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California Air Resources Board

Annual Research Plan

Fiscal Year 2015-2016



ANNUAL RESEARCH PLAN
FISCAL YEAR 2015 - 2016

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Introduction

The Air Resources Board's (ARB or Board) research program is guided by the mission of providing sound and timely scientific results to support ARB's policies and programs. As with California's other environmental policy successes, the State's progress on air quality and climate change issues relies on a strong scientific foundation. ARB's research goals of informing health-based air quality standards, reducing air pollution exposures, and protecting California from the potential impacts of climate change are met through a diverse portfolio of projects. This Research Plan (Plan) outlines the projects for funding in fiscal year (FY) 2015-2016.

For more than 40 years, ARB and key academic, public, and private partners have collaborated to make California an internationally renowned center for air pollution research. Results from ARB's health research program, as well as from studies funded by the United States Environmental Protection Agency (U.S. EPA), the Health Effects Institute (HEI) and the National Institutes of Health, constitute the scientific basis for both national (NAAQS) and state ambient air quality standards (CAAQS) for particulate matter (PM) and ozone (O₃), which are the only pollutants that still exceed national ambient air quality standards. Health-based ambient air quality standards identify outdoor pollutant levels that are considered safe for the public – including those most at risk of adverse effects with exposure to air pollution, such as children, the elderly, and people who are active outdoors. ARB has a strong legacy of funding fundamental research on the health effects of air pollution. The research outlined in this Plan will continue this legacy and support the development of future air quality standards and regulations by investigating the extent and effects of air pollution exposure on the State's vulnerable populations.

This Plan also continues a growing trend over the last few years to fund program-driven projects that provide needed information, data, and approaches to answer and address key questions for meeting California's air quality and climate goals over the next four decades (Figure 1).

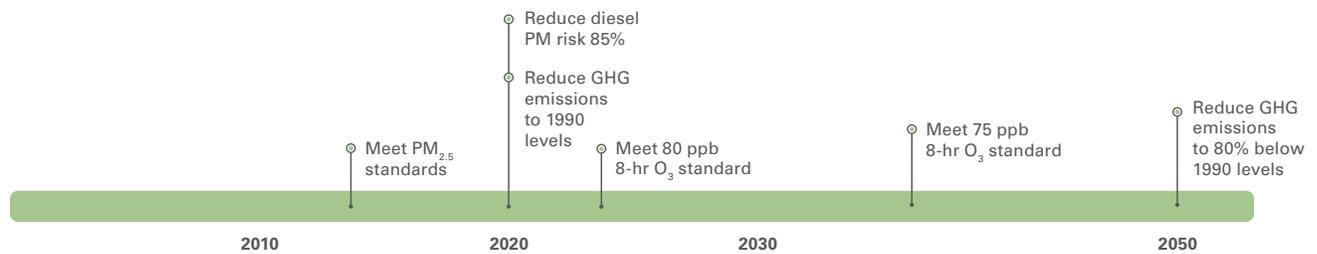
These projects support the development of new policies and regulations, and track implementation of existing programs. Several of the projects included in this Plan are designed to support California's State Implementation Plans (SIPs) to meet the air quality goals established by the federal and California Clean Air Acts. They will lead to improvements in our understanding of the influence of background ozone and meteorology on attainment of air quality standards, and better estimates of compliance with existing standards and emissions for trucks and buses.

The 2013 Update to the AB 32 Scoping Plan outlined strategies to keep California on track to meet the goals of the Global Warming Solutions Act of 2006 (AB 32). This Research Plan will continue to address ARB's climate-related research needs through studies that:

- Develop recommendations to improve ARB's clean vehicle incentive programs
- Evaluate sustainable communities strategies
- Improve understanding of short-lived climate pollutants (SLCPs)
- Perform economic assessments of greenhouse gas (GHG) emission reduction strategies

ARB will also continue to evaluate the environmental justice (EJ) implications of its air quality and climate programs; projects that address this theme are highlighted in each section.

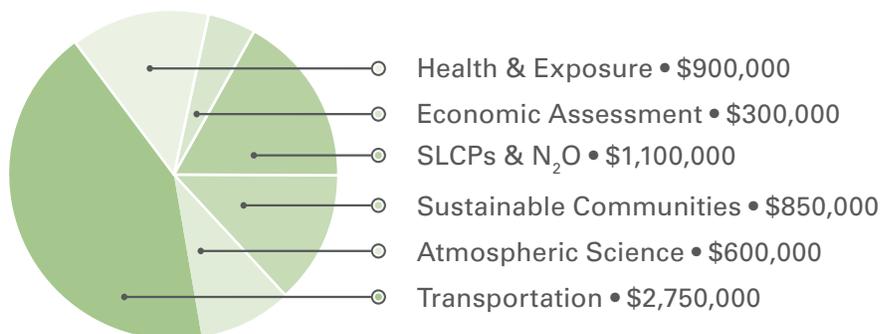
Figure 1. California’s key air quality and climate change milestones through 2050



Funding Distribution

The Fiscal Year 2015-16 Research Plan includes 17 research concepts, requiring approximately \$6.5 million in funding. As shown in Figure 2, funding is allocated to research related to health and exposure (14%), atmospheric science (to inform SIPs) (9%), the transportation system (including passenger vehicles, trucks, and buses) (42%), sustainable communities (13%), SLCPs and nitrous oxide (N₂O) (17%), and economic assessment (5%).

Figure 2. ARB research funding allocation for Fiscal Year 2015-16



CLEANER AIR

Despite significant success in reducing overall pollution levels, air pollution continues to be an important public health problem. The majority of Californians breathe unhealthy levels of one or more air pollutants during some part of the year, leading to health effects such as asthma. Attainment of health-based national and state ambient air quality standards drives many of ARB’s regulatory programs, which have led to the dramatic improvement in California’s air quality. For example, Los Angeles has not had a Stage 1 smog alert (one-hour peak of 0.20 ppm or more) since 1998. In 1990, the standard was higher and there were nearly 200 days exceeding the national standard. By 2011, the standard was reduced and there were about 100 exceedance days.

Coordination, Leveraging, and Collaboration

Coordinating our research with other State agencies, federal agencies, local air districts, and research institutions is an important goal of the Research Division in order to avoid duplication of effort, leverage funding, identify opportunities for collaborative efforts, and maximize the utility and applicability of research results.

ARB staff make every effort to keep research costs as low as possible and seek co-funding opportunities and other ways to leverage limited research dollars. ARB benefits from the cost-effective contract terms that have been negotiated with the University of California (UC) Office of the President¹, and the numerous world-class researchers that are part of the UC system. Research coordination with other funding agencies also enables ARB to participate in projects and studies outside the reach of ARB's research budget alone. Recent examples of this type of collaboration include ARB's involvement with the National Aeronautics and Space Administration's (NASA) DISCOVER-AQ field study in the San Joaquin Valley, and the Los Angeles Megacities project (funded by the National Institute of Standards and Technology [NIST]), which are major efforts that will produce results of interest to ARB. ARB has also previously leveraged substantial funding from federal and other State agencies, such as the 2010 CalNex study, a major air quality and climate change field campaign, in which ARB invested about \$5 million and the National Oceanic and Atmospheric Administration (NOAA) invested \$15 million. ARB is currently contributing \$1 million in funding to research at the National Center for Sustainable Transportation, leveraging an additional \$10 million invested in the Center by the U.S. Department of Transportation, the California Energy Commission (CEC), and California (Caltrans) and other states' Departments of Transportation. To promote coordination, information is shared at all stages of the research process, from project development to updates on research progress and final reports.

1 ARB is required by the [California Health and Safety Code, Section 39704](#) to consider the expertise of the University of California system when awarding contracts.

ARB-FUNDED RESEARCH

World Class Publications

Since 1990, ARB has funded more than 450 research contracts which have resulted in a similar number of peer-reviewed, highly-cited publications in high-impact journals. On average, these ARB-funded publications are cited about 50 times each by other articles, and 80 percent are published in the top quartile of journals in terms of scientific impact, which compares favorably to other funding organizations such as the United States Environmental Protection Agency and the Health Effects Institute. Health and exposure, atmospheric science, and emissions monitoring and control publications have received the most citations, and reflect ARB's long-standing research strengths. ARB research also has been cited in reviews of the National Ambient Air Quality Standards and in dozens of ARB regulatory documents. Publications resulting from ARB research contracts have won the Haagen-Smit Prize for outstanding papers published in the journal *Atmospheric Environment*, and the Arthur C. Stern Distinguished Paper award from the Journal of the Air and Waste Management Association.

Other activities to promote coordination with funding agencies include participation in interagency groups, such as the Climate Action Team (CAT) Research Working Group and the Transportation Research Roundup, which includes ARB, Caltrans, and the CEC. In the development of the research topics included in this plan, ARB staff coordinated with numerous State and federal agencies and partners, including:

Federal:

- U.S. Environmental Protection Agency
- U.S. Departments of Energy and Transportation
- The National Institute of Environmental Health Sciences

State:

- Governor's Office of Planning and Research
- California Energy and Public Utilities Commissions
- California Department of Transportation
- Office of Environmental Health Hazard Assessment
- Housing and Community Development
- Strategic Growth Council

ARB has also worked with local air districts and non-governmental organizations such as the Health Effects Institute (HEI) and the Coordinating Research Council (CRC). This Research Plan also addresses several of the research topics identified in the [Climate Action Team \(CAT\) Research Plan](#), developed by the CAT Research Working Group, notably projects related to greenhouse gas inventory and efforts to reduce GHG emissions.

SHARING RESEARCH RESULTS

ARB staff disseminates new research results to other researchers and to the public through conferences, stakeholder meetings, webinars, press releases, final reports, and updates at Board Meetings.

ARB's research [website](#) provides an overview of all of ARB's research-related activities and products, including webinars and final reports. An initiative to increase media attention, in conjunction with an added focus on research seminars and workshops, has produced a 40 percent increase in web hits in fiscal year 2013-14 compared to the previous year, and a related shift in interest from ARB constituencies.

Research



Policy

Air Quality Standards

Protecting Californians' health by limiting outdoor air pollutants to safe levels



Climate Goals

Protecting California from the most dangerous impacts of climate change

Fundamental Research

Informing health-based air quality standards, air quality plans, and GHG emission inventories



Health & Exposure



SIPs



GHG Emissions

Programs and Regulations

Developing, refining, tracking



Trucks



Buses



Cars



Sustainable Communities



Fuels



Sustainable Freight

Research and Review Process

Research Plan Development

- Staff solicit research ideas from the public
- Staff identify program-driven research needs and priorities
- The Board's external Research Screening Committee and other funding organizations (e.g., air districts, state and federal agencies) provide input on priorities
- Board approves proposed research plan

Contract Development

- Staff develop scopes of work and proposal solicitations for priority projects
- The Research Screening Committee and other funding organizations provide input on proposals
- Board approves funding for proposals

Project Oversight

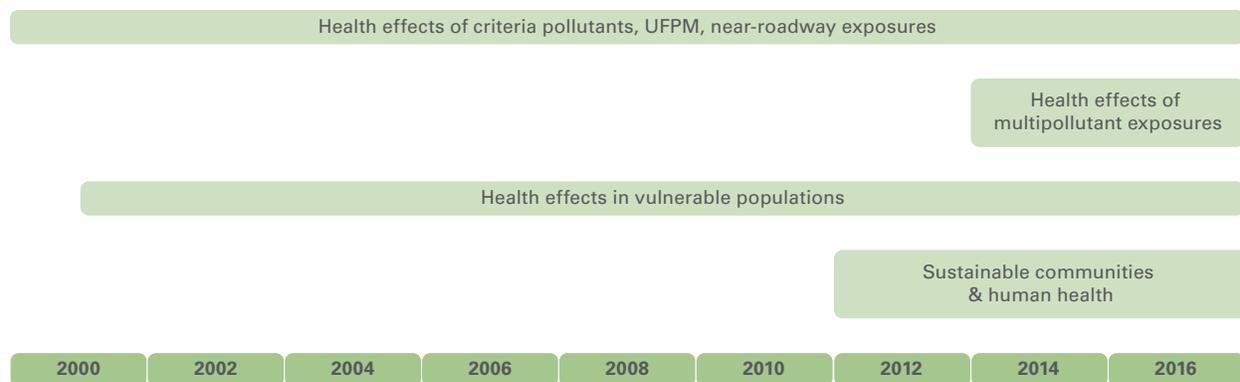
- Staff manage research projects closely and solicit input from interested parties on a quarterly basis
- Large and important projects include advisory panels of subject matter experts
- The Research Screening Committee reviews draft final reports and recommends revisions (10 percent of funding is withheld from investigators until the Committee approves their final report)
- Researchers give a webcast [research seminar](#) to present findings at the end of their contract, sometimes held jointly with other related projects that are completed around the same time



Health and Exposure

ARB funds research on the effects of air pollution on the health of all Californians, including sensitive sub-groups and those living in disadvantaged communities. This health research supports the establishment of ambient air quality standards and actions to reduce public exposure to air pollution. Health-related research projects span toxicological and epidemiologic investigations, as well as controlled human and animal exposures. California has made substantial progress in reducing ambient concentrations of criteria air pollutants and toxic air contaminants, but exposure to pollutants in communities and in microenvironments still remains a concern. ARB's health and exposure research program seeks to develop strategies to mitigate the harmful health effects of air pollution, particularly in environmental justice (EJ) communities where research on cumulative impacts and vulnerability is needed to inform ARB's EJ and climate change programs, initiatives, and policies.

Figure 3. ARB health effects research since 2000

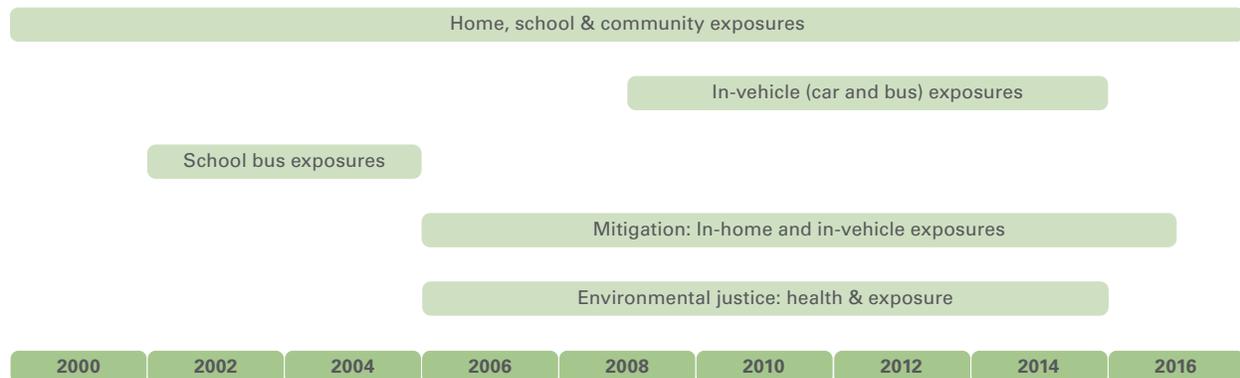


ARB-funded health effects research has added to the body of evidence on the health impacts of exposure to air pollutants, especially PM and ozone (Figure 3). The highly cited Children's Health Study remains the premier study of the effects of air pollution on children. Subsequent ARB-funded research has included epidemiologic studies of other vulnerable populations, and toxicological studies focused on elucidating the mechanisms by which PM and ozone can harm human health. Although studying the effects of individual pollutants continues to be important, ARB has expanded its research portfolio to look at multipollutant exposures and other areas of current national and statewide interest, such as the health effects of ultrafine PM and the impact of sustainable growth (SB 375) on human health (Figure 3). ARB is continuing to fund research to quantify the degree to which vulnerable groups are more sensitive to air pollution impacts. For example, a recently completed ARB-funded study of elderly people with cardiovascular disease in Los Angeles provided information on the effects of air pollution exposures from different sources, including traffic.

ARB-funded exposure research continues to investigate near-roadway and ultrafine particulate matter (UFPM) exposures (Figure 4). A current study of asthmatic children is examining the impacts of primary and secondary organic components of PM_{2.5}, including UFPM, on acute asthma exacerbations.

ARB also is studying ways to mitigate pollution exposures for those who live in close proximity to roadways and may therefore be exposed to higher levels of traffic pollution. A current study will result in the development of guidance on the use and cost-effectiveness of in-duct, high-efficiency filtration for reducing exposure to air pollution from indoor sources and from outdoor sources, such as traffic, that have infiltrated into the indoor environment. Another study is evaluating the impacts of sound wall/vegetation combinations on downwind levels of traffic-related pollution including PM_{2.5}, ultrafine particles, black carbon, and oxides of nitrogen (NO_x). These studies will shed light on potential strategies to reduce exposure to traffic-related air pollutants. Results from these research projects are expected in 2015 and 2016.

Figure 4. ARB exposure research since 2000



To support ARB’s environmental justice policies, ARB funded the development of the Environmental Justice Screening Method (EJSM). ARB’s EJSM research laid the foundation for CalEnviroScreen, which is informing the selection of disadvantaged communities under AB 32. These communities will receive investments from the Cap-and-Trade auction proceeds. We continue the development of EJSM through a research contract to update, automate, and expand EJSM to cover the entire State. Use of the most current data sets will better capture patterns of cumulative impact and vulnerability of importance to environmental justice communities statewide. This effort will enhance the understanding of the geographic patterns of cumulative impacts and vulnerability, including data limitations and gaps, and will provide valuable information to support CalEnviroScreen and other environmental justice programs, initiatives, and policies.

The health research and exposure focus for FY 2015-16 is to improve our understanding of the health impacts of exposure to particulate matter and mixtures of air pollutants, such as those found near roadways. The research described below includes a study that will provide insight into the difference in susceptibility to air pollution exposure between women and men. Recent epidemiological evidence has pointed to an increased sensitivity to PM in women, which this research addresses using a toxicological approach. The second project will examine whether changes in immune function induced by air pollution exposure can be passed on to offspring.



Women’s Cardiovascular Risk from PM Exposure

Objective: The objective of this study is to investigate the epidemiological finding that older women may be more susceptible than men to the cardiovascular effects associated with particulate matter exposure. The results would provide information for consideration in the process of evaluating the adequacy of air quality standards to protect women’s health.

Concept: Epidemiological studies suggest that women have a greater relative risk of cardiovascular mortality than men. Yet animal studies designed to shed light on the mechanism

of toxicity for particulate matter are mostly conducted on male animals. This study will investigate the mechanism of toxicity occurring in females compared to males using a rodent model. Evidence from the scientific literature shows that: (1) $PM_{2.5}$ exacerbates cardiovascular disease severity and progression, and (2) impaired ovarian function is associated with cardiovascular disease. Studies that focus on women's health have found an increased risk of mortality from exposure to air pollution compared to studies with both men and women. These studies include the California Teachers Cohort Study, Women's Health Initiative, Nurses' Health Study, and the Adventist Health Air Pollution Study. Statistically, heart attacks are more deadly and disabling for women than for men; 38 percent of women die within one year of their first heart attack, compared with 25 percent of men. This research project will investigate whether the cardiovascular effects of PM exposure observed in women are due to ovarian function using female rodents. Animals exposed to particulate matter will be evaluated for evidence of cardiovascular disease such as markers of oxidative stress, decreased heart rate variability, and atherosclerotic plaque development. The results are expected to help us understand why epidemiological studies have found a greater risk of cardiovascular mortality for women than men, which would suggest that women's cardiovascular health be included in the next national ambient air quality standards review.

Level of Funding: \$600,000



Are Adverse Health Effects from Air Pollution Exposure Passed on from Mother to Child?

Objective: A previously funded study of infant primates exposed to high levels of ambient $PM_{2.5}$ and ozone mixed with wildfire smoke found changes in lung function and epigenetic changes in two markers of immune function compared to animals of the same age which had not been exposed to wildfire smoke. This suggests that exposure during infancy can alter immune responses. This follow-on study will investigate: (1) whether female animals can pass these immune function changes on to their offspring, and (2) whether these changes have impacted the animals' overall health.

Concept: There is some evidence from epidemiologic and animal studies suggesting that air pollution exposures during early life could lead to persistent changes in physiological function that impact health later in life. Recent evidence indicates that these physiological changes may be due to exposure-induced changes in gene function. These changes in gene function can be passed on to offspring, who then have the same change in responses as their parent, without having experienced the exposures. A previous ARB-funded study investigated the impact of early life episodic ozone and particulate matter exposure on lung function and immune responses to a microbial challenge in a cohort of California National Primate Research Center (CNPRC) outdoor colony rhesus monkeys. The animals were born within three months prior to the Trinity and Humboldt County wildfires of June/July 2008. Compared with a cohort of age-matched

RESEARCH HIGHLIGHT

A number of published studies have shown that inhaled $PM_{2.5}$ affects the cardiovascular system. For example, ARB research found an increased risk of stroke among women who had never had one before, particularly among those who were post-menopausal. However, the mechanism by which inhaled $PM_{2.5}$ can alter cardiovascular function remains a key knowledge gap. Results from a recent ARB funded study on the cardiovascular health impacts of exposure to $PM_{2.5}$ have already provided insights into the mechanisms leading to those impacts. This study investigated how $PM_{2.5}$ exposure could contribute to heart attacks and strokes through activation of platelets, the key cells involved in blood clotting.

control monkeys, peripheral blood cells from exposed animals showed reduced response to microbial challenge, suggesting reduced ability to respond to infectious diseases. This reduction in immune response was correlated with increased airway hyper-responsiveness and reduced lung compliance in exposed female animals. There was evidence that these changes related to exposure-induced changes in genetic function. Using minimally invasive techniques, the investigators will test: (1) airway mechanics (lung function tests), and (2) the innate immune response to microbial challenge in the female animals that participated in the previous study, as well as in their offspring and their mothers. The results will contribute to development of health-protective ambient air quality standards, will increase our understanding of how air pollution affects infants, and will address the question of how early life air pollution exposures influence health later in life.

Level of Funding: \$300,000

LEVERAGING RESEARCH DOLLARS

ARB staff constantly seeks to keep research costs as low as possible. One example of leveraging funds is the study in this Plan to explore whether genetic effects of air pollution can be passed on to an exposed primate's offspring. This project will leverage other ongoing research at the California National Primate Research Center to perform cutting-edge air pollution research at relatively low cost.



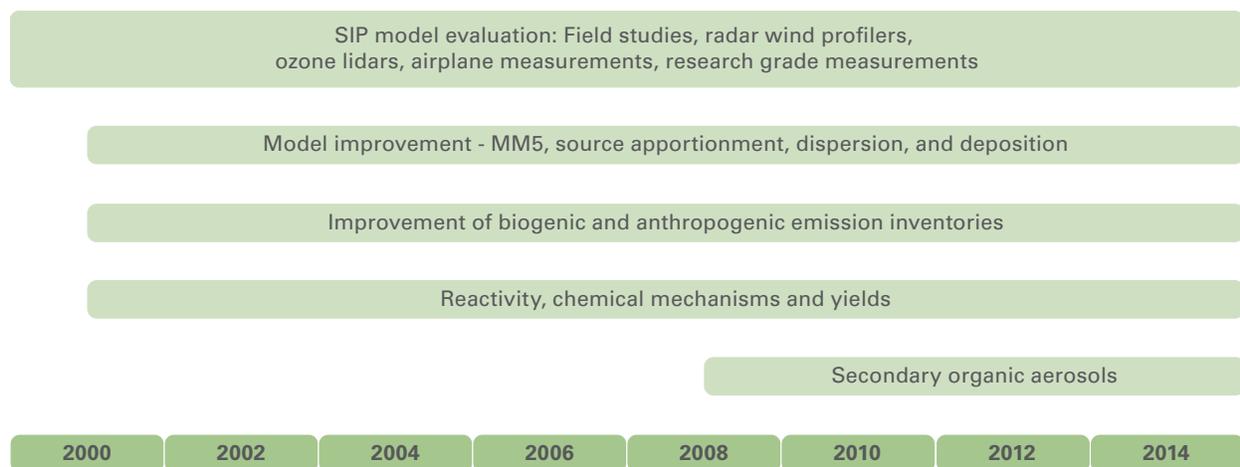
Atmospheric Science

ARB research continues to improve the scientific foundation for California's efforts to meet air quality standards and reduce the health risk from air pollution. To improve understanding of the nature of the air pollution problems in the South Coast and San Joaquin Valley Air Basins (Figure 5), the two areas still in nonattainment of NAAQS for ozone and $PM_{2.5}$, ARB invests in research to improve air quality models used in developing SIPs, and has funded and participated in field studies and other efforts to improve emissions inventories. Decision-makers rely on results from air quality models to provide predictions of future air pollution levels for use in developing required air quality plans and emission reduction strategies. Air quality models are also used to explore the relative effectiveness of reducing specific air pollutants, and their precursors, to meet air quality standards and inform policy decisions.

Air quality modeling systems can be improved with enhanced input data, updated modeling algorithms, and refinements to key components of the models such as chemical mechanisms. Air quality field studies have provided numerous opportunities to leverage other agencies' research investments. CalNex 2010 was an important field study that was designed by ARB and NOAA staff to answer 12 policy-relevant science questions on air quality, climate, and their nexus throughout California. ARB's contribution to this research effort was leveraged by major contributions from NOAA and dozens of independently funded academic research groups who joined the study. ARB also benefits when other agencies select California as a site for air quality field studies. The Carbonaceous Aerosol and Radiative Effects Study (CARES) study, funded by the U.S. Department of Energy, focused on the formation of carbonaceous particles in the Sacramento/foothills transport corridor, and, in January/February 2013, the San Joaquin Valley was one of the deployment locations for NASA's DISCOVER-AQ. ARB is supporting additional analysis of $PM_{2.5}$ components from the CARES study, and is funding ongoing research on $PM_{2.5}$ data generated during DISCOVER-AQ.

To improve air quality models, ARB continues to support updates to the Statewide Air Pollution Research Center (SAPRC) chemical mechanism for gases, and to develop the Statistical Oxidation Model (SOM) to provide multiple tools for modelers to address the complex problem of modeling secondary organic aerosol (SOA) formation. Organic aerosols are a significant component of $PM_{2.5}$ in California. The sources, impacts of existing controls, precursors, and processes that form SOA are the focus of several research projects. Increasing our knowledge of the processes associated with SOA (e.g., sources and mechanisms of SOA formation) will improve $PM_{2.5}$ modeling used in SIPs. ARB is also funding projects to address questions concerning organic compounds used in consumer products. These projects will answer questions about the actual impact of these compounds on ozone and SOA formation and the environmental fate of currently exempt "low-vapor-pressure" volatile organic compounds.

Figure 5. ARB research to support State Implementation Plan development since 2000



This year's two projects will improve ozone and PM_{2.5} modeling. Background ozone concentrations can make up a significant portion of measured ozone in California. Thus, understanding the variability in background ozone and the role it plays in ozone exceedances is vital to support ozone SIP modeling and plan development, especially in the face of more stringent ambient ozone standards. The second project will support updates to the particulate matter modeling for the South Coast and the San Joaquin Valley Air Basins needed to address the more stringent annual-average PM_{2.5} standard adopted by the U.S. EPA in 2012. This project will incorporate recent field observations of PM_{2.5} exceedances into improved models of the stagnation events leading to PM_{2.5} exceedances.



Improved Understanding of Pollution Sources and Atmospheric Processes Contributing to Ozone Exceedances in the San Joaquin Valley

Objective: Because health effects research has consistently led to more stringent ambient air quality standards for ozone, California must continue to achieve significant, new reductions in ozone precursor emissions. The SIP planning process must demonstrate how ground-level ambient ozone will be reduced over time to levels below the health-based standards. An important consideration in this process is evaluating the impacts of sources (both precursors and ozone itself) outside of California (e.g., global background, long-range transport, stratospheric to tropospheric exchange), as well as regional ozone and its precursors that remain in the atmosphere from the previous day (often in layers aloft that the routine, ground-based monitoring network cannot detect). This research effort focuses on better quantifying the frequency and magnitude that these sources contribute to exceedances of the ozone standard.

Concept: Intermittent field studies have documented instances of elevated ozone concentrations aloft (associated with global, regional, and local sources) that could potentially be relevant to ground level exceedances. There have been limited, episodic campaigns of instrumented aircraft flights sponsored by federal, state, and regional groups (e.g., the National Oceanic and Atmospheric Administration - NOAA, the National Aeronautics and Space Administration - NASA, the San Joaquin Valley Air Pollution Control District, the ARB) as well as weekly ozonesonde launches on the north coast of the State (sponsored by NOAA) to investigate ozone events and processes. Modeling exercises focused on the contributions of long-range transport and the stratosphere to ozone in the western United States (including California) have been conducted. These photochemical models rely on atmospheric boundary conditions specified by coarse resolution global models that have not performed well historically in California due to its complex terrain and meteorology.

This research effort is intended to address two policy relevant questions with ambient measurements. First, what is the frequency of enhanced ozone concentrations aloft being transported to California? Second, do these elevated ozone concentrations significantly impact ground-level ozone concentrations on days when ambient air quality standards are exceeded in the San Joaquin Valley?

This research effort consists of an initial phase, and a subsequent phase, if supported by the conclusions of the first phase. In the first part of this research, ARB staff will work with a contractor to critically review, analyze, and synthesize the available data and modeling to develop recommendations. The recommendations of minimal and comprehensive monitoring efforts that cost-effectively answer the above questions will focus on the San Joaquin Valley and the appropriate upwind coastal area. The recommended monitoring program design options will document the required locations and frequencies of measurements (e.g., ozonesondes, ozone lidar, aircraft) that will provide the necessary temporal and spatial resolution to support subsequent analytical and modeling efforts to answer the policy relevant questions. If the analysis and design project identifies a cost-effective measurement program, a contractor would be engaged to conduct the additional measurements, data validation, and initial analytical efforts.

Level of Funding: \$400,000 (*seeking collaboration with NOAA and local air districts*)

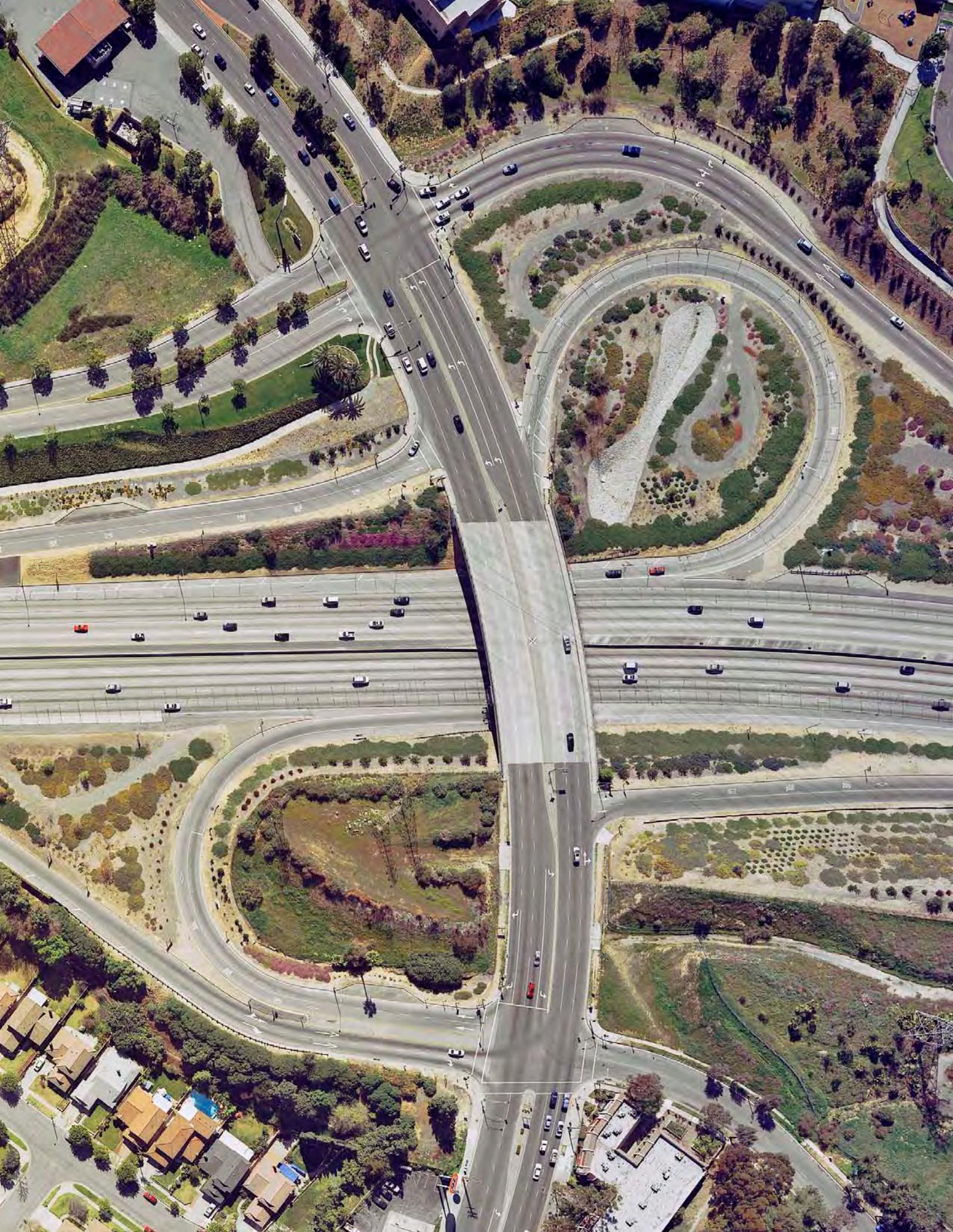


Investigation and Modeling of High PM_{2.5} Episodes in the South Coast and San Joaquin Valley Air Basins during Recent Years

Objective: Over the last decade, control strategies developed to reduce PM_{2.5} levels in the South Coast and San Joaquin Valley Air Basins have resulted in a significant decrease in PM_{2.5} concentrations. However, PM_{2.5} episodes with daily concentrations above the 24-hour PM_{2.5} standard still occur with peak concentrations routinely more than twice the standard. This research will use regional air quality modeling and analysis of observations to improve our understanding of PM_{2.5} episodes through investigation of the meteorological conditions and chemical processes that led to recent (2010-2014) PM_{2.5} episodes in the South Coast and San Joaquin Valley Air Basins, and contrasting these recent episodes to episodes that occurred during the California Regional PM₁₀/PM_{2.5} Air Quality Study (CRPAQS) in 2000-2001.

Concept: PM_{2.5} episodes with peak daily concentrations above the 24-hour NAAQS still occur, particularly during extended periods with stagnant weather conditions that are conducive to the build-up and formation of PM_{2.5}. These elevated PM_{2.5} episodes contribute to exceedances of the 24-hour and annual-average PM_{2.5} standards. Therefore, the nature of these episodes needs to be well understood in order to properly represent them in modeling simulations and develop effective control strategies. Key episodes between 2010 and 2014 will be selected for initial analysis using meteorological and air quality data from the routine monitoring network and ARB's detailed emissions inventory, supplemented with data from field studies such as CalNex and DISCOVER-AQ when possible, to develop a basic conceptual model(s) for the episodes. Meteorological conditions, emission sources/patterns, and chemical processes leading to the elevated PM_{2.5} events will be examined in detail. Select episodes will be contrasted to historical episodes that occurred during CRPAQS to determine if and how the underlying physical and chemical processes driving PM_{2.5} production and buildup have changed over time (e.g., fog events vs. drier conditions, changes in emissions). Representative episodes will then be modeled using advanced meteorological and regional air quality models and model performance will be evaluated using both qualitative and quantitative metrics. Updates to the modeling will be investigated in detail with a focus on improving the meteorological representation and chemical pathways contributing to PM_{2.5} formation, and updating the emission inventory.

Level of Funding: \$200,000



Transportation System

ARB has many research projects underway to support California’s efforts to reduce criteria pollutants and greenhouse gas emissions from the transportation system. These research projects seek to improve emissions estimates and to identify and improve strategies to cost-effectively reduce those emissions, and encompass fuels as well as the vehicles that move people and goods through the transportation system.



Sustainable Freight

ARB is working with a number of agencies on the development of strategies to transform California’s freight transport system to one that is more efficient and sustainable. This effort is designed to address local and regional public health goals, to reduce greenhouse gas emissions, and to support a vibrant California economy. A transition to zero- and near-zero emission technologies over the next several decades is needed to meet these ambitious goals. The effort involves collaboration among agencies and stakeholders encompassing air quality, transportation, energy, and economic issues. ARB has funded some research on this topic over the last few years (Figure 6) and future research on this topic is expected but not included in this year’s Plan.

Figure 6. ARB freight-related research since 2010

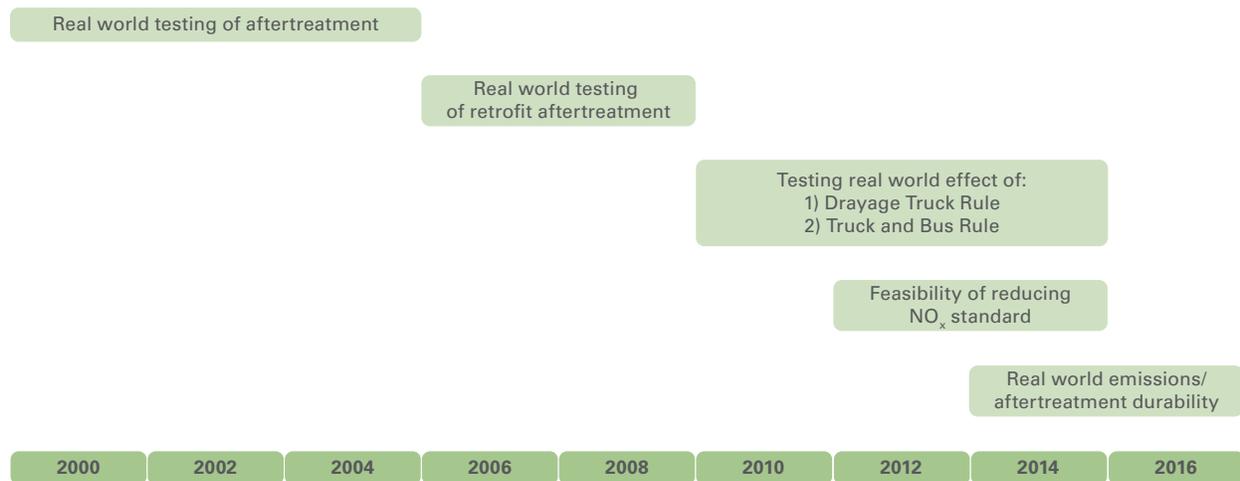


Trucks and Buses

California has a long and successful history of adopting technology-advancing vehicle emission standards to protect public health, built on a strong research foundation. ARB-funded research on emissions from trucks and buses is fundamental to the development of accurate emissions inventories and projections of future emissions. This research also supports strategies to meet NAAQS, reduce health risk from toxic air contaminants, and meet GHG emission reduction goals. ARB-funded research on vehicles and associated emissions also monitors the effectiveness of emission reduction strategies to ensure that the expected air quality and public health benefits are achieved.

Much of ARB’s recent research on heavy-duty (HD) vehicles and their emissions (Figure 7) has focused on tracking the results of regulatory efforts to meet the goal of the Diesel Risk Reduction Plan, adopted in 2000, to reduce diesel PM emissions by 85 percent by 2020. Research on diesel emissions has included research on the effect of in-use rules for heavy-duty diesel vehicles (i.e., Drayage and Truck and Bus Rules), the durability, degradation, and failure rates of exhaust aftertreatment devices (such as Diesel Particulate Filters [DPFs] and Selective Catalytic Reduction [SCR]) that reduce NO_x (a product of combustion that contributes to the formation of smog) and diesel PM, and the real-world efficacy of NO_x controls. Research is also underway to explore the ability of current diesel control technology to achieve NO_x reductions beyond the current emission standards, which will be needed to meet increasingly stringent NAAQS over the next decade and to inform future policy decisions to best meet these standards.

Figure 7. ARB heavy-duty vehicle emissions research since 2000



ARB’s Truck and Bus Rule requires that nearly all heavy-duty diesel vehicles operating in California be equipped with diesel particulate filters by 2014, and the 2010 HD engine emissions standard for NO_x will result in the use of SCR in most late model HD diesel vehicles. ARB has research projects in place to evaluate how well DPF and SCR aftertreatment perform in the real world over time. This research will also address the issue of cold starts and low-load operation in the HD diesel fleet since SCR requires minimum temperatures of almost 200°C before NO_x can be reduced. Results from this work will determine the overall effectiveness of SCR in reducing NO_x from heavy-duty diesel vehicles.

Current research also includes the investigation of the long-term durability and degradation rates of DPF and SCR. This will be accomplished using measurements of emissions from the in-use fleet in tunnels and at weigh-in-motion stations in California. In-house research also includes the deployment of a mobile measurement platform. The mobile measurement platform measures key gaseous and particle species, including PM_{2.5}, black carbon, carbon dioxide, and NO_x, with high spatial and temporal resolution. This effort has shown that emissions of black carbon (a component of PM and a key contributor to global warming) and NO_x from heavy-duty diesel trucks on a port truck dominated freeway were reduced by 40 percent or more from 2009 to 2011, with preliminary results suggesting decreases in pollution in nearby neighborhoods as well. In the coming years, this research tool will help evaluate the ability of sound walls to reduce the impact of traffic emissions in nearby neighborhoods, and the effect of the built environment on air pollution exposures.

Additional research on in-use emissions from HD vehicles is needed to adequately understand deterioration and failure rates of DPF and SCR systems and to better understand real-world NO_x emissions from SCR-equipped engines. The projects below could provide the foundation for a revision of certification procedures, such as the not-to-exceed (NTE), in-use compliance, warranties, and, coupled with economic analysis, an HD vehicle inspection and maintenance (I/M) program.



Expand Measurements of Real World Emissions Rates to Assess Deterioration and Determine Cause of Any Failures

Objective: New heavy-duty engine standards and ARB's Truck and Bus Regulation are leading to the introduction of exhaust after-treatment devices to reduce emissions of PM and NO_x from on-road heavy-duty diesel engines. The objective of this program is to increase the geographic and temporal coverage of our current in-use emissions measurement research program aimed at quantifying emission benefits, identifying unintended consequences, and assessing degradation and failure rates of emissions control technologies.

Concept: The introduction of new engine emissions standards has resulted in a substantial decrease in PM and NO_x emissions that will continue over the coming years. The reductions are achieved using aftertreatment devices such as DPF and SCR to reduce PM and NO_x respectively. Due to recent introduction of these devices, especially SCR, little data exists on their deterioration and failure rates. Trucks with degraded or malfunctioning aftertreatment devices can have emissions that are orders of magnitude higher than a truck meeting certification standards, and it is important to examine the real-world on-road performance. ARB is conducting ongoing studies to measure individual emissions rates from thousands of trucks over a course of multiple years at the Port of Los Angeles, the Cottonwood CHP Inspection Facility, and the Caldecott Tunnel. The data is used to assess compliance with fleet rules, and to assess the effectiveness of aftertreatment devices including their durability and degradation. While these studies are providing useful data, additional sampling campaigns will be needed at these sites to increase temporal coverage, and at other sites such as the San Joaquin Valley to increase geographic coverage. Increased coverage by these programs would also better support enforcement activities and the design of heavy-duty inspection and maintenance (I/M) programs currently being developed by ARB. New sites will be identified in conjunction with ARB staff to perform additional sampling campaigns spaced out to fill in spatial and temporal gaps. PM, NO_x, black carbon (BC), carbon monoxide (CO), and carbon dioxide (CO₂) need to be measured from thousands of trucks, with truck identification information determined using license plate capture. The data are used to develop emission factors from individual trucks categorized by model year. The results from this study will help assess the emissions benefits, the degradation rates, and the failure rate of aftertreatment devices, and will be used to update emission inventories and guide rule development. The results will also assist the heavy-duty I/M program to target high emitters and evaluate the cause of aftertreatment failure.

Level of Funding: \$600,000



Certification and In-Use Compliance Testing for Heavy-Duty Diesel Engines to Understand High In-Use NO_x Emissions

Objective: The proposed study investigates the differences between NO_x emissions from model year 2010 or newer heavy-duty diesel engines (HDDE) in-use, compared to the emissions measured from the same engines during certification. This study will also evaluate in-use compliance requirements to control in-use NO_x emissions from heavy-duty diesel vehicles (HDDV). The results will provide insight into current certification and in-use compliance procedures and whether they need to be updated to help meet ambient air quality targets for ozone and PM in California.

Concept: A heavy-duty diesel engine needs to be certified to emission standards before being integrated to a vehicle chassis for commercial use. Engine certification tests are conducted on an engine dynamometer over the Federal Test Procedure (FTP) cycle that represents real-world HDDV driving patterns. Because engine dynamometer testing is very time-, and resource-intensive, in-use testing of HDDV emissions is carried out on a chassis dynamometer over the Urban Dynamometer Driving Schedule (UDDS), which is similar in speed and torque to the FTP engine dynamometer cycle, and on-road using Portable Emission Measurement Systems (PEMS). Because speed and torque over the FTP cycle are comparable to speed and torque over the UDDS cycle, the NO_x emissions over the FTP cycle should be comparable to the NO_x emissions over the UDDS cycle. However, recent studies have shown that NO_x emissions measured from 2010 in-use HDDV on chassis dynamometers over the UDDS cycle were substantially higher than the certification results and even the certification standard of 0.2 g/bhp-hr NO_x measured on engine dynamometers. This discrepancy needs to be investigated.

In addition to meeting engine certification standards, a diesel engine integrated into a vehicle chassis for commercial use needs to comply with in-use HDDV not-to-exceed (NTE) testing requirements and emission limits. The NTE requirements are intended to ensure that HDDV emissions are controlled over a wide range of speed and load, especially during sustained high load, steady-state operations. But there are a host of speed, load, temperature and duration requirements that must be met before NTE emission limits are applicable, which exclude a substantial fraction of vehicle activity and NO_x emissions from having to meet the NTE emission limits. The NTE requirements are designed mostly to prevent off-cycle emissions from high-speed, high-load, line-haul operation, such as steady-state cruise on freeways. Those requirements do not control emissions from frequent stop-and-go, low-speed, low-load, operations such as local goods delivery operation, which also contribute a substantial fraction of vehicle activity and NO_x emissions. This project will investigate potential modifications to the NTE operating limits, and potential for development of new in-use testing methods and requirements, that would increase the effectiveness of in-use testing programs in controlling NO_x emissions from real-world HDDV operations.

Level of Funding: \$500,000



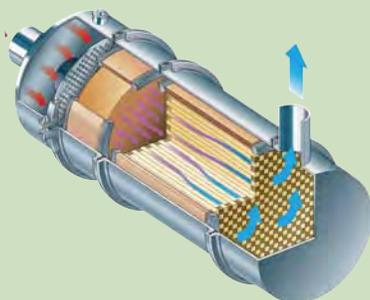
Design, Demonstration, and Economic Analysis of a Heavy-Duty Vehicle Emissions Verification Program Prototype



Objective: This study will design, field test, and assess the cost effectiveness and economic impacts of a heavy-duty vehicle emissions inspection/maintenance (I/M) program. Study findings will support SIP development and ARB regulatory program design for the purpose of meeting NO_x and PM standards in non-attainment regions.

Concept: California's tailpipe emissions I/M (or "Smog Check") program for light-duty vehicles has evolved substantially in its methods and design to improve environmental effectiveness and manage costs. This study will apply lessons learned by California's light-duty Smog Check program and by heavy-duty verification programs in other jurisdictions to the design, field-testing, and economic assessment of an optimally cost-effective and technologically feasible heavy-duty I/M program for California.

RESEARCH HIGHLIGHT



ARB-funded research has evaluated technological options for reducing diesel emissions such as diesel particulate filters (shown in the illustration), and selective catalytic reduction and lean NO_x catalysts for NO_x control. Nitrogen oxides are typically created during combustion processes and are major contributors to ozone, PM_{2.5}, and acid deposition.

The California DMV and the Bureau of Automotive Repair's Smog Check program have decades of program implementation data and an extensive literature focusing on program design, implementation, and effectiveness. Similar programs in other states and countries offer additional raw material for the design of a heavy-duty vehicle testing program for California. Recent Smog Check program advances, such as the elimination of tailpipe sampling in favor of on-board diagnostic (OBD) data collection will be evaluated, as will alternative methods of detection, verification, and compliance enforcement.

After a comprehensive review of the literature and analysis of I/M program implementation results and alternatives, the study team will design a heavy-duty I/M program prototype. Criteria for program design will include practicality, technological feasibility, and cost-effectiveness for both regulated and regulatory entities. Field testing of the program prototype will enable fine-tuning of program design and provide empirical data to support economic and environmental impact analysis. Economic analysis will assess the annual and long-term statewide economic impacts of a scaled-up program based on the results of field testing, and will integrate the latest economic projections for the on-road heavy-duty truck transportation sector. Study findings will support design and development of a regulatory program for on-road heavy-duty vehicle emissions verification.

Level of Funding: \$500,000

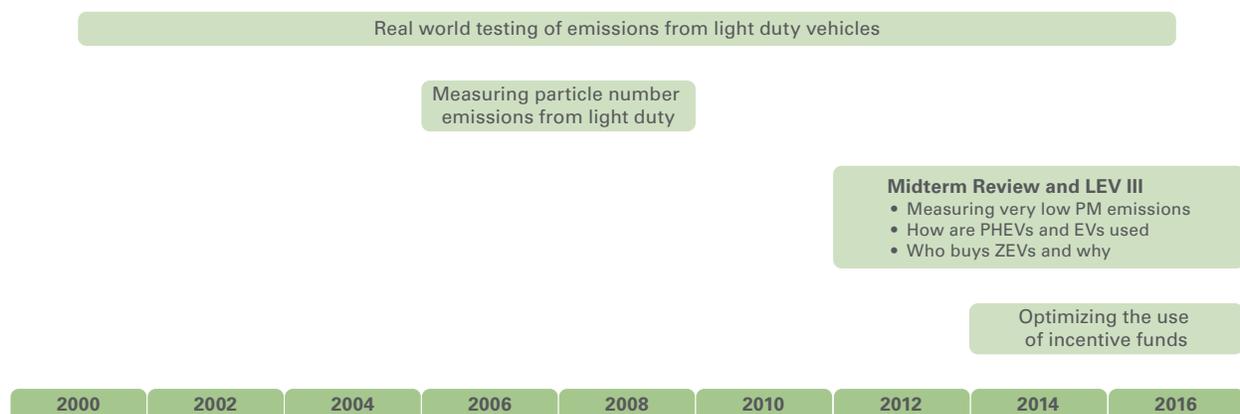


Passenger Vehicles



In January 2012, the Air Resources Board adopted the Advanced Clean Cars program to reduce emissions from passenger vehicles in accordance with California's long-term air quality and climate goals. The program combines the control of ozone, PM, and GHGs, and requirements for greater numbers of zero-emission vehicles (ZEVs) into a single package of standards. As with other components of the transportation system, ongoing research on passenger cars and trucks improves emission inventories and projections, identifies, and improves, strategies to reduce those emissions, and tracks progress as strategies are implemented. ARB-funded research has improved understanding of real-world emissions from the current fleet and has resulted in new measurement techniques for determining very low levels of PM emissions. Additional research is investigating the long-term trend in measurements of emissions using remote sensing from light-duty vehicles in Los Angeles and elsewhere, which will provide an understanding of how well the emission controls continue to perform in vehicles subject to ARB's Low Emission Vehicle standards (LEV I and LEV II) (Figure 8).

Figure 8. ARB research on passenger vehicles since 2000



More recently, the focus for passenger vehicle research has turned to understanding market forces and consumer acceptance of new vehicle technologies, such as plug-in hybrid electric vehicles (PHEVs) and ZEVs, that will be on the road in increasing numbers as auto manufacturers meet the Advanced Clean Cars standards for model years 2017-2025. The Advanced Clean Cars program will undergo a “Midterm Review”, when the appropriateness of the ZEV targets and GHG and PM standards will be evaluated. ARB has initiated a number of research projects to inform that evaluation, including research that will improve understanding of the factors which influence car buyers to purchase (new or used) advanced technology vehicles, analyze the driving and charging behavior of electric vehicle drivers, and quantify the potential emission benefits of vehicle load reduction. Research in these areas is being coordinated with U.S. EPA and the National Highway Traffic Safety Administration.

Further research is needed as plug-in vehicles age and new vehicle technologies enter the market to evaluate the real world emission benefits of these vehicles. The State also invests in clean vehicle rebates to encourage the growth of the market for ZEVs, and more research is needed to optimize the return on those incentive dollars.



Tracking the Emissions Benefits of Older PEVs and New ZEV Technologies



Objective: The emissions benefits of advanced technology vehicles depend on how drivers use and charge them, and the extent to which cleaner vehicles are used for trips that would otherwise have been made using higher emitting vehicles. The objective of this research is to characterize how drivers are using and charging/refueling plug-in electric vehicles (PEV) and fuel cell vehicles (FCV) over time and to improve estimates of the real world emission benefits of these vehicle technologies.



Concept: Zero emission vehicles, including PEVs and FCVs, are expected to play a major role in achieving California’s long-term air quality and climate goals. How consumers use and charge/refuel their advanced technology vehicles is not well understood, especially given the increasing diversity of vehicle designs and driving ranges. Vehicle charging/refueling and usage behavior will likely vary depending on the type of vehicle technology (e.g., different battery capacities and architecture) or age of the vehicle (e.g., in response to battery deterioration). ARB has begun to acquire data from a few plug-in vehicle types from which staff will estimate the share of a vehicle’s miles traveled that emits zero tailpipe emissions and improve our understanding of how PEVs are used in a household context over time in a systematic and comparable manner. This project will build upon this ongoing research and expand it to include new plug-in and fuel cell vehicle technologies as they enter the market, and to track middle-aged plug-in vehicles. The researcher(s) will recruit a stratified sample of plug-in electric and fuel cell vehicle-owning households and instrument all vehicles within the household to evaluate the emissions profile of total household vehicle miles traveled and charging/refueling behavior. Results of this research will be useful to refine long term projections of emissions benefits from PEVs and FCVs, will provide insight into electricity demand and grid management as well as siting of new public charging and refueling infrastructure, and will inform future decisions by ARB policymakers on the treatment of these vehicles by various ARB programs, such as incentives, durability requirements, and vehicle crediting.

Level of Funding: \$650,000



Maximizing the Air Quality, Climate, and Social Equity Benefits of Light-Duty Vehicle Incentive Programs



Objective: ARB provides significant funding for financial incentives to encourage transformation of California’s light-duty vehicle fleet for both the adoption of near- and pure-zero emission vehicles and the retirement of older high emitters. The objective of this research is to comprehensively evaluate the costs and benefits of various options for modifying these incentives, both in the near- and long-term, in order to maximize their ability to accelerate advanced technology adoption to provide air quality, climate, and social equity benefits.



Concept: Zero emission vehicles, including PEVs and FCVs, are expected to play a major role in achieving California’s long-term air quality and climate goals. Projections of the growth of the market for ZEVs are somewhat uncertain, but some form of financial incentive is likely to be needed for a number of years to build a sustainable market. ARB has been providing incentives to California consumers to encourage them to retire old, high-emitting vehicles and to support the uptake of new, low- and zero-emission vehicles, through the Enhanced Fleet Modernization Program (EFMP) and the Clean Vehicle Rebate Project (CVRP), respectively. As the market for clean vehicles grows, incentives will need to evolve to ensure they continue to make the best use of limited State funds. ARB is currently funding several research projects to analyze the market for new and used ZEVs, and the role that the financial incentives, charging infrastructure, and other benefits (e.g., high-occupancy vehicle [HOV] lane access, free parking or charging for ZEVs) play in driving that market. There is also a growing body of literature examining the efficacy and environmental benefits of incentives for scrappage and clean vehicle purchases.



This project will build on existing and ongoing research by analyzing the current and potential longer-term development of the clean vehicle market and will examine vehicle purchase and replacement patterns in response to various forms of financial incentives. The researcher(s) will also evaluate how incentives interact with potential ZEV advancements, such as lower costs and increased vehicle performance, new vehicle model offerings, and various consumer demographics, to drive vehicle purchase decisions. This project will investigate how varying forms and amounts of incentives for vehicle purchases can most effectively encourage adoption of the cleanest vehicle technologies. This will include an evaluation of the relative efficacy of various forms of financial incentives, such as rebates, registration fee reductions, sales tax exemptions, subsidized purchase financing, etc. This project will also evaluate the effectiveness of additional incentives that target low-income communities, such as access to alternative forms of transportation, ZEV education programs, and financing programs. The results of this study will inform decisions about the future of incentive programs in support of widespread ZEV adoption across California and in disadvantaged communities.

Level of Funding: \$500,000



Low-Carbon Fuels

ARB’s current fuels-related research supports the implementation of ARB’s Low Carbon Fuel Standard (LCFS), which calls for a reduction of at least 10 percent in the carbon intensity of California’s transportation fuels by 2020. The LCFS incentivizes the production and sale of low carbon-intensity transportation fuels by establishing a set of performance standards in the form of declining carbon-intensity levels that fuel producers and importers must meet each year for their fuel pools beginning in 2011. The research program began with an investigation of the air quality impacts of projected biomass and biogas utilization in the San Joaquin Valley and South Coast Air Basins. Two projects on the commercialization potential of alternative fuels are examining the potential to produce renewable natural gas and drop-in fuels at the commercial scale in California. Research is also underway to develop life-cycle analysis data that will be used to create novel LCFS pathways. Research on fuel infrastructure is focused on how current fuel

infrastructure can be developed to accommodate zero and near-zero carbon fuels when they are ready to be produced at the commercial scale (Figure 9). These existing projects address ARB's immediate research needs, and no additional projects are included in this year's Plan.

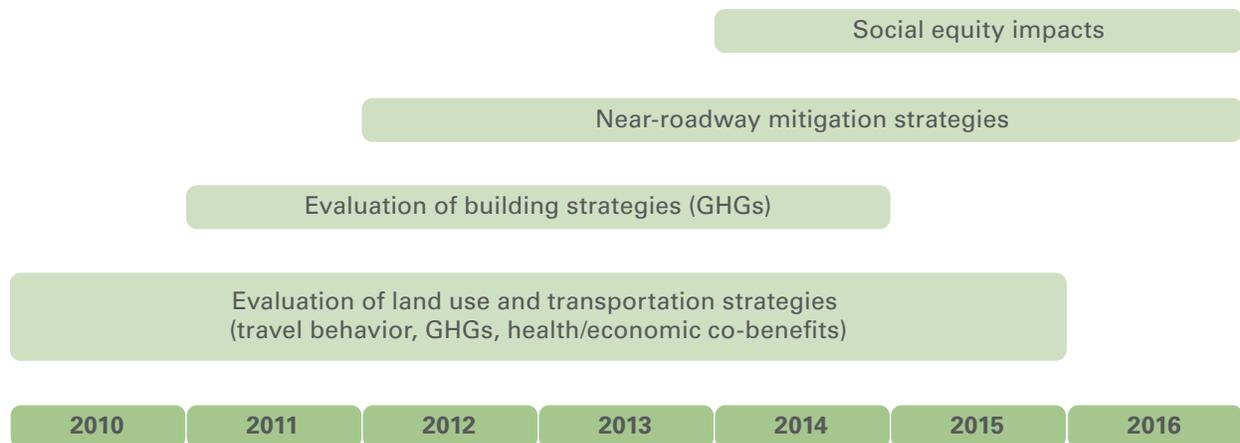
Figure 9. ARB fuels research since 2012





Sustainable Communities

Figure 10. ARB sustainable communities research since 2010



ARB has a variety of research projects underway to support California’s efforts to reduce greenhouse gas emissions from land use, transportation, and buildings. ARB’s sustainable communities research supports implementation of Senate Bill 375 (SB 375), the Sustainable Communities and Climate Protection Act of 2008, and helps pave the way for the 2050 climate goal. ARB research underway in this area covers a wide range of activities. Over the last few years, the Board has sponsored projects that address building energy use, consumer behavior, and reducing vehicle miles traveled and energy use through land use and transportation planning (Figure 10). Results from these projects will be translated into products that will assist local governments, planners, and other practitioners to further reduce GHG emissions from the built environment.

As California cities build more compact, transit-oriented development, the health and social equity implications of this type of development should be assessed in order to identify and address any unintended consequences. A recently launched project will assess how more compact development may alter air pollution exposure of pedestrians and transit users near traffic-related pollution sources, and examine how urban designs and traffic management might mitigate such exposures. ARB is also conducting research to evaluate the potential for displacement of lower-income residents as a result of compact, transit-oriented development investment. This research will also investigate possible solutions (if the results suggest they are needed). Several research projects are underway to support updates to the building standards and better quantify greenhouse gas reductions of green buildings. Current research is also looking to reduce GHGs from the building sector by investigating how Californians interact with building technology in the residential and commercial sector.

This year’s focus is evaluation of sustainable communities strategies. The projects will document land use changes in response to SB 375, study changes in travel demand co-benefits associated with affordable housing in transit-oriented developments, and inform future building-related strategies to meet the State’s long-term climate goals by evaluating the technical feasibility of zero or near-zero carbon buildings.



Tracking Land Use Changes That Support Sustainable Communities

Objective: Since Senate Bill 375 (SB 375) was enacted in 2008, regions across the State have been enacting plans to better integrate land use, housing, and transportation planning with the goal of reducing travel demand and subsequent greenhouse gas emissions. There is a need to understand the extent to which shifts in regional and local planning are resulting in actual changes in land use across the state through time.

Concept: SB 375 requires Metropolitan Planning Organizations (MPOs) in California to develop a Sustainable Communities Strategy (SCS) as part of their federally mandated Regional Transportation Plan (RTP), to demonstrate how, largely through reduced travel demand and vehicle miles traveled, they will meet regional passenger vehicle greenhouse gas reduction targets set by ARB. As California regions pursue more compact, transit-oriented development (TOD) to meet these targets, there is a need to track progress toward land use improvements through time throughout California. To do this, the project will establish a baseline and select and develop appropriate land use indicators that can be used to measure change through time. Land use change indicators will be developed and mapped using Geographical Information Systems for the entire State. The indicators must rely on reliable data that is readily available now and anticipated to be so in the future. Potential indicators include: average residential and employment densities; new housing start mix (e.g., percent new dwellings that are multi-family vs. small lot attached vs. large lot detached); land use mix; and changes in housing affordability relative to local wages. Potential data sources could include parcel level data, satellite aerial imagery, and/or building permits. The results of this study would provide a baseline for the measurement of future land use changes that align with the goals of SB 375.

Level of Funding: \$150,000



EJ Evaluation of Impact of Transit-Oriented Affordable Housing on Travel Demand



Objective: Preserving and building affordable housing in transit-oriented developments (TOD) is a potential travel demand reduction strategy that has not been formally evaluated in the literature. This research would evaluate the travel demand reduction benefits, as well as the economic, health, and well-being co-benefits to residents of building affordable housing in transit-oriented development areas.



Concept: The placement or preservation of affordable housing opportunities near public transit has been referred to as a strategy to reduce vehicle travel demand. While no formal or empirical research has been conducted to evaluate the travel or greenhouse gas impact of placing affordable housing in transit-oriented development, it is thought that placing traditional transit-users near public transit will have a greenhouse gas benefit over designating housing for higher-income, car-owning households. To support these efforts, the California State Budget allocated \$130 million of the Cap-and-Trade proceeds to support an Affordable Housing and Sustainable Communities Program. This strategy not only has potential air quality and climate benefits, it also may have economic, health, and other impacts on residents. Currently however, there is very limited research on the impact of transit-oriented affordable housing on travel demand and other impacts.

This research would provide a first of its kind empirical evaluation of the travel demand reduction benefits, as well as economic, health, and well-being impacts of select affordable housing projects in California. One possible project design could be to compare the travel behavior of transit-oriented affordable housing residents to that of market-rate residents, taking methodological considerations for capturing travel behavior of each group prior to living in a highly transit-accessible area. In other words, the methodology should take care to develop a robust, defensible counterfactual. This project will combine quantitative travel behavior analysis with qualitative research exploring health and other impacts to residents. The results

of this research can provide data and information to city planning and housing departments on the efficacy of transit-oriented affordable housing as a Sustainable Communities Strategy. In addition, the results can also provide information to help in the evaluation of projects funded by Cap-and-Trade auction proceeds.

Level of Funding: \$300,000



Zero Carbon Building Technical Feasibility Study

Objective: Zero Carbon Buildings were identified in the Scoping Plan Update as the next generation of buildings that will contribute significantly to achieving California’s 2050 climate goal. This research will explore the technical feasibility of zero or near-zero carbon building which will support the development of State goals and a policy and programmatic path towards transition to zero carbon building.

Concept: California is on track to achieving the 2020 GHG target, however much more must be done long-term to ratchet down emissions to a level needed for climate stabilization. The First Update to the Scoping Plan identified future actions and policies that can help California achieve our post-2020 climate goals, including advancing Zero Net Energy buildings to be Zero Carbon Buildings. A zero or near-zero carbon building would generate nearly no greenhouse gas emissions over the course of a year from the energy, water, waste and transportation impacts of the building. Zero carbon buildings will utilize high performance design solutions, generate renewable energy on-site, and employ other techniques to eliminate or offset the GHG emissions associated with these impacts. To date, no research has been conducted on this novel concept.

Research is needed to evaluate the technical feasibility of achieving zero or near-zero carbon buildings for both the residential and commercial building sectors. This assessment would, at a minimum, include:

- Identification of high-performance design solutions, technologies, and building operation strategies to help achieve zero/near-zero emissions across the sectors
- Simulate building performance utilizing these strategies to determine zero carbon feasibility
- Evaluate extent to which zero-carbon buildings would surpass existing green building codes
- Estimate construction cost premium and return on investment associated with zero-carbon building, to the extent possible

The results of this study would be used to assess the practicality and appropriate timeframe for a zero or near-zero carbon building State policy or program.

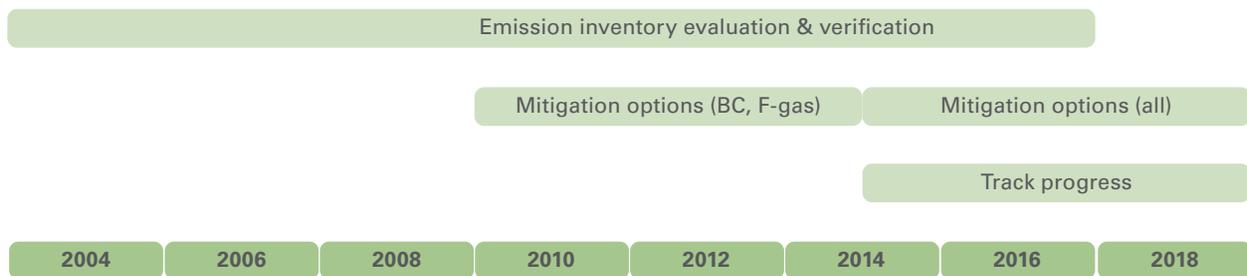
Level of Funding: \$400,000



Short-Lived Climate Pollutants and Nitrous Oxide

ARB’s efforts to meet California’s climate goals encompass a variety of GHGs. To verify and improve the State’s GHG emission inventory and identify promising emission reduction strategies and policies, ARB funds research on a variety of GHGs that have higher global warming potentials (GWP) than CO₂, including short-lived climate pollutants (SLCPs) and nitrous oxide (N₂O) (Figure 11). SLCPs are climate forcing agents that have a relatively short lifetime in the atmosphere (days to a few decades), whereas N₂O has an atmospheric lifetime of 120 years. ARB’s research on SLCPs focuses on black carbon (BC; a component of PM and a key contributor to global warming), methane (CH₄; the principal component of natural gas) and fluorinated gases (F-gases), such as hydrofluorocarbons (used in refrigeration and air-conditioning systems), which often have high global warming potential (GWP).

Figure 11. ARB short-lived climate pollutant and N₂O research since 2004



Using California’s existing GHG monitoring network, ARB is investigating the sources and trends of CH₄ emissions in Los Angeles by complementing a five-year GHG monitoring project funded by the National Institute of Standards and Technology. The initial analysis, utilizing the monitoring network data, suggests an underestimation of CH₄ and N₂O, but further work is necessary to confirm the results and identify the source(s) of the poorly characterized emissions. ARB’s mobile monitoring platform was successfully deployed to measure CH₄ emission rates at a landfill and a natural gas compression station, and further work is planned to use mobile GHG instruments to better characterize sources of CH₄ and N₂O and assess local impacts of implemented regulations. Some of the sources to be monitored may include oil and gas production sites, natural gas pipelines, wastewater treatment plants, landfills, and composting facilities.

ARB’s recent research demonstrated a 90 percent reduction in black carbon since the 1960s, and the importance of brown carbon. An ongoing study is investigating brown carbon sources and climate forcing in California. Current research on F-gases is addressing emissions from landfilled insulating foam and is examining the cost-effectiveness and technical feasibility of using low-GWP refrigeration systems in California. The results will be used to inform refrigeration and waste foam management policies, and to update the carbon offset protocol that encourages responsible destruction of these materials.

ARB has focused its N₂O research program on nitrogen fertilizer use in California cropping systems, including developing mitigation strategies. ARB, the California Energy Commission, and the California Department of Food and Agriculture are currently conducting field experiments in a number of crop production systems, characterizing effects of different nitrogen management practices on N₂O emissions, especially those with mitigation potential. ARB is also funding

research to expand a geochemical model called DeNitrification-DeComposition (DNDC), which is widely used for simulating GHG emissions from agricultural ecosystems, to quantify the mitigation potential of N₂O from California agricultural soils.

Additional research is needed to confirm research results suggesting that emissions of CH₄ and N₂O in California are underestimated, and to identify the source(s) of the poorly characterized emissions. California dairy operations are a major source of greenhouse gases of methane and nitrous oxide, and the two projects below will improve emissions estimates and identify mitigation opportunities for manure management and enteric fermentation.



Continuation of Greenhouse Gas Monitoring in California

Objective: The objectives of this project are to continue GHG measurements at the Walnut Grove Tower for an additional three years which will allow for more comprehensive inverse modeling to evaluate the statewide CH₄ and N₂O inventories using a larger dataset (5 years+) to reduce the uncertainty.



Concept: ARB has been operating a statewide GHG monitoring network since 2010, which in association with an inverse modeling research contract, has suggested an underestimation in the statewide CH₄ inventory by a factor of 30 to 70 percent, and is pointing to N₂O underestimation by an even larger fraction. However, these results were based on data from a limited number of stations operating for a short period of time (in some cases, only over a year of operation), and therefore have certain inherent uncertainties in the results. Since the previous studies, the statewide network has been expanded to over seven stations operated by ARB, and two additional stations operated by ARB's research contractors (Walnut Grove and San Bernardino), all of which can be useful in better identification of sources and reducing the uncertainty in inverse modeling exercises.



This research project will continue measurements at the Walnut Grove Tower for an additional three years (a critical station for inverse modeling efforts), and will include more comprehensive data analysis for evaluating the statewide CH₄ and N₂O inventories using a larger dataset (five years or more) to reduce the uncertainty. The research will focus on emission sources in the San Joaquin Valley and will improve estimates of sector specific emissions such as dairies, oil and gas operations, and landfills.

Level of Funding: \$200,000



Characterize Additional and Uncertain N₂O Emission Sources

Objective: Several N₂O emission studies involving atmospheric monitoring and inverse modeling indicate that the current California N₂O inventory, based on international greenhouse gas emission protocols, may be underestimated, perhaps up to three-fold. This project will conduct field measurements at selected sites to monitor and quantify N₂O emissions from potentially missing or underestimated N₂O sources and identify mitigation opportunities to reduce N₂O emissions from these sources.



Concept: Potential missing or underestimated sources of N₂O are those that are suspected or known sources of emissions, but that lack sufficient field data to allow for accurate emission estimates. Their emissions thus may be missed or significantly underestimated in the current California inventory. These sources include landfills, sewage systems, ocean upwelling, nurseries, golf courses, etc. Preliminary in-house studies have detected spikes of N₂O fluxes from several of the listed sources. Further research is necessary to verify emissions estimates from these sources so that they can be accurately reflected in California's current inventory.

Due to the diversity of potential missing and underestimated sources, this project will focus on sewage systems, landfills, and urban landscape (particularly golf courses where high fertilizer use and irrigation depth would favor N_2O production). Preliminary data from ARB in-house studies, indicating significant emissions from sewage systems, landfills, as well as golf courses are consistent with limited observations reported in the literature. However, N_2O emissions are known to vary by type and composition of waste and site-specific conditions. Characterizing urban landscape sources will also include investigating urban fertilizer sale and use data in California. The project will identify several representative landfills, sewage systems, and urban landscape sites in California. Monitoring plans will then be developed to capture the spatial and temporal emission patterns of N_2O from these selected sources. Potential mitigation opportunities will also be identified. The project will help resolve the discrepancy of N_2O emission estimates and will inform future efforts to reduce N_2O emissions in California.

Level of Funding: \$400,000 (possible co-funding from CDFA for fertilizers)



Characterize Physical and Chemical Properties of Manure in California Dairy Systems to Improve GHG Emission Estimates

Objective: California dairy operations are a major source of GHGs, including CH_4 and N_2O . The emissions estimates in the California inventory, however, rely on assumptions based on global or national default values due to lack of California-specific information. The objectives of this project are to determine the chemical and physical characteristics of California dairy manure and manure management practices and to characterize their relationship with GHG emissions.

Concept: California livestock is modeled to excrete hundreds of kilotons of nitrogen (N) annually in the form of livestock manure, an amount equivalent to more than half of the annual chemical nitrogen fertilizer sales in the state based on the fertilizer tonnage data. Roughly half of the livestock manure nitrogen is produced from dairy farms (dairy cows and heifers). The ultimate fate of dairy manure nitrogen, and emission factors for manure, need further study. According to the current California GHG inventory, using default national or global emission factors, manure management contributes roughly 1/3 of statewide N_2O emissions (~4-5 $MMTCO_2e$) and about a quarter of statewide CH_4 emissions (~10 $MMTCO_2e$). Despite its importance, N_2O and CH_4 emissions from manure management have received little attention in research. Field measurements to characterize manure in representative dairy farms, including manure collection and storage facilities (bedding, gutters, lagoons, etc.), are needed to understand manure-related N_2O and CH_4 emissions and to refine emission factors associated with various manure management practices. The results of this project will be used to develop California-specific model inputs to refine the California GHG inventory.

Level of Funding: \$400,000



Characterize California-specific Cattle Feed Rations and Improve Modeling of Enteric Fermentation for California's GHG Inventory

Objective: The objective of this study is to improve California's GHG inventory modeling methodology for cattle enteric fermentation by collecting California-specific feed data, then modeling that data compared to the current inventory's use of a national default model as well as other potential models.

Concept: California dairy operations are a significant source of GHGs. Enteric fermentation (bacterial decomposition of feed in ruminant stomachs) emits GHGs. Enteric fermentation from cattle alone contributes nearly 30 percent of the statewide methane emission inventory. Total mixed rations fed to California cows have not been widely surveyed, so feed data must first be collected in order to more accurately model California-specific emissions. The research will be conducted in coordination with the California Department of Agriculture.

Level of Funding: \$100,000



Economic Assessment

ARB conducts ongoing economic assessments of its proposed and current programs and policies to evaluate the impacts of air quality and climate strategies on California’s economy (Figure 12). For example, prior to the implementation of regulatory measures under AB 32, the anticipated micro- and macro-economic costs of the suite of regulatory measures were estimated. The 2013 Scoping Plan Update includes new strategies and recommendations. It promises further economic analysis for the next update in 2018 to evaluate the Plan’s impacts on the California economy including: further impact analysis and how the Plan measures and regulations have impacted different economic groups (distributional impacts).

Figure 12. Economic assessments of AB 32 impacts on California’s economy since 2008



A project identified in the 2013 Scoping Plan Update will evaluate strategies to reduce emissions of F-gases beyond current ARB and U.S. EPA regulations.



Evaluation of a Variety of F-Gas Emission Reduction Strategies

Objective: F-gas emissions, primarily HFCs, are the fastest growing source of greenhouse gases in the State, nationally, and globally. There is a need to evaluate the effects of various mitigation options – such as command and control, market mechanisms, and incentive programs – on emissions, costs, and distributional impacts that may result from an expansion of existing F-gas emission reduction strategies.

Concept: As ozone-depleting substances are replaced by HFCs, their use continues to increase. Even with current ARB regulations in place, HFC emissions are projected to more than double between 2014 and 2050, from 18 to 40 MMTCO₂e annually in California. Additional F-gas reduction measures are required if California is to meet its 2050 GHG reduction goal. The 2014 Scoping Plan Update specifically recommends an upstream mitigation fee on sales of F-gases,

an HFC phasedown, and low-GWP gas requirements where feasible and cost-effective. While some low-GWP alternatives exist, they face barriers to market entry such as higher capital costs. This study will identify strategies that could best incentivize and potentially fund better F-gas containment in existing systems, improvements in end-of-life recovery, and the transition to low-GWP alternatives. An evaluation of the different mitigation options would identify differences in feasibility, level of effort, cost, enforceability, efficient distribution of revenues, the industries and business types that would be the most responsive, and the potential cost pass-through to consumers. The results of this study will be crucial in identifying a successful suite of strategies to meet more stringent F-gas emission reduction targets that would assist in the next phase of GHG emission reductions.

Level of Funding: \$300,000

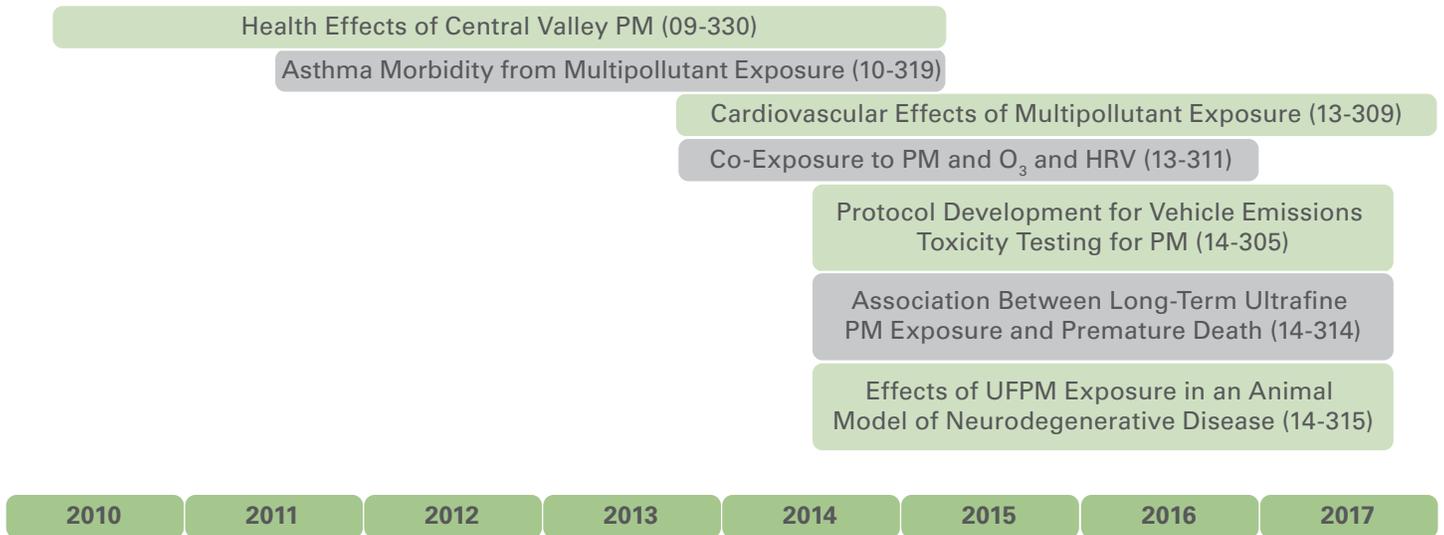


Next Steps

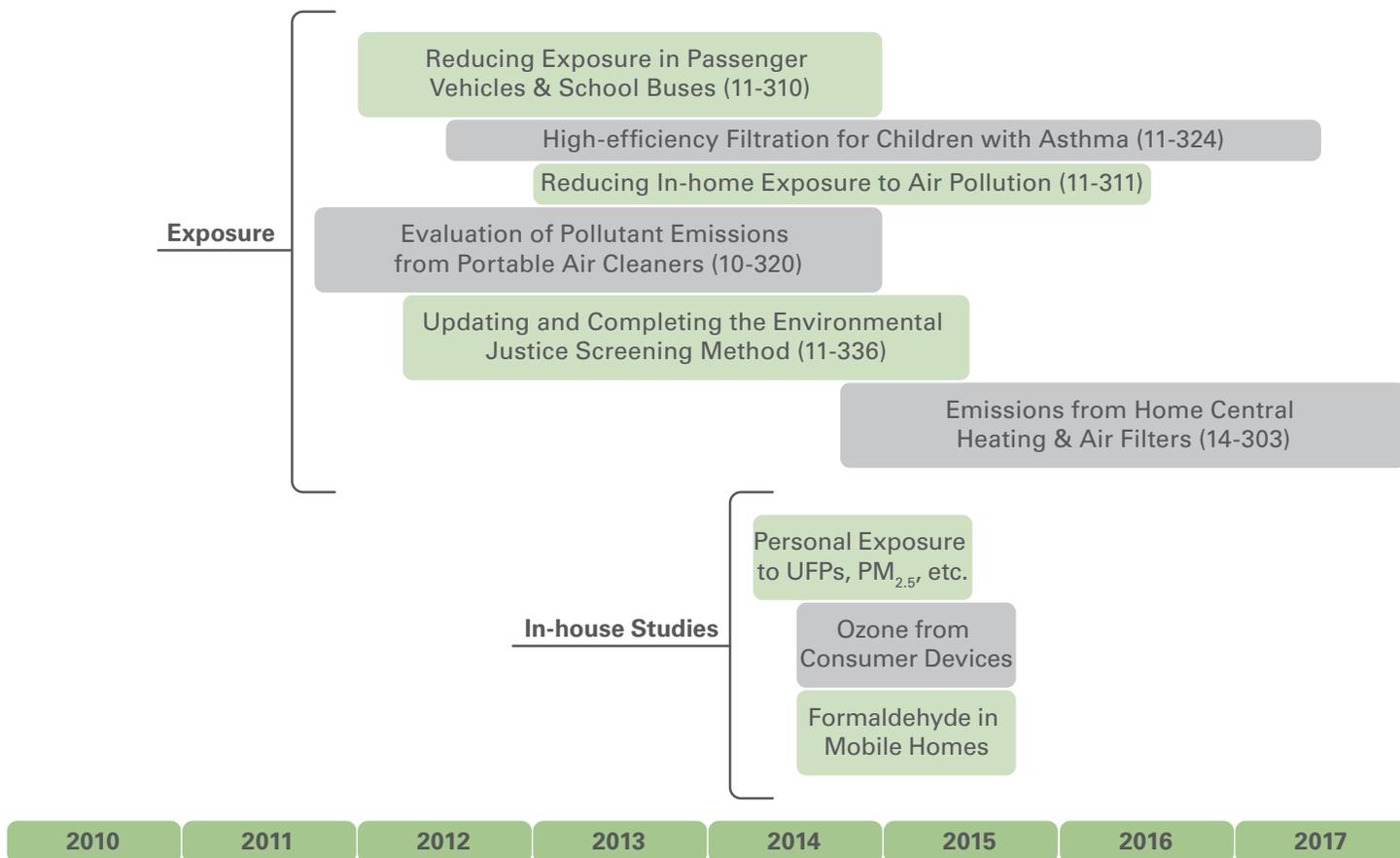
The 17 research projects in this plan address key knowledge gaps and will strengthen the scientific foundation of health, air pollution, and greenhouse gas control programs, help develop future clean air regulations and programs, and measure the effectiveness of ARB's programs. Following Board action on the Plan, staff will proceed to work with researchers to develop these research projects into complete proposals to be reviewed by ARB's Research Screening Committee and then brought to the Board for final funding approval. Results are anticipated in three to five years.

Current Research Projects

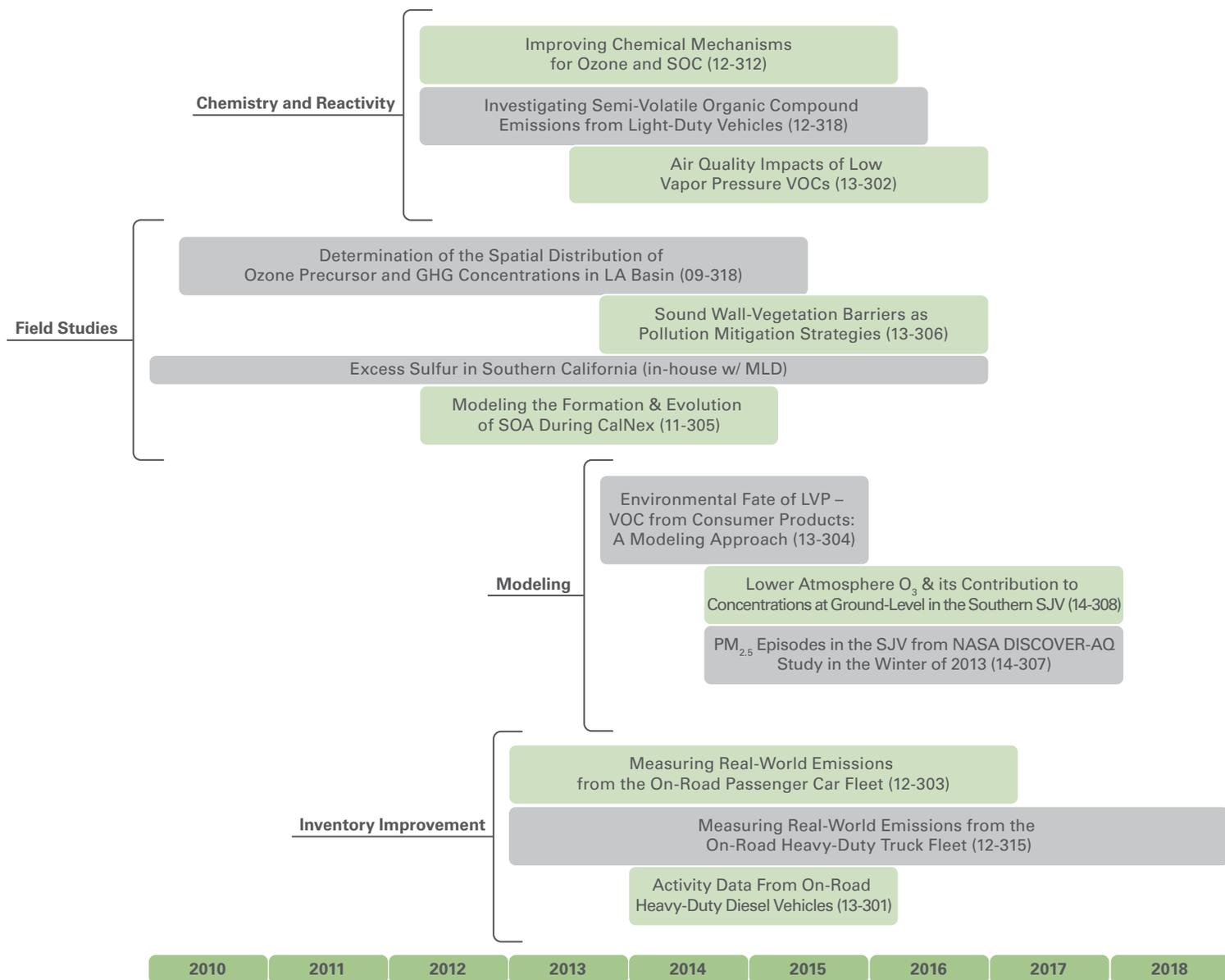
Health Effects Research Projects



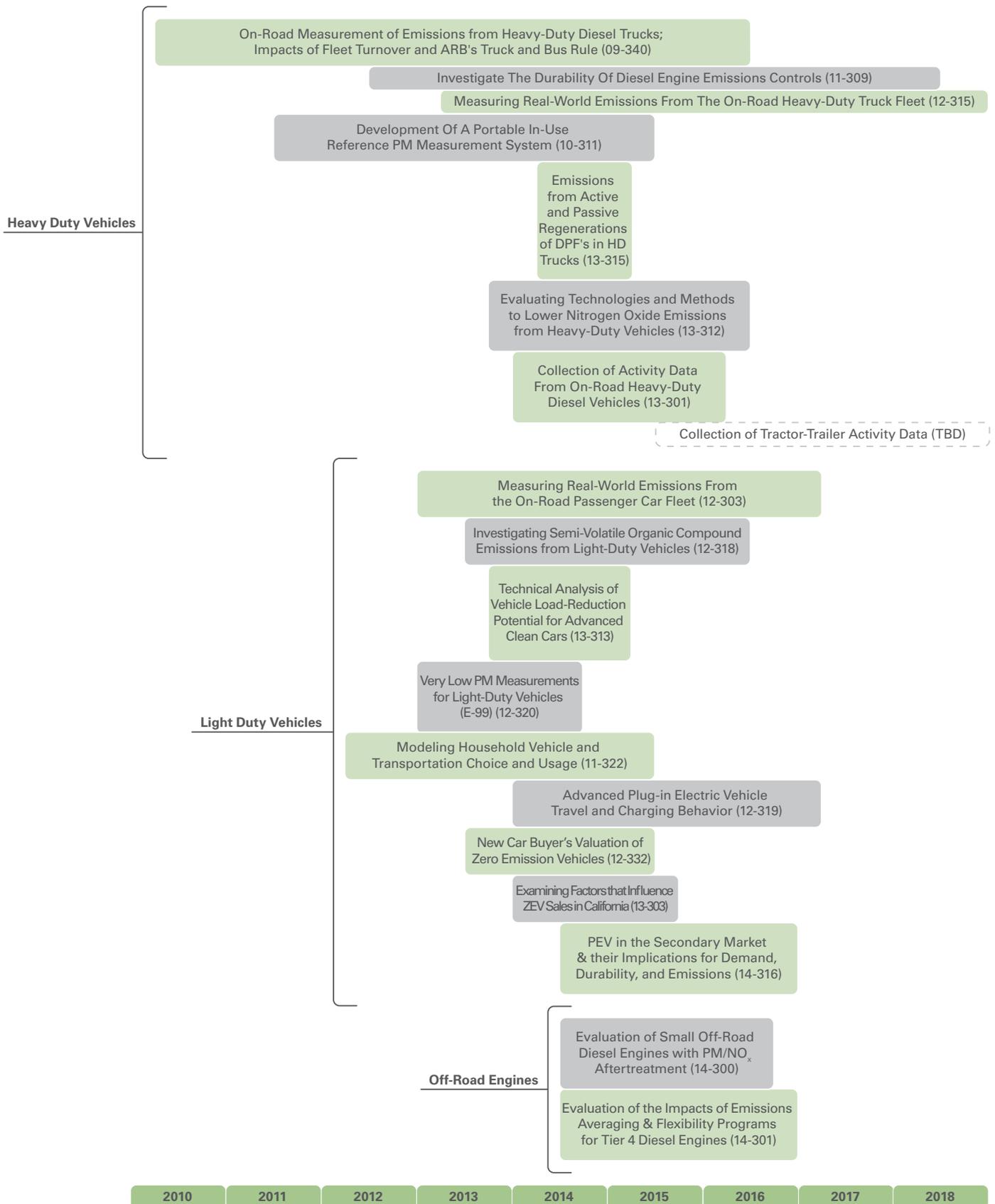
Exposure Research Projects



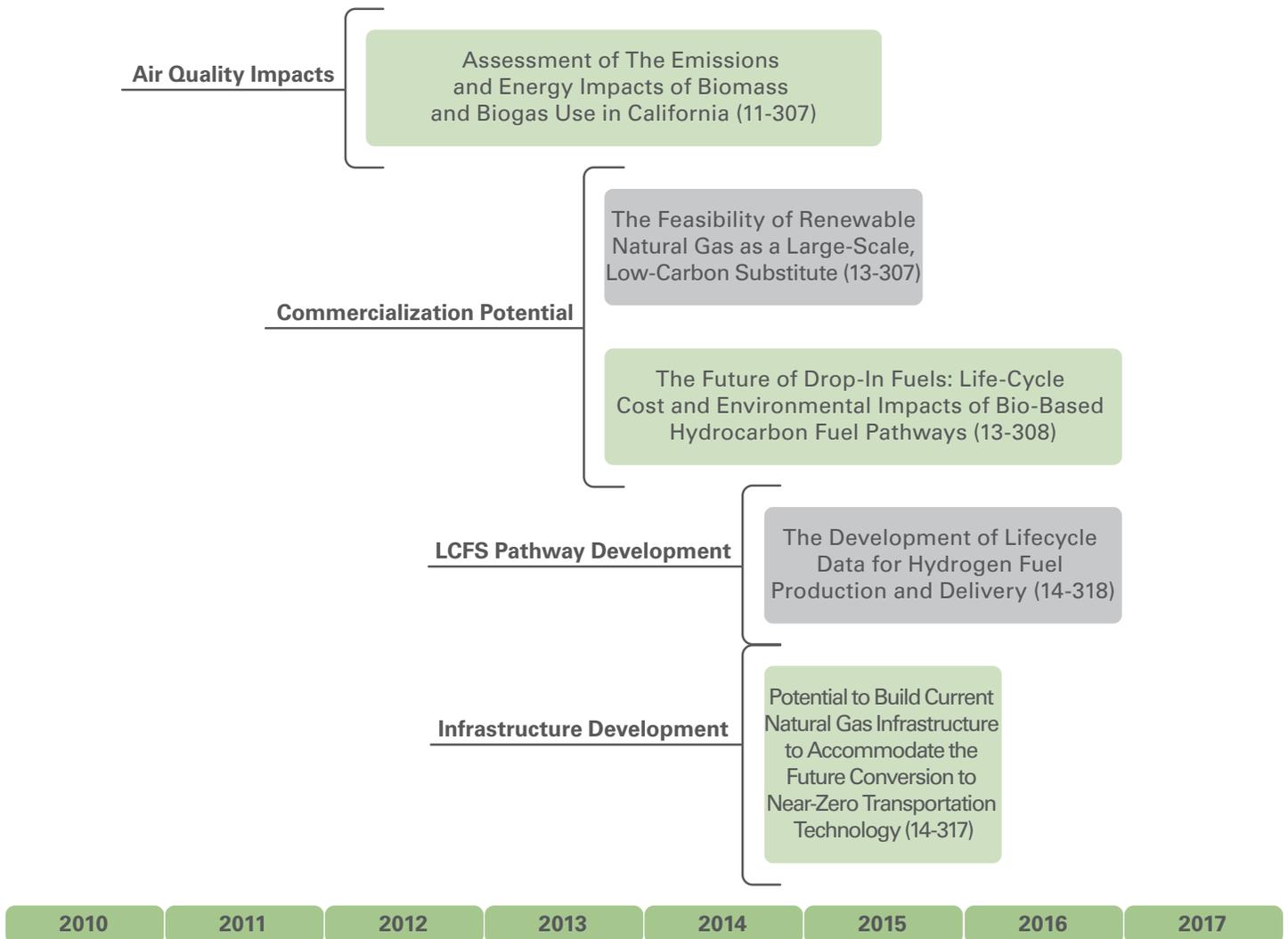
Atmospheric Processes and Field Studies Research Projects



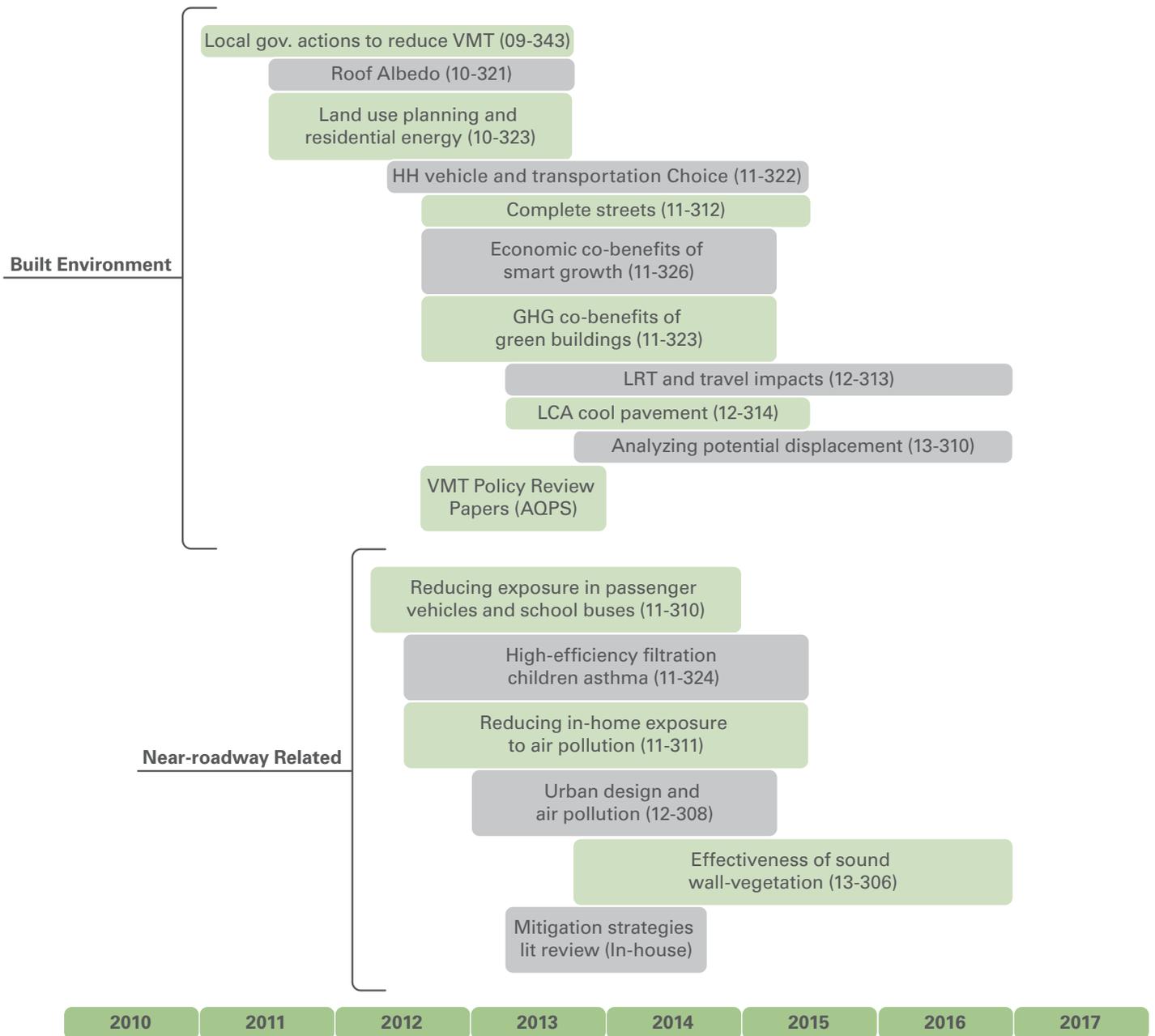
Vehicle and Engine Related Research Projects



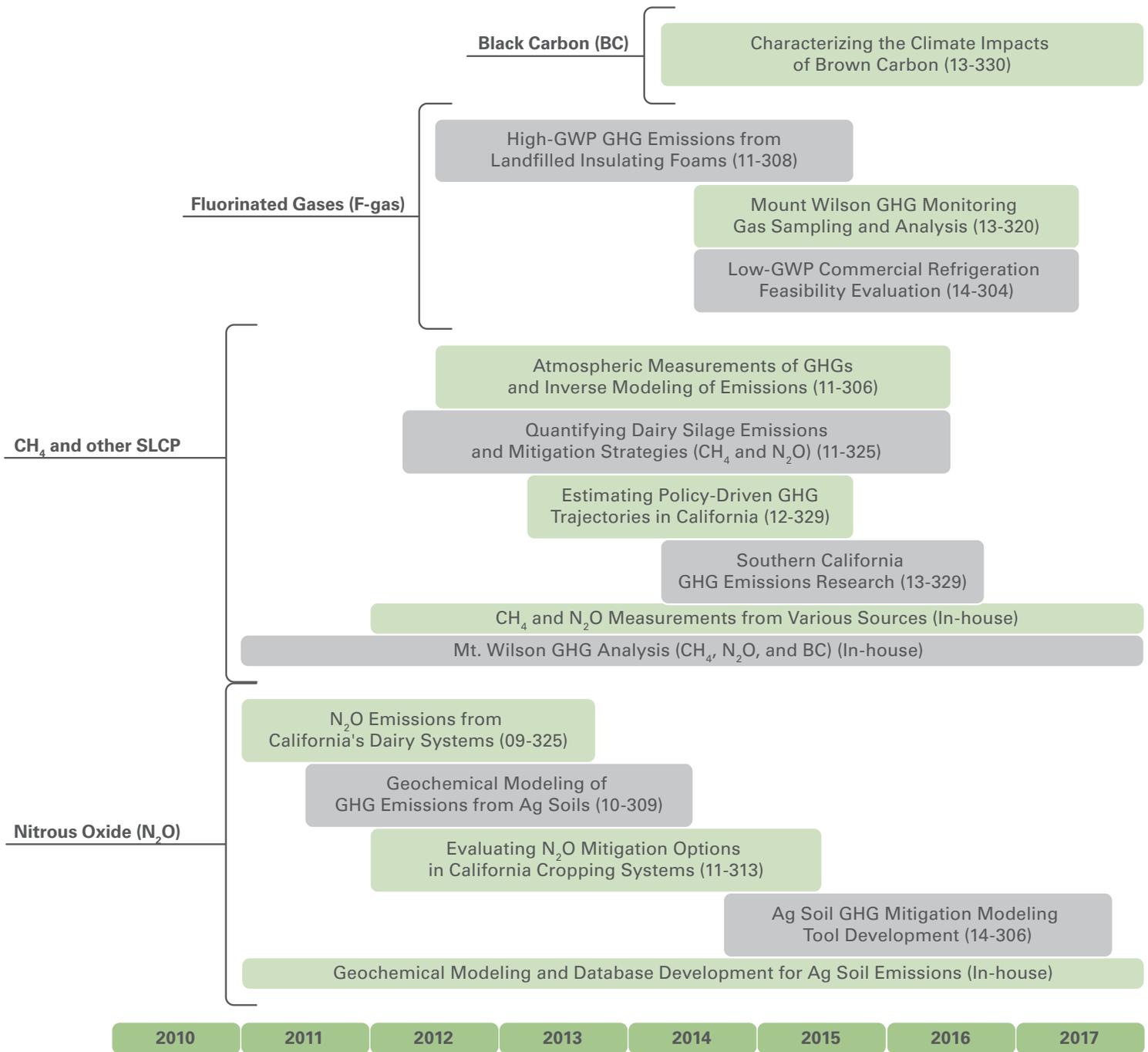
Fuels Research Projects



Sustainable Communities Research Projects



SLCP Research Projects





Recently Completed Research Projects

Health and Exposure

Contract Number 04-324. Hinds, William C. Cardiovascular health effects of fine and ultrafine particles during freeway travel. (January 2010)

Contract Number 05-305. Nazaroff, William. Ultrafine particle concentrations in schoolrooms and homes. (March 2010)

Contract Number 05-302. Matsumura et al. Assessment of Health Impacts of Particulate Matter from Indoor Air Sources Phase I: Development of In Vitro Methodology. (April 2010)

Contract Number 05-341. Riedl et al. Differences in inflammatory responses to exposures of concentrated ambient particles in susceptible volunteers. (April 2010)

Contract Number 04-308. Pastor et al. Air Pollution and Environmental Justice: Integrating Indicators of Cumulative Impact and Socio-Economic Vulnerability into Regulatory Decision-Making. (May 2010)

Contract Number 04-348. Winer, Arthur and Suzanne Paulson. Investigation and characterization of air pollution concentrations and gradients in port-adjacent communities and west and downtown Los Angeles using a mobile platform. (May 2010)

Contract Number 07-325. Delfino, Ralph J., MD, PhD. Personal endotoxin exposure in school children with asthma. (May 2010)

Contract Number 07-356. Lynch, Susan V., PhD. Analysis of urban aerosols in major US cities - implications for asthmatic airways. (May 2010)

Contract Number 04-320. Kleinman, Michael. The role of inhaled particles in the pathophysiology of cardiovascular disease. (May 2010)

Contract Number 05-342. Kleinman, Michael. Effects of Inhaled Fine Particles on Lung Growth and Lung Disease. (June 2010)

Contract Number 06-321. Smith, Kirk. Development of the UCB-L Particle Monitor for future California applications in environmental justice. (November 2010)

Contract Number 07-304. Sheridan, Scott. A spatial synoptic classification approach to projected heat vulnerability in California under future climate change scenarios. (February 2011)

Contract Number 07-337. Tablin, Fern. Systemic platelet activation in mice exposed to fine particulate matter. (February 2011)

Contract Number 05-317. Sioutas, Constantin. Fine-scale spatial and temporal variability of particle number concentrations within communities and in the vicinity of freeway sound walls. (April 2011)

Contract Number 05-347. Piazza, Thomas and Michael Apte. Indoor environmental quality and HVAC survey of small and medium size commercial buildings. (August 2011)

Contract Number 06-311. Bennett, Deborah. Indoor Environmental Quality and HVAC Survey of Small and Medium Size Commercial Buildings. (October 2011)

Contract Number 04-322. Balmes, John. Effects of ozone exposure on cardiovascular responses in healthy and susceptible humans. (October 2011)

Contract Number 06-336. Lipsett, Michael M.D. Extended analyses of air pollution and cardiovascular disease in the California Teachers Study cohort. (October 2011)

Contract Number 04-302. McKone, T. E. Quantifying pollution emissions from office equipment: a concern in energy-efficient buildings. (November 2011)

Contract Number 06-332. Jerrett, Michael Ph.D. Spatiotemporal analysis of air pollution and mortality in California based on the American Cancer Society cohort. (November 2011)

Contract Number 07-308. Thatcher, Tracy and Thomas Kirchstetter. Assessing near-field exposures from distributed residential wood smoke combustion sources. (December 2011)

Contract Number 03-315. Balmes, John. Effects of GSTM1 genotype on ozone-induced allergic airway inflammation. (March 2012)

Contract Number 08-305. Bradman, Asa. Environmental exposures in early childhood education environments. (April 2012)

Contract Number 06-331. Wexler, Anthony. Toxicity of source-oriented ambient submicron particulate matter. (May 2012)

Contract Number 07-309. Meng, Ying-Ying. Is disparity in asthma among Californians due to higher pollutant exposures, greater susceptibility, or both?. (May 2012)

Contract Number 07-310. Delfino, Ralph. In-vehicle air pollution exposure measurement and modeling. (June 2012)

Contract Number 09-357. Paulson, Suzanne, and Arthur Winer. Mobile platform III: Characterizing spatially inhomogeneous non-criteria pollutants in the Los Angeles air basin. (November 2012)

Contract Number 07-307. Kleinman, Michael T. Cardiopulmonary health effects: Toxicity of semi-volatile and non-volatile components of ultrafine PM. (April 2013)

Contract Number 08-307. Delfino, Ralph and Scott Bartell. Personal, indoor, and outdoor particulate air pollution and heart rate variability in elderly subjects with coronary artery disease. (April 2013)

Contract Number 10-303. Miller, Lisa. Persistent immune effects of wildfire PM exposure during childhood development. (July 2013)

Contract Number 10-302. Wilson, Dennis . Location specific systemic health effects of ambient particulate matter. (January 2014)

Contract Number 09-342. Morrison et al. In-duct air cleaning devices: Ozone emission rates and test methodology. (March 2014)

Contract Number 08-306. Kleinman, Michael. Central nervous system effects of ambient particulate matter: the role of oxidative stress and inflammation. (April 2014)

Contract Number 09-341. Delfino, Ralph. Peripheral blood gene expression in subjects with coronary artery disease and exposure to particulate air pollutant components and size fractions. (April 2014)

Atmospheric Science

Contract Number 07-335. Blake, Donald R.. ARCTAS-California 2008: An airborne mission to investigate California air quality. (January 2010)

Contract Number 05-344. Zhang, Ruihong. Process-based farm emission model for estimating volatile organic compound emissions from California dairies. (May 2010)

Contract Number 05-351. Yates, Scott R. Reducing emissions of volatile organic compounds (VOCs) from agricultural soil fumigation. (May 2010)

Contract Number 07-357. Prather, Kimberly. Analysis of ATOFMS datasets for apportionment of PM_{2.5} in California. (May 2010)

Contract Number 04-349. Kleeman et al. Climate change impact on air quality in California. (June 2010)

Contract Number 06-319. Iacobellis et al. Impact of Climate Change on the Frequency and Intensity of Low-Level Temperature Inversions in California. (July 2010)

Contract Number 06-328. Cohen, Ronald. Analysis of satellite measurements to improve California's models for ozone and PM. (October 2010)

Contract Number 06-330. Phares, Denis J. Deployment of a novel aerosol mobility/mass spectrometer for quantitative chemical analysis of organic aerosols from mobile sources. (November 2010)

Contract Number 06-322. Cocker, David R. III. Development of updated ARB solvent cleaning emissions inventories. (May 2011)

Contract Number 07-339. Carter, William P.L. Environmental chamber studies of ozone impacts of coatings VOCs. (May 2011)

Contract Number 06-329. Goldstein, Allen. Flux measurements of biogenic precursors to ozone and particulate matter in the central valley. (August 2011)

Contract Number 07-332. Yates, Scott. Reducing emissions of volatile organic compounds (VOCs) from agricultural soil fumigation : Comparing emission estimates using simplified methodology. (January 2012)

Contract Number 07-318. DePaolo, Donald. Using Pb and Sr isotopes to assess asian aerosol impacts in urban and interior California. (February 2012)

Contract Number 08-318. Stutz, Jochen. Nocturnal chemistry in the urban boundary layer of Los Angeles. (April 2012)

Contract Number 07-333. Schauer, James. Source apportionment of carbonaceous aerosols using integrated multi-variant and source tracer techniques and a unique molecular marker data set. (May 2012)

Contract Number 08-326. Carter, William P.L. SOA formation: Chamber study and model development. (May 2012)

Contract Number 09-337. Russell, Lynn and Ranjit Bahadur. Are There Any Counteracting Effects that Reduce the Global Warming Benefits Attributed to Black Carbon Controls? Assessment of Cloud Drop Number Concentration Changes and its Importance in Modeling Cloud Albedo Effects on Climate. (December 2012)

Contract Number 08-316. Goldstein, Allen and Ronald Cohen. Characterization of the atmospheric chemistry in the southern San Joaquin Valley. (May 2013)

Contract Number 08-319. Jimenez, Jose-Luis. Characterization of ambient aerosol sources and processed during CALNEX 2010 with aerosol mass spectrometry. (May 2013)

Contract Number 08-327. Sullivan, David W. Development of an updated base case ambient VOC mixture for assessing atmospheric reactivity. (May 2013)

Contract Number 09-328. Russell, Lynn. Improved characterization of primary and secondary carbonaceous particles. (June 2013)

Contract Number 09-316. Goldstein, Allen. Hourly in-situ quantitation of organic aerosol marker compounds during CALNEX 2010. (July 2013)

Contract Number 09-356. Russell, Lynn. Cal-Mex 2010: US and Mexico collaborative project on air quality and climate change in the California-Mexico border region. (July 2013)

Contract Number 09-333. Prather, Kimberly. Three-dimensional measurements of aerosol mixing state during CALNEX 2010 using aircraft aerosol time-of-flight mass spectrometry. (September 2013)

Contract Number 09-317. Volkamer, Rainer. AMAX-DOAS trace gas column observations from the research aircraft over California. (February 2014)

Contract Number 10-305. Zhang, Qi. Extended analysis of the CARES aerosol chemistry data to characterize sources and processes of organic aerosol in the Sacramento Valley of California. (February 2014)

Contract Number 10-313. Kleeman, Michael. Understanding primary organic aerosol volatility at atmospherically realistic concentrations for SIP analysis. (February 2014)

Contract Number 10-326. Parrish, David and Joost de Gouw. Synthesis of policy relevant findings from the Calnex 2010 field study. (March 2014)

Contract Number 09-339. Goldstein, Allen. Improving regional biogenic VOC emission estimates using an airborne PRTMS eddy flux measurement system. (April 2014)

Contract Number 10-312. Durbin, Thomas. Construction of a DOAS instrument for installation at CARB for the low level measurement of SO₂ to investigate the relation between SO₂ and sulfate. (May 2014)

Sustainable Freight

Contract Number 07-320. Corbett, James J. PhD. Improved geospatial scenarios for commercial marine vessels. (March 2010)

Contract Number ICAT 06-01. Mercury Marine. Development and demonstration of a low emissions four-stroke outboard marine engine utilizing catalyst technology. (March 2010)

Contract Number ICAT 06-04. Weaver, Christopher. Retrofitting compact SCR and diesel particulate filters to a passenger ferry. (April 2010)

Contract Number 06-333. Faloona, Ian. An investigation of offshore ship emissions of CO from shoreline measurements and a survey of vessel operations. (May 2010)

Contract Number 07-314. Corbett, James J. Development of a California geospatial intermodal freight transport model with cargo flow analysis. (December 2010)

Contract Number 09-303. Dwyer, Harry. Evaluation of potential for refrigerant recovery from decommissioned shipping containers at California ports. (April 2012)

Vehicle Emissions

Contract Number ICAT 06-02. Gautam, Mridul and Donald Stedman. Correlation of the real-time particulate matter emissions measurements of a ESP remote sensing device (RSD) and a dekatel electronic tailpipe sensor (ETaPS) with gravimetrically measured PM from a total exhaust dilution tunnel system. (March 2010)

Contract Number ICAT 06-06. Conway, Ray and Mark Schmale. Mobile Off-Road Retrofit SCRT System Demonstration Program. (April 2010)

Contract Number ICAT 07-2. Baer, Doug. High Accuracy Mobile Emissions Laboratory. (May 2010)

Contract Number ICAT 07-4. Honeywell ACS Laboratories. Demonstration of particulate matter (PM) sensor in post-DPF environment. (May 2010)

Contract Number 05-323. Durbin, Thomas. Light Duty Gasoline PM: Characterization of High Emitters and Valuation of Repairs for Emission Reduction. (August 2010)

Contract Number 06-342. Baker, Rick and Andrew Burnette. Characterizing MAC refrigerant emissions from heavy-duty on and offroad vehicles in California. (September 2010)

Contract Number ICAT 06-08. Cummins Westport, Inc. Development, demonstration & commercialization of a 0.20 G/BHP-HR NO_x natural gas engine. (2010)

Contract Number 05-308. Sioutas, Constantinos. Physicochemical and toxicological assessment of the semi-volatile and non-volatile fractions of PM from heavy-duty vehicles operating with and without emissions control technologies. (May 2011)

Contract Number 07-340. Gautam, Mridul. Testing of Volatile and Nonvolatile Emissions from Advanced Technology Natural Gas Vehicles. (July 2011)

Contract Number 06-324. Bogdanoff, Michael. Collaborative lubricating oil study on emissions (CLOSE). (August 2011)

Contract Number ICAT 08-1. Smith, Andrew. Fuel efficient active flow control for tractor trailers. (October 2011)

Contract Number 08-302. Jung, Heejung. Measurement of diesel solid nanoparticle emissions using a catalytic stripper for comparison to Europe's PMP Protocol. (November 2012)

Contract Number 08-315. Durbin, Thomas. Study of in-use emissions from diesel off-road equipment. (April 2013)

Sustainable Communities

Contract Number ICAT 05-1. Gas Technology Institute. Integrated CHP using ultra-low-NO_x supplemental firing. (April 2010)

Contract Number ICAT 07-1. Lee, Eric. Suncache solar water heating system demonstration project. (March 2011)

Contract Number 07-322. Horvath, Arpad. Retail climate change mitigation: Life-cycle emission and energy efficiency labels and standards. (January 2012)

Contract Number ICAT 6-12. Werts, Hack, McDonell. Adaptive low emission microturbine for renewable fuels. (January 2012)

Contract Number 09-344. Kammen, Daniel M. and Chris Jones. Measuring the climate impact of residential buildings: GreenPoint-rated climate calculator version 2. (September 2012)

Contract Number 08-325. Kahn, Mathew E. A field experiment to assess the impact of information provision on household electricity consumption. (January 2013)

Contract Number 09-326. Meier, Alan. Identifying determinants of very low energy consumption rates observed in some California households. (April 2013)

Contract Number 10-308. Arens, Edward. Air movement as an energy efficient means toward occupant comfort. (November 2013)

Contract Number 10-323. Mozingo, Louise. Residential energy use and greenhouse gas emissions impacts of compact land use types. (November 2013)

Contract Number 09-327. Meier, Alan. Behavioral strategies to bridge the gap between potential and actual savings in commercial buildings. (February 2014)

Contract Number 09-343. Salon, Deborah. Quantifying the effect of local government actions on vehicle miles traveled (VMT). (February 2014)

Contract Number 10-321. Levinson et al. Using remote sensing to quantify albedo of roofs in seven California cities. (March 2014)

Contract Number 10-332. Delmas, Magali. Behavioral responses to real-time individual energy usage information: a large scale experiment. (March 2014)

Contract Number 09-346. Yeh, Sonia and Christopher Yang. Modeling optimal transition pathways to a low carbon economy in California. (April 2014)

Greenhouse Gas Emissions

Contract Number 06-334. Stover, Cynthia. Emissions of HFC-134a in Auto Dismantling and Recycling. (July 2010)

Contract Number 07-312. Vetter, Arnie A.J. and Paul Ashford. Developing a California inventory for ozone depleting substances and hydrofluorocarbon foam banks and emissions from foams. (March 2011)

Contract Number 07-313. Wolf, Katy. Developing a California inventory for industrial applications of perfluorocarbons, sulfur hexafluoride, hydrofluorocarbons, nitrogen trifluoride, hydrofluoroethers and ozone depleting substances. (March 2011)

Contract Number 07-330. Mathis et al. Lifecycle analysis of high-global warming potential greenhouse gas destruction. (October 2011)

Contract Number 09-366. Okhuysen, Victor. SF6 replacement evaluation in magnesium sand and investment casting. (December 2011)

Contract Number 09-348. Fischer, Marc L. and Seongeun Jeong. Inverse modeling to verify California's greenhouse gas emission inventory. (April 2012)

Contract Number 09-306. Wagner, Mark and Pamela Mathis. Greenhouse gas performance analysis for commercial buildings with large refrigeration and air conditioning systems. (May 2012)

Contract Number 08-324. Horwath, William R. Assessment of baseline nitrous oxide emissions in California cropping systems. (June 2012)

Contract Number 08-323. Ramanathan, V. Black carbon and the regional climate of California. (April 2013)

Contract Number 09-325. Horwath, William R. Assessment of baseline nitrous oxide emissions in California's dairy systems. (November 2013)

Contract Number 09-329. Horwath, William R. Determining NO_x emissions from soil in California cropping systems to improve ozone modeling. (November 2013)

Contract Number 10-309. Li, Changsheng. Calibrating, validating, and implementing process models for California agriculture greenhouse gas emissions. (February 2014)

Economic Assessment

Contract Number 07-321. Horvath, Arpad. Evaluation of efficiency activities in the industrial sector undertaken in response to greenhouse gas emission reduction targets. (April 2010)

Contract Number 06-323. Delucchi, Mark. Lifecycle analysis of climate-change mitigation strategies of the California Air Resources Board. (June 2010)

Contract Number 07-315. Ferrier, Grant. The clean energy industry in California: an economic analysis assessing the current market in the global economy. (February 2011)

Contract Number 08-312. Bunch, David and David Greene. Potential design, implementation, and benefits of a feebate program for new passenger vehicles in California. (February 2011)

California Environmental Protection Agency

 **Air Resources Board**

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