May 2016

California Air Resources Board

PROPOSED

Annual Research Plan

Fiscal Year 2016-2017

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Proposed Annual Research Plan
Fiscal Year 2016 - 2017

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Introduction

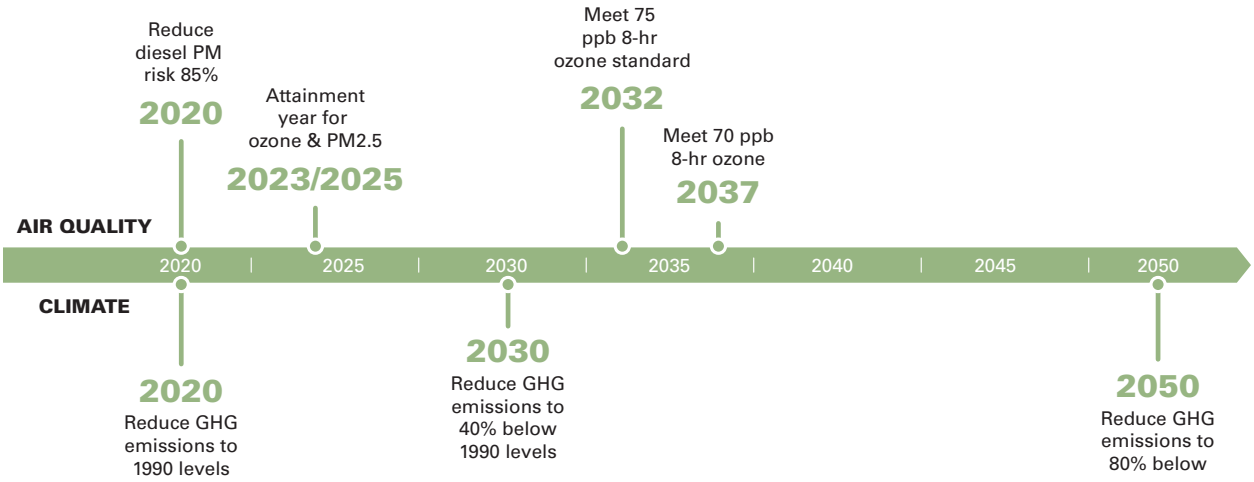
As required by State law (Health and Safety Code Section 39700), the California Air Resources Board's (ARB or Board) sponsors a research program that is guided by the mission of providing sound and timely scientific results to support ARB's policies and programs. ARB's research program develops a research plan on an annual basis to outline the use of past and current research, and describe new research initiatives in a given year. This report, Proposed Research Plan, Fiscal Year 2016-2017 (Plan), reflects a concerted effort to identify the highest priority needs of ARB, and maximize leveraged research dollars through coordination efforts.

The projects outlined in this Plan build on past research, and leverages over $10 million of complementary research supported by other funding organizations to focus on issues that are unique to California, or specific to its vulnerable populations and regions. The projects are designed to provide answers to near-term questions that are important for program implementation, and to explore the benefits of longer-term strategies. Together, they will provide essential data and tools to support actions to meet California's air quality and climate goals.

Research to Inform Policy

ARB's research program assesses what it will take to meet federal deadlines for national air ambient air quality standards (NAAQS), and greenhouse gas (GHG) reduction goals in 2020, 2030, and beyond (Figure 1).

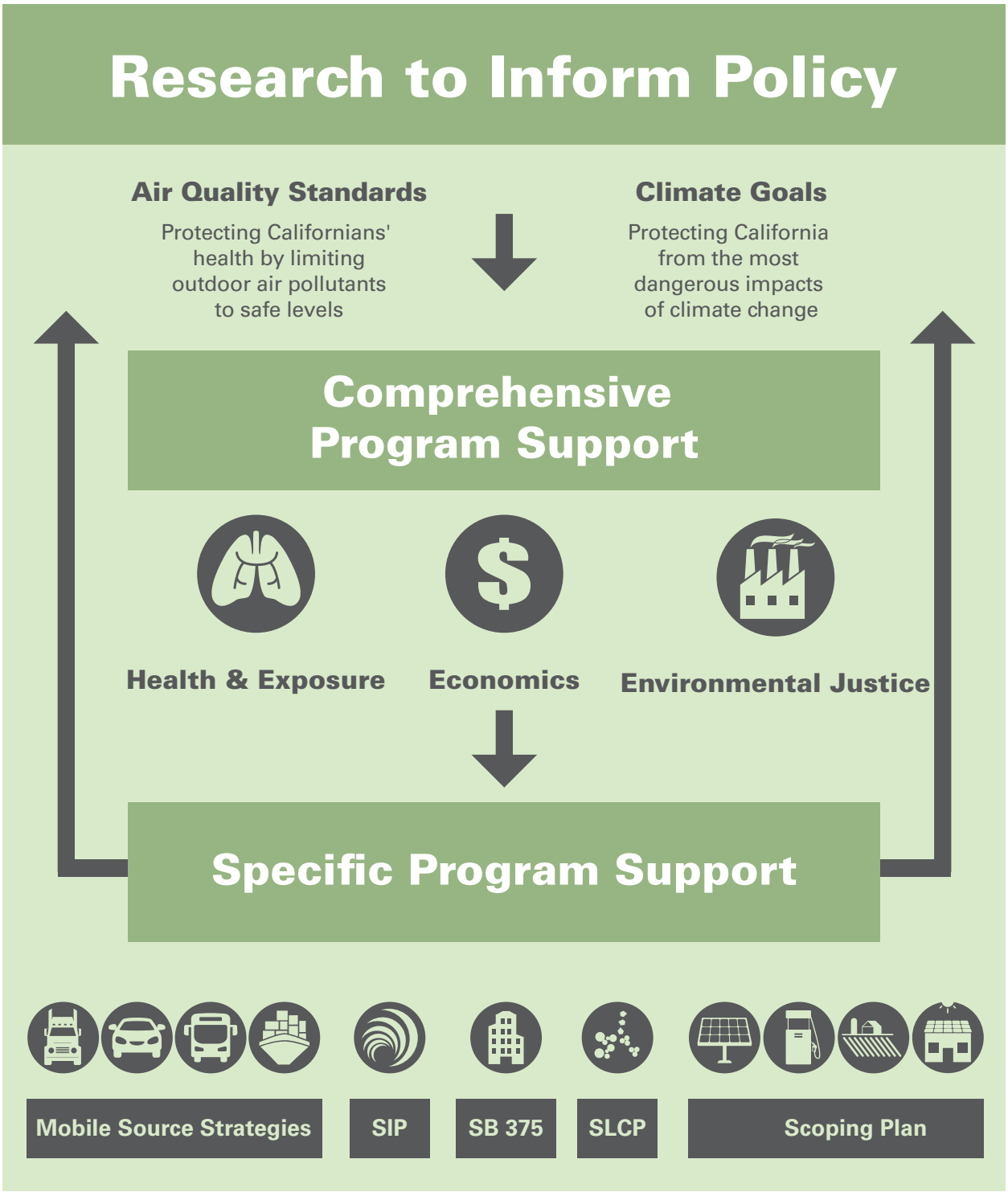
Figure 1: California's key air quality and climate change goals through 2050.



The foundation of ARB's research program provides comprehensive program support to inform health-based air quality standards, reduce air pollution exposures, and protect all communities and vulnerable individuals from the potential impacts of climate change. In-house expertise on health, exposure, and environmental justice, as well as a diverse portfolio of external contracts, provides state of the science research results to support the development, and sustainable implementation of all ARB programs (Figure 2). ARB's research on the health effects of air

pollution has helped to set national air quality standards, and focuses on emerging issues of importance to protect California's communities. Improving the understanding of transportation-related air pollution exposures, and developing exposure mitigation strategies, continues to be a high priority.

Figure 2: Research results from ARB's projects aim to ensure the policies aimed at meeting air quality and climate goals are successfully implemented, avoid unintended impacts, and provide information for future policy development.



ARB's research program also supports specific ARB programs to ensure that they are guided by the best and latest science. The research program's efforts to support these programs has required a broad portfolio of research studies, and in-house research initiatives, that have helped in the development and implementation of mobile source emission reduction strategies, State Implementation Plans (SIPs) for ozone and PM2.5, SB 375 per capita transportation targets, the Short-lived Climate Pollutant (SLCP) Strategy, and the AB 32 Scoping Plan for greenhouse gas (GHG) reduction.

ARB's air quality research program has supported the development of SIPs through improvements in emission inventories, chemical mechanisms and air quality models. ARB's mobile source emissions research program supports California's effort to meet NAAQS and GHG reduction goals by examining the effectiveness and durability of technologies that reduce these emissions. The mobile source research program also monitors the progress of emission reduction rules currently in place. The climate change research program that has supported the development of multiple State planning efforts to reduce GHG emissions, and investigates the societal impacts of recommended actions. Research results from all of these programs are also intended to inform the development of new policies and programs.

Planning Process

This Annual Research Plan addresses the Board's highest priority program needs by considering an extended timeframe for program goals, including federal deadlines for national air ambient air quality standards (NAAQS), and greenhouse gas (GHG) reduction goals in 2020, 2030, and beyond.

The process to develop the Plan begins with the submission of research ideas through an online public submission process. Feedback from ARB program staff on the publicly submitted comments, as well as their input on the Board's regulatory priorities and challenges for both near-term and longer-term needs are assessed. Projects are then discussed with State and federal agencies, and other funding organizations to ensure that there is no duplication of effort and that leveraging is maximized. Based on the external input, as well as internal dialogue among ARB's divisions, executive office, and the Office of the Chair, ARB staff prioritized specific program needs, and developed additional research concepts to address knowledge gaps. Projects are carefully reviewed for scientific rigor, policy relevance, and strong links to ARB's programs and mission.

A proposed Plan is then presented to the Board and, if approved, full research proposals are developed through a solicitation that recognizes the academic assets of the University of California and California State University systems. Draft proposals are evaluated by technical review teams that include partners from federal and other State agencies as well as air districts. The developed projects are then brought back to the Board's Research Screening Committee – with experts in health, environmental justice, atmospheric science, engineering, and climate change – for their advice and recommendations, and to the Board to request approval for funding of each project. State law directs ARB to consider the capabilities of the University of California system where possible, so ARB's research program frequently draws upon the expertise of internationally recognized scientists in California.

Program History

The Board's research program was established by the Legislature in 1971 and has formed the basis of ARB's regulatory programs since its inception. Over the past 45 years, ARB has carried out innovative research in areas as diverse as health effects of air pollution on vulnerable populations, complex atmospheric chemistry, indoor air quality, and greenhouse gas emissions. Some of these studies are long-term and build on unique data sets, while others address specific implementation or knowledge gaps.

Foundational studies on the science of air pollution continue to be a main emphasis of ARB's research program, which has grown in scope over time in response to several legislative mandates (Figure 2). ARB's research has always focused on the impact of implementing strategies to achieve long-term air quality and climate goal on health and the economy. However, in recent years, the research program has made a strong effort through external and in-house research efforts to quantify the impacts of these strategies on disadvantaged communities. ARB's 2016-17 Research Plan reflects new program needs, long-term goals, and builds upon the comprehensiveness of California's existing research efforts.

Figure 3: New research topics that have emerged as ARB's research program has evolved in response to new legislative mandates.

ADVANCING THE SCIENCE

ARB-Funded Research in World Class Publications

Since 1990, ARB has funded more than 460 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 (17 citations per article) and the Health Effects Institute (20 citations per article). 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.

ARB's Research Staff Produce High-Impact Publications

During the past 15 years, Research Division staff have co-authored 121 peer-reviewed scientific articles that were published in widely-read, prestigious journals. These articles were cited 2,640 times in subsequent journal articles by other researchers in the field (on average about 20 times each by other articles).

Coordination and Research Dissemination

ARB's research program is a collaborative effort other State agencies, federal agencies, air districts, and research institutions. Collaboration and coordination with these partners allows ARB to leverage air pollution research funding both nationally and internationally, avoids duplication of effort, provides opportunities for collaborative research, and maximizes the utility of research results. These efforts enable ARB to participate in projects and studies outside the reach of ARB's research budget alone.

To promote coordination, information is shared at all stages of the research process, from project development to updates on research progress and final reports. Coordination with other State agencies is done through the participation in interagency groups, such as the Climate Action Team (CAT) Research Working Group and the Transportation Research Roundup. These groups provided a forum for State agencies to discuss and coordinate their proposed research activities, but also facilitate coordination with external groups including academia, federal agencies, the international community, and private entities.

Providing sponsorship for other research entities is another way that ARB's research program coordinates and leverages expertise in the research community. Sponsorship opportunities also provide an opportunity for ARB to guide research initiatives at other institutions and ensure that ARB's research results are elevated to national and international platforms. Examples of entities that ARB engages with include the National Center for Sustainable Transportation (NCST) and the Sustainable Transportation Energy Pathways (STEPS) Center at the University of California, Davis. ARB is also involved in the research activities of the Coordinating Research Council (CRC), the Health Effects Institute (HEI), the Transportation Research Board (TRB), and several federal agencies.

ARB staff disseminates new research results to the public through seminars, press releases, newsletters, final reports, and updates at Board Meetings. ARB also co-sponsors workshops with other State agencies on a variety of research topics. The workshops provide a public setting for researchers funded by multiple State agencies to showcase their efforts, provide an opportunity for an in-depth discussion of the implications of their results, and identify remaining research gaps.

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 (*www.arb.ca.gov/research/research.htm*) 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, and a related shift in interest from ARB constituencies.

Comprehensive Program Support

Health

ARB's health program provides in-house health assessments – guided by the latest science – for all ARB programs, plans, strategies, and regulations. The health program also funds external research to fill research gaps in the literature on topics ranging from air pollution health effects to exposure studies and mitigation strategies.

Health Effects → **Exposure Assessment** → **Mitigation Research**

Past Successes

The health research program supports the establishment and continual review of ambient air quality standards and actions to reduce public exposure to air pollution. ARB-funded health effects research has added to the body of evidence on the health impacts of exposure to air pollutants, especially PM2.5 and ozone. ARB has also sponsored many pioneering research projects that prompted similar national studies such as those on the impact of air pollution on children's health. In addition, the health research has led to new State laws, including the first legislation in the nation to protect people from some of the most harmful indoor exposures and a focus on the health of infants and children in setting ambient air quality standards and reducing air toxics.

Assessing the health impacts of near-roadway, ultrafine particulate matter (UFPM), and multi-pollutant exposures using a variety of approaches has consistently been a research priority for ARB, as the results may contribute to the development of health protective regulations and policies. For example, a recently completed study with rodents investigated the cardiovascular effects from exposure to UFPM. The study results showed that the organic constituents of UFPM contribute to the development of atherosclerotic plaques, a condition leading to hardening of the arteries.

The research program has also funded a number of studies aimed at quantifying the degree to which vulnerable groups, such as the elderly, children, and women, are more sensitive to air pollution impacts. These studies have also explored new ways to study vulnerability, such as examining the impact of genetic variability on health in populations exposed to different sources of air pollution. For example, a recently completed ARB-funded study of elderly subjects with cardiovascular disease in Los Angeles provided information on the effects of air pollution exposures from different sources, including traffic. In addition, ARB sponsored research has contributed to our knowledge regarding the sensitivity of women to air pollution, and has prompted additional research to shed light on the basis for the increased sensitivity.

A previous study of formaldehyde emissions from building materials and many other products prompted ARB's regulation limiting formaldehyde emissions from compressed wood products. Recent Federal legislation requiring the U. S. EPA to develop a national regulation should assure that all Americans are protected from excessive formaldehyde exposures from plywood, particleboard, and other wood-based building materials that are prevalent in modern construction. Similarly, research conducted by ARB staff on purported "air cleaners" that intentionally emit ozone prompted legislation in 2006 (AB 2276, Pavley) directing ARB to regulate ozone emissions from indoor air cleaning devices. ARB now certifies indoor air cleaners under the new regulatory program, and high ozone-emitting devices are prohibited from sale in California. Also, ARB's joint study on air quality in portable classrooms contributed to a number of state and school district policy changes that have improved health conditions in California schools.

As California cities build more compact, transit-oriented communities, it is important to understand the health co-benefits of this type of development, and to identify solutions for any potential unintended consequences. Therefore, the health research program has focused on exposure mitigation strategies, such as high efficiency filtration in homes and vehicles. A recently completed study on exposure mitigation indoors has provided new information for the development of guidance on the use and cost-effectiveness of some in-duct, as well as other, high-efficiency filtration systems for reducing exposure to air pollution from indoor sources and from outdoor sources, such as traffic, that have infiltrated into the indoor environment. These studies will shed light on potentially useful mitigation measures that can be developed to reduce near-roadway exposures.

The sustainable community research has examined means to further reduce exposure to traffic pollution, particularly for communities already located near major roadways. One project examined how more compact development may alter air pollution exposure of pedestrians and transit users near traffic-related pollution sources, and how urban designs and traffic management can mitigate such exposures.

Current Research and Coordination Efforts

ARB continues to fund research to improve our understanding of the near-roadway health impacts of exposure to fine and ultrafine particulate matter and mixtures of air pollutants, particularly in vulnerable populations. While single pollutant studies have been essential to the process of establishing health protective levels for NAAQS, ARB has expanded its research portfolio to look at how concurrent exposure to ozone and PM2.5 may affect public health, which is the focus of a research project now underway.

RESEARCH HIGHLIGHT

One of the pollutants of greatest concern for California and nationally is particulate matter, especially PM2.5 which has consistently been linked to increased premature mortality and hospitalizations. ARB contracted research to specifically examine the health impacts of air pollution in California, which may be different from those found in the US studies. In this California-specific study, the investigators found that exposure to PM2.5 significantly elevated the risks for premature death from ischemic heart disease. Results from a second study specifically in women also showed that exposure to PM2.5 elevated the risks for premature mortality from ischemic heart disease. However, this study additionally found an increased risk of stroke among women who had never had one before, particularly among those who were post-menopausal. A third study addressed the mechanism by which PM2.5 can contribute to heart disease. It investigated the role of activated platelets, the key component involved in blood clotting and the role that PM2.5 exposure can play in inactivation of clotting mechanisms that can trigger heart attacks and strokes. This study was the first to hypothesize a mechanistic pathway from PM2.5 inhalation to altered cardiovascular function.

Exposure of vulnerable populations, especially women, to air pollutants also continues to be a focus of study for ARB. Recent epidemiological evidence has pointed to an increased sensitivity to fine PM in women. ARB has responded to this remaining research gap by funding a study to address this using a toxicological approach. In addition, the health effects of UFPM exposure in women is being investigated using an epidemiological approach. Another study is examining whether changes in immune function induced by air pollution exposure can be passed on from mother to offspring. This project will leverage other ongoing research to perform cutting-edge air pollution research at relatively low cost. In order to leverage limited research funding, ARB health staff will continue on-going efforts to coordinate with experts at State, federal, and international research institutions, such as the Health Effects Institute (HEI).

A major priority of ARB is to assess what remaining pollutants Californians are exposed to, including ozone, PM, ultrafine PM, and toxics. One project is concerned with ozone emissions from consumer products and home appliances. Many of these products can emit ozone either intentionally or as a by-product of their functions, but, other than air cleaners, their ozone emissions have not been investigated. An in-house study measured ozone emissions and impacts on indoor ozone levels and associated exposures from 17 consumer products and home appliances. The results showed that some products elevated the room ozone concentrations to levels that greatly exceed the level of the 1-hr California Ambient Air Quality Standard for ozone.

In another in-house study staff investigated exposure to ultrafine PM. In this pilot study twelve volunteers were followed for 24-hour periods using small, portable monitors. The results revealed the level and location of the majority of exposure. This information can be used to help design strategies to mitigate pollutant exposure. In a future study, ARB staff will estimate personal exposures of commercial gardeners to the emissions from gasoline-powered lawn and garden equipment in California. The study results will be used to estimate the health benefits of zero-emission technologies for lawn and garden equipment, and support the anticipated regulation for small off-road engines.

ARB is also interested in understanding the current exposures to formaldehyde of Californians living in mobile homes. This research is being conducted because mobile homes tend to contain more composite wood than traditional homes and thus, in the past, have had notably higher levels of formaldehyde than other single-family homes Preliminary results for 44 (of about 55) homes show a range of formaldehyde levels well above OEHHA's chronic and 8-hour reference exposure level for formaldehyde.

In collaboration with other state and federal agencies and research centers in the UC system, ARB leverages expertise to continue to drive research that will evaluate the effectiveness and cost of indoor air filtration as a strategy to mitigate exposure to air contaminants. One study will further investigate how effective indoor air filtration is in reducing asthma symptoms in children. Research from these studies can help guide State and local agencies seeking air pollution mitigation options to protect communities already living near freeways and other major sources of particulate matter.

Remaining Needs

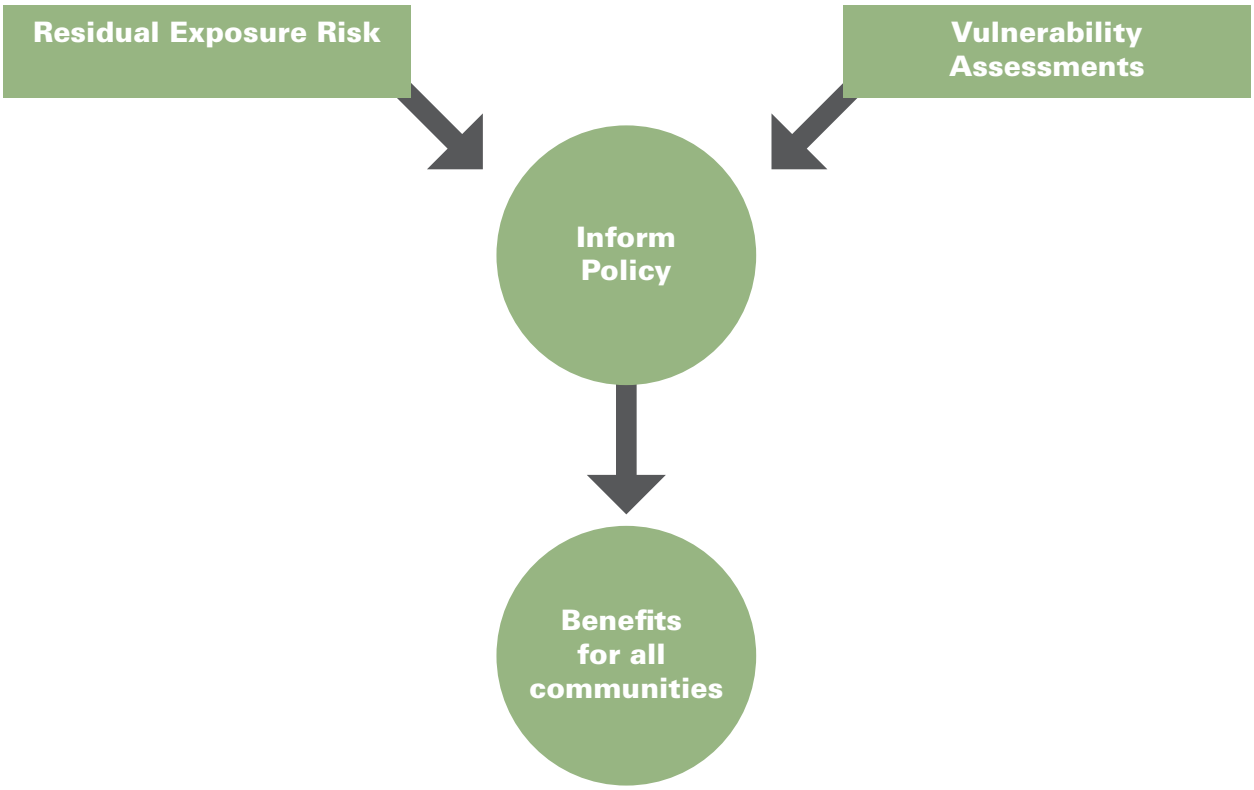
California has made substantial progress in reducing ambient concentrations of criteria air pollutants and toxic air contaminants, but exposure to pollutants in communities and in microenvironments still remains a concern.

ARB continues to seek collaborative research endeavors, and focus in-house efforts, to identify situations and environments with harmful levels of pollutants, and to develop strategies to mitigate them. A study that is nearing completion has examined the impacts of the conversion of traditional streets to complete streets on pollution levels and travel behaviour. In-house research efforts underway will examine the impacts of walkability in neighborhoods on health

and physical activity while also considering levels of air pollution in these neighborhoods. Future studies will investigate the impacts of such issues as greenness and physical activity and noise levels with different built environment designs.

Environmental Justice

ARB is committed to achieving environmental justice by reducing the disparate exposure to air pollutants in disadvantaged communities. ARB has partnered with local and community organizations, carried out research projects and air monitoring studies to identify residual exposure risks, conducted vulnerability assessments of communities, ports and rail yards, adopted regulations, and refocused enforcement efforts and incentive programs, all in support of environmental justice goals. These actions have resulted in large improvements in air quality, especially in those communities where air pollution impacts have historically been the greatest.



RESEARCH HIGHLIGHT

The Environmental Justice Screening Method was the first GIS-based map to identify areas of concern with regard to the cumulative impacts of hazard proximity, air pollution, exposure and health risk, and social vulnerability. It formed the basis for CalEnviroScreen which is being used to identify disadvantaged communities for the purposes of identifying areas that receive climate investments from the Greenhouse Gas Reduction Fund. In fiscal year 2014 2015, $275 million was targeted towards projects that benefit disadvantaged communities.

Past Successes

ARB has conducted a number of studies that address issues of environmental justice for people who are often highly exposed to traffic, but whose pollutant exposures are not routinely monitored. These studies have used a variety of methods and models to examine health related parameters (e.g., risk and severity of asthma attacks and other respiratory illnesses) resulting from traffic-related exposure. This work has covered several regions in California, including Alameda County, Los Angeles County, and low income areas in Orange County, in addition to leveraging access to state-wide surveys and datasets. These studies are part of the growing literature showing that people living in poor and minority communities are more vulnerable to the effects of high exposures to traffic-related air pollution. Findings from these studies have helped to inform policy decisions on motor vehicle emissions control and enforcement, and asthma prevention, control, and education in low socioeconomic status populations.

To support ARB's environmental justice initiatives for all ARB programs, 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 proceeds of cap and trade revenue. ARB's research program continues to develop the 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.

Current Research and Coordination Efforts

ARB's research program continues to monitor levels of harmful pollutants in environmental justice communities. To address the issue of vulnerability of low-income and minority populations to exposure to air pollution and the resulting air pollution-related illnesses, ARB is conducting in-house research and has sponsored external research. Current in-house research is focused on comparing the trends in pollutant concentrations in high and low socioeconomic status communities. This work allows ARB to track the effectiveness of current rules and regulations to reduce traffic-related pollutants, as well as to quantify their impact on specific vulnerable communities to ensure that California's underserved communities benefit equitably from California's air pollution control programs. This study is in collaboration with Manuel Pastor, Rachel Morello-Frosch, and James Sadd. The extramural research program is also funding a pilot study to characterize the potential health and equity impacts of oil and gas extraction activities in California.

ARB also researches the impacts of SB 375 and regulatory actions like the Zero-Emission Vehicle (ZEV) program on disadvantaged communities. ARB is funding a research project to evaluate the potential for displacement of lower-income residents as a result of compact, transit-oriented development investment stemming from SB 375. ARB is also examining the factors that influence ZEV Sales in California. The project will assess the costs effectiveness and equity of various ZEV purchase incentives based on income levels and vehicle price cap.

In addition to collaboration with outside researchers, ARB is also providing technical support for monitoring studies by Edmund Seto in Imperial Valley and San Ysidro, and ARB is lending Ogawa samplers for a study led by Michael Jerrett, Beate Ritz and Jason Su to establish a network of 60 passive air sampling sites around Sacramento. The study will focus on the association of cognitive decline and dementia in the elderly in a population of Mexican Americans that are enrolled in the "Sacramento Area Latino Study on Aging" (SALSA) cohort study.

Proposed Research

Improving CalEnviroScreen Score at US-Mexico Border

The objective of this research is to identify the locations of stationary, area, and mobile sources on the Mexico side of the US-Mexico Border as inputs to CalEnviroScreen. CalEnviroScreen identifies the census tracts with the greatest cumulative exposure and social and health vulnerability. In addition to the data at each census tract, CalEnviroScreen uses the information from nearby census tracts to evaluate cumulative exposure, including the location of potential air pollution sources. This information is lacking on the Mexico side of the US-Mexico border leading to the appearance that there is very little pollution in border communities. The investigators will use Mexico's version of the Toxic Release Inventory (Registro de Emisiones y Transferencia de Contaminantes) and Google Earth to verify locations and geocode stationary and area sources. The results will be used to improve the CalEnviroScreen analysis at the US-Mexico border and will complement on-going monitoring studies by Edmund Seto of the University of Washington in the Imperial Valley and San Ysidro.

Remaining Needs

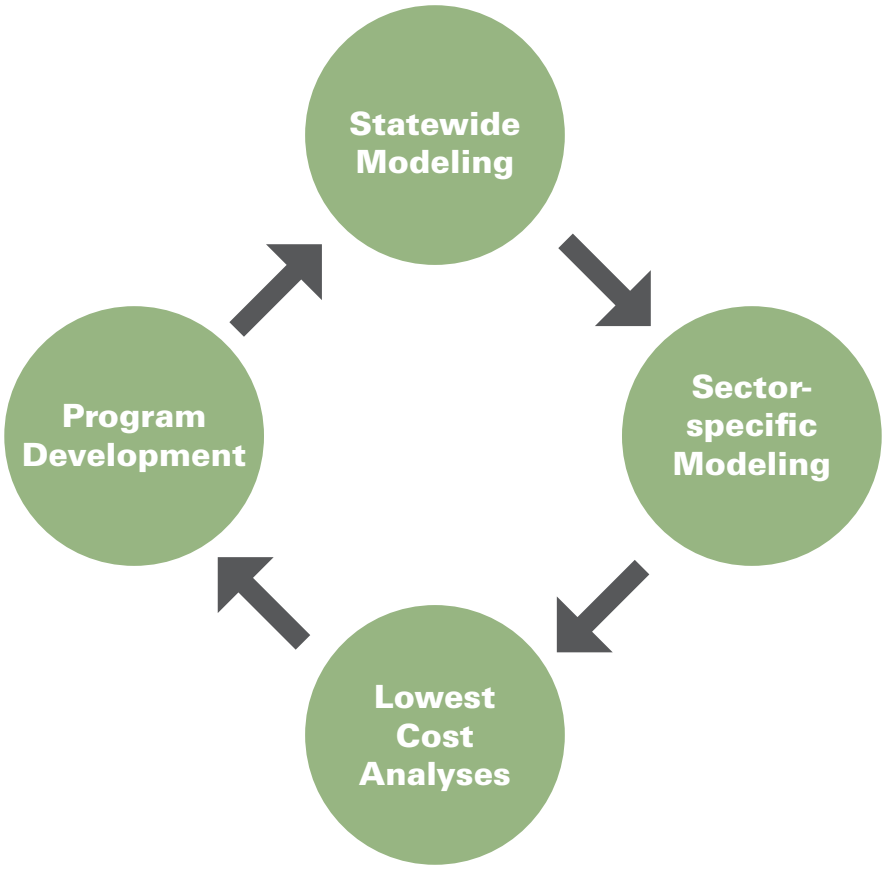
Given that past research efforts have established that environmental justice communities suffer disproportionately from asthma or asthma-like symptoms, additional research is needed to identify factors that increase vulnerability to pollutant effects in these sensitive populations. The research will provide crucial information to support and focus efforts to protect these potentially vulnerable populations. The development of a walkability index to assess the health impacts from built environment design changes is also essential for determining the impact of new sustainable city planning efforts on the health of all populations, but is of particular importance for ensuring the health and safety of low socioeconomic status populations.

Evaluating the effectiveness of ARB regulatory programs in disadvantaged communities and identifying remaining health risks is a research priority for ARB. We will continue to investigate pollution trends in low- versus high-SES communities using the EJSM and ARB monitoring network. The areas of investigation include ozone trends, Toxic Air Contaminant trends, and the disparity in DPM exposure related to distance from truck routes.

RESEARCH HIGHLIGHT

ARB funded a research project to quantify the economic benefits of the Clean Energy Industry (CEI) in California, and to project its future growth. Results indicated that the CEI is an important contributor to California's economy, and will become increasingly important in the near future. By 2020, the CEI is expected to become a major industry in California, accounting for 4.2 percent of the state's economy and over 2 percent of its total employment. While California currently plays a leading role in low-carbon power, energy storage, green building, and adaptation industries, by 2020, California is also expected to become a major player in transportation and carbon markets. In addition, this research demonstrated that government incentives, increasing energy costs, government standards (Renewable Portfolio Standard and Renewable Electricity Standard), climate policy, and corporate image are important market drivers for this growing industry.

Economics



Past Successes

ARB's economic research supports regulatory programs and long-term planning by designing and managing extramural research projects that deliver mission-critical economic analyses and modeling tools. Results from these projects ensure the accuracy of in-house analyses that are performed by a team of economists, led by an Economic Advisor in ARB's Executive Office. In addition to research contracts, ARB staff also works to leverage expertise from academics and economic experts in the private sector. Examples of this type of coordination are the formation of economic advisory committees on a range of issues, including the AB 32 Scoping Plan and the Cap and Trade regulation, and the placement of an Economics Fellow in ARB's Office of the Chair that facilitates collaboration with researchers at the University of California. Ongoing coordination with other State agencies, such as the California Department of Finance, and non-profit organizations, like Next 10, will continue to help ARB assess the significance and impact of California's growing green economy.

ARB has funded the development of modeling tools to assess the statewide economic impacts of air quality and GHG emission control regulations and to inform discussion on the technology and policy options for reaching California's long-term emission reduction goals. These contracts have resulted in the Environmental Dynamic Revenue Analysis Model (E-DRAM), a computable general equilibrium model of California's economy designed specifically to assess the effects of emission control regulations, and CA-TIMES, a mathematical model of the structure and operation of the California energy system through 2050. CA-TIMES identifies optimal transition pathways to a low-carbon California economy by minimizing the cost of supplying the resources, infrastructure, and

technologies needed to meet future energy demand while satisfying selected emission targets and policy constraints.

Several other recently completed studies have examined the economic implications of specific ARB programs, including diesel risk reduction efforts, light-duty emission standards, and SB 375. ARB conducts in-house analyses of the health benefits (e.g. avoided premature mortality, hospitalizations, and asthma emergency room visits), and their economic valuation. This analysis has been done for the Short-Lived Climate Pollutant Strategy, the Carl Moyer Program, and all diesel rules and major regulations, like the Truck and Bus Rule. ARB also funded a comprehensive study to assess the potential design, implementation, and benefits of a feebate program for new light-duty vehicles in California, and development of CARBITS, a market simulation model for the passenger vehicle market in California. CARBITS was used to evaluate market response under alternative regulation scenarios during development of ARBs pioneering "Pavley I" and Advanced Clean Cars (LEV III) GHG tailpipe emissions regulation. A new vehicle choice model at the household-level that incorporates the effect of other vehicles in the household on purchase decisions and also includes vehicle usage is being developed to replace CARBITS.

In support of ARB's role in the implementation of SB 375, a recently completed extramural project analyzed the economic benefits and costs of smart growth projects recently undertaken in California from regional, municipal, and household perspectives. The project concluded that there can be synergies between reducing GHG emissions and improving housing affordability, and the results will help planners assess the impacts of smart growth interventions on residential and commercial development, municipal budgets, and vehicle travel.

Current Research and Coordination Efforts

One of ARB's current projects was developed to assist in the development of cost-effective methods to reduce harmful emissions from agricultural equipment in the San Joaquin Valley (SJV). The results from this work are intended to provide ARB with the best available data on farmers, and agricultural-related businesses, to enhance ARB's existing cost and economic impact methodologies. This information will be used to develop a proposed regulation on mobile agricultural equipment in the SJV to transform their fleet to the clean technologies at the least cost.

Several current projects inform ARB's light-duty zero and near-zero emission vehicle programs. One project supports ZEV policy development by analyzing how socioeconomic, demographic, market, and regulatory factors influence the growth of ZEV sales in California. Using historical vehicle registration and incentive program data at the census-tract level, the study assesses the impacts of changing fuel prices, alternative incentive structures, and other parameters on ZEV sales. A second project consists of an economic assessment of the used PEV market in California, including a survey to identify who purchases used PEVs, their motivations, concerns, purchase details, and driving/charging behavior. This project will help determine if ARB policy modifications are needed based on the health of the used PEV market. A third project will provide a better understanding of low- and moderate-income household vehicle retirement and purchase decisions, including the role different incentives play in those decisions.

ARB's economic research is also supporting the implementation of sustainable community strategies adopted under SB 375. A project that will begin soon will assess the travel demand and co-benefit impacts of affordable transit oriented developments (TOD). This work will build on previous research that found synergies between GHG reductions and improved housing affordability by quantifying, with primary data collection, the GHG benefit of pursuing a smart growth strategy like TOD housing. The study will also examine other co-benefits, such as impacts on the health, economics, and the wellbeing of low income residents. Another project is collecting a variety of baseline information with the ultimate goal of developing metrics that can be used in a future statewide monitoring system for tracking progress toward achieving

SB 375 goals. One indicator in this project is access to jobs. EDD is participating in the advisory committee for this project, and may provide employment data to support the exploration of job access and/or jobs-housing balance as an indicator of progress toward reducing VMT, and thus GHGs under SB 375.

Remaining Needs

Additional economic research is needed to support ARB's programs and ensure that economic prosperity and environmental sustainability can be achieved together. Estimating the economic impact of AB 32 measures can provide insight into future regulatory implementation and has been identified as a near-term research need. In addition, research is needed related to the quantification and monetization of economic impacts, including emissions and health co-benefits and eco-system impacts, across air quality and climate changes programs.

Economic research on the use of incentives can also benefit ARB's current suite of programs. ARB oversees several incentive programs to promote the use of low-emission, clean vehicle technology that needs to be incorporated into our light-, medium-, and heavy-duty fleets to meet long-term air quality and climate goals. Research on the efficient deployment of incentives is needed to ensure emission reductions are optimized across vehicle and driver populations. Continued research on this topic will ensure that California obtains the greatest emission reductions possible per dollar of incentive funding spent.

On-going Program Support

SIP Program Support

ARB's research continues to improve the scientific foundation that supports the development of effective strategies to meet Clean Air Act requirements for State Implementation Plans (SIPs) for meeting National Ambient Air Quality Standards (NAAQS). ARB's air quality research has improved emissions inventories, chemical mechanisms and air quality models that provide the technical foundation for California's SIPs. To support these efforts, numerous field studies have been conducted to improve our understanding of the nature of the air pollution problems in the South Coast Air Basin, San Joaquin Valley, and other areas of the State.

Emissions, Meteorology, Chemistry

Photochemical Models

Inform NAAQS Planning Efforts

Past Successes

For over 40 years ARB funded research has provided foundational insights into the processes by which air pollution forms over the state. Research in laboratories, environmental chambers, and source testing has led to a better understanding of emissions to the air, the chemistry these emissions undergo in the atmosphere and how to model these processes. The many air quality field studies conducted in the State have documented the changing environment, while taking advantage of ever-improving scientific methods and tools to collect data on emissions, meteorology, and chemical mechanisms to improve air quality modeling systems. Field studies also provided numerous opportunities to leverage other agencies' scientific expertise and research investments. A recent example of a major field study is CalNex2010 which was designed by ARB and the National Oceanic and Atmospheric Administration (NOAA) staff to answer 12 policy relevant science questions on air quality, climate, and their nexus throughout California. A synthesis report of policy relevant findings from the CalNex2010 was presented it to the Board in the spring of 2014.

RESEARCH HIGHLIGHT

In May and June of 2010, the *CalNex study* examined the nexus between air pollution and climate change, involving four airplanes, an ocean-going research ship, two air monitoring supersites (Bakersfield and Pasadena), and more than 150 highly trained scientists in a joint collaboration between the National Oceanic and Atmospheric Administration (NOAA) and ARB. The study answered important scientific questions about emissions, chemical transformations, atmospheric transport, and climate processes in California. The data collected during CalNex is helping improve ARB's emission inventory for GHGs, and informing air quality models used to help develop strategies for attaining clean air goals for ozone and PM2.5 in the South Coast and San Joaquin Valley Air Basins.

ARB 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 PM2.5 components from the CARES study, and is funding ongoing research on PM2.5 data generated during DISCOVER-AQ.

Despite very dramatic improvements in air quality in the State, California must continue to achieve significant new reductions to meet ambient air quality standards for particulate matter and ozone. For non-attainment areas, the SIP must demonstrate how control strategies will reduce ground-level ambient ozone or PM to levels to meet the health-based standards. 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. Improvements to air quality modeling systems involve improvements in input data, modeling algorithms, and key components of the models such as chemical mechanisms.

Current Research and Coordination Efforts

TTo 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 PM2.5 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 PM2.5 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.

A large number of observations around the world have documented the presence of elevated ozone concentrations aloft that could potentially impact ground level exceedances. While some field studies have collected measurements of aloft ozone near and over California, these relatively short-term efforts do not provide sufficient information to fully understand the spatial and temporal variations in baseline ozone concentrations entering California and the processes by which baseline ozone aloft may mix down and contribute to surface ozone exceedances in the San Joaquin Valley (SJV). The California Baseline Ozone Transport Study (CABOTS), which starts this month and continues into August, was designed to investigate policy relevant questions about the content and daily variability of ozone vertical profiles as they enter the State from the Pacific, and the extent to which trans-Pacific long-range transported ozone mixes down to surface sites in the SJV. CABOTS is a coordinated effort with San Jose State University and NOAA. Aircraft flown by two NASA programs, as well as two additional ABR funded contracts and a surface ozone monitoring site in the Coast Ranges supported by the San Joaquin Valley Air Pollution Control District will add significantly to the study. The field measurements will provide key data to begin to quantify the contribution of baseline ozone aloft to surface ozone exceedances in the SJV.

An additional project begun last year will support updates to the particulate matter modeling for the San Joaquin Valley Air Basin needed to address the more stringent annual-average PM2.5 standard adopted by the U.S. EPA in 2012. This project will incorporate recent field observations of PM2.5 exceedances into improved models of the stagnation events leading to PM2.5 exceedances.

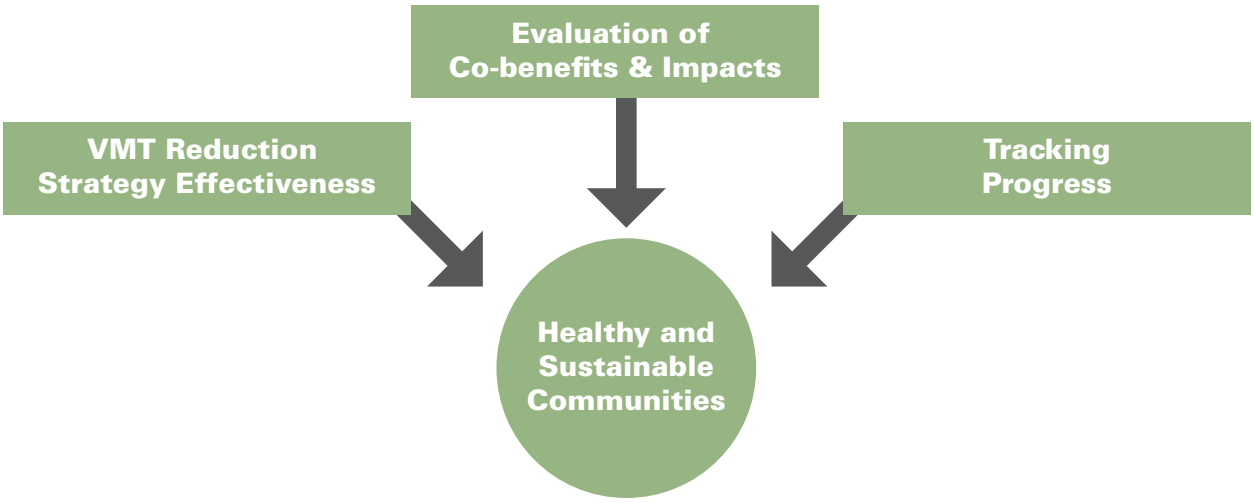
In addition to collaborating with the research community on specific projects, ARB coordinates with researchers, and other entities interested in improving air quality, through sponsorship of two major series of scientific conferences biennially at the University of California at Davis; the International Conference on Atmospheric Chemical Mechanisms (ACM), which mainly focuses on gas-phase chemistry that leads to ozone formation, and the International Aerosol Modeling Algorithms (IAMA) conference, which focuses on the particulate matter formation mechanisms.

Remaining Needs

Although there is a significant amount of current in-house, sponsored, and leveraged research activity to support SIP development, additional research needs remain. In the San Joaquin Valley, modeling of ammonium nitrate, the single largest component of PM2.5, could be improved through targeted collection of chemical mechanism and atmospheric processes data for ammonia emissions. In the Central Valley, the air quality impacts of the Delta breeze requires further investigation, as well as improved estimates of particulate matter emissions from fugitive sources. Inter-laboratory comparisons of chamber results would also provide improved quantification of SOA yields.

SB 375 Program Support

State law (SB 375) encourages California transportation and land use agencies to consider the greenhouse gas impacts of their planning processes and requires them to create "sustainable communities strategies" (SCS) that describe how vehicle miles traveled (VMT) and associated greenhouse gas (GHG) emissions will be reduced to meet state climate goals. Since the passage of SB 375 in 2008, ARB's research program has worked to support the implementation of SB 375. Research themes include investigating strategies that reduce VMT and resulting GHG emissions from land use and transportation, evaluating the co-benefits and potential impacts of those strategies, and tracking progress toward SB 375 and SCS implementation. These projects have resulted in the identification of strategies to maximize the benefits of sustainable planning (including reduced air pollution, greater energy efficiency, and cost savings), and developed tools to monitor and quantify these benefits. These research projects seek to synthesize these research results for policy makers and local governments to provide tools to reduce GHG emissions without unintended impacts on health and social equity, and to guide future policies.



Past Successes

Achieving the goals of SB 375 requires that the strategies included in SCSs can effectively reduce VMT. There are many variables that can influence the effectiveness of strategies, so ARB has funded research that evaluates these variables, quantifies potential effectiveness of different strategies, and provides guidance and tools to planners to help them identify the strategies that are most appropriate for the local context.

ARB's first effort here was to review and summarize existing research evaluating the VMT and GHG impacts of known land use and transportation strategies. To date, 23 strategies have been evaluated, and the literature reviews and accompanying policy briefs have been made publicly available. This documentation is regularly used by regional and local planning agencies help select strategies that can bring about significant reductions in travel demand.

ARB also funded first-of-its-kind research to characterize and quantitatively estimate how strategy effectiveness varies based on location and neighborhood type. The research project also resulted in the development of the "VMT Impact Tool" that cities, counties, and regions can use to evaluate possible land use and transportation strategies and make better-informed policy and investment decisions.

Empirical research is also a useful for evaluating how land use and transportation strategies play out in the real world. ARB co-funded a project that examined the impacts of the new Expo line in Los Angeles. The research found that, once the Expo line opened, households located near the new light rail stations traveled on average 10 miles less every day than similar households not near the line. And this change in travel behavior held a year after the opening. This is a remarkable change in travel and demonstrates that light rail transit is a very robust alternative in the Los Angeles metro area and similar parts of California.

A strong understanding of the range and magnitude of benefits and potential impacts that may result from SB 375-related strategies is important for encouraging public engagement and participation in SCS adoption and implementation and for identifying and addressing any health- or equity-related unintended consequences. To investigate potential co-benefits, ARB has funded research analyzing the economic impacts of smart growth plans and policies characteristic of those adopted in current SCSs.

Regarding investigating potential co-benefits, ARB has funded research analyzing the economic impacts of smart growth plans and policies characteristic of those adopted included in SCSs. Through a case study approach of existing communities that have implemented smart growth policies or plans, the researchers found that smart growth typically results in net benefits for residential development, commercial development, municipalities, and households.

ARB research has also characterized the potential environmental co-benefits of SB 375-related strategies. One project confirmed, using actual household energy usage data, that California homes in higher density developments use less energy than homes in lower density developments. This research also resulted in the creation of a tool that local governments can use when updating their General Plans or Climate Action Plans to estimate the residential energy use and GHG emissions associated with future development.

Another research project sought to identify potential unintended consequences and co-benefits of strategies that encouraged "complete streets" implementation, whereby more roadway infrastructure and other investments are made to encourage more non-personal vehicle travel (e.g., walking, biking, and transit use). The study examined differences in travel behavior and street users' exposure on complete streets versus conventional streets and found that differences vary greatly depending on the location and function of the street in question (local context matters).

Current Research and Coordination Efforts

ARB continues to conduct research evaluating the potential co-benefits and impacts of SB 375, in order to identify how that all Californians can benefit from a transition toward more sustainable communities. A current research project evaluates the potential for displacement of lower-income residents as a result of investments in compact, transit-oriented developments (TOD). The study also identifies possible policy solutions, evaluates how regional transportation and land use models can flag potential displacement, and considers the potential VMT-related impact of displacement. One project will examine the relationship between VMT, affordable housing, and TOD more closely. Researchers will collect primary data and conduct analyses comparing the travel behavior (including VMT) of affordable housing residents living near transit with the travel behavior of affordable housing residents that do not live near transit.

Another important research focus concerns near-roadway air pollution exposure, which is motivated by the concept that pursuing more compact development to reduce regional air pollution and GHGs may place more people in areas with high traffic-related pollution. ARB staff has conducted literature reviews to identify effective mitigation options and has found that, while many strategies seem promising, there are significant gaps in our understanding of what is the most effective and where. To help fill these gaps, research is underway to evaluate potential mitigation options, including vegetative-sound wall barriers, in-home filtration, and urban design strategies. A recently completed study looking at how pollutants disperse in typical Southern California streetscapes has found that assessing how pollution flows and accumulates along a street can largely be done with three simple variables describing the street and local meteorology. This work can allow for the prediction of pollution hotspots, and this information may be used to inform future urban design decisions. Staff is currently coordinating with various state and federal agencies, academic experts, and other stakeholders to translate findings from the literature into a Technical Advisory that can be used when near-roadway pollution exposure is a concern, particularly when linked to SB 375-related efforts.

Studies of near-roadway health impacts indicate that air pollution is not the only cause; noise may also be a significant contributor to health impacts that have been associated with proximity to traffic. ARB currently has plans to dispatch noise monitors along with personal air pollution monitoring devices to collect data on commuters' exposure to noise, which will be an important first step into improving our understanding of the health effects related to noise and characterizing how noise may come into place in more compact communities with infill development in the future.

Tracking progress toward meeting the goals of SB 375 is important for ensuring that adopted SCSs and the long-term strategies they contain help the state achieve its climate change goals. Tracking progress requires consideration of both the effectiveness of strategies as well as the implementation of SCSs, which in many cases must happen at a local level. ARB has funded research, in collaboration with Caltrans, to lay the foundation for a future statewide monitoring system that will track implementation of strategies contained in SCSs. The ARB-funded portion will identify, evaluate, and select indicators, indices, and data sources that can be used for monitoring. Caltrans is funding a second phase of this project that will pilot the monitoring system in Los Angeles County.

Remaining Needs

While the unintended impacts of SB 375-related strategies have been addressed in a number of research projects sponsored by ARB and other research institutions, several concerns and knowledge gaps remain. First, more research is needed to understand how, and if, near-roadway exposure and associated health impacts will evolve as a result of long-term changes in California's transportation system. Tailpipe emissions are expected to decrease as a larger share of vehicles are electrified, but it is uncertain how non-tailpipe emissions will change. For example,

electric vehicles will continue to produce pollution from brake- and tire-wear, and these particles are understudied in the research literature. It is also unclear how these vehicle technologies may offset brake- and tire wear concerns. Will regenerative braking decrease brake-wear, and if so, by how much? Noise is another variable that will likely continue to be an issue, particularly near high-speed roads where most of the sound is generated by tire contact with pavement, not engine noise.

More research is also needed to evaluate the overall net health effect of SB 375 implementation. While it is possible that more people will face increased exposure to traffic related air pollution near their homes in compact, infill neighborhoods, it is possible that reduced in-vehicle exposure resulting from shorter commutes will offset these increases in near-home exposure. Also, it is possible that regional reductions in VMT will reduce regional pollution levels, and this could lower the background concentrations that would be experienced by near-roadway receptors. Finally, there is a growing body of literature examining the health benefits of walkable communities and neighborhoods that facilitate active transportation and increased physical activity, and it may be possible to quantify those health benefits and add them to the equation for evaluating the net health effects of SB 375.

Advanced technology and new data collection techniques may be used in the future to improve our understanding of the impacts of SB 375, to identify ways to address unintended consequences, to increase the effectiveness of existing strategies, and to identify new strategies. ARB will continue to work with its partners and other stakeholders to identify opportunities to use new tools to converge on strategies that maximize the benefits of sustainable communities for all Californians while also bringing the state closer to its long-term climate goals.

SLCP Strategy Support

Climate science underscores the need to immediately reduce emissions of short-lived climate pollutants (SLCPs), which include black carbon (soot), methane (CH_4), and fluorinated gases (F gases, including hydrofluorocarbons, or HFCs). These gases are powerful climate forcers, and harmful air pollutants that have an outsized impact on climate change in the near term, compared to longer-lived GHGs, such as carbon dioxide (CO_2). SLCP emission reductions are critical to achieving California's GHG reduction goals set by AB 32 and Governor Brown's 2030 target. ARB's research program has sponsored external research, and developed in-house research initiatives to support the agency's efforts to inventory, mitigate, and track the emissions of SLCPs.

Past Successes

ARB research on black carbon began with the creation of a California inventory for black carbon. An ARB research study on black carbon observed a 50 percent reduction in black carbon measured at monitoring sites throughout California over the past twenty years, and a 90 percent reduction of the past 45 years. The 50 percent reduction in black carbon accounted for a 25 percent decrease in atmospheric heating in California. Through a collaborative research effort with NOAA, ARB was able to produce direct measurements of this forcing in the atmosphere. These results agree with the expected emission reductions associated with California's diesel emissions control program. Further reduction will likely be shown in the future due to ARB's Advanced Clean Car program and district burning restrictions.

California has made extraordinary progress to reduce PM and black carbon emissions, especially from on-road mobile sources. This record of success makes California an international leader in reducing harmful PM and black carbon emissions to protect health, the environment, and climate. The strategies and technologies developed in California can also be applied to other regions to yield additional emission reductions.

ARB's research program on F-gases has inventoried California's sources of these high-global warming potential gases. The inventory demonstrated that emissions of these gases are growing rapidly in California and are produced from a variety of sources. Several research projects highlighted the importance and cost-effectiveness of reducing these emissions, and led directly to adoption of rules to reduce hydrofluorocarbons from commercial refrigeration, motor vehicle air conditioning systems, and other sources. In addition, based on this research, ARB adopted a protocol to provide incentives to recover and destroy ozone-depleting substances as part of the cap-and-trade program. In many cases, federal bans of HFCs that have been imposed by the U.S. EPA have been modeled off of programs that were first demonstrated in California. These State and national efforts will lead to significant reductions in HFC emissions in California through 2030, compared to "business as usual". However, HFC emissions in California are expected to grow by more than 60 percent without additional action. ARB's research program has worked with stakeholders and experts in the field to develop additional recommended actions that are described in the Short-Lived Climate Pollutant Strategy to further reduce HFC emissions to 2030 and beyond.ARB's tower network includes seven GHG monitoring stations throughout the state, coordinated with eleven stations operated by other groups. The first tower was established at Mount Wilson, in the Los Angeles basin, in 2010. The network was established in coordination with NOAA and the California Energy Commission to improve air quality models, refine emission inventories, determine the effectiveness of new emission control technologies, and improve measurement methods. ARB's mobile monitoring platform measurements complement the monitoring efforts in the tower network, and have been successfully deployed at a landfill and a natural gas compression station to better characterize sources of CH_4 and N_2O. ARB's effort to measure sources and trends of CH_4 emissions in Los Angeles have also been complemented by a five-year GHG monitoring project funded by the National Institute of Standards and Technology, called the Megacities Carbon Project. Through these coordinated efforts, an evaluation of CH_4 emissions in the Los Angeles was developed, which resolved uncertainties in the inventory, and led to several peer-reviewed publications.

RESEARCH HIGHLIGHT

Aliso Canyon, the largest natural gas storage facility in California managed by Southern California Gas Company (SoCalGas), reported a natural gas leak on October 23, 2015. After the discovery of the leak, ARB responded by working with leading researchers to measure and quantify the leaked CH_4 emissions based on a series of ambient measurement efforts. The monitoring included over 15 downwind flights with a small airplane and several passenger cars, equipped with CH_4 monitors. The research teams are also leveraging existing monitoring resources that are in place to make routine measurement of CO_2, CH_4, and other GHGs in the Los Angeles area. These measurements are being used to calculate an emission rate and will be used for developing and implementing a Climate Impact Mitigation Program. ARB's indoor air quality research group also responded by providing the affected community, and SoCalGas staff, with information to mitigate the exposure to odorous compounds associated with the leak. ARB, in coordination with other State agencies and SoCalGas, has continued to monitor the situation very closely. ARB installed continuous CH_4 monitors in the affected community to inform the public about CH_4 concentrations from the natural gas plume in the community, and posts real-time measurement data through a Community Methane Monitoring website.

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Current Research and Coordination Efforts

New studies have suggested that certain fractions of organic carbon known as "brown carbon" could be a stronger absorber of solar radiation than previously understood. The warming effect of brown carbon may offset the cooling impact of other organic carbon particles; hence, quantification of that absorption is necessary so that climate models can evaluate the net climate effect of organic carbon. To help characterize and differentiate sources of brown carbon from black carbon and understand their climate impact in California, a current ARB-funded research project is applying advanced measurement methodology along with regional and global climate modeling simulations to characterize the extent to which brown carbon contributes to climate forcing in California. This project will improve our understanding of the fundamental processes that dominate brown carbon formation, and help to determine the potential climate benefit of mitigating sources of brown carbon emissions in California.

ARB is continuing to collaborating with scientists at NASA's Jet Propulsion Laboratory to identify large "hot spot" CH_4 sources through systematic aerial and ground surveys of high- CH_4 emitters in the agriculture, waste, and oil and gas sectors. This research will aid in future control and regulatory plans to reduce GHG emissions in California. ARB's CH_4 monitoring work not only leverages multi-million dollar effort with experts within the State, but also continues to collaborate with researchers doing similar work nation-wide, such as the Environmental Defense Fund and the U.S. Department of Energy.

RESEARCH HIGHLIGHT

Waste insulation foam from buildings and refrigerator-freezers contains high-global warming fluorinated gases (F-gases). When landfilled, the waste foam was presumed to be a significant source of GHG emissions. However, hundreds of landfill gas samples showed that F-gas emissions from landfills were up to 90 percent less than initially believed, due to the required methane gas collection and treatment systems required at all large California landfills. The F-gases from waste foam are collected along with the methane in the landfill, which is then combusted at very high temperatures, destroying 99.8 percent of all F-gases. Most emissions of F-gases from insulating foam occur prior to landfilling. Significant reductions of foam F-gas emissions are achievable through eliminating their use at the time of foam manufacture by substituting lower-GWP compounds.

ARB is starting two projects focused on improving California's CH_4 emissions from cattle operations. California dairy operations are a major source of greenhouse gases, 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. A project on manure management will determine the chemical and physical characteristics of California dairy manure and manure management practices and to characterize their relationship with GHG emissions. A second project will collect California-specific feed data to improve California's estimate of GHG emissions from enteric fermentation.

ARB is also sponsoring research to assess the feasibility of renewable natural gas (RNG) as a low carbon alternative fuel in order to divert CH_4-producing waste from landfills, and evaluate the volume of fuel that could be made commercially available. The project is estimating the savings in emissions and fuel prices compared to traditional hydrocarbon-based transportation fuels. Results are expected at the end of 2016.

ARB is also investing in state-of-the-art monitoring equipment to expand our air monitoring capabilities throughout the State. To that end, we are expanding our partnership with leading research experts from JPL, NASA, NIST, and NOAA to identify additional monitoring stations in the South Coast Air Basin to study the regional CH_4, N_2O, and CO_2 emissions. ARB's research program is also evaluating options to expand our air-monitoring capabilities to measure real-time regional F-gas concentrations in the across the State. Additionally, these techniques will also allow us to measure other volatile organic compounds (VOC) tracers in the ambient air, which will enhance our ability to study and understand the GHG emissions contributions of the various sources.

Current research on F-gases is determining the technical feasibility, cost, and potential GHG reductions of low-GWP commercial refrigeration. Additionally, ARB is also funding research contracts with University of California to study the long-term ambient air concentration trends of fluorinated gases in the South Coast Air Basin.

Not only is science needed to guide ARB's efforts to reduce SLCPs in response to mandates described above, Governor Brown's 2016-2017 Proposed Budget includes $215 million from Cap-and-Trade expenditures specifically targeting SLCP emission reductions. These include $40 million for black carbon residential wood-smoke reductions, $20 million for HFC reductions from refrigerants, $100 million for waste diversion, $20 million for Healthy Soils, and $35 million for dairy digester development. Several research projects have helped to guide the use of these investment funds. Continuing to support research related to SLCP mitigation is essential to guide future investments and ensure that SLCP mitigation strategies are successful, cost-effective, and that they don't lead to unintended consequences.

Proposed Research

California Methane Survey

Objective: The objective of this research is to conduct an aerial and ground-level survey of methane (CH_4) emissions over key regions in California to gain a better understanding CH_4 sources, their emission characteristics, and the distribution of the State's largest emitters.

Background: Knowledge of the sources and distributions of fugitive CH_4 emissions is critical given the importance of CH_4 as a high global warming potential greenhouse gas and ozone precursor. The State of California has recently introduced legislation (AB 1496) recognizing CH_4's impact as a greenhouse gas and the need for better understanding of sources statewide. Persistent atmospheric CH_4 enhancements observed over California's Central Valley using satellite data further emphasize the need to identify the many contributing point sources in this and other important regions that dominate the State's CH_4 budget. The growing evidence in the literature that a large portion of fugitive methane emissions is attributed to a small number of large point sources, suggesting the need for remote sensing methane surveys to identify these "super-emitters".

Multiple exploratory, short- duration aircraft field campaigns by the Jet Propulsion Laboratory (JPL) and collaborators have demonstrated the efficacy of remote sensing for CH_4 point source detection over large spatial areas. These campaigns, conducted in California, Colorado, and the 4 Corners region (2014-2015), have resulted in detection of hundreds of fugitive CH_4 plumes from individual emission point sources associated with oil and gas production, natural gas pipelines, landfills, wastewater management, dairies, natural seeps, etc. The California campaigns over portions of California's San Joaquin Valley and South Coast Air Basin included contemporaneous surface measurements that validated the remotely sensed CH_4 plume detections. This proposed study will be part of a broader project covering all major CH_4 emission source sectors in the state, and the California Energy Commission (CEC) will provide co-funding for the airborne survey of the oil and gas sector.

Method: The investigators will use JPL's next generation Airborne Visible/Infrared Imaging Spectrometer (AVIRIS-NG) and the Hyperspectral Thermal Emission Spectrometer (HyTES) instruments to conduct the statewide CH_4 survey. The data will be processed into maps of large point source emitters detected in the areas flown, a database of point source locations, sizes, and types will be generated along with a summary report including source distribution statistics.

Utility of Results: The results of this study can both inform near-term decision-making by California agencies and facility operators by providing better understanding of methane sources, their emission characteristics, and the distribution of super-emitters, as well as serving as a baseline to guide potential future monitoring of specific emitters and infrastructure, inventory improvements and verification of mitigation efforts of methane emissions.

Remaining Needs

Estimated black carbon (BC) emissions are very sensitive to the choice of source profile used to convert PM2.5 to BC. Additional representative source measurements are needed to better characterize BC emissions (and speciated profiles) by emissions source, fuel type, and combustion conditions. These data are needed to improve BC emission factors and inventories, and to help develop emissions and modeling uncertainties. Open biomass burning, including both prescribed fires and wildfires, represents a potentially large but far less certain portion of the California BC inventory.

California's CH_4 inventory would benefit from additional research on the emissions of CH_4 from landfills as they age, as well as will variations in landfill cover technology. Since CH_4 is

known to migrate laterally through landfills before it is emitted to the atmosphere, leakage of emissions from the periphery of landfills needs further refinement to accurately assess emissions associated with a given site. Additional studies to improve California's greenhouse gas inventories include a quantification of CH_4 emissions from light-duty vehicles, and analyses of speciation data from the combustion of different biomass under a variety of burn scenarios to improve the black carbon inventory.

The SLCP Strategy calls for the development of regulations to ensure emission reductions of CH_4 for dairy maure and livestock enteric fermentation. To support these efforts, research is needed on the use and effectiveness of solid separators and converting flush systems to dry manure management systems to reduce CH_4 emissions, as well as the potential to impact air and water quality. Information is also needed to help identify financing options to reduce costs and improve the economic feasibility of dairy digester projects since the transaction costs of owning and operating a digester are not well understood. Other research gaps include improving the availability of information for potential markets for organic wastes co-digested with manure on dairy farms, potential markets for materials other than biofuels and electricity, and costs and performance associated with other opportunities to reduce manure CH_4 emissions. Lastly, additional research is also needed to evaluate strategies that can reduce enteric fermentation emissions from cattle and livestock in the California context.

Sulfuryl fluoride (SO2F2) is a pesticide used primarily for the fumigation of drywood termites in homes and structures. Recently, it was identified as a high-GWP compound, with a 100-year GWP value of 4090. Approximately 3 million pounds of SO2F2 are used in California annually, with a GHG impact of 5.5 million metric tonnes of CO_2-equivalents. The California Department of Pesticide Regulation (DPR) strictly regulates SO2F2 as a pesticide and toxic air contaminant, but it is not currently regulated as a greenhouse gas. Alternatives to sulfuryl fluoride include orange oil, structure heating or extreme cooling, microwaves, and electricity. Previous research indicates that alternative treatments work as a spot treatment, but not on a whole-structure basis. UC Riverside Department of Entomology reports, "No alternative treatments have been identified to date that have the same consistency, completeness, and degree of efficacy as sulfuryl fluoride fumigation for pest elimination." It is not clear if additional research at this time on alternatives to sulfuryl fluoride will result in any new information not already published. ARB and DPR will continue to assess alternatives to sulfuryl fluoride as they are developed.

Scoping Plan Program Support

California's seminal Global Warming Solutions Act, AB 32 (Nuñez, Chapter 488, Statutes of 2006), charges the ARB with developing a Scoping Plan that describes the approach California will take to reduce GHGs to achieve the goal of reducing emissions to 1990 levels by 2020. The Scoping Plan was first approved by the Board in 2008, with an update to the Plan in 2014. Additionally, Governor Brown has identified "five pillars" to meet an overarching goal to reduce California's GHG emissions by 40 percent below 1990 levels by 2030, focused on reducing demand for petroleum and energy, ramping up renewable energy production, and carbon sequestration in the land base (Executive Order B-30-15). Key drivers for these reductions will come from 2030 targets for 50% renewable electricity and a doubling of energy efficiency savings in existing buildings, which are now required by statute (SB 350). ARB is moving forward with a second update to the Scoping Plan to reflect the 2030 target.

Past Successes

ARB's research program includes a number of research projects to support the development of GHG reduction strategies to achieve the objectives outlined in ARB's Scoping Plans. Research has primarily focused on the agricultural, energy, building sectors, and has used models to estimate different mixes of efficient technologies in these sectors. Many of ARB's external contracts have leveraged our State's world-class research institutions, which have made California perhaps the most studied region in the world when it comes to GHG emissions and climate policy. As a result, the mix of technologies needed to reduce emissions through 2050 is fairly well established, and has resulted in valuable models and tools to support ongoing policy planning and implementation.

ARB, in coordination with other State agencies, such as the California Energy Commission, has supported studies that provide a snapshot of the mix of technologies necessary to reduce statewide GHG emissions. These studies share many common conclusions, including the overarching conclusion that the 2050 emissions target is achievable, mostly with technologies that are commercially available today. Together, they show that achieving the 2050 target will require continued energy demand reduction through efficiency, activity changes, and electrification in many sectors. The studies vary in several important assumptions, however, which offer opportunities to pursue additional emission reductions or select alternative policy and technology paths forward, depending on population and economic growth in the State, technology and market development, and changing activity and behavior patterns.

These models of sector efficiencies have leveraged past research projects focused on energy efficiency and behavior change to reduce energy usage in existing buildings. Research looked at how to reduce GHGs from the building sector by investigating how Californians interact with building technology in the residential and commercial sector. One project focusing on how to maximize energy savings in commercial building through changes in operations provided recommendations that can be applied by building operators, managers, and occupants. These projects, as well as research on customer response to electricity consumption information, will help utilities target customers in their efforts to lower household energy use.

Green buildings and improving energy savings through our interactions with buildings and appliances offer a comprehensive approach to support California's climate change goals across multiple sectors, including energy, water, waste, and transportation while protecting the environment and public health. In coordination with the California Energy Commission (CEC) and California Public Utilities Commission (CPUC), ARB has sponsored a couple of research projects to better quantify GHG reductions of green buildings. One research project reviewed, enhanced, and validated a green home climate calculator, which estimates the GHG emission reduction potential of green homes compared to conventional homes regardless of occupant behavior. An additional research project quantified, for the first time, the GHG emission reductions co-benefits of green office buildings. Overall, existing buildings that are operated and maintained as certified green buildings can help to achieve additional and significant GHG emission reductions.

Past research has also looked at how to reduce GHGs from the building sector by investigating how Californians interact with building technology in the residential and commercial sector. This research showed that energy use was not correlated to income in the Sacramento area, and identified factors that play into energy consumption in residential and commercial buildings. These projects, as well as research on customer response to electricity consumption information, will help utilities target customers in their efforts to lower household energy use. A project focusing on how to maximize energy savings in commercial buildings through changes in operations provided recommendations that can be applied by building operators, managers, and occupants.

ARB has focused its agricultural research on developing models to predict emissions of nitrous oxide (N_2O), and strategies to mitigate N_2O emissions from California's croplands. N_2O is a potent GHG, contributing about 15 million metric tonnes of CO_2 equivalents, or three percent of the California's GHG inventory. The majority of N_2O in California is produced by microbe-driven processes of nitrification and denitrification in the environment. Quantifying NO emissions is difficult due to the high variability of N_2O fluxes both temporally and spatially. Starting in 2008, ABR, in coordination with the California Energy Commission, the California Department of Food and Agriculture, and agricultural stakeholders, has supported a number of projects providing field measurements of N_2O that allowed the revision and validation of a geochemical model, called DeNitrification-DeComposition (DNDC) to predict N_2O emissions from leading California-specific cropping systems. This model can now be used to characterize the effects of different soil and crop management practices on N_2O emissions, especially those with mitigation potential.

Current Research and Coordination Efforts

Current research on GHG mitigation in the agricultural sector is building on previous work to develop the California-specific DNDC model by refining this tool to allow for the quantification of the emission reduction potentials from various N_2O mitigation strategies that have been identified through previous ARB research.

Research results from zero carbon buildings will be key as we continue to pursue an integrated approach to reduce the greenhouse impact of new and existing buildings while improving indoor air quality. This research will evaluate the technical feasibility of achieving zero or near-zero carbon buildings for both the residential and commercial buildings. The results of this study will be used to assess the practicality and appropriate timeframe for a zero or near-zero carbon building State policy or program, which can put California on track to achieve mid-term and long-term climate goals.

Current research is also underway to reduce GHG emissions from the transportation sector through the use of alternative fuels. This reseach also 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 first project is examining the potential to produce renewable natural gas (RNG) at the commercial scale in California by updating information on the availability of feed-stocks in the State and developing cost curves to determine the production capacity needed to create a sustainable market. Results from this research will maximize the market penetration of these alternative fuels and identify the technical, commercial, financial, marketplace, and regulatory barriers that need to be addressed. The second project is developing full lifecycle assessments for renewable drop-in gasoline and diesel fuels created from agricultural and forestry waste products. This project will provide information on how the production of these fuels can contribute to meeting our long-term air quality and climate goals. A third project is developing lifecycle assessments for production pathways of renewable hydrogen fuel. These pathways will help expand the portfolio of the LCFS. A fourth project is investigating how natural gas infrastructure can be built in the near-term to accommodate a long-term shift to the use of alternative fuels. Costs of dual-purpose infrastructure that can accommodate both fossil natural gas and hydrogen will be compiled and used for an assessment of the potential for policies and incentives to be used to encourage the switch to alternative fuels.

Proposed Research

CO_2 Monitoring and Source Apportionment in Los Angeles

Objective: This project will extend existing efforts to measure emissions of CO_2 in the Los Angeles basin to track changes in emissions as California follows its mandate to reduce emissions by 2020 and beyond. Isotope analyses will allow the researchers to distinguish fossil fuel combustion from biogenic CO_2 sources.

Background: CO_2 is the greenhouse gas (GHG) most frequently identified as the dominant cause of global warming. In order to fully understand the role of anthropogenic CO_2 emissions in climate change, and to track mitigation efforts, we must understand the nature and the spatial and temporal distribution of their sources. Measurements of CO_2 and Δ14C have been ongoing since 2006 at Pasadena, CA and 2009 at Palo Verdes, CA, with added CH_4 capability in 2012 and CO (and N_2O) capability(s) in 2013 at Pasadena, CA. The isotopic CO_2 measured at Pasadena, CA is the longest Δ14C record measured in California. Measurements and analyses of CO, CO_2, δ13C, and Δ14C have been identified as an effective way to distinguish among fossil fuel combustion, and biosphere contributions to CO_2 in the atmosphere. In addition, this dataset can be used to evaluate ARB's bottom-up CO_2 inventory. By extending the CO_2 time series through 2020, the State will be able to track the long-term progress of mitigation measures. Having the ability to perform source attribution of CO_2 is necessary for future mitigation plans and policy making and will play an integral part in reaching AB32 goals.

Method: The investigators will examine concentrations and sources of CO_2 in the Los Angeles basin through: 1) continued operation of two in-situ sites in the Los Angeles basin (Pasadena and Palos Verdes peninsula) to study CO_2 emissions from anthropogenic sources and to understand their temporal variability, 2) continued flask analyses of Δ14C and Δ13C to track changes in CO_2 emissions as California follows its mandate to reduce emissions by 2020 and beyond, and 3) to perform data analysis on the four years of measurements collected under this project (and for the entire 2006-2020 period) and to compare the results to bottom-up inventory information.

Utility of Results: The collected data can be used to develop a long-term comprehensive understanding of carbon emissions and source contributions in the Los Angeles basin and will aid in verifying ARB's inventory, and tracking the progress made by AB32.

Remaining Needs

Remaining research needs include the development of novel GHG reduction strategies, as well as improved analyses to quantify GHG reductions from projects aimed at sequestering carbon in natural and working lands. Cap-and-Trade investment funds are currently being used to develop projects to reduce GHG emissions in multiple sectors, in addition to sequestering carbon in natural and working lands. While these projects include methodologies to estimate GHG reductions, or sequestration associated with the project, additional science is needed to improve these estimates. This is especially true for projects aimed at sequestering carbon in natural and working lands, since variations in climate, soils type, and many other site-specific parameters, can affect the outcome of these evaluations. Projects aimed at reducing GHGs in the transportation sector would also benefit from analyses of impacts on GHGs and other co-benefits before and after the project is implemented.

Multiple studies on long-term strategies to achieve GHG reductions have indicated that carbon capture and sequestration (CCS) has the potential to reduce carbon emissions by millions of metric tons, and may be an integral part of meeting California's climate goals. ARB is currently developing a quantification methodology for CCS that may be adopted for use in the Cap-and-Trade and Low Carbon Fuel Standard programs as determined appropriate in rulemaking(s). To support these efforts, additional research is needed to develop promising novel techniques for

extracting carbon from industrial emissions, and evaluating costs and geospatial planning for CCS and other new low C technology.

Additional research is also needed at the water-energy nexus to reduce GHG emissions associated with the water sector. High priority needs include the identification of system efficiencies associated with moving water around the State. Accurate measurements of GHG emissions associated with de-salinization and the movement of water are also needed to improve inventory estimates and to better inform policy decisions and State investments in efficiency projects going forward.

While recent research begins to better quantify GHG emission reductions of green buildings, additional research is needed to fully understand the GHG reduction potential of green buildings. Further research is also needed to consider life cycle performance to develop state-of-the-art equipment and technologies that provide a lower carbon footprint.

Mobile Source Strategies Support

ARB's mobile source emissions research program supports California's effort to meet NAAQS, reduce health risk from toxic air contaminants, and meet GHG reduction goals. Research on vehicles and fuels supports the development and implementation of regulations and incentive programs that reduce transportation related emissions. ARB research promotes advanced emission reduction technologies and monitors the effectiveness of emission reduction strategies to ensure that the expected air quality and public health benefits are achieved. Research results from this suite of projects inform policy makers to ensure the policies aimed at reducing emissions don't have any unintended impacts, and provide information for future policy development.

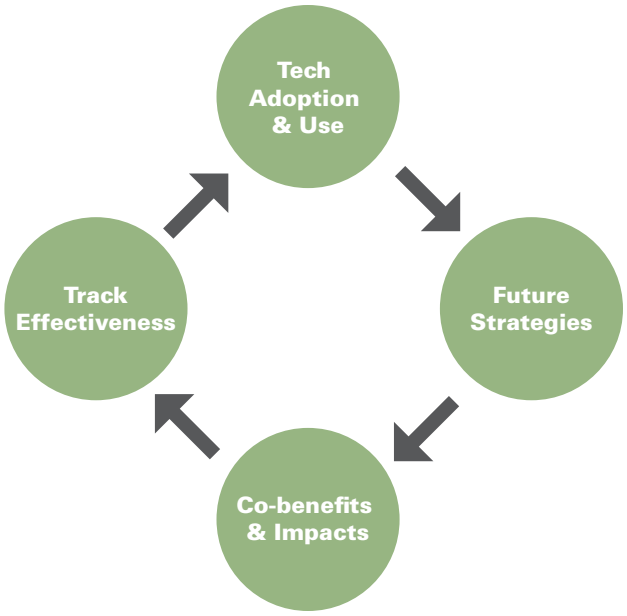
Past Successes

California has a long and successful history of adopting technology-advancing vehicle emission standards to protect public health, built on a strong research foundation. In both previous and on-going research to support the midterm review of the Advanced Clean Cars program, ARB has worked collaboratively with a number of research institutions and state and federal agencies, including the U.S. Environmental Protection Agency (EPA), National Highway Traffic Safety Administration (NHTSA), and the U.S. Department of Energy (DOE). These research projects have examined the technical feasibility and cost-effectiveness of emissions reduction technologies to optimize the use of incentive funds, improved our understanding of real-world emissions from the current California light-duty vehicle fleet, explored how new car buyers' perceptions of zero-emission vehicles (ZEVs) influence their vehicle purchase decisions, and validated new measurement techniques for determining very low levels of PM emissions.

ARB's recent research on heavy-duty vehicles, and their emissions, has focused on tracking the results of regulatory efforts to meet the goal of the Diesel Risk Reduction Plan. Beginning in 2000, a multi-agency collaboration, led by ARB, measured tailpipe emissions from diesel- and compressed natural gas-fueled transit buses with different types of aftertreatment and under a range of operating conditions. Continued collaboration with our partners led to a major effort to

RESEARCH HIGHLIGHT

Recently complete research to support the Advanced Clean Cars program performed simulations across all 2014 model year vehicles and quantified the effect on CO_2 emissions of incorporating best-performing load reduction technologies, such as aerodynamic drag improvements, reduced tire rolling resistance, and mass optimization. The researcher found that by adopting current best-performing load reduction technologies and re-optimizing the powertrains to these lower loads, a CO_2 emission reduction of 10.4%, or nearly one third of the requirements, could be realized.



characterize the effectiveness, durability, degradation, and failure rates of aftertreatment systems that reduce emissions of nitrogen oxides (NO_x) and diesel particulate matter (DPM), and the real-world efficacy of NO_x controls. This was accomplished using measurements of emissions from the in-use fleet in tunnels, at ports, and at weigh-in-motion stations in California.

In-house research to support this work included the deployment of a mobile measurement platform in collaboration with UCLA. The mobile monitoring platform measures key gaseous and particle species, including PM2.5, black carbon, carbon dioxide, and NO_x, with high spatial and temporal resolution. The mobile monitoring platform measured vehicle-related emissions on the 710 freeway (a major drayage route in Los Angeles) between 2009 and 2011. Results showed a 60% reduction of NO_x and a 70 percent reduction in black carbon, thereby quantifying the immediate benefits of the Drayage Truck Rule. Similar work by UC Berkeley has shown reductions near the Port of Oakland. These significant reductions in diesel-related pollutants in heavily impacted communities, which includes the neighborhoods adjacent to ports in California, will aid in reducing the prevalence of health-related impacts due to exposure of emissions.

RESEARCH HIGHLIGHT

Heavy-duty diesel trucks emit the majority of nitrogen oxides (NO_x) and diesel particulate matter (PM) in urban areas in California. Black carbon (BC), which is a short-lived yet potent absorber of solar radiation, comprises the majority of diesel PM. The Drayage Truck Regulation (DTR) is part of the Air Resources Board's ongoing efforts to improve air quality associated with goods movement by reducing these emissions from diesel-fueled engines. An ARB contract, completed in 2013, examined the effects of heavy-duty drayage truck fleet modernization, and diesel particulate filters (DPFs) retrofits, through measurements of truck emissions near the Port of Oakland. Results showed that the Phase 1 of California's DTR led to an increase in Port trucks equipped with DPFs from 2 to 99%, and a decrease in median engine age from 11 to 6 years. Over the same period, fleet-average emission factors decreased substantially for BC and NO_x. The BC reductions resulted primarily from increased use of DPFs, whereas NO_x reductions were attributed to replacement of the oldest trucks with newer equipment that met more stringent NO_x emission standards.

Current Research and Coordination Efforts

To support the upcoming midterm review for the Advanced Clean Cars program and in support of the Clean Vehicle Rebate Project, ARB has been sponsoring new light-duty vehicle research aimed at optimizing our use of incentive funds and consumer acceptance of new vehicle technologies, such as plug-in hybrid electric vehicles (PHEVs) and battery electric (BEV) vehicles (collectively referred to here as PEVs). A new research project will survey low- and moderate-income households to gain insight into their vehicle retirement and purchase decisions, including the role that different incentives play in those decisions. New research focused on adoption and use will quantify the electricity powered miles driven by advanced technology vehicles, and analyze the charging behavior of electric vehicle drivers. For example, current research on dynamics of PEVs in the secondary market will determine the longer term emissions benefits of these vehicles. While manufacturer compliance with the Zero Emission Vehicle (ZEV) program is based on new vehicles sales, the expected emissions benefits will require that these vehicles, including PEVs, remain in the fleet past the first owner. The results of this study will be useful to refine long term projections of emissions benefits from PEVs, and to inform future policy decisions, on the treatment of these vehicles by various ARB programs, such as incentives, durability requirements, or vehicle crediting.

Current research on heavy-duty diesel vehicles is underway to adapt diesel filter use to a wider variety of engines, develop and deploy zero-emission technology and infrastructure, and identify the emission benefits from alternative fuels. To support and inform the Sustainable Freight Action Plan, the 2016 SIPs, and other ARB emission reduction planning efforts, ARB and the South Coast Air Quality Management District have been conducting technology and fuel assessments for a variety of source categories. The assessments will provide essential information on the technologies and fuels that will provide the most benefit for California to meet its air quality and climate goals, including black carbon reductions.

Reducing transportation emissions will have dramatic air quality and public health benefits, especially in many of California's environmental justice communities. Therefore, ARB's mobile source research also monitors the effectiveness of emission reduction strategies to ensure that the expected air quality and public health benefits are achieved. For light-duty vehicles, research is investigating the long-term trend in measurements of emissions from light duty vehicles in Los Angeles using remote sensing, which will provide an understanding of how well the emission controls continue to perform in vehicles subject to LEV I and LEV II.

ARB's research aimed at monitoring emissions from the heavy-duty sector is improving our understanding of trends in on-road emissions and tracking the benefits of regulations (i.e., Drayage and Truck and Bus Rules), and programs to reduce DPM emissions by 85 percent by 2020. Research on diesel emissions is multipronged, and includes research on the effect of in-use rules for heavy-duty diesel vehicles, the durability, degradation, and failure rates of aftertreatment that reduces NO_x and DPM, and the real-world efficacy of NO_x controls. This will be accomplished by measuring emissions from the in-use fleet on laboratory dynamometers, in tunnels, at ports, and at weigh-in-motion stations in California. 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.

Current research is also focused on reducing and tracking emissions in the off-road sector. In the off-road sector, emissions standards have allowed smaller engines to be made and sold with minimal aftertreatment control technologies. The assumption has been that advanced aftertreatment would severely impact the cost of these smaller engines. However, given the need for further emission reductions, research into whether more advanced aftertreatment is feasible and cost-effective for these engines has been initiated. Additional research is looking at the impact of an alternative to current allowances for averaging fleet emissions to demonstrating compliance to gain a better understanding of the distribution of engines with the best available controls and emission impacts of current rules.

Proposed Research

Pathways Towards a Near-Zero Heavy-Duty Sector

Objective: Determine the costs, GHG, air toxic, and criteria pollutant emissions, and impacts to disadvantaged communities from multiple advanced technology scenarios in the heavy duty sector (including trucks, marine, rail and aviation). Multiple long-term scenarios will be developed to identify benefits and barriers, and determine the best policies and economic mechanisms to encourage pathways that allow California to achieve its long-term air quality and climate goals.

Background: Transitioning to biofuels can result in reduced GHG emissions, but does not reduce engine criteria pollutant emissions. Recent research suggests that biorefineries to produce biofuels may also have larger criteria pollutant footprints than the fossil fuels they would replace. Given these constraints on the production of biofuels in a State with ambitious GHG and criteria pollutant reduction plans, a holistic approach to assessing which alternative fuel and energy sources can be generated in the future is needed. This proposed research will focus on the heavy duty sector, with the assumption that the majority of other sectors can be electrified. A more accurate assessment of the best uses of California's feedstocks for the production of biofuels would help inform the best heavy duty fleet choices in the long-term.

Since additional criteria pollutant reduction strategies will be needed to meet SIP requirements, even with the use of alternative fuels, additional NO_x reduction strategies need to be considered. Recent developments in the literature have shown that intelligent technologies, such as vehicle automation and connections between vehicles, as well as connections between vehicles and transportation infrastructure, is beginning to show promise for practical application in the real world with benefits to fuel efficiency. This technology also has the potential to reduce criteria pollutant emissions in busy freight corridors, where disadvantaged communities are often located. The extent to which the application of these technologies can improve fuel efficiency and air quality needs to be explored, as well as the policies to ensure that the deployment of advanced technology vehicles and fuels allows the State to meet both air quality and climate goals without any unintended negative consequences.

Method: This project will start by examining the benefits of existing State programs to reduce GHG and criteria pollutant emissions and develop scenarios for further improvements in the heavy duty sector through the use of advanced technologies, fuels and energy sources. Researchers will carry out four main tasks: 1) Analyze the best use of renewable feedstocks to fuel heavy-duty vehicles. This analysis should include the latest lifecycle analyses and costs for a suite of alternative fuels (e.g., renewable natural gas, renewable diesel, renewable hydrogen, electricity, dimethyl ether (DME)), and include the potential role of power to gas technologies; 2) Given constraints from future fuel mixes and economics, examine the long-term viability of heavy-duty natural gas vehicles. This analysis should include liquid and compressed natural gas vehicles, in multiple size classes, and to the extent possible, marine, rail, and aviation fuel needs and fleet choices should also be considered; 3) Investigate the role of connected and automated technology and efficiency upgrades in the heavy duty sector, including the potential to improve air quality in disadvantaged communities. This should include an analysis of how State policies support connected and automated technologies that are used in combination with renewables sources of electricity; and 4) Provide expert advice on the best policies and economic incentives to encourage each low-carbon heavy-duty pathway.

Utility of Results: This project is part of California's continued efforts to decarbonize the heavy duty sector. Past regulations and incentive funding has put California on the path towards meeting our 2020 GHG and air quality targets, however, continued research is needed to guide current policies, identify new policies, and inform the best uses of incentive funding to meet stricter long-terms goals.

Measurement of In-Use Emissions and Fuel Consumption from Vocational Heavy-Duty Vehicles with Conventional and Alternative Engine and Fuel Technologies in Southern California

Objectives: The objectives of this research are to characterize the impact of conventional and alternative heavy-duty engine and fuel technologies on in-use emissions and fuel consumption, and to explore comparative benefits of reducing NO_x and PM emissions using conventional and alternative engine and fuel technologies for heavy-duty vehicles in various vocational uses.

Background: The recently introduced 2010 heavy-duty engine emission standards have reduced both NO_x and PM emissions significantly statewide and in the South Coast Air Basin (SoCAB). However, it is projected that heavy-duty vehicles will still be a dominant source of those emissions in the SoCAB and there is a need for additional reductions in NO_x emissions to meet upcoming National Ambient Air Quality Standards requirements for ambient PM2.5 and ozone. Understanding the impact of conventional and alternative engines, and fuel technologies, on in-use emissions and fuel consumption is critical for developing State Implementation Plans as well as for understanding the effectiveness of potential rules to further lower emission standards for heavy-duty vehicles.

The South Coast Air Quality Management District, California Energy Commission, Southern California Gas Company, and ARB have jointly developed a research plan for measuring in-use engine emissions and fuel consumption from heavy-duty vehicles in various vocation types. ARB will participate in this project as a co-funding organization. ARB's current research investigations characterizing heavy-duty vehicle activity profiles by their vocational types and quantifying the potential greenhouse gas emission reduction benefits of aerodynamic features on heavy-duty vehicles using onboard diagnostics data loggers do not include measurements of in-use emissions and fuel consumption due, in part, to limited resources. ARB will be able to leverage the findings from this planned research work to expand our understanding of vocational heavy-duty vehicle use and to develop effective strategies for reducing GHG emissions from heavy-duty vehicles and achieving the federal ambient air quality standards.

Method: The investigators will recruit up to 200 heavy-duty vehicles in transit, school bus, refuse, delivery, and goods movement applications powered by diesel, bio-diesel, natural gas (NG), renewable NG, NG-electric hybrid, and electric engines. The investigators will instrument those vehicles with portable emissions measurement systems, portable vehicle activity measurement systems, and other instruments to monitor daily vehicle activities, fuel usage, and instantaneous emissions. They will then use the measurements to characterize the impact of heavy-duty engine and fuel technologies on in-use engine emissions and fuel consumption, and to explore the comparative benefits of reducing NO_x and PM using conventional versus alternative engines and fuel technologies in various vocational services.

Utility of Results: Results from this research will be used to measure the effectiveness of heavy-duty vehicle engine and fuel technologies to improve emission inventories for air quality planning, to explore the effective applicability of engine and fuel technologies to specific vocation types, and to develop effective strategies for achieving the federal ambient air quality standards.

Remaining Needs

On May 3, 2016, State agency leaders released the Draft California Sustainable Freight Action Plan (Action Plan), an ambitious and unprecedented document that lays a foundation for modernizing California's multi-billion dollar freight transportation system. Developed in response to Governor Brown's Executive Order B-32-15, the draft Action Plan responds to the Governor's Executive Order by articulating one shared vision to improve the efficiency of California's freight system while reducing its pollution, while also bolstering the competitiveness of California's goods movement system nationally and internationally.

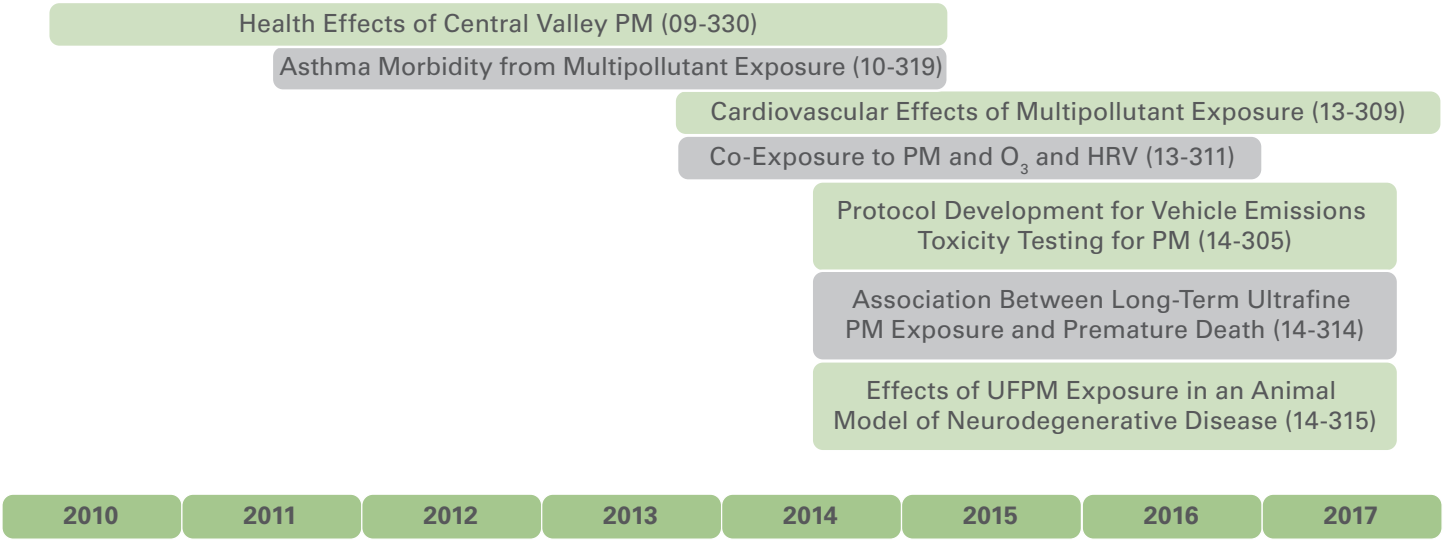
Achieving the vision set out in the draft Action Plan will require strategic partnerships and well-coordinated investments in new technologies and major infrastructure upgrades. Moving forward, ARB, in coordination with other State agencies, will be gathering additional information, developing actions, pilot projects, and other concepts identified in the Action Plan further. To support further development of these strategies research on system-wide techno-economic models to identify emission reductions at the least cost is needed. While there is already a significant amount of data available for the development of these models, the refinement of these models for California-specific needs, as well as additional data on costs, duty cycles, and power use profiles is needed.

Next Steps

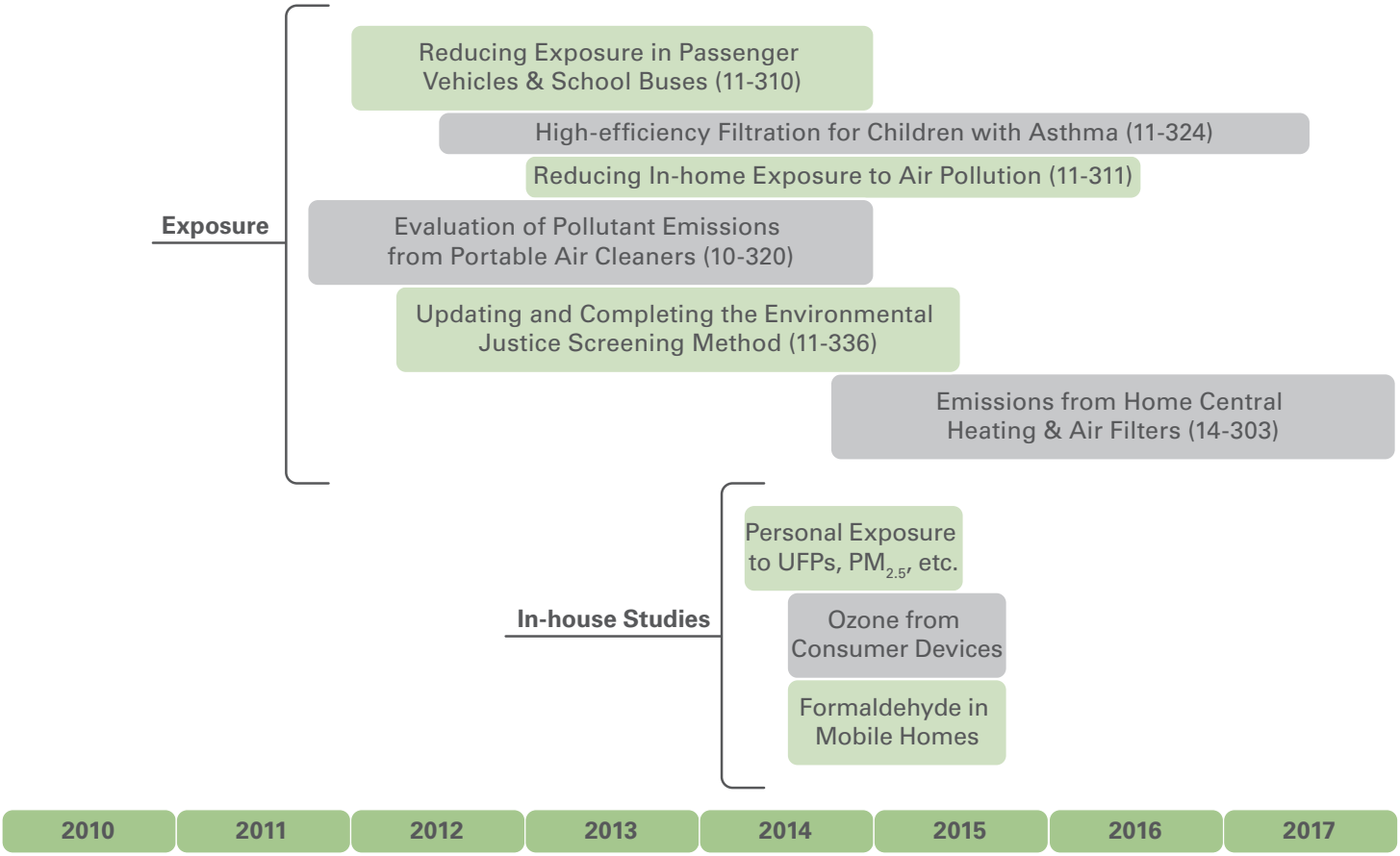
The four research projects proposed in this plan address key knowledge gaps and will strengthen the scientific foundation of health, air pollution, and climate control programs, help develop future clean air regulations and programs, and measure the effectiveness of ARB's programs. Following Board action 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.

Appendix 1: Current Research Projects

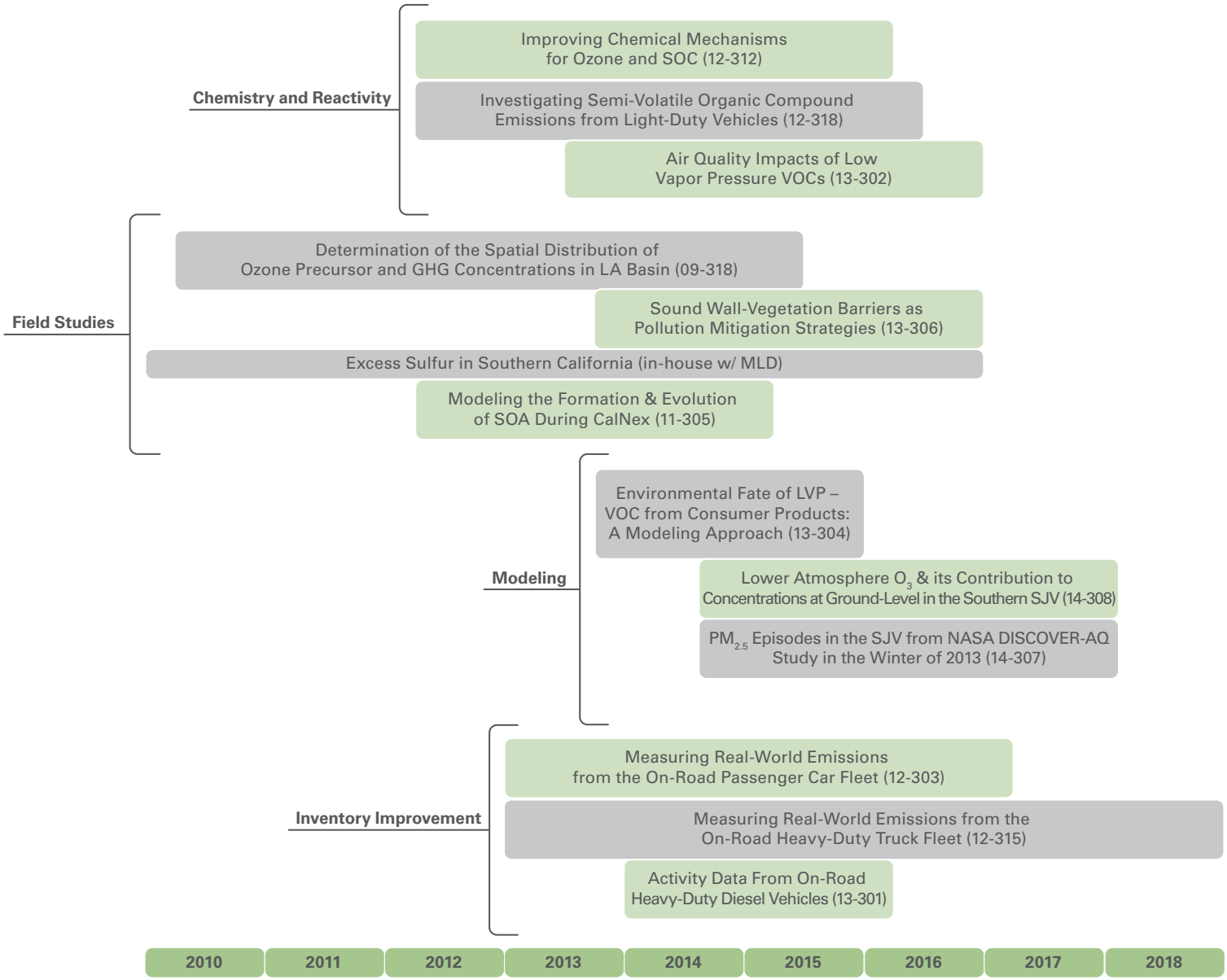
Health Effects Research Projects



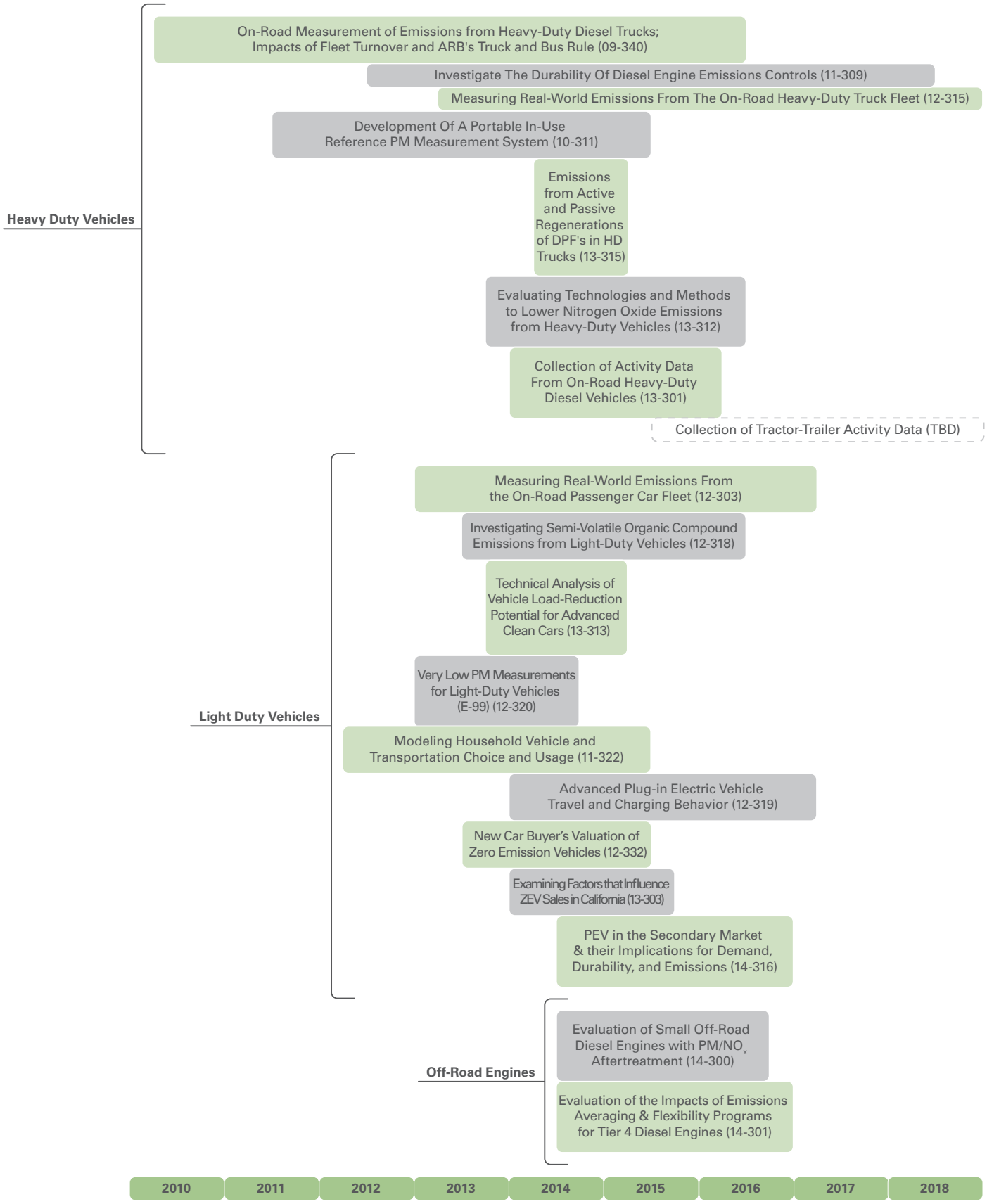
Exposure Research Projects



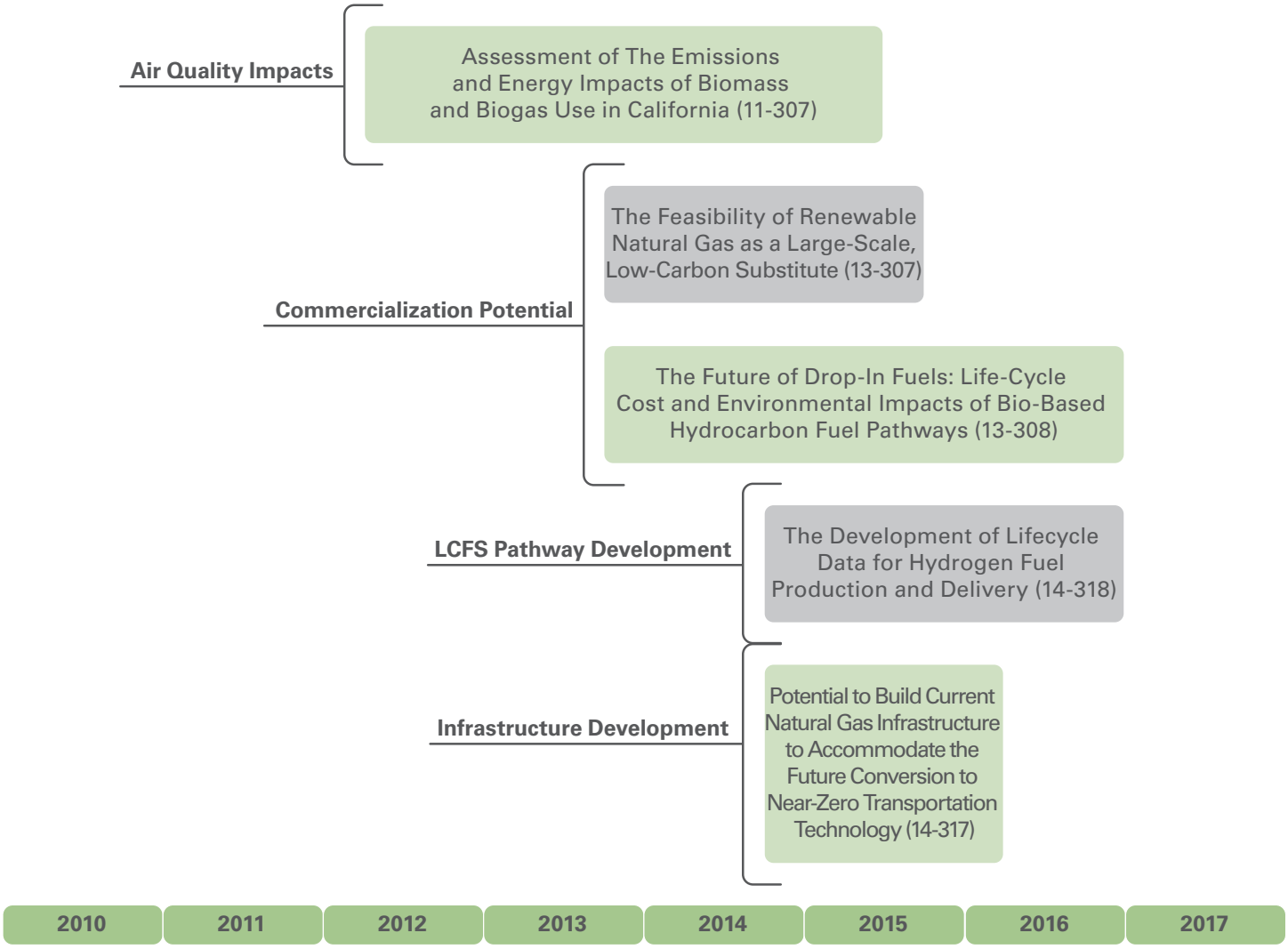
Atmospheric Processes and Field Studies Research Projects



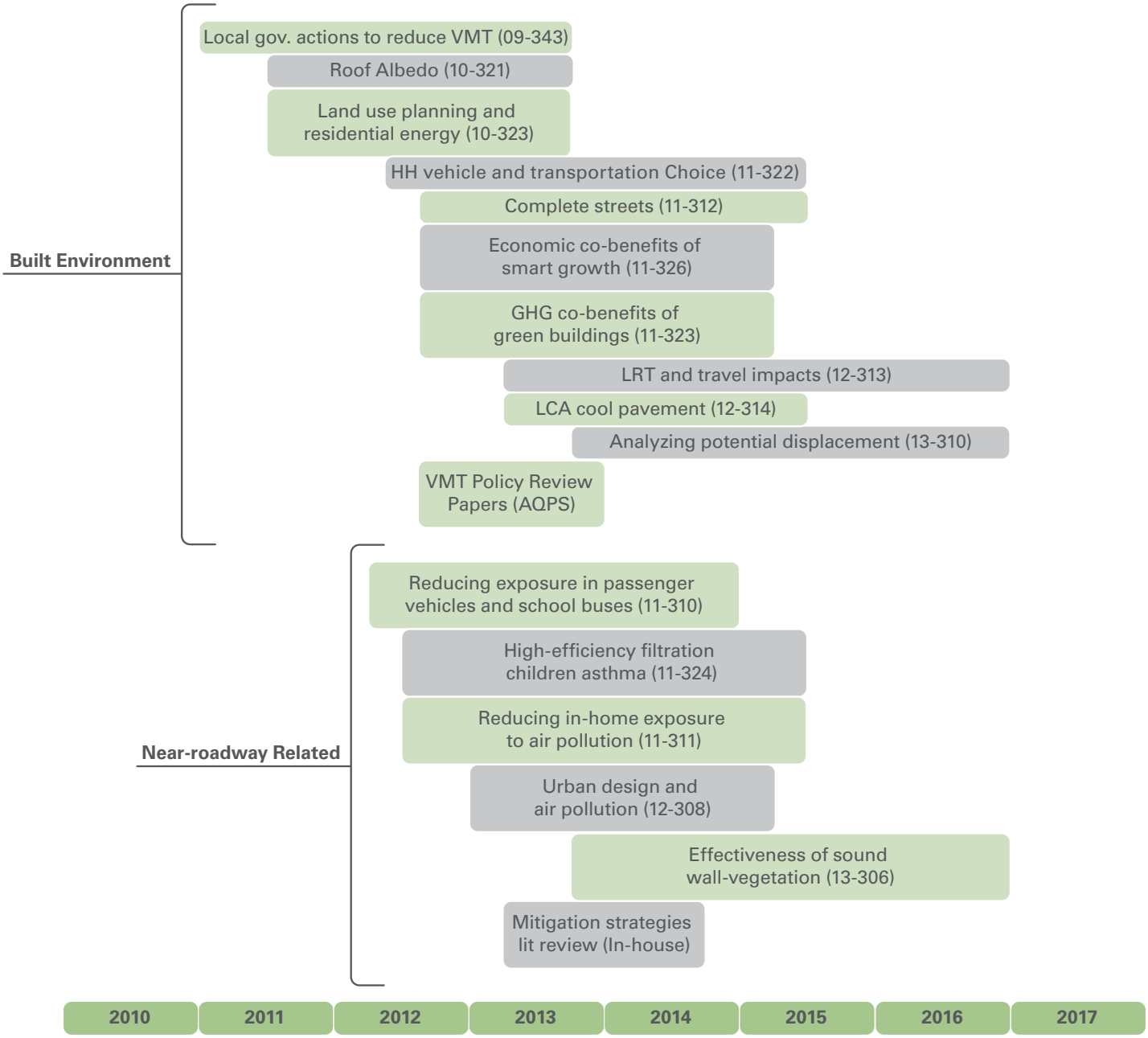
Vehicle and Engine Related Research Projects



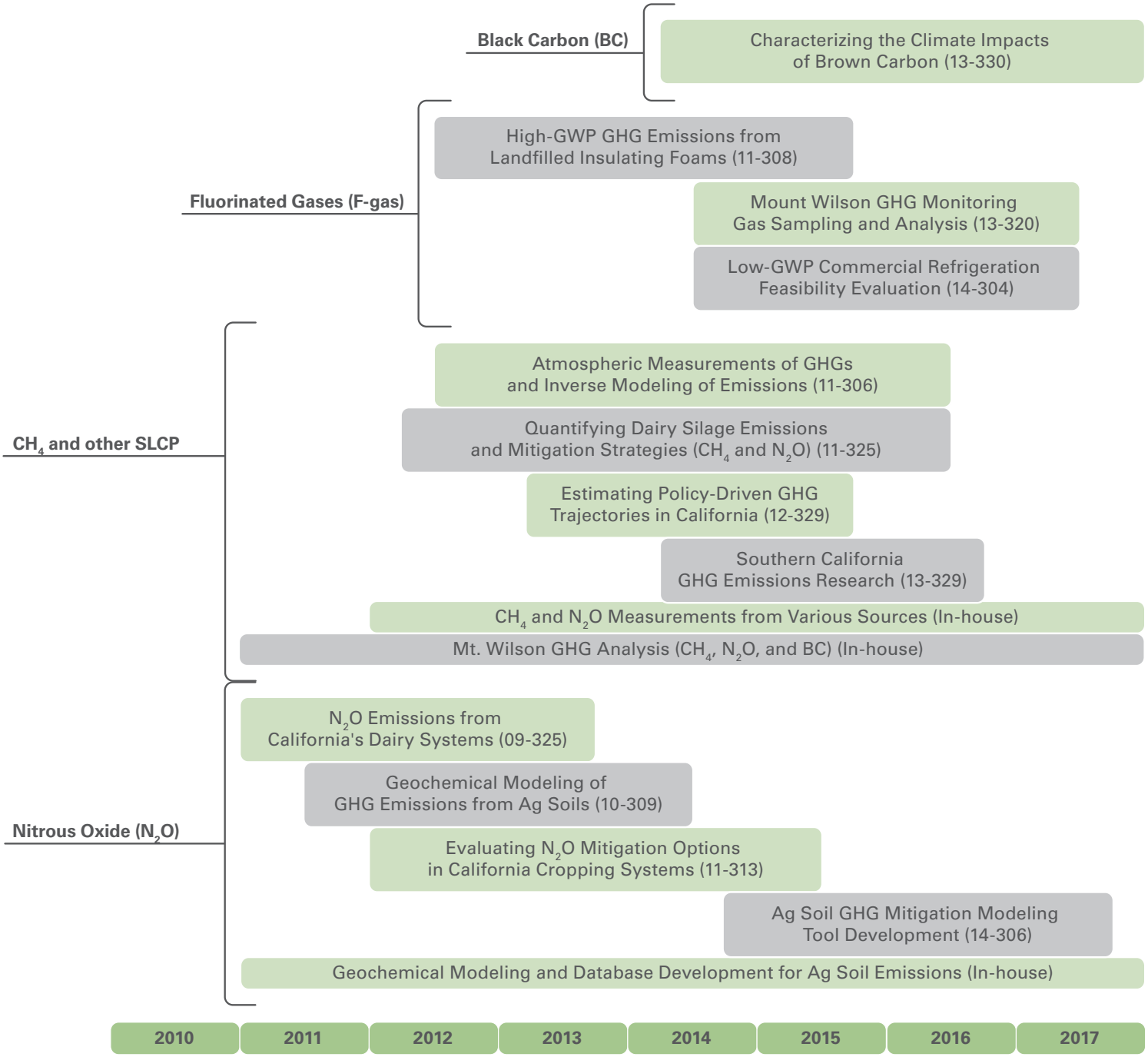
Fuels Research Projects



Sustainable Communities Research Projects



SLCP Research Projects



Appendix 2: Research Highlights

Health

Childhood Exposure to High Particulate Matter Levels Compromises the Development of the Immune System and Lung Function

An unexpected confluence of factors – a large colony of primates that live outdoors, and a series of wildfires in the Sacramento Valley that occurred just after the annual birthing season – presented a unique opportunity to assess the effects of high-level wildfire-enriched PM2.5 exposure on infants. As the first study of infant exposure to wildfire-enriched PM2.5, the results suggest that infancy is a period during which high PM2.5 exposures may adversely influence development of the branch of the immune system that combats infectious disease, and also adversely affects the development of lung function, leading to changes that will persist into adulthood. Final Report 10 303

Risk of Pediatric Asthma-Related Hospital Visits from Multipollutant Exposures

In an effort to further understand the impact of primary (directly emitted from combustion sources) and secondary (photochemically-produced in the atmosphere) organic aerosols, researchers evaluated whether these important characteristics of particulate matter were associated with emergency room visits and hospital admissions for asthma. The study focused on subject homes near traffic-related air pollution sources. Associations of asthma with ambient pollution, including carbon monoxide, oxides of nitrogen, and PM2.5, were stronger among children exposed to high traffic-related air pollution at their homes. African-American and Hispanic children, as well as those without private insurance, tended to live in areas associated with higher levels of traffic-related air pollution, further increasing their vulnerability. Results of the study underscore the importance of ARB's regulations to reduce traffic-related air pollution. ARB Contract 10-319

Urban PM2.5 May Be More Toxic than Rural PM

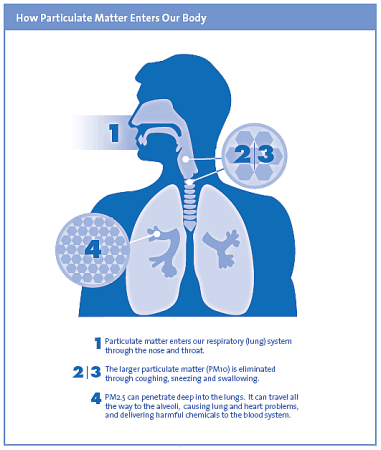
Biological mechanisms through which inhaled particles influence heart and lung disease are not completely understood, and the extent to which differences in PM2.5 chemical composition between urban and rural particles influence health effects is largely unknown. Mice were exposed to PM2.5 from urban (Sacramento) and rural (Davis) locations, as well as to samples of the same PM2.5 treated to neutralize metals or endotoxin. The study compared the production of mediators of blood clotting and inflammation in lungs and blood. Both urban and rural PM2.5 elicited inflammatory effects, although effects were greater with exposure to urban PM2.5. In addition, the results suggest that metals did not contribute to inflammatory effects, while endotoxin was a significant contributor to the inflammatory effects of both urban and rural PM2.5. Final Report 10 302

Traffic Pollution Negatively Impacts the Health of the Elderly

The effect of air pollution on elderly residents with coronary artery disease living in retirement communities in the Los Angeles area was studied as part of a larger study funded by the National Institutes of Health. Although the residents spend most of their time indoors, this does not shield them from outdoor pollutants as a detailed exposure assesment revealed that a sizeable portion of indoor particles originate from traffic. An association was found between the exposure to traffic-related air pollutants and the expression of genes linked to pathways involved in oxidative stress, inflammation, and coagulation. These pathways are postulated to be part of the mechanism by which air pollution contributes to the progression of cardiovascular disease. Final Report 09 341

Health Effects of Central Valley Particulate Matter

Numerous studies have investigated the health effects of particulate matter exposure, but because investigators typically measure all endpoints at the same time post-exposure, responses that occur both before and after the measurement time may not be captured. This animal exposure study was undertaken to explore the time-course for development of lung, cardiovascular and systemic health-related responses to particulate matter exposure. The particulate matter used for the exposures was collected in two Central Valley locations. The results demonstrate that different categories of health effects (cardiovascular vs. systemic vs. pulmonary) follow different time courses for development and resolution. The results add new insights for future research study design and help to explain inconsistencies noted in previously published research. ARB Contract 09-330



PM2.5 Exposure Can Be Associated with Brain Inflammation and Other Central Nervous System Effects

Numerous studies have demonstrated that exposure to PM2.5 is associated with increased heart and lung disease and death; however, little is known about the effects on the central nervous system. This study took advantage of a multi-city project sponsored by the Health Effects Institute to expose mice for six months to concentrated ambient PM2.5 in five cities with very different pollutant source profiles – Irvine CA, Lansing MI, New York NY, Sterling Forest NY, and Seattle WA. Both inflammatory and oxidative changes in brain tissue were observed, with site-specific variations that could be related to seasonal or source differences. Final Report 08 306

Indoor Air Quality

Reducing Air Pollution Exposure in Passenger Vehicles and School Buses

Exposures to vehicle-emitted particle pollutants have been associated with adverse health effects. As a potential strategy to mitigate in-cabin exposure, this "proof-of-concept" study showed that, for both passenger vehicles and school buses, the use of high efficiency cabin air (HECA) filtration was effective in reducing ultrafine particles (UFPs) by 82-98%, black carbon (BC) by 66-96%, and PM2.5 by 30-75%, on average, under different driving conditions. Results suggest that HECA filters are especially useful for reducing in-vehicle levels of diesel exhaust particles; in-cabin exposure reduction in all tested vehicles was greatest for UFPs, followed closely by BC, and was somewhat less for PM2.5. ARB Contract 11-310

Evaluation of Pollutant Emissions from Portable Air Cleaners

The Air Resources Board's *Air Cleaner Regulation*, adopted in September 2007, is designed to protect public health by limiting the ozone emitted from indoor air cleaning devices. All air cleaning devices sold in California must meet the regulation requirements. A new generation of portable, stand-alone air cleaners relies on technologies that can generate potentially harmful by-products, including volatile organic compounds (VOCs), ultrafine particles (UFP) and/or reactive oxygen species. Emissions originating from six portable air cleaners were measured, and results reveal that, rather than removing pollutants, some devices (using ozone-generating ultraviolet bulbs, plasma generation, photocatalytic oxidation, or ceramic heating with ionization) actually produced or had net emissions of VOCs. Some emissions were estimated to produce room concentrations that would exceed California health-based standard levels for ozone, formaldehyde, and benzene under realistic scenarios. The study's results show a need for improved designs for certain types of air cleaners to prevent harmful pollutant emissions and to improve pollutant removal rates, and for standard test methods to measure air pollution other than ozone (e.g., formaldehyde) produced by air cleaners. ARB Contract 10-320

Residential In-duct Air Cleaners Can Emit Indoor Ozone above the Current California Limit

ARB's air cleaner regulation limits ozone emissions from portable air cleaning devices, but residential in-duct devices are exempt due to a lack of an accepted test method. In this project, a test method was developed and a laboratory test apparatus constructed (photo at left), and several types of in-duct devices were tested in the apparatus and in homes. Two of the devices produced substantial amounts of ozone. Based on test results and modeling analyses, some in-duct air cleaners can increase residential levels of ozone above the current California limit for portable air cleaners. Final Report 09 342

State Implementation Plan Support

Development of Modeling Tools to Evaluate the Availability of LVP-VOCs from Consumer Products for Ozone Formation

Low Vapor Pressure-Volatile Organic Compounds (LVP-VOCs) used in consumer products are exempted from VOC limits in ARB's *Consumer Product Regulations*. LVP-VOCs are found in some consumer products used in down-the-drain applications (e.g., laundry detergents, fabric softeners, dishwashing detergents, and other laundry products). Environmental modeling tools were developed and evaluated to determine what portion of a LVP-VOC volatilized to air during use of the products which can lead to form ozone as well as what portion of a LVP-VOC disposed down the drain during use will be emitted to air and subsequently form ozone. To address ozone formation issues for Southern California, an area with an extreme ozone non-attainment, researchers used conditions representative of the South Coast Air Basin. Based on the modeling results for the selected 33 LVP-VOCs, loss by volatilization at a wastewater treatment plant was negligible for most compounds, suggesting that a majority of the LVP-VOCs will not contribute to ozone formation once they are disposed down the drain. In contrast, when a consumer product is volatilized to air during use, greater than 90% will remain in the air and may participate in photochemical reactions either at the source location or in the downwind areas. The study provides important information and modeling tools to evaluate the role that consumer products play in affecting California's air quality. ARB Contract 13-304

Air Pollution and Climate Change Study

The *CalNex* study in May and June of 2010 examined the nexus between air pollution and climate change, involving four airplanes, an ocean-going research ship (photo at right), two air monitoring supersites (Bakersfield and Pasadena), and more than 150 highly trained scientists in a joint collaboration between the National Oceanic and Atmospheric Administration (NOAA) and the California Air Resources Board (ARB). The study answered important scientific questions about emissions, chemical transformations, atmospheric transport, and climate processes in California. The data collected during CalNex is helping improve ARB's emission inventory for greenhouse gases and informing air quality models used to help develop strategies for attaining clean air goals for ozone and PM2.5 in the South Coast and San Joaquin Valley Air Basins. Final Report 10 326 synthesizes results from the over 100 peer-reviewed publications that resulted from the study. Final Reports 09 317 and 09 333 describe important results for ozone and particulate matter less than 2.5 microns (PM2.5). Final Report 10 305 analyzes data from the associated Carbonaceous Aerosols and Radiative Effects Study (CARES) that took place in northern California in June 2010.

Primary Organic Aerosol Volatility

To improve air quality models used to help develop strategies for attaining clean air goals for PM2.5, the primary organic aerosol (POA) emitted from gasoline- and diesel-fueled vehicles was studied at atmospherically realistic concentrations (photo at right). The majority (~75 80 percent) of the particle emissions were elemental carbon that will not evaporate in the atmosphere, with the highest emissions occurring during the cold start and/or hard accelerations. The remaining fraction (~20 25 percent) was POA that could be broadly classified as a semi-volatile material (similar to motor oil) or an effectively non-volatile material (hypothesized to be fuel combustion products). The POA emissions were generally more volatile during the cold start and less volatile after the engine and exhaust system reached operating temperatures. Final Report 10 313

Measurement of Low Levels of Sulfur Dioxide Emissions

Sulfur is an important component of combustion and lubricant-derived particles, but current instruments are not capable of measuring the very low sulfur dioxide concentrations typical of vehicles burning ultra low sulfur fuels. A differential optical absorption spectrometer (DOAS) that can measure low levels of sulfur dioxide emissions was constructed and tested for ARB's heavy-duty vehicle emissions testing program (photo at right). Final Report 10 312

Evaluating California's Biogenic Volatile Organic Compound Emission Inventory

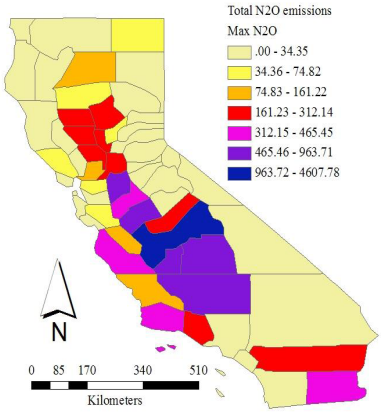
Vegetation in California is a large source of biogenic volatile organic compounds (BVOCs) that contribute to ozone and PM2.5 formation. Isoprene is the most important BVOC, with the vast majority of emissions assumed to be from oak trees, based on measurements at leaf and branch levels. First-time aircraft measurements at an ecosystem scale throughout California found that the BVOC emission inventory was generally within 20 percent agreement with the measurements. The measurements confirmed oak woodlands in the foothills of the Sierra Nevada and Costal Ranges as the critical isoprene emission source in the state, with a limited contribution from eucalyptus trees in the Central Valley. Where the model differs from the airborne data, the issue is likely a combination of discrepancies in the underlying land cover maps, meteorological parameters, or leaf area index data. Final Report 09 339

Improvements to Ozone Precursor and Greenhouse Gas Emissions Inventories in the Los Angeles Basin

Degradation of air quality and climate change is driven by anthropogenic emissions of ozone and aerosol precursors and their chemical transformations, as well as emissions of various greenhouse gases. It is thus crucial to accurately quantify trace gas levels, their spatial distribution, and their emissions to best support the development of air pollution and climate change mitigation strategies, such as AB 32. The current approach to monitoring air pollutants relies on a limited number of surface monitoring sites, while networks for greenhouse gases are only just emerging. This project developed and deployed two novel remote sensing methods from a mountaintop overlooking the Los Angeles Basin to measure the spatial distribution of several ozone precursors (nitrogen dioxide and formaldehyde) and greenhouse gases (carbon dioxide, methane, and carbon monoxide) for three years. The observations improve the geographic resolution of the greenhouse gas and ozone precursor emissions inventories and help determine trends in ozone production sensitivity and greenhouse gas emissions, which in turn will support ARB's ability to strategically target mitigation efforts for air quality and climate change. ARB Contract 09 318

Short-Lived Climate Pollutants and Nitrous Oxide Emissions

California's Agricultural Greenhouse Gas Emissions



Agricultural production is an important source and sink of greenhouse gases. A modeling tool that incorporates California-specific soil, crop, and management practice information was developed and compared against field test data. Nitrous oxide (N_2O) from fertilizer use was the major greenhouse gas emitted from California croplands. Major N_2O emitter crops are corn, lettuce, grape, cotton, and rice, while rice is the sole methane emitter. The major carbon dioxide emitter crops are cotton and tomato; and the major carbon-sequestering crops are alfalfa, corn, and grape. Manure amendment and crop residue incorporation are the major sources of soil carbon sequestration. Final Report 10309

Evaluating California's Greenhouse Gas Emissions Inventory

A robust emissions inventory is necessary for the successful development and implementation of California's greenhouse gas reduction program. ARB and several partners have established a *Statewide Greenhouse Gas Monitoring Network* to measure methane, carbon dioxide, and other climate pollutants. An analysis of the network data suggests that statewide methane emissions are 1.3 to 1.7 times greater than previously known. The majority of emissions are located in the Central Valley, and ongoing research is expected to provide new information to better understand sources of methane and their emissions. Final Report 09348

Oxide of Nitrogen Emissions from Agricultural Soils

Soils are a source of oxides of nitrogen (NO_X), precursors for the formation of ozone and PM2.5. Production of nitric oxide (NO) occurs through soil microbial processes using ammonium from nitrogen fertilizer and manure inputs, or soil mineral nitrogen (N). The lowest average NO_X emission fluxes were measured during low soil moisture conditions and in subsurface drip-irrigated tomato fields. The highest average emissions occurred in high N input systems, such as silage corn, while alfalfa, almond, and furrow-irrigated tomato were intermediate. The NO_X emissions were related to N inputs, time since fertilizer applications, temperature, and soil moisture. The NO_X emissions are predictable in systems receiving N at recommended rates, but in systems receiving large N inputs, episodes of very high, difficult-to-predict NO_X emissions were observed. Final Report 09 329

Nitrous Oxide Emissions from California's Feed Production at Dairy Farms

The greenhouse gas nitrous oxide (N_2O) is produced by soil microorganisms. Nitrogen (N) inputs,and soil moisture and carbon stimulate the production of N_2O, which accounts for about one third of all greenhouse gases from California's agricultural sector. Nitrogen inputs, crop N removal, and cumulative N_2O emissions were measured in three dairy feed production systems receiving liquid and solid manure, as well as synthetic N fertilizer. The annual emission rate of N_2O from the dairy feed fields varied substantially. The N application rate, soil water content, and soil texture all seemed to be the main factors controlling N_2O emissions. To lower N_2O emission potential, applying N incrementally in moderate doses with the irrigation water according to crop N demand is recommended. Final Report 09 325

High-Global Warming Potential Fluorinated Gas Emissions from Landfills

Waste insulation foam from buildings and refrigerator-freezers contains high-global warming fluorinated gases (F-gases), greenhouse gases that are thousands of times more warming than carbon dioxide. When landfilled, the waste foam was presumed to be a significant source of greenhouse gas emissions. However, hundreds of landfill gas samples analyzed for 14 different F-gases showed that F-gas emissions from landfills were up to 90 percent less than initially believed, due to the required methane gas collection and treatment systems required at all large California landfills. The F-gases from waste foam are collected along with the methane in the landfill, which is then combusted at very high temperatures, destroying 99.8 percent of all F-gases. Most emissions of F-gases from insulating foam occur prior to landfilling, either from foam shredding, or off-gassing during the foam lifetime. Significant reductions of foam F-gas emissions are most achievable through eliminating their use at the time of foam manufacture by substituting lower-GWP compounds. ARB Final Report 11-308.

SB 375 Program Support

Evaluating the Benefits of Light Rail Transit

This research project implemented the first-ever before-and-after evaluation of the impact of a light rail transit investment in California on travel behavior and the active transportation co-benefits for nearby residents. The study found that long-term households living within walking distance (about 1/2 mile) of a new Expo Line light rail station in south Los Angeles had lower personal vehicle miles, on average 11 miles less each day, compared to control households. While travel behavior changed, living near the light rail station was not associated with a change in walking or bicycling travel. New residents that moved in after the light rail station opened were younger, had higher rental rate and income, and had different travel behavior including double the light rail ridership rates than the longer-term residents. These findings provide insight into the potential of transit investments to reduce vehicle miles traveled and increase active travel. ARB Contract 12-313

Local Government Planning Assistance

Two tools were developed to assist California local and regional governments with AB 32 and SB 375 compliance in meeting greenhouse gas and per capita vehicle miles traveled (VMT) targets. The VMT Impact Tool allows users to easily estimate the implications of neighborhood type – for any census tract, city, or region in California – on eight different land use and transportation system characteristics. Final Report 09 343

The Land Use and Residential Energy (LURE) Tool allows local governments to quickly compare various land use scenarios accommodating new growth in residential housing to identify which scenario would result in the lowest residential energy use and greenhouse gas emissions. Final Report 10 323

A third study used remote sensing to quantify cool roof reflectance and potential in seven California cities: Bakersfield, Long Beach, Los Angeles, Sacramento, San Diego, San Francisco, and San Jose. Final Report 10 321

Scoping Plan Program Support

Quantifying the Comprehensive Greenhouse Gas Co-benefits of Green Buildings

Green buildings offer a comprehensive approach to reduce greenhouse gas (GHG) emissions by minimizing the energy, water, waste, and transportation impacts from buildings. Green buildings also offer improved indoor air quality to protect occupant health, assure comfort, and maximize productivity. Previous research has focused on the operational energy performance of green buildings and its GHG consequences, but little has been done to quantify the GHG consequences of other building operations and management strategies rewarded by green building certification systems like the Leadership in Energy and Environmental Design (LEED) green building rating system. This research project is the first-known effort to quantify the real-world performance of almost 200 commercial buildings throughout California that obtained green building certification under the LEED for Existing Building Operations and Maintenance (LEED-EBOM) rating system. On average, the certified green commercial buildings cut GHG emissions from both water consumption and solid waste by 50 percent and lowered transportation-related GHG emissions by 5 percent, when compared to traditional California office buildings. Transportation is over 100 times more GHG-intense per square foot of office building than either water or waste, and is also more than twice as GHG-intense per square foot as operational energy. Results suggest that building-level transportation strategies have the potential to substantially reduce building-associated GHGs. This information can support incorporation of GHG reduction strategies in the state's mandatory Green Building Standards Code and local government building codes. ARB Contract 11-323

Health-based Messaging More Effective at Inducing Energy Conservation

Advanced residential energy monitoring technology was deployed in 120 apartments in Los Angeles to investigate how real-time appliance-level energy usage information and periodic messages can induce conservation behavior. Health-based messages, which communicate the public health impacts of electricity production, outperform monetary savings information as a driver of behavioral change in the households. Health messaging was particularly effective for families with children, who achieved up to 20 percent savings. No significant conservation impact was found for participants who received messages informing them about monetary savings. Final Report 10 332

The CoolCalifornia.org Challenge: A Pilot Inter-City Household Carbon Footprint Reduction Competition

The CoolCalifornia.org City Challenge engaged thousands of households in participating cities by providing a community-based competition framework for achieving measurable voluntary reductions of energy use and vehicle travel. Analysis of the competition data provided insights into the demographic and socioeconomic characteristics, attitudes, and motivations of households that participated in the pilot project. Participation in the Challenge was most intense as program deadlines approached, and results reveal that households which tracked electricity saved an average of 14% relative to a control population. Together, these results suggest that inter-city competitions can be a promising strategy to reduce community-wide greenhouse gas emissions. Due to the project's success in encouraging collaboration and participation through social marketing strategies, and demonstrating measurable GHG reductions, additional rounds of the competition are underway and can be used to engage households in energy efficiency and sustainability. ARB Contract 10-325

Air Movement as an Energy-Efficient Way to Achieve Occupant Comfort

In California, heating and cooling in commercial buildings consumes roughly a third of their total energy use. Energy savings of 15 20 percent can be achieved by a widened thermostat setpoint range adjustment of 5oF. Acceptable office comfort can be provided by very low-wattage fans for a wide range of interior temperatures and humidities. Fans can be used to augment the performance of other energy-efficient technologies, such as radiant-cooled ceilings and natural ventilation. Computer control over fan speed and direction will enable a new generation of extremely efficient and effective devices for providing air movement cooling within buildings. Final Report 10 308

Modeling Optimal Pathways to a Low-Carbon Economy in California

An optimization model of the California energy system was used to understand how California can meet the 2050 target for greenhouse gas emissions (80 percent below 1990 levels). This model represents the energy supply (energy resources, electricity generation, and fuel production and infrastructure) and energy demand (commercial, residential, transportation, industrial, and agriculture) sectors in California and simulates the technology and resource requirements needed to meet projected energy service demands. These model choices vary based upon policy constraints (e.g., a carbon cap, fuel economy standards, renewable electricity requirements), as well as technology and resource costs and availability. Multiple scenarios were developed to analyze the changes and investments in low-carbon electricity generation, alternative fuels and advanced vehicles in transportation, resource utilization, and efficiency improvements across many sectors. Model results show that major energy transformations are needed but that achieving the 80 percent reduction goal for California is possible at reasonable average carbon reduction costs, ranging from $75 savings to $124 cost per metric ton of carbon dioxide. Final Report 09 346

Building Operators are the Key to Bridge the Gap between Potential and Actual Energy Savings in Commercial Buildings

Changes in operations can save 5-30 percent of building energy use at low cost, yet these changes are often not implemented. Two main obstacles were identified in how building operators approach energy use and conservation in their work. First, while building operators have the technical means to reduce energy use, social, organizational, and technical constraints limit their ability and motivation. Second, current combinations of buildings, management, and expectations leave many occupants dissatisfied with their indoor environment. These results suggest that shifting the focus of energy use reduction strategies to better include building operators requires: 1) increasing the visibility and status of building operators, 2) improving their ability to see how energy is used, and 3) better integration of the indoor environment with energy efficiency. Final Report 09 327

Mobile Source Strategies Support

Technical Analysis of Vehicle Load-Reduction Potential for Advanced Clean Cars

Passenger car and light truck manufacturers are implementing strategies such as aerodynamic drag improvements, reduced tire rolling resistance, and mass optimization to reduce greenhouse gas emissions and improve fuel economy. Model year 2014 vehicles were studied to determine the extent to which vehicle load reduction technolgies have already been applied. The potential reduction in CO_2 emissions from the application of best-in-class load reduction technologies is up to 10.4% which is nearly one third of the 34% required to achieve the reductions required by California's Advanced Clean Cars Program. This analysis provides valuable input for the Mid-term Review of the Advanced Clean Cars regulation, and will help ARB shape light-duty vehicle policy going forward. Manufacturers, as well as tire manufacturers, continue to look for designs and materials that give them lower rolling resistance that still satisfy handling and durability criteria. ARB Contract 13-313

Assessment of the Emissions and Energy Impacts of Biomass and Biogas Use in California

In recent years, biomass has provided about 2% of California's electric power mix, but could provide 6% more by 2020. Most of this biomass has come from woody material, but power is increasingly being derived from the following sources: municipal solid waste, food processing waste, animal manure, and wastewater treatment. This study assessed the air quality impacts of existing and projected bioenergy capacity in California, focusing on biomass feedstocks and advanced

technologies. Emission factors were combined with facility locations and entered into an air quality model to predict impacts from possible biopower scenarios. With current technology, the maximization of biopower production potential would lead to significant increases in ozone and PM concentrations by 2020. However, the use of technological upgrades and emission controls would lessen these air quality impacts. A shift from the production of biopower to the production of compressed natural gas for vehicles could reduce air quality impacts further, and also reduce greenhouse gas emissions. The results should assist in the development of strategies to meet the state's *Renewable Electricity Standard* and *Low Carbon Fuel Standard*. ARB Contract 11-307

Impacts of Fleet Turnover and ARB's Drayage Truck Regulation

Heavy-duty diesel trucks emit the majority of nitrogen oxides (NO_x) and diesel particulate matter (PM) in urban areas in California. These emissions contribute to exceedances of fine particulate matter (PM2.5) and ozone air quality standards, and may lead to adverse health effects for exposed individuals. Black carbon (BC), which is a short-lived yet potent absorber of solar radiation, comprises the majority of diesel PM. *The Drayage Truck Regulation* is part of the Air Resources Board's ongoing efforts to improve air quality associated with goods movement by reducing PM and NO_x emissions involved in production of both ozone and PM from diesel-fueled engines. Between 2009 and 2013, the effects of heavy-duty drayage truck fleet modernization and diesel particulate filters (DPFs) retrofits were examined through measurements of truck emissions near the Port of Oakland. Results show that the Phase 1 of California's Drayage Truck Regulation led to an increase in Port trucks equipped with DPFs from 2 to 99% and a decrease in median engine age from 11 to 6 years. Over the same period, fleet-average emission factors decreased substantially for BC and NO_x. The BC reductions resulted primarily from increased use of DPFs, whereas NO_x reductions were attributed to replacement of the oldest trucks with newer equipment that met more stringent NO_x emission standards. The distributions of emission factors for Port trucks have become increasingly skewed over time, with a minority of trucks now responsible for the majority of emissions of all pollutants—except carbon dioxide—measured in this study. ARB Contract 09-340

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