantial opportunity to reduce carbon emissions by collecting previously unused forest residuals for biofuels, increasing thinnings of overly dense stands at risk of unnatural fires that are prone to release substantial emissions, to increase investments in short rotation wood crops, and to better utilize mixed waste streams for energy. California biofuel opportunities are unlike most other regions requiring site-specific analysis to estimate potential sources and not covered in the nationally supported workplan. This proposal augments the existing workplan to include California biofuel collection and processing. (p. 79)

Proposed funding level: $275,000

Assessing California's Potential Emissions Reductions from Utilization of Advanced Storage for Ancillary Services and Integration of Renewables at Commercial and Industrial Facilities

Advanced Storage devices can facilitate increased deployment of wind and solar projects by alleviating potential ramping issues, regulate frequency, and serve commercial and industrial facilities as a back-up generation/storage devices to potentially remove the need for diesel generation or as a demand response tool. This study will assess whether significant emission reductions can be obtained from the main uses of advanced, fast-response storage technologies throughout the State of California. (p. 81)

Proposed funding level: $150,000

Analysis of Changes in Light-Duty Vehicle Holdings by California Households

The proposed research will analyze existing vehicle registration databases to better understand recent changes in the composition of the current vehicle fleet (by type and age), at the household level. These databases can be monitored in the future to understand how changes in fuel prices and policies affect vehicle holdings and new vehicle purchases, and perhaps vehicle miles traveled and fuel consumption, at the household level. (p. 83)

Proposed funding level: $200,000

Using Social Marketing to Alter Community Behavior and Reduce Greenhouse Gas Emissions: Morgan Hill Case Study

This research will measure the impact of a city-wide intervention, the "Lose 5,000 Pounds of Carbon in 30 Days" program, that involves using social marketing prompts, the diffusion model and small eco-teams. This study will provide an empirical foundation

for program planning and evaluation of local government-initiated social marketing campaigns to addresses climate change. (p. 85)
Proposed funding level: $250,000

Develop Tools to Assess Public Health Co-Benefits of Climate Change Policy
Implementation of climate-related regulations, such as the Low Carbon Fuel Standard and SB 375, will change emissions profiles and air pollution as well as time-activity patterns of Californians. Integrated assessment of health co-benefits and risks associated with climate policy is critical to ARB's mission. In addition to aggregate health impacts, tools to assess public health co-benefits and risks of climate change policy should illuminate distribution of effects. Analyses with these tools will be used by ARB to develop and implement climate-related regulations that maximize health benefits, and will guide city planners in developing healthy "cool" communities. (p. 87)
Proposed funding level: $400,000

Social Responses to Climatic Changes and Extremes: Potential for and Constraints on Adaptation in the North Coast Wine Country
This is intended to characterize the vulnerabilities, adaptation options, and constraints of the North Coast winegrowing sector to climate change over the next several decades. Based on a social science/physical science vulnerability framework, the project attempts to assess exposure, sensitivity, coping capacity, and adaptation of the sector. This sector is an important economic element in California. Understanding the impacts of a changing climate is the first step in developing plans for dealing with unavoidable impacts. (p. 89)
Proposed funding level: $199,885

The Impact of Changes in Economic Growth on California's GHG Emissions
The volume and trend of California's aggregate GHG emissions will vary with its economic growth, increasing the difficulty of estimating the macro-economic effects of achieving a cap in a given year and the effect on certain policies such as the expected price of carbon in a cap and trade program. This California-specific study will analyze data on GHG emissions across the State's major economic sectors in the period during and prior to the current economic contraction to quantify observed relationships between changes in economic growth and related changes in GHG emissions. Results will shed light on the relationship between changes in economic growth and changes in GHG emissions, improve projections regarding aggregate and sector-specific GHG emissions of California's economy, and foster more effective design of market-based GHG emission reduction programs. (p. 91)
Proposed funding level: $100,000

Scenario Planning for 80% Reduction in 2050
Reducing greenhouse gases by 80 percent will require a complete transformation of the state's energy economy affecting every sector including electricity production, transportation and fuels, rural and urban land use, industry, agriculture and even the way we heat our homes and businesses. This research will help ARB develop a set of plausible and positive scenarios for the future of California that achieves the 2050 targets (80% reduction) for greenhouse gas emissions. Scenarios will include sufficient detail such that they could be used to inform the policy makers who are working to

achieve the goal, including technical, institutional, and political barriers that need to be addressed. (p. 93)
Proposed funding level: $150,000

Concepts Recommended for Funding

TITLE: Determination of the Spatial Distribution of Ozone Precursor and Greenhouse Gas Concentrations and Emissions in the LA-Basin

PROBLEM: Observation of the spatial distribution of air pollutant and greenhouse gas concentrations and emission fluxes is a crucial aspect of monitoring air quality as well as the current efforts, mandated by AB32, to curb greenhouse gas emissions in California. To date the strategy to monitor atmospheric trace gases and their emissions on a regional scale has relied upon networks of in-situ ground observations and simple comparison with results from urban air-shed models. The limited number of ground sites in these networks often poses challenges due to possible influence of local emissions and large spatial gaps between the stations. Without complementary data from aircraft, balloons, satellites or other exotic platforms, the ground-based network is inadequate to characterize the emissions of pollutants and greenhouse gases. The quantitative analysis of the observations in models also is often difficult and time consuming. Novel observational and modeling methods are therefore needed to address California's challenges in regulating and reducing the emission of pollutants and greenhouse gases.

PREVIOUS WORK: A pilot study using multi-axis Differential Optical Absorption Spectroscopy (MAX-DOAS) to measure NO_2, HCHO, and aerosol extinction from the new NASA-Jet Propulsion Laboratory (JPL) "California Laboratory for Atmospheric Remote Sensing" (CLARS) has been performed at Mt. Wilson, showing that enough information can be derived to retrieve spatial concentration fields of these compounds in the South Coast air basin. Through a NASA-sponsored project we have built a dedicated near-IR FTIR to measure the spatial distribution of various greenhouse gases. The instrument is based on a long heritage of Fourier transform spectrometers developed at JPL for ground-based, aircraft, balloon and spaceflight applications. The near-IR capability will be fully operational by summer of 2009. At this point in time first results of this setup will become available in spring of 2009. The CMAQ model has been coupled with the WRF model and applied to simulate ozone in the LA Basin. Additionally, an adjoint of the CMAQ model has been developed, which enables the assimilation of observations using a variational approach.

OBJECTIVE: The proposed work offers the first steps towards an air quality monitoring and forecast strategy for pollutants and greenhouse gases by developing and employing a combined observation and modeling system. Optical remote sensing from Mt. Wilson will provide spatial and temporal distributions of the column densities of various pollutants (NO_2, HCHO, CO, aerosol extinction) and greenhouse gases (CO_2, CH_4, N_2O). The observations will be assimilated into the CMAQ model and the adjoint of the model will provide improved emission fluxes and concentrations of NO_X, VOC's, CH_4, and N_2O in the LA-Basin.

DESCRIPTION: JPL's "California Laboratory for Atmospheric Remote Sensing" (CLARS) is located on a mountain ridge at Mt. Wilson with a near full view of the South Coast air basin. Investigators propose to perform field observations during different seasons in the years 2010 and 2011, measuring the spatial and temporal distribution of

various pollutants (NO_2, HCHO, CO, aerosol extinction via O_4) and greenhouse gases (CO_2, CH_4, N_2O) using a UV-vis MAX-DOAS and a near-IR FTIR spectrometer. Both instruments will use scanning systems to measure the absorptions of these trace gases in different viewing directions. Concentration fields of these compounds with a vertical resolution of 0.2 to 1km, a horizontal resolution of at least one kilometer, and a temporal resolution of 0.5 - 1 hour, will be retrieved using radiative transfer calculations and inversion techniques.

However, our main emphasis for this project will be to circumvent this inversion by expanding UCLA's CMAQ model with a radiative transfer code to directly simulate and assimilate the trace gas slant column densities observed from CLARS. The assimilated data can then be used in the existing adjoint of the CMAQ model to derive improved emission fluxes of NO_X, VOC's, CH_4, and N_2O in the LA-Basin. We propose to perform these calculations for different seasons and meteorological conditions in the LA-Basin. The results of this exercise will be compared to existing emission inventories. The improved model will be tested against ground observations to investigate the performance of our novel approach.

BENEFITS: The State of California is currently pursuing an ambitious plan to reduce its greenhouse gas emissions and to improve its air quality over the next decade. The proposed novel observation/modeling strategy will provide a unique tool to support these activities, by allowing the validation and improvement of emission inventories and urban airshed models. While our current proposal adopts a campaign style strategy, the proposed approach can easily be expanded into a year-round system to monitor changes in trace gas concentrations and emissions in the South Coast air basin and other urban areas in California. An assimilated CMAQ system that uses instantaneous observations, such as those from remote sensing instruments, would provide the next generation of air quality analysis and forecast tools.

COST: $300,000

COFUNDING/COLLABORATION OPPORTUNITIES: This research will be carried out in close collaboration with ARB staff who are already performing greenhouse gas air sampling at Mt. Wilson, as well as with the SCAQMD for the validation of our observations with ground observation. Collaborations with the NASA satellite community are already established and will be further expanded in this project.

TITLE: Pilot Study of Inverse Modeling to Verify California's Greenhouse Gas Emission Inventory

PROBLEM: Inventory estimates of California's greenhouse gas (GHG) emissions are based on international protocols that may not be representative of California sources and conditions for non-CO_2 GHG. Thus, there is a need to independently verify current emissions estimates. In addition, Assembly Bill 32, the Global Warming Solutions Act of 2006, mandates the California Air Resources Board (ARB) to verify future GHG emission reductions resulting from mitigation measures. The academic community has proposed a statewide continuous GHG monitoring network and the use of air quality models to back-calculate current emissions ("inverse modeling") and to follow emission trends. The proposed network would be a multi-million dollar commitment and a workshop jointly conducted by ARB and UC Irvine in January 2008 raised questions about the necessary number of monitors, the desired locations, and current inverse modeling capabilities. In order to provide a database to test the inverse modeling approach, ARB staff are deploying ten relatively low-cost (but high precision and hourly resolution) $CO/CO_2/CH_4$ monitors in the Central Valley of California. As part of the CalNex field study in May-June 2010, the National Oceanic and Atmospheric Administration (NOAA) will make flights over the monitoring sites and throughout the Central Valley to provide further spatial information. ARB has a highly spatially resolved (4 x 4 km) CO emission inventory of known accuracy that can be used to verify the inverse modeling approach.

PREVIOUS WORK: UC San Diego operates two sites (Scripps Pier and Trinidad Head) that provide hourly resolution for multiple GHG. ARB has provided high resolution CO monitors for these sites so they can be part of the $CO/CO_2/CH_4$ network. In 2007, two new projects were initiated. First, UC Irvine and ARB conducted 10-day measurement campaigns over four seasons at the Mt. Wilson Observatory, overlooking greater Los Angeles. By correlating GHG with simultaneous CO measurements and using the CO emission inventory for Los Angeles, the study estimated emissions for several GHG (CH_4, CFC-12) that were higher than the emission inventory. Second, a collaborative study by the Lawrence Berkeley National Laboratory, NOAA, and the California Energy Commission, began continuous measurements of multiple GHG at a site near Sacramento (Walnut Grove) and in the San Francisco Bay Area (Sutro Tower). The study demonstrated an inverse modeling approach for a portion of the Central Valley by using the Walnut Grove measurements to estimate CH_4 emissions.

OBJECTIVE: The objective of this project is to demonstrate inverse modeling tools for data collected from ARB and UC San Diego's $CO/CO_2/CH_4$ measurement network.

DESCRIPTION: The proposed work involves four major tasks: 1) Demonstrate an inverse modeling approach for CO using the ARB/UC San Diego measurement network. Annual, summer and winter inventories at county or sub-county resolution are desired for comparison to the existing ARB CO emission inventory. 2) Calculate annual CO_2 and CH_4 emission inventories using the ARB/UC San Diego measurement network. Compare to county-level emission inventories, to be proved by ARB staff. (ARB staff also have two mobile monitoring platforms available to investigate unexpected hot spots.) 3) Use the NOAA aircraft and other data (e.g., Walnut Grove)

to improve the emission inventory estimates and make recommendations on the optimal number and locations of monitors. 4) Turn over the inverse modeling tool to ARB staff and conduct a training course.

BENEFITS: The project will improve CH_4 emission inventory and verify future CH_4 emission reductions in California as mandated by AB32.

COST: $275,000

REFERENCES:

Fischer, M.L., C. Zhao, W.J. Riley, and A.C. Andrews (2009). Observation of CH_4 and other Non-CO_2 Green House Gas Emissions from California. California Energy Commission, PIER Energy-Related Environmental Research. CEC-XXX.

TITLE: Assessment of Baseline Nitrous Oxide Emissions in California's Dairy Systems

PROBLEM: In California, nitrous oxide (N_2O) may contribute as much as 50% to the total net agricultural greenhouse gas (GHG) emissions (California Energy Commission, 2005), but there is a great uncertainty associated with this estimate because actual field measurements of N_2O in California are lacking and N_2O emissions vary greatly among agricultural systems. With the passage of the Global Climate Change Solution Act (AB 32), quantifying N_2O emission from California agricultural land is vital to determining GHG emission budgets needed to address the mandated reduction in GHG emissions by 2020 and to develop appropriate mitigation strategies. Three State agencies (CEC, CDFA, ARB) recently funded research to determine baseline N_2O emissions in 9 of California's acreage-wise and economically most important types of cropping systems. However, no research has been commissioned to develop N_2O inventories for irrigated forage cropland that receives liquid manure from anaerobic storage ponds and corral manure. Dairy waste is applied to some 400,000 acres of forage cropland, which has one of the highest annual throughputs of nitrogen (N) of any cropping system in the world and, therefore, the potential of producing substantial N_2O emissions.

PREVIOUS WORK: The main driver for increasing N_2O emissions in North America is management of manure and manure application to soils (IPCC 2007). To date, N_2O emissions have not been measured on California's dairy farms, where water waste is typically applied year-round to forage crops surrounding the dairy facilities. According to our most recent research, the N inputs into these cropping systems (mainly as lagoon water and fertilizer through the flood irrigation systems) range from 500 to 1200 kg N ha^{-1} yr^{-1}, versus 350 to 600 kg N ha^{-1} yr^{-1} removed in the harvested crop. Many studies have shown that high N inputs significantly increased N_2O emissions (Bouwman et al., 2002; Eichner, 1990; Stehfest and Bouwman, 2006), and that N_2O emissions increased sharply in response to N inputs that exceeded crop N requirements (Edis et al., 2008; McSwiney and Robertson, 2005). Manure enhances denitrification; furthermore, manure stored in anaerobic lagoons contains volatile fatty acids, which have a high biochemical oxygen demand and likely provide an additional stimulus to denitrification (Coyne, 2008).

OBJECTIVE: The goal of the proposed research is to determine baseline N_2O emissions in forage production systems receiving dairy lagoon water waste.

PRPOSED WORK: Task 1: At least three farms with differing soil types will be selected for the N_2O monitoring. Sites will be selected with a history of regular manure additions. Task 2: On each farm, measurements of N_2O flux will be made during one summer corn growing season and also during one winter, when winter forage (triticale, oats, wheat etc.) are grown.

Episodes of high N_2O emissions occur when both soil inorganic N concentrations and water-filled pore space (WFPS) are high (Bronson and Mosier, 1993; Burger et al., 2005; Dobbie et al., 1999; Simojoki and Jaakkola, 2000). Therefore, frequent N_2O flux sampling will take place immediately before and after irrigation with dairy lagoon water

with the goal of capturing the extent of elevated N2O fluxes until the fluxes subside to background levels. When N_2O flux has receded and soils are relatively dry, measurements will be taken less frequently. Frequent sampling will also take place in the winter if the WFPS stays high for extended periods.

Nitrous oxide flux will be measured, using a static chamber technique (Hutchinson and Livingston, 1993). During measurements, vented, insulated, rectangular thin-wall stainless steel chambers (approx. 50 x 30 x 10cm) will be fitted onto previously inserted bases (depth about 8 cm) in beds and furrows. Chamber headspace air will be removed from a sampling port with butyl rubber septa *via* syringe and needle after 0, 30 and 60 min and stored in evacuated glass vials. The headspace air samples will be analyzed by a Shimadzu gas chromatograph (Model GC-2014) linked to a Shimadzu auto sampler (Model AOC-5000) in Dr. Horwath's laboratory. The system will be calibrated daily using analytical grade N_2O standards from a reputable source. Soil and air temperature, and soil moisture will be recorded during each gas sampling. Task 3: Periodically, inorganic N to a depth of 15 cm will be determined in soil extracts, and pH will be measured in soil slurries. Bulk density in the 0-15 cm layer will be determined seasonally. The ancillary data will be used to characterize the environmental factors that control N_2O emissions. The yearly N inputs into these systems will be estimated from the inflow, determined by flow meters, and the concentration of total N in the irrigation water. Task 4: The yearly N_2O emissions in these dairy systems will be calculated from the N_2O fluxes measured following the irrigation or rainfall events and from estimates based on the background fluxes that are expected when soils are relatively dry. Emission factors will be estimated for these dairy systems from the total yearly N_2O -N emissions divided by the amount of the yearly N inputs. The deliverables of this research will be a baseline estimate of annual N_2O emissions in dairy systems that can be used to estimate the N_2O emissions from the same land use in California. The emission factors (EFs) can be compared with those of other systems, for example corn cropping systems supplied with varied amounts of synthetic fertilizer that are being monitored for N_2O emissions in the Fresno area by our collaborators (PI Dr. Goorahoo).

BENEFITS: Baseline N_2O emission estimate for Central Valley dairy systems will improve the State's N_2O emission estimates. The EFs of dairy systems in comparison with EFs of other California cropping systems will provide guidance in developing best management practices to lower N_2O emissions in California's dairy systems.

COST: $82,000

COFUNDING/COLLABORATION OPPORTUNITIES: The proposed research will complement N_2O monitoring in other projects funded by State agencies. This project will benefit from shared protocols, flux chamber design, and streamlined analytical procedures established in the other N_2O monitoring projects underway. The data generated in the proposed research can also be used to calibrate and validate N_2O flux modeling, as proposed in some of the other projects funded by State agencies.

TITLE: Are There Any Counteracting Effects That Reduce the Global Warming Benefits Attributed to Diesel and Other Black Carbon Controls?

PROBLEM: The IPCC concluded that black carbon (a major component of coal, diesel and other combustion-generated PM) may be the second most important pollutant contributing to global warming, but chose not to assign a global warming potential (GWP) for two reasons. First, its short atmospheric lifetime (1-2 weeks) is incompatible with the long lifetimes (decades to centuries) of CO_2 and other well globally mixed gases. However, this property makes it attractive as a means to immediately reduce global warming impacts through directed controls of black carbon sources. And to slow loss of Arctic sea ice and glaciers around the world as black carbon deposited on snow and ice accelerates their melting. Second, because of uncertainties regarding how it influences climate in an indirect manner through the modification of the properties and abundance of clouds. While this "indirect aerosol effect" does not appear to offset the benefits of black carbon control, its magnitude needs to be understood.

PREVIOUS WORK: The Desert Research Institute just finished an emission inventory of black carbon sources in California. The ARB is funding Scripps to assess the impact of black carbon on California's climate through a balanced approach involving observations, data analyses, and modeling studies. Results from this research project will address the question of the importance of black carbon (both overseas transport and local sources) on recent observed trends of warming, drying and early melt of the Sierra Nevada snow pack. NOAA is funding Caltech (as part of CalNex) to investigate the impacts of PM (including black carbon) on climate forcing and cloud formation. They will address the origin and nature of California PM by flight plans that seek to track the evolution of the size and composition of the particles as they travel from source-rich to downwind areas. Caltech, NASA and Stanford have developed global climate models of the "indirect aerosol effect". ARB staff have assisted Michael Walsh and the University of Illinois in developing global emission inventories of black carbon and GHG reductions for the on-road transportation sector. These inventories include both BAU and control scenarios that extend California's diesel engine standards and retrofit programs to the U.S., EU and China.

OBJECTIVE: Run a model intercomparison study to isolate the direct effects of black carbon from the indirect, using global scenarios of on-road transportation controls.

DESCRIPTION: An extensive literature review by Caltech concluded that no global climate modeling study exists in which the effect of changing black carbon on aerosol indirect effects has been specifically diagnosed. Several global climate models exist that include the requisite detailed PM size distribution and composition treatment, coupled to an explicit cloud drop number concentration parameterization, to carry out such a calculation. The proposed study would be carried out with Calech, NASA and Stanford and would involve a series of equilibrium climate simulations in which the effect of reductions in black carbon emissions from the on-road transportation sector on the indirect aerosol effect is diagnosed. In particular, we are interested in determining whether a reduction in black carbon will lead to an increase or decrease in cloud radiative forcing. In short, would mitigating black carbon result in some counteracting warming due to consequent reduction in the indirect effect of aerosols on climate?

BENEFITS: Black carbon emissions from Asia and local sources contribute to global warming and accelerated melting of the Sierra Nevada snow pack. If California's example of strict diesel control is applied to other regions of the U.S. and world, these impacts could be reduced.

Greenhouse gases such as carbon dioxide have atmospheric lifetimes of decades allowing them to mix over a broad geographical area. In contrast, the removal timescales for BC particles are less than a week with greenhouse effects felt much closer to the emissions source. Changes to the emissions of light absorbing carbon particles could result in rapid, regionally specific changes to the radiative forcing. Therefore, reduction of black carbon offers a unique opportunity to mitigate the effects of global warming trends in the short term.

COST: $90,000

COFUNDING/COLLABORATION OPPORTUNITIES: This proposal builds on work already funded by NASA and NOAA, so the funding needs are modest.

TITLE: Quantifying the effect of local government actions on VMT

PROBLEM: The State of California has laid out ambitious greenhouse gas emissions reduction goals in AB 32 and in Executive Order # S-03-05. The transport sector is responsible for 38% of California's greenhouse gas emissions. Although technological advances in vehicles and fuels can go a long way toward reducing transportation emissions, it is now accepted that part of the strategy to meet these climate goals must be to reduce the overall vehicle miles traveled (VMT).

SB 375 requires California's regions to prepare Sustainable Community Strategies as part of their transportation planning, identifying a set of actions at the region level that would bring transportation greenhouse gas emissions down to target levels. There are plenty of policy ideas out there for local and regional governments to reduce VMT in their jurisdictions. Road and parking pricing, mixed use zoning, investments in alternative modes, and household travel planning programs represent just a small sample of the possibilities. Unfortunately, resources are limited, and they cannot all be implemented.

To responsibly do their part in the state's effort to meet emissions reduction goals, planners and local government officials need to have a clear way of prioritizing actions to reduce greenhouse gas emissions in their communities. In order to properly prioritize options, it is necessary to know—among other things—how much each option will actually reduce the greenhouse gas emissions of the community. However, the emissions effect of actions that reduce emissions through behavior change is highly uncertain; all actions that aim to reduce VMT are in this category.

The challenge is that the particulars of the local and regional context play a large role in determining which actions will be most effective where. For instance, road pricing will generally be most effective in reducing VMT where there are alternative modes of transportation. Incremental investments in transit will be most effective in places where those investments are filling gaps in existing service. It is impossible to create a simple table with actions in one column and greenhouse gas impacts in the next.

The extent to which people will reduce their VMT in response to government actions (their elasticity) is instead a *function* of contextual variables, and it is this function that must be investigated to help local and regional governments prioritize actions.

OBJECTIVE: To estimate the likely impact of local government actions on VMT as a function of local/regional context variables.

DESCRIPTION:
The research should include three subtasks, which will be refined in accord with RTAC dialogue and other SB 375-related developments:

1. Synthesize available evidence on the effects of local and regional government actions on VMT.
2. Use available travel survey, census, and GIS land use data to develop models that estimate elasticity of VMT with respect to a variety of major local/regional

policy variables (e.g. cost of travel, density of land use, transit availability) in a variety of urban and suburban contexts.

3. Create a simple spreadsheet model tool that synthesizes the resulting elasticity functions into usable policy parameters for local government decision making.

BENEFITS: Research results will support ARB's responsibilities under SB 375 and help planners and local government officials prioritize actions to reduce greenhouse gas emissions in their communities by offering a context-dependent tool to estimate greenhouse gas emissions reductions from a variety of VMT control strategies.

COST: $125,000

TITLE: Develop Assessment Tool and Verify Emissions Reductions from Green Homes: GreenPoint Rated Climate Calculator Version II

PROBLEM: A number of lifestyle-based carbon calculators have been developed to estimate an individual's or household's carbon footprint, but few tools exist to measure the total avoided greenhouse gas emissions from building green homes. Existing calculators typically rely on self-reported data, rather than third-party verification. At the national level, there is no systematic method of quantifying the greenhouse gas reductions from LEED projects; each project/developer uses its own methodology. And while the energy-related emissions savings from the building industry are well understood, research on the non-energy benefits of green buildings is very limited.

PREVIOUS WORK: The first version of the GreenPoint Rated Climate Calculator, developed by a team led by Green Building in Alameda County, quantifies the impacts of a core set of residential green building practices that go beyond energy. Our agency has taken a lead in identifying and quantifying the greenhouse gas reductions possible from recycling construction and demolition waste. Version I includes other non-typical quantification protocols, including indoor and outdoor water efficiency measures, benefits for locating near transit, and planting shade trees as ways to reduce a home's overall carbon footprint. A final report documenting our findings and methodologies is publicly available and is being used by public agencies in developing climate action plans.

OBJECTIVE: Our objective is to expand the number of green building measures that can be quantified in the Climate Calculator by undergoing a second phase of research, called Version 2. We will also revise current methodologies to ensure their compatibility with emerging green building protocols and/or cap and trade systems as appropriate.

DESCRIPTION: The second phase of research will follow similar methods used in Version I:

The measures included in the Calculator are drawn from the Green Building Guidelines published by Build It Green, the residential green building standard that is most commonly promoted by local governments in California. The GreenPoint Rated program offers third-party verification of these measures. The project team encountered some challenges as they sought to develop a Calculator based on accurate, verifiable data and assumptions. To be credible the Calculator had to reference valid standards, research reports, and assumptions. Perhaps most challenging, the Calculator had to work for third-party raters in the field. A calculator that is too onerous to fill out would drive up the cost of ratings, while an overly simplified calculator would lack credibility.

Unlike some calculators, the GreenPoint Rated Climate Calculator isn't a do-it-yourself rating tool that estimates the impacts of individual's behaviors, although it may be complementary to those behavior-based calculators. The GreenPoint Rated score and the Climate Calculator results are independent of the occupants' behavior in most cases because they are based on industry standards. The assumptions used in the Calculator remain valid for that building regardless of ownership or occupancy, unless significant

changes are made to the building's structure or systems. For this reason the Climate Calculator is different from other calculators used for estimating CO_2E attributed to homes.

The GreenPoint Rated Climate Calculator bridges the gap between those calculators that estimate the carbon footprint of individuals; and the large, industry-wide emissions reporting protocols. Other methodologies, such as the World Resources Institute methodology, measure impacts on climate change at a macro level, either by assessing the emissions of a business, an entire industry sector, or a local or regional government's jurisdiction. Home carbon footprinting tools, like those that allow users to offset their air travel or purchasing habits, are specific to the behavior of the occupants. The GreenPoint Rated Climate Calculator, however, provides a way to estimate the benefits of building green as compared to a conventionally built home of the same vintage.

As part of the Version 2 update process, Green Building in Alameda County will contact key stakeholders including experts, state agencies, local governments, builders, GreenPoint raters and climate registries. We will review the latest research to expand the number of green building measures that can be quantified and to update current methodologies. We will undertake pilot projects of different residential building types.

BENEFITS: The climate calculator outputs can influence home buying and renovation decisions by quantifying a home's impact. This data will also help local governments to develop local climate actions plans, and in particular, improve their existing housing stock.

COST: $100,000

COFUNDING/COLLABORATION OPPORTUNITIES: The Green Building in Alameda County program will be committing $25,000 in hard costs and in-kind staff time to developing Version II of the Climate Calculator. By funding this project, the state will be leveraging two years of past research on this project. The Green Building in Alameda County program has already invested $75,000 in hard costs in the development of Version I and has provided data to the ARB's Climate Change research division for the green building portion of the draft Scoping Plan.

TITLE: Evaluation of Models for Economic Analysis: ARB Regulations and Alternative Approaches to Reduce Greenhouse Gas Emissions

PROBLEM: Support for reducing greenhouse gas (GHG) emissions to reduce future climate change has increased substantially over the last decade. The California Legislature has set year 2020 targets for GHG emissions, and the Governor has passionately pursued and emphasized efforts and programs to further GHG reductions. The California Air Resources Board has adopted a Scoping Plan for GHG reductions to meet the targets, and is adopting regulations to implement the plan.

Major issues that arise in many of the proposed regulations or alternative approaches are economics based. Economic impacts of GHG reduction policies that materially change the energy markets, transportation alternatives, and land use are significant issues for the policy makers, the public, and the business communities. Economic models come in a variety of structures, sector focus, and completeness, which make the model selection and choice for a specific regulation or policy an important step.

OBJECTIVE: This project would assess and evaluate several models applicability to and usefulness for economic impacts analysis of ARB regulations and policies.

DESCRIPTION: This project would be in three phases that would involve ARB staff, outside advisors, and panel of experts.

Phase I would be conducted in-house by ARB Economics Studies Section Staff. In this phase, staff would:

- Gather information on several state and national level models that are being used either in California or within the U.S.
- Summarize the models structures, definitions, coverage, usage, and other information useful for model evaluations.
- Develop a set of criteria for model evaluations.
- Consult with other ARB divisions to assess economic modeling needs and the sectors that most likely would need full economic analysis.
- Perform a preliminary evaluation of the models.
- Prepare issue documents on each of the models.

Phase II would involve recruiting and consulting with outside advisors. Experts and professors from the University of California or leading economics institutions will be recruited to advise the ARB. The experts will:

- Review the model information gathered by the staff and advise on the completeness of the coverage.
- Review the staff analysis of the model applicability, and preliminary evaluations.
- Prepare a set of recommendations on all of the models reviewed based on the staff and their own analysis of the pros and cons of each model.
- Recommend the leading models that should go to a conference or panel of experts before the ARB stakeholders.

- Prepare documents and formally submit to the ARB.

Phase III would consist of a one-day conference where the recommended and leading models would be discussed according to specific criteria developed by the staff and the Phase II experts. The ARB stakeholders would be invited to participate in a portion of the panel discussions. The panel would:

- Review the prepared documents and models prior to the conference.
- Discuss the evaluation criteria for the models.
- Express their concurrence or rejection of previous evaluation findings on the models.
- Present their own evaluation of the models.
- Summarize and make recommendations.

BENEFITS: This research will aid ARB in choosing, using, and improving economic models that are used to estimate economic impacts of greenhouse gas reduction strategies. Improved models and better understanding of their results will help resolve issues related to differing estimate of regulatory control of greenhouse gas emissions.

COST: $120,000

TITLE: Identify Factors that Support Low Residential Energy Consumption Observed in Some California Households

PROBLEM: This research will investigate the circumstances which correspond to (very) low energy consumption levels in a subset of California households. Although inter-household variation in kWh consumption is acknowledged to be much larger than differences in end use technologies or household size could explain, the determinants of low usage have not been studied. The roles played by social factors such as habits, attitudes, and knowledge of energy matters, and demographic factors such as age, race, and social class are not well understood. This research can overcome the present uncertainty about what life lived at ten percent of current average energy consumption entails.

PREVIOUS WORK: According to data supplied by Pacific Gas & Electric (PG&E), inter-household variation in monthly electricity and gas consumption by residents of the City of Berkeley varies by more than a factor of 100. An investigator serving on the Berkeley Energy Commission initiated and coordinated a series of local contests designed to confirm the existence of very low usage and reveal the patterns underlying it. Subsequent research using consumption data acquired through these contests revealed a very low correlation between the energy efficiency of end use technologies and electricity consumption. Another investigator and potential collaborator conducted research on both low usage behaviors as well as variation in energy usage among otherwise similar households beginning in the late 1970s.

OBJECTIVE: This research aims to identify what factors are responsible for the low levels of energy use within an unstudied segment of the California residential sector, and establish a framework within which to assess the contributions of different social, cultural, and behavioral factors toward such low consumption levels. The research aims to generate a set of household profiles corresponding to different combinations of physical and social factors that yield low energy use. Finally, an understanding of low energy usage patterns could supply a template of what California's Global Warming Solutions Act (AB32) might require in five or ten or even twenty years.

DESCRIPTION: Through in-home interviews and a detailed survey this research will explore both the physical, social, and behavioral factors contributing to low energy use as well as attitudes among low use customers about their uses of energy.

1) Acquire a dataset from PG&E consisting of usage histories of approximately 5,000 residential accounts at the bottom end of the usage spectrum for both gas and electricity. This number encompasses all residential accounts up to the 10^{th} percentile usage level. These accounts would include 12 consecutive months of electricity and natural gas consumption and either the account number or a code allowing subsequent matching to the account number. The approximate monthly billing cutoff levels for such data extraction are: 70 kWh and 5 therms. This data set would then be sorted using criteria for culling accounts with no occupants or where significant fuel substitution is responsible for the exceptional usage.

2) Screen the data set to remove apparently unoccupied residences as well as customers whose bills reflect fuel substitution, e.g., low gas users with above-average electric consumption.

3) Design a study participation consent form. To protect customer confidentiality, personal information in the data set would be redacted. Research staff would have no ability to access personal information or contact customers until customers have consented in writing.

4) Mail the form to the screened dataset (expected to be between 2,000 and 3,000 accounts). The form would include a pre-printed account number or other identification code. Those residents willing to participate would respond to research staff directly. The advantage of such an approach is that it ensures anonymity of account holders while affording them the opportunity to participate. The computational requirements for PG&E are also minimized. Other approaches to protecting customer privacy while encouraging participation are possible.

5) Develop sampling criteria for identifying a subset of participating households to be interviewed in their homes. Conduct and transcribe interviews with low-use households. Interviews are designed to establish a working understanding of the circumstances and parameters corresponding to low use patterns and to facilitate development of appropriate survey questions.

6) Draft, pretest, and mail a detailed survey to all households agreeing to participate.

7) Analyze findings from interviews and household surveys. Identify household profiles using physical, social-demographic, and attitudinal categories developed through analyzing the responses.

8) Derive applications, focusing on the potential for significant reductions in energy consumption through transferable strategies.

BENEFITS: The household profiles generated by this research can yield strategies, insights, and concrete examples of how Californians live with (much) less energy. These permit and suggest a policy approach grounded in the experience of actual California households. Expert knowledge would be utilized not to prescribe standard bundles of technical solutions to everyone, but to identify combinations of habits, behaviors, technologies, and building characteristics that correspond to low energy consumption patterns commensurate with the long-term mandates of AB32.

COST: $95,000

TITLE: Behavioral Strategies to Bridge the Gap Between Potential and Actual Energy Savings in Commercial Buildings

PROBLEM: Space conditioning and ventilation represent 28% of the electricity use and 38% of the natural gas consumption in California's commercial sector (1). Efforts to reduce these levels and associated greenhouse gas emissions have typically focused on developing technological solutions and devising prescriptive approaches. Yet buildings rarely work as designed, in large part because they are operated and inhabited by people. This mismatch between building operations in theory and building operations in practice places serious limits on the success that solely technology-oriented solutions can have. The mismatch also points to the undertapped social and behavioral potential of building operators and occupants to work *with* the built environment to provide indoor spaces that require less energy and cause less greenhouse gas emissions without causing undue stress on occupants.

PREVIOUS WORK: Work in the U.S. and the U.K. indicates that commercial buildings often perform much differently than theorized. For example, energy consumption in new commercial office buildings is often higher than predicted (2), while occupant satisfaction survey data show that most office buildings, whether old or new, deliver levels of occupant thermal comfort that are much poorer than design values specify, often because of overprovision rather than underprovision of space conditioning (3).[1] There is limited published research, however, on the orchestration of real day-to-day operations of buildings, which encompass the decisions of the building operators, the influence of property management, and the behaviors and reactions of building occupants. Several large occupant satisfaction survey databases, including the Occupant Indoor Environmental Quality Survey developed by the Center for the Built Environment (CBE) at University of California Berkeley, have amassed data that help begin to answer these questions.

OBJECTIVES: The objectives are three-fold: (1) Understand key differences between theory and actual practice of thermal comfort provisioning in commercial buildings, addressing technological and operational elements simultaneously; (2) Identify barriers and opportunities in socio-technical systems of practice toward reduced energy consumption, such as expanding comfort temperature bands while maintaining or increasing the satisfaction of building occupants. Consider how these opportunities can be fulfilled in actual building operation, retrofit, and design; (3) Provide a structure to highlight the above issues so that they can be better recognized and integrated in future research and practice on the commercial built environment.

DESCRIPTION: This research would involve two intertwined streams. The first stream would analyze field observations and interviews with building operators, occupants, and property managers. The second stream would interview academic and practicing building experts, to draw out unpublished and informal knowledge and experience. A third stream could be added, subject to data and resource availability, to combine

[1] Research shows that just 38% of survey respondents said they were satisfied with temperature in their workspaces. Over half of occupants' stated dissatisfaction with temperature *in the summer* is from temperatures that are too cold, rather than too hot, according to the Occupant Indoor Environmental Quality Survey database (http://www.cbe.berkeley.edu/research/survey.htm) at U.C. Berkeley.

analysis of observed energy consumption and temperature ranges with "what if" scenarios (e.g., for expanded thermal comfort ranges).

Select California buildings for which occupant satisfaction and building technical characteristics data have already been archived in CBE's Occupant Indoor Environmental Quality Survey database, and obtain necessary permissions from management.[2] Use existing survey results and consultations with building experts to develop interview and focus group protocols. Employ interviews and focus groups to speak with building operators, building occupants, and property management to better understand current practices and to ascertain barriers and opportunities for lower energy use. The focus would be on the thermal environment, but other aspects of the built environment would be included as they arise. Analyze results to determine themes of how buildings are "really" operated and why, and to identify barriers and opportunities for modifying practices toward reduced building energy use. Themes could include, for example: traditions in setting air conditioning and heating levels and their rationale (e.g., assumptions about how temperature affects sales or productivity), roles of various parties in determining operating choices, what systems do not work, how complaints are managed, window and door opening practices, degree of occupant control, occupant adaptation to discomfort, performance data availability, clashing interests of operators, managers, and occupants, relationships to outdoor environment, etc. Investigate in particular the possibilities for increasing the range of indoor temperature, and whether and how this could be achieved by changes in operating practices, changes in occupant and management expectations, as well as technologies and practices of adaptation.

BENEFITS: Results would offer ways in which building operators, management, and occupants could collectively establish building practices that use less energy, resulting in lower GHG emissions and potentially more satisfying commercial indoor spaces. Results would also inform theory of commercial building operation and design for comfort provision, toward better accounting for actual operations and uncertainties, thus contributing to better design and more realistic theoretical approaches to lower building energy consumption.

COST: $135,000

COFUNDING/COLLABORATION OPPORTUNITIES: In using CBE's survey database, this research leverages past funding by the California Department of General Services, CEC, GSA, and other agencies, as well as the collective work of 50,000 building occupants. It also links to a research proposal that CBE is developing, at the request of CEC, to study comfort from a broader perspective, integrating outdoor comfort and building user expectations.

REFERENCES:

(1) California Commercial Energy Use Survey, available online at: http://capabilities.itron.com/CeusWeb/Chart.aspx

[2] There are currently 34 surveyed buildings in California in the CBE survey archives. Additional buildings could be surveyed at relatively low cost. In total, CBE archives surveys from over 400 buildings, primarily in the U.S.

(2) B. Bordass, R. Cohen, and J. Field, “Energy performance of non-domestic buildings: closing the credibility gap,” presented at the 2004 International Conference on Improving Energy Efficiency in Buildings, Frankfurt, http://europrosper.energyprojects.net/links/IEECB04BordassCredGap2.pdf.
(3) S.A. Fard, *Post-Occupancy Evaluation in U.S. Office Buildings: Do Green Buildings Have More Satisfied Occupants?*, MS. Thesis, U.C. Berkeley, 2006.

Concepts Recommended if Funding Available

TITLE: Emission Reduction and Energy Efficiency using SOFCs running on Anaerobic Digester Biogas from a Dairy Farm

PROBLEM: There are currently 1.8 million cows in 1900 farms that produce 90,000 tons of waste per day in California. With the purpose of generating power, heat, and reducing greenhouse and volatile organic compound emissions, some dairy farms generate biogas by digesting manure in anaerobic digesters. However, current emission standards for IC engines are not being met by generator sets running on biogas.

PREVIOUS WORK: Attempts have been made to add catalytic converters to process the exhaust gases of generator sets to reduce NO_x and CO emissions. Current converters have been designed for operation with NG and not for biogas, so they tend to fail after a short period of operation. Solid Oxide Fuel Cells (SOFCs) have been tested with biogas (mainly CH_4/CO_2 mixtures) and have even shown recovery after exposure to small H_2S concentrations that can be present even when sulfur cleaning is applied before the injection to the SOFC anode.

OBJECTIVE: Demonstrate the capability of SOFCs in using biogas from a manure digester as the anode fuel, with an increase of the energy efficiency and a reduction of pollutant emissions. The biogas will be obtained from a manure digester located at Joseph Gallo Farms, in Atwater CA.

DESCRIPTION: Anaerobic digesters constitute a proven technology for cow-manure management that reduces the emissions of methane to the atmosphere. The biogas obtained from the digester can be used on-site or provided to a nearby local user, it may be cleaned into biomethane and sold to public utilities or be used for distributed power generation purposes, producing electricity for use on-farm, off-farm or sold to utilities. There is an additional positive effect when it is used to help to reduce the load on an already saturated power transmission line.

A typical composition of the biogas obtained from a digester has between 55 and 62% CH_4, 30 to 35% CO_2, small fractions of O_2, N_2, and 0.2% of H_2S which requires the use of a scrubber. Due to the higher fractions of CO_2 and N_2, a spark-ignited IC engine running on biogas shows a penalty in performance compared to natural gas or gasoline [Crookes 2006]. An increase in the compression ratio improves performance but increases the levels of NO_X, CO, and HCs. Information obtained from a San Joaquin Valley Air Pollution Control District operating permit (see attached document) for a 575 BHP Caterpillar generator engine indicates maximum emission levels of 0.15 g- NO_X /bhp-hr, 0.1 g-PM10/bhp-hr, and 0.5 g-CO/bhp-hr. Although the PM and CO emissions have been met, so far, measured levels of NO_X emissions are above the regulatory requirement.

Due to their capability of operating with CH_4/CO_2 mixtures obtaining higher efficiencies than ICEs or GTs, and the relative insensitivity to the contaminants present in biogas

(provided a desulfurization step) SOFCs may present a viable alternative to IC engines for power generation and emission reduction (Van herle 2003 and 2004, Shiratori 2008, Santarelli 2008). However their performance running on biogas from a manure digester has not been documented previously. The main concern in the utilization of SOFCs with biogas is the presence of H_2S which is stable at the operating conditions of a SOFC. The poisoning becomes more serious at increased levels of H_2S and decreasing operational temperature (Sasaki 2006). However, experimental results indicate that SOFCs can recover from exposure to low quantities of H_2S (below 1 ppm) (Sasaki 2008). Carbon deposition is also a problem if steam or O_2 is not added (Van herle 2004).

Before a transition from IC-engines to fuel cells can take place, a comprehensive analysis of the performance and emission levels of SOFCs running on biogas needs to be performed. The proposed project intends to run a series of tests to collect data and determine the exhaust emissions levels and power generation performance of a solid oxide single cell **operating** on biogas from a digester. The biogas will be obtained from the manure digester at Joseph Gallo Farms in Atwater, CA. Based on funding availability a 1 kW SOFC stack could also be installed at the Joseph Gallo Farms facilities for performance, reliability, and real-time operation analysis.

The proposed list of tasks includes

1. Obtain a benchmark test data of emissions levels and power generation of a single solid oxide cell operating with CH_4/H_2O mixtures (steam-to-carbon ratio higher than 2).
2. Measure emissions levels and power generation performance of a single solid oxide cell operating with simulated biogas composed of 60% CH_4 and 40% CO_2.
3. Measure emissions levels and power generation performance of a single solid oxide cell operating with scrubbed and raw biogas from digester.
1. Analysis of carbon deposition on solid oxide single cell.
2. Quantify degradation effect of H_2S.

BENEFITS The use a waste material for aims of power generation at high efficiency and low pollutant emissions. Low exhaust emission levels and high-efficiency distributed power generation will significantly reduce Californians' respiratory illnesses and will lower the load on saturated transmission lines.

COST: $328,000

TITLE: Carbon Life Cycle Impacts from Increased Biofuel Collection and Processing in California

PROBLEM: Biofuel collection and processing to displace fossil fuels provides an important opportunity for reducing carbon emissions. The US Forest Service (USFS) has provided $500,000 funding to measure the Life-Cycle Inventories (LCI) for collection and processing of biomass suitable for bioprocessing (forest residuals, thinnings, short rotation crops and mixed waste streams). A national workshop of experts prioritized potential projects and estimated that comprehensive coverage would require a total budget in excess of $1 million. They established an initial set of priorities singling out regions and biofuel processing models that were already producing useful data to generate the most and highest quality results per unit cost. As a large energy using state, California has a substantial opportunity to reduce carbon emissions by collecting previously unused forest residuals for biofuels, increasing thinnings of overly dense stands at risk of unnatural fires that are prone to release substantial emissions, to increase investments in short rotation wood crops, and to better utilize mixed waste streams for energy. California biofuel opportunities are unlike most other regions requiring more site-specific analysis to estimate potential sources and not covered in the USFS supported workplan. This proposal extends the existing workplan to include California biofuel collection and processing.

PREVIOUS WORK: The Consortium for Research on Renewable Industrial Materials (CORRIM) a non-profit research consortium formed by 15 research institutions, mostly universities, has developed LCI information and carbon equivalent Green House Gas (GHG) assessments for all structural wood products for the major US producing regions including an integration of the impacts from alternative building materials for the construction, use and disposal of residential buildings for cold and warm climates, along with impacts for residential and light commercial structures meeting seismic codes in Los Angeles www.corrim.org. CORRIM is just beginning to develop biofuel collection and processing LCIs based on regional supply analysis and a sample of key biofuel processing alternatives including pyrolysis, gasification and fermentation. This new CORRIM project in conjunction with this proposal can extend the California Biomass to Energy Study for a select region of the state that was recently completed under the supervision of Mark Nechodam of the USFS Pacific Southwest Research Station providing.

OBJECTIVE: Extend the coverage being provided by a USFS grant to CORRIM to develop LCIs for biofuel collection and processing to include California sourced biofuels and carbon mitigation impacts sourced by forest residuals, thinnings, short rotation high yielding crops and mixed wastes, supplying a range of processing technologies. Provide information that will motivate increased biofuel uses such as biofuel processing for liquid fuels.

DESCRIPTION: Provide estimates of life cycle impacts for biofuel collection of residuals and fire reduction thinnings and short rotation woody crops and their bioprocessing alternatives based on processing models that will ultimately lead to LCIs for scale facilities once they are in operation.

Specific Tasks include:

1. Identify best thinning strategies by extending a current USFS funded study to establish best practices for a range of inland-west forest types by including specific California forest types and their related fire risks.
2. Analyze growth, yield and life cycle impacts for fast growing California species such as eucalyptus.
3. Develop life cycle impacts for forest residuals that could be collected if incentives supported by increasing carbon values or fossil fuel prices are realized.
4. Consider mixed feedstock sources and their impact on volumes and LCI measures.
5. To the degree possible leverage use of the data collected in prior USFS and California's Air Research Board (ARB) supported studies and customize collection and processing alternatives appropriate to California infrastructure.
6. Develop estimates of the magnitude of emissions reduction available from increased biofuel collection and processing for California under a range of economic conditions.
7. Assess other environmental burdens that may result from increased use of biofuels.
8. Peer review all findings integrated with the CORRIM LCI biofuel and collection project reviews for increased credibility and enhanced support for implementation.

BENEFITS: California specific LCI information on increased biofuel opportunities that are peer-reviewed integral with the USFS effort will identify new opportunities to reduce green house gas emissions (GHG) in California and provide direction for implementation and the reduction of barriers.

COST: $275,000

CO-FUNDING COLLABORATIVE OPPORTUNITIES: The USFS funded biofuel LCI collection and processing study ($500k) will provide research protocols for consistent analysis across many regions in identifying opportunities in California and provide benchmarks for comparisons across collection and processing alternatives. The study will also benefit from a pellet study ($50k, supported by the State of Wisconsin) in cooperation with CORRIM, ongoing field studies on the accessibility of forest residuals ($300k, supported by State of Washington), and a wood products study being completed under industry funded grants for assessing the impact of increased biofuels in the manufacture of structural products ($18K). The study will also build off of a USFS study on fire risk reduction and carbon mitigation opportunities specific to a range of forest types in the west ($300K). Without the extended coverage provided by this proposal, the opportunities for California's working forests and unique species and site conditions will not be available at least in the foreseeable future. With this proposal data for California will likely be more complete than for most other regions. The participating CORRIM research institutions will also provide matching funds of 20%.

TITLE: Assessing California Emission Benefits from Utilization of Advanced Storage for Ancillary Services and Integration of Renewables at Commercial & Industrial Facilities

PROBLEM: Advanced Storage devices are expected to have an increase in utilization in the state of California. The targeted uses for storage are (1) Assisting with increased implementation of wind and solar projects by alleviating potential ramping issues, (2) Offering ancillary Services such as frequency regulation, and (3) Serving commercial and industrial facilities as a back-up generation/storage devices to ease demand for diesel generation or foster demand response.

Each of these uses has the potential to provide significant emission reductions for the state of California if widespread adoption is encouraged. However, to date, studies have not quantified this benefit. The proposed study would use a proprietary simulation model to assess the whether significant emission reductions can be obtained from the main uses of advanced, fast-response storage technologies throughout the State of California.

PREVIOUS WORK: A publicly-available study has assessed potential emission savings for Beacon Power's 20 MW Flywheel Power System when used for Frequency Regulation:
http://library.corporateir.net/library/12/123/123367/items/227756/BeaconEmissionReport_1_8_07.pdf
The study was conducted for Beacon Power, Sandia National Labs, and the U.S. DOE.

OBJECTIVE: The purpose of the proposed study is to quantity the potential emission savings gained by the adoption and utilization of fast-response storage devices in the state of California.

DESCRIPTION: The tasks will use a dynamic simulation model to assess specific storage applications, their impacts on emissions, and then quantifying the total potential savings. The project will examine two application areas and scenarios within those applications.

Application 1: Ancillary Services (1) Base Case: assessment (as in the Beacon Flywheel Report) for utilizing fast response storage for the California's current level of regulation or regulation alternative. (2) Renewable Energy Case: assessment for using fast response storage for the amount of projected regulation that will be required under California's 2020 Renewable Energy goals

Application 2: Commercial C&I Applications – As duration, transportability, and capacity of storage technologies increase, the technology may be able to replace a large amount of diesel generator utilization.
(1) Case 1: assess the emission savings gained from using storage in place of traditional generation technologies that participate in DR Programs.
(2) Case 2: measure the emission savings that is gained by using storage vs. diesel generation to cover outages or cases where traditional generation is used to maintain facility operations.

For the project, investigators will utilize a proprietary KREMLIN simulation tool capable of modeling entire electricity grid systems. The model has been used extensively to assess storage impacts for frequency regulation and use with renewables. It has been applied to ISO areas in the U.S. and is capable of working with up to 1,000 generators. The model has been adopted to include storage applications, emissions from the power plants and generators, and additional renewable applications such as wind, large solar and solar farms. This model will be set up specifically for the California ISO electricity grid.

BENEFITS: Californians can benefit from energy-generating technologies that reduce emissions of CO_2, NO_X, and SO_X,. This study will look at the potential application of advanced storage technologies and assess the emissions savings that can be gained by their use. In each of the cases, storage devices may also have better performance characteristics than current technologies. Hence, the study will help show how storage can not only demonstrate better performance for specific applications, but will also help the state reduce emissions as well.

COSTS: $150,000

TITLE: Analysis of Changes in Light-duty Vehicle Holdings by California Households

PROBLEM: ARB has adopted ambitious goals to reduce greenhouse gas emissions to 1990 levels by 2020; achieving these goals will require large reductions in emissions from all sources. To ensure that the state is on target to meet its objectives, data should be collected and monitored to verify that reductions are occurring on schedule, and to identify sectors or components that are not achieving their targets. In 2004 California light-duty vehicles accounted for 33% of all CO_2 emissions from fuel combustion, and 64% of all CO_2 emissions from mobile sources. Analysis of fuel sales data can provide insight into whether general AB32 targets for the transport sector are being met, but they do not provide information on whether fuel reductions are coming from greater use of more efficient vehicles in the current fleet, reductions in vehicle miles traveled, or purchases of more efficient vehicles.

PREVIOUS WORK: CARB's EMFAC model is a sophisticated tool that estimates the effects changes in vehicle stock, emission rates, and activity have on criteria pollutant and CO_2 emissions. The latest version of EMFAC includes vehicle counts by vehicle type and county, and estimates of annual mileage driven by vehicle type and model year from analysis of Smog Check inspection records. However EMFAC is updated only every few years, and provides information only at the county level.

OBJECTIVE: The proposed research will analyze existing vehicle registration databases to better understand recent changes in the composition of the current vehicle fleet (by type and age), at the household level. These databases can be monitored in the future to understand how changes in fuel prices and policies affect vehicle holdings and new vehicle purchases, and perhaps vehicle miles traveled and fuel consumption, at the household level.

DESCRIPTION: The Department of Motor Vehicles maintains vehicle registration records for all vehicles in the state. The data include vehicle license plate and identification number (VIN), as well as the vehicle owner and address, including zip code. The owner address can be used to infer driver characteristics (such as median household income or education level) from the 2000 (and later) national Census, at the zip code, tract, or block level; such data can be aggregated by vehicle age, type, and make/model, for all vehicles registered in the state. (It may be possible to obtain more exact information on household income and size from state income tax returns.) In addition, multiple vehicles registered to the same address can be aggregated to determine characteristics of vehicle "fleets" owned by California households.

Multiple years of DMV data can be assembled to characterize vehicle holdings of households (by number of vehicles and vehicle model year, type, and make/model) and to track vehicle movements within, into, and out of California and air basins. The data can be used to estimate how state policies influence households' purchases of new vehicles (for example, replacing a light truck with low fuel economy, with a car with higher fuel economy).

Vehicle holdings by household can eventually be merged with data on vehicle activity and fuel use to estimate fuel use by geographic area and household type, and to track fuel use over time in response to government policies. Smog Check inspection records provide odometer readings and miles traveled for individual vehicles. However, newer vehicles up to 6 years old, vehicles manufactured before 1976, and vehicles registered in many rural areas of the state are exempted from the Smog Check program; other sources would be needed to estimate the activity of these vehicles. In addition, Smog Check records only provide information on vehicle use over the two-year period between Smog Check inspections. Future efforts to collect more frequent data on vehicle activity, and fuel use, could be combined with vehicle holdings by household to track household vehicle activity and fuel use over time.

BENEFITS: An ongoing system to monitor the light-duty vehicle stock of California's households can be used to analyze what impact changes in fuel prices and government policies have on vehicle ownership patterns. Coupled with data on vehicle activity and/or fuel use, the system could also be used to track fuel use in response to government policies to reduce CO_2 emissions. The merged data can also be used to identify which geographic and socio-economic segments of the population should be targeted for further reductions in light-duty vehicle CO_2 emissions, in order to meet the CO_2-reduction goals of AB32.

COST: $200,000

TITLE: Using Social Marketing to Alter Community Behavior and Reduce Greenhouse Gas Emissions: Morgan Hill Case Study

PROBLEM: A survey conducted by Yale University indicated that although many people are concerned about climate change, adopting sustainable behaviors conflicts with the social norms of American culture. In addition, addressing climate change requires more than one behavioral change, and many people do not know how to begin or question the impact their personal changes will have on a global scale. Finally, since making a significant difference requires more than one individual, personal efforts may seem futile in a world surrounded by unwilling participants. When addressing communitywide climate change, local government agencies do not have a long history of knowing which programs are effective and are similarly challenged by these personal dynamics.

PREVIOUS WORK: Research indicates that local governments underestimate the influence of social norms and rarely plan social marketing campaigns in accordance to the diffusion model. The diffusion model uses "early adopters" (15% of the population) to lead the way for a new behavior to be adopted by the "early majority" (next 35% of the population.) The expected outcome is that the "late majority" (additional 35% of the population) will be persuaded to implement the new behavior with little marketing effort and the behavior will be considered a norm. In addition, research also suggests that a small group working together to reduce their impact on climate change is more effective than a mass marketing campaign. Small groups effectively address barriers because individuals feel more accountable about their actions, are more likely to adopt a new sustainable behavior when they see others doing it, have a greater pooling knowledge and at the same time are creating a new social norm for the community.

OBJECTIVE: This research aims to determine the expected impact that the "Lose 5,000 Pounds of Carbon in 30 Days" program can have by using social marketing prompts, the diffusion model and small eco-teams.

DESCRIPTION: The City of Morgan Hill has piloted two Carbon Diet Clubs that have reduced an estimated 105,000 pounds of the community's greenhouse gases. The results of the pilot indicate that the program can be easily extended to the larger community and that on average a participant reduces 10,000 pounds of annualized greenhouse gas emissions. This research will extend this campaign to 35% of the households (4,400) in Morgan Hill over a three year period, affecting the majority of the population to create a social norm, and subsequently quantify the program's results.

The program is simple with participating households working in small groups made up of 5 to 8 households, known as a Carbon Diet Club. Each household commits to losing 5,000 pounds of annualized carbon dioxide emissions over a 30 day period. Carbon diet kits are given to each member containing the following:

- *A Carbon Diet Workbook:* This is the most vital component in the campaign. The workbook contains 24 actions split into two sections: cool lifestyles and cool households systems. Each action provides a carbon reduction number if the activity is done (e.g., a participant can reset his/her thermostat and claim a 1,200 lbs. carbon reduction.)

- *Kill-A-Watt:* Participants can check out this device to find phantom energy loss
- *Shower timers*, *reusable shopping bags* and *environmental information* related to reducing greenhouse gas emissions
- *A Free Home Energy Audit*

Weekly meetings are hosted by City staff or student interns during the participation month. During the meetings, households act as a support group and discuss problems and solutions to achieving their reduction goal.

This project involves extensive evaluation of the program's results. Specifically, the following research results are anticipated:

- Evaluate the effectiveness of using small groups to address more than one behavioral change to reduce a community's carbon footprint
- Analyze the long-term behaviors that were adopted from the campaign by comparing annual energy bills, vehicle mileage and behaviors before and after participation
- Create a social marketing model that can be utilized in other communities
- Apply the social diffusion model to 12,500 households in Morgan Hill
- Analyze effective groups for campaign targeting, such as churches, homeowner's associations neighborhood blocks or randomly formed groups, that will result in long term behavior changes
- Study how the campaign raised awareness in other areas, e.g. workplace practices
- Survey how home energy audits influence behavior and consumer choices
- Explain how to create a highly visible campaign and provide a cost benefit analysis

This research will provide a model that breaks down the barriers that prevent individuals from changing their behavior. The carbon diet kit in conjunction with group meetings makes the transition to sustainable behaviors easier and more consistent. Households are able to quantitatively define the difference they have made and the campaign creates a social norm.

BENEFITS: Provides a logical process for program planning and evaluation of a social marketing campaign that addresses climate change. Many other California communities will be able to reduce residential greenhouse gas emissions using the results of this research.

COST: $250,000

COFUNDING/COLLABORATION: The City has budgeted funding to pay 50% of the campaign implementation and has received initial supplementary funding to provide home energy audits from PG&E. The City has begun exploring a relationship with the Lucas Graduate School of Business at San Jose State University to coordinate the evaluative steps of the project.

TITLE: Develop Tools to Assess Public Health Co-Benefits and Risks of Climate Change Policy

PROBLEM: In 2006, the Legislature passed and Governor Schwarzenegger signed AB 32, the Global Warming Solutions Act of 2006, which set the 2020 greenhouse gas emissions reduction goals into law. It directed the California Air Resources Board (ARB) to begin developing discrete early actions to reduce greenhouse gases while also preparing a scoping plan to identify how best to reach the 2020 limit. Implementation of climate-related regulations, such as the Low Carbon Fuel Standard and SB 375, will change emissions profiles and air pollution as well as time-activity patterns of Californians. Integrated assessment of health co-benefits and risks associated with climate policy is critical to ARB's mission. In addition to aggregate health impacts, a tool to assess public health co-benefits and risks of climate change policy should illuminate distribution of effects. For example, facilities will be erected to produce alternate fuels demanded by the Low Carbon Fuel Standard and land will be converted, and the local impacts may be distributed unevenly. While reduced fossil fuel consumption should improve air quality on a regional scale, actual exposures on community levels must be investigated. For example, there is evidence that smart growth and reduced urban sprawl can help combat obesity and its associated risks as well as reduce vehicle miles traveled, thus reducing in-vehicle traffic exposures. However, more pedestrian-friendly environments can also be associated with greater pollution exposures. In addition, land use changes may result in activities to produce alternate fuels, such as agriculture and biorefineries, being located near communities resulting in a changed profile of exposure in these communities.

PREVIOUS WORK: While several studies investigate particular impacts related to climate change policy in isolation, an integrated assessment of climate policy impacts is critical to ARB's mission. For example, studies indicate that neighborhoods with increased walkability reduce obesity and lower blood pressure[1], providing a benefit to the health of the inhabitants of the neighborhood in addition to reducing vehicle miles traveled[2]. However research also indicates that pedestrian friendly environments may results in higher air pollution exposures[3]. There has been a call for a cost-benefits analysis of the impact of built environment interventions on greenhouse gas emissions and public health, particularly on the more vulnerable populations[4].

OBJECTIVES: Support ARB's mandate to control greenhouse gas emissions while protecting public health developing a tool for integrated assessment of health co-benefits and risks associated with climate policy is critical to ARB's mission. In addition to aggregate health impacts, this tool should illuminate distribution of effects.

DESCRIPTION: There are several areas that could be emphasized to support the goals of this effort, including:

1. Identify how climate change regulations that alter emissions profiles, such as the Low Carbon Fuel Standard, impact public health at the local and individual level, including the impacts of reduced or changed exposures. Effects on children and the elderly and those with preexisting disease will also be assessed because they are more vulnerable to air pollution.

2. Assess how increases in smart growth may reduce pollution from traffic due to reduced vehicle miles traveled and increased health from reduced exposures and reduced stress due to less time spent in vehicles.
3. Assessment of possible exposures from biorefineries, agricultural activities to grow the crops needed in alternative fuels, as well as processing plants and alternative fuel plants (such as wind power plants) which may increase near communities. The focus will be on groups most affected by these changes, such as lower socioeconomic status communities, since they have fewer resources to move away from areas where increased farming or fuel production plants may be located.
4. Perform a cost-benefit analysis of the impact of interventions in the built environment on greenhouse gas emissions and public health.
5. Evaluate how the potential change in area dedicated to green space due to land use changes may result in health impacts.

BENEFITS: Analyses with these tools will be used by the Air Resource Board to develop and implement climate-related regulations that maximize health benefits, and will guide city planners in developing healthy "cool" communities.

COST: $400,000

REFERENCES

1. Sallis JF, Glanz K. Physical activity and food environments: solutions to the obesity epidemic. Milbank Q 2009;87(1):123-54.

2. Cao, X., Mokhtarian, P. L., & Handy, S. L. (2007a). Do changes in neighborhood characteristics lead to changes in travel behavior? A structural equations modeling approach. Transportation: Planning, Policy, Research, Practice, 34(5), 535-556.

3. de Nazelle A, Rodriguez DA, Crawford-Brown D. The built environment and health: Impacts of pedestrian-friendly designs on air pollution exposure. Sci Total Environ 2009;407(8):2525-35.

4. Younger M, Morrow-Almeida HR, Vindigni SM, Dannenberg AL. The built environment, climate change, and health: opportunities for co-benefits. Am J Prev Med 2008;35(5):517-26

TITLE: Social Responses to Climatic Changes and Extremes: Potential for and Constraints on Adaptation in the North Coast Wine Country

PROBLEM: Specialty agriculture such as winegrowing is an essential part of California's economy and society. Increasing evidence suggests that winegrowing is highly sensitive to climate change, particularly changes in climate extremes. However, the nature and extent of the biophysical and social (management) sensitivities, as well as the potential capacity and constraints on adaptation of the industry, remain relatively uncharted. These are critical to understand to promote the continuation of a viable local wine industry. The industry presents an excellent case study for examining the vulnerability to climate change as well as the adaptive capacity and barriers to adaptation, which are relevant to other forms of agriculture, and would greatly support California's emerging efforts in adaptation planning.

PREVIOUS WORK: Investigators have demonstrated that winegrape yields are sensitive to the changes in climate projected for California (Lobell et al., 2006a, b; 2007). Initial work also indicates that winegrape quality is sensitive to climate (Hayhoe et al., 2004). General frameworks for vulnerability assessments and adaptive capacity are available (e.g., Adger et al., 2007; Adger, 2006; Smit and Wandel, 2006), and some initial thinking on the types and importance of barriers to adaptation can be used as a first iteration on the constraints that may affect California's viticulture in adapting to climate change (Adger et al., 2009; Moser, 2009).

OBJECTIVE: The overall objective of this project is to comprehensively characterize the vulnerabilities, adaptation options and constraints of the North Coast winegrowing sector to climate change over the next several decades. An integrated social science/physical science vulnerability framework will be used to assess exposure, sensitivity, coping capacity and adaptation constraints of winegrowers to changes in relevant climatic conditions.

DESCRIPTION: Investigators will work closely with members of the wine industry in the North Coast region (here defined to include Napa and Sonoma counties) to conduct a vulnerability analysis of the coupled social-ecological system of winegrowing to climate change. Under this framework, the potential for harm (vulnerability) is a function of *exposure* to a stress such as changes in temperature or other climatic variables, *sensitivity* to that stress, and *ability to respond or adapt* to that stress. Investigators will examine historical management responses to past climate stresses, evaluate current levels of preparedness for climate change in the wine industry, and combine this information with existing and emerging statistically and dynamically downscaled climate scenarios to project the future vulnerability of the industry to climate change.

This work has three main goals, each to be reached through specific tasks: (1) Enhance California's experience in effective decision support through stakeholder dialogue, a broad survey of winegrowers, face-to-face interviews, and ongoing communication with stakeholders; (2) Understand key drivers of the North Coast winegrowing social-ecological system's vulnerability to climate variability and change through a characterization of biophysical and socio-economic sensitivity, exposure and adaptive capacity of winegrowers and the integration into a comprehensive vulnerability

assessment; and (3) Identify the real-world options, priorities, and constraints to adaptation to inform improved adaptation policies and practices through characterization of past vineyard responses to climate stresses, assessment of present preparedness for climate change, and analysis of future adaptation options**.**

This project will have a specific focus on how extreme events affect winegrowing, as these present some of the most challenging management situations in the winegrowing industry, and are likely to reveal the most difficult constraints on decision-making under uncertainty. We will conduct an economic valuation of the impacts of past extreme events as a first-order baseline for a preliminary and likely incomplete estimation of future economic impacts of climate change on this sector.

Importantly, the proposed project aims not only to advance scientific understanding in several key areas, but to serve as a pioneering test case for California's emerging efforts to identify adaptation options and barriers and use this understanding to provide decision-makers with effective decision support. Insights and results will also be communicated back to the science community to inform future research and scientific assessments such as the state's Climate Action Team reports and the next IPCC assessment.

BENEFITS: This project represents an important advance in California's climate impacts and adaptation research, offering a bottom-up perspective on the State's capacity to deal with unavoidable impacts. Additionally, it will strengthen California's capacity for effective decision support while also advancing several research frontiers.

COST: $199,885

TITLE: The Impact of Changes in Economic Growth on California's GHG Emissions

PROBLEM: The volume and trend of California's aggregate GHG emissions will vary with its economic growth, increasing the difficulty of estimating the macro-economic effects of achieving a cap in a given year and the effect on certain policies such as the expected price of carbon in a cap and trade program. Every three years from 2012 through 2020, (and beyond), ARB will establish declining aggregate GHG emissions limits (caps) for California. As ARB estimates the feasible and cost-effective greenhouse gas emission reductions that can be achieved through market mechanisms in any given compliance period, it will be helpful to understand how baseline GHG emissions in a range of sectors would respond to projected changes in California's economic growth rate in the absence of climate policy.

BACKGROUND: Three variables strongly influence anthropogenic GHG emissions: population, economic productivity/capita, and carbon-intensity of production. Total GHG emissions can be estimated as the product of these three factors, and their rate of change can be used to estimate the trend of an economy's GHG emissions.

No one of these factors alone can determine the trend of California's GHG emissions. But, all else being equal, a prolonged economic contraction is expected to reduce an economy's rate of GHG emissions growth. Shrinking GDP should reduce per-capita GDP as well as population. In addition, reduction of California's GHG intensity is expected to slow during an economic contraction, as investment in emission-lowering technologies declines. In a prolonged economic expansion, we would expect the opposite impacts.

PREVIOUS WORK: In a 2008 report to Congress, the Congressional Research Service examined the interrelationships of the variables discussed above to explore their implications for policies that address climate change.[3]

The US Energy Information Administration has developed a national model that predicts energy use in a variety of economic sectors through 2030:
http://www.eia.doe.gov/oiaf/aeo/aeohighmac.html.

The World Resources Institute has developed a Climate Analysis Indicators Tool[4]
with a comprehensive and comparable database of greenhouse gas emissions data (including all major sources and sinks) and other climate-relevant indicators.

OBJECTIVE:
This California-specific study analyzes data on GHG emissions across the State's major economic sectors in the period during and prior to the current economic contraction to quantify observed relationships between changes in economic growth and related changes in GHG emissions.

[3] Greenhouse Gas Emission Drivers: Population, Economic Development and Growth, and Energy Use John Blodgett, Specialist in Environmental Policy; Larry Parker, Specialist in Energy and Environmental Policy December 31, 2008
[4] http://cait.wri.org/

DESCRIPTION: The proposed work will entail identification of econometric and emission indicators for selected economic sectors during a defined time period, collection of economic and emission data for the study period. Data analysis will quantify observed relationships between econometric indicators and emissions for selected sectors. Using findings from previous step, investigators will develop sector-specific and aggregated adjustment factors for near-term (3-5 year) GHG emissions projections.

BENEFITS: Results of this research will offer improved understanding of the relationship between changes in economic growth and changes in GHG emissions, the ability to more accurately project aggregate and sector-specific GHG emissions of California's economy, and more effective design of market-based GHG emission reduction programs.

COST: $100,000

TITLE: Scenario planning for 80% reduction in 2050

PROBLEM: Reducing greenhouse gases by 80 percent will require a complete transformation of the state's energy economy affecting every sector including electricity production, transportation and fuels, rural and urban land use, industry, agriculture and even the way we heat our homes and businesses. One of the challenges of developing strategies and policies to achieve this target is the difficulty of envisioning what our state might look like when we succeed. Scenario planning is a process of visualizing (1) probable future conditions or events, (2) consequences or effects of these future conditions, and (3) skillful means to respond to, or benefit from, future conditions. Scenario planning can be a valuable tool to help policy-makers and stakeholders define a portfolio of programs, policies, and strategies that will be most effective in achieving goals.

OBJECTIVE: To develop a set of plausible and positive scenarios for the future of California that achieves the 2050 targets (80% reduction) for greenhouse gas emissions. Scenarios will include sufficient detail such that they could be used to inform the policy makers who are working to achieve the goal. This would include information on technical, institutional, and political barriers that would need to be addressed to achieve the scenario.

DESCRIPTION: The research should include four subtasks, including:

1. Evaluation of existing long-range scenarios including those from CEC, UC, USDOE, IEA, Shell, and others and their relevance to California.
2. Development of a set of comprehensive scenarios across all sectors to illustrate several futures in which California achieves its 2050 goal of reducing economy-wide GHG's by 80%.
3. Development of a set of sector-specific scenarios to address more detailed questions including for the following sectors:
    a. Transportation (example below)
    b. Power generation
    c. Industrial, Residential and Commercial facilities (IRC), including cooling and space/process heating
    d. Agriculture/Forestry
    e. Other? (High GWP, Black carbon, etc.)
4. Engage with key stakeholders to inform the scenario development and discuss the implications of the scenarios for policy-making.

For Transportation (example – other sectors to be fleshed out in solicitation):
Scenarios should consider all transportation subsectors, and identify strategies for improving efficiency, lowering the carbon intensity of fuels, and reducing travel demand. This analysis should address the following specific questions:

- What potential combination of vehicle sales, fleet composition, fuels usage, and GHG emissions is implied by achieving 80% GHG emission reductions by 2050?
- What are the various technology barriers and market constraints that must be overcome to achieve market share for the most promising low-carbon options?
- What are the resource constraints on pursuing the various energy carriers (electricity, hydrogen, low-carbon liquid biofuels)?

BENEFITS: Results of this research will help ARB synthesize a portfolio of regulations that will support realization of climate change goals and identify promising policies to support technologies and economic investment that will facilitate realization of climate change goals.

COST: $150,000