Appendix D – In-House Research Projects

CARB's Research Program supports both external research contracts and in-house studies. The following is a summary of recent and ongoing in-house research projects that provide technical support and inform the successful implementation of CARB programs.

Long-term Trends in Emissions from Heavy-Duty Diesel Vehicles

CARB collects real-world tailpipe emissions data from on-road heavy-duty vehicles by monitoring vehicle activity and emissions data over extended periods. This in-use data collection enables CARB to evaluate how regulations impact emissions from heavy-duty vehicles across the state, including those traveling through overburdened communities. Analysis of tailpipe emissions by engine model year indicates that CARB's Heavy-Duty On-Board Diagnostic (HD OBD) regulations have significantly reduced in-use oxides of nitrogen (NOx) emissions by more than half between 2010 and 2018. These findings are informing updates to CARB's emission inventories, the evaluation of existing control measures, and assessments of NOx control system degradation in the in-use fleet. The research also supports the development of future strategies to further reduce emissions and ensure continued compliance among existing vehicles.

Zero-Emission Vehicle Brake, Energy, and Non-Exhaust Emission Research

As zero-emission vehicle (ZEV) adoption grows, key data gaps remain regarding real-world energy use characteristics, including duty cycles, energy consumption, energy savings, auxiliary loads, and the performance of emerging technologies. CARB is addressing these gaps by analyzing data from both in-use ZEVs and controlled laboratory testing. This research aims to compare fuel economy between ZEVs and conventional vehicles, and to quantify the co-benefits of ZEV adoption, such as reductions in non-exhaust emissions, to support the continued development of effective clean transportation programs.

Behavioral Economics: Messaging and Program Design

CARB's Research Program is also focused on understanding how to effectively engage the public in making low-emission choices and protecting their health. For example, CARB is partnering with local air districts to evaluate different messaging strategies for air quality alerts. One test showed a 46% increase in sign-ups when the postcard headline was changed from "Protect your family's health" to "How do you know when air quality is low?" Insights from this work are being used to help improve outreach efforts across other CARB programs.

In addition, CARB is evaluating how to improve the design and accessibility of state and federal incentive programs that promote low-emission technologies, such as ZEVs and indoor air cleaners. These programs can face barriers such as limited funding and complex application processes that disproportionately affect underserved populations. Ongoing research aims to identify strategies to reduce these barriers and improve participation, particularly among communities that stand to benefit the most.

Expansion of Health Endpoints in CARB's Health Analysis

In November 2022, CARB updated the agency's health analysis endpoints in alignment with evidence in the U.S. EPA's *Integrated Science Assessments for Particulate Matter*. The U.S. EPA incorporated several new estimates relating fine particulate matter (PM2.5) exposure to health endpoints (effect estimates) into their health impact assessments. After careful review, CARB adopted many of these new effect estimates and endpoints, enhancing the agency's ability to assess the health impacts of air pollution more comprehensively. To better reflect the California population, staff also recommended using state-specific population and health incidence data.

As part of the implementation process, CARB hosted a public workshop to present the proposed updates and gather feedback on the inclusion of these studies and endpoints into future health assessments.

This work is part of a broader, ongoing effort to expand CARB's health analysis capabilities in response to emerging research. Initiated in April 2020 by *Board Resolution 20-13* (Health Evaluation of Air Quality and Climate Regulations and Programs), this effort seeks to improve how CARB evaluates the health benefits of air quality and climate regulations. The goal is to ensure that CARB's assessments capture the full range of public health benefits associated with cleaner air in California.

Climate Benefits of Addressing Short-Lived Climate Pollutants

California is taking comprehensive action to reduce greenhouse gas (GHG) emissions across all economic sectors, as directed by AB 32, SB 32, and SB 1383. While carbon dioxide (CO_2) remains the dominant contributor in the state's GHG inventory, reducing emissions of short-lived climate pollutants (SLCP), such as methane (CH_4), hydrofluorocarbons (HFCs), and black carbon, can achieve more rapid and noticeable reductions in global warming, especially in the near term. Demonstrating measurable changes in ambient SLCP levels is essential for evaluating the effectiveness of California's GHG emission reduction and mitigation strategies.

For over 15 years, CARB has partnered with NASA's Jet Propulsion Laboratory (JPL) to install and operate advanced instrumentation at the Mount Wilson Observatory. Tools such as Aethalometers and Cavity Ring-Down Spectrometers provide high-resolution, daily measurements of black carbon, allowing staff to better identify pollution sources, evaluate emissions trends, inform mitigation strategies, and track progress toward climate goals. These long-term efforts help inform California's SLCP Reduction Strategy and support legislative mandates under AB 1496 and SB 1383 to curb emissions from potential climate forcers.

Improved understanding of the dynamic factors driving PM2.5 concentrations

Fine particulate matter (PM2.5) is composed of various chemical components, including carbonaceous material, sulfate and nitrate compounds, and crustal elements. California's diverse landscape, which includes major urban centers, agricultural regions, deserts, and areas prone to wildfire smoke, results in a wide range of emission sources and complex PM2.5

composition. Assessing and quantifying the impacts of various factors (e.g., emissions, meteorology, and large-scale climate variability) on key PM2.5 components can provide important insights for identifying the sources of precursors and informing the development of effective PM2.5 control strategies.

CARB is currently evaluating how inorganic and organic fractions of PM2.5 respond to changes in precursor gases and meteorological conditions. This work integrates CARB-funded research contracts with in-house analysis to examine relationships among emissions, environmental drivers, and the effect of local and regional policy measures.

Enhancing key monitoring sites to be "Supersites"

To better understand the sources of air pollution, CARB set up advanced air monitors (Figure 1) at regulatory monitoring sites in Fresno and Bakersfield to collect long-term, high-resolution data. These monitors measure pollutants like black carbon, gases such as formaldehyde (HCHO), carbon monoxide (CO), CO_2, CH_4, ammonia (NH_3), and volatile organic compounds (VOCs). They also use lidar technology to measure the height of the boundary layer, which is a critical factor influencing air pollutant dispersion. By integrating these advanced measurements with existing regulatory air quality data and detailed PM2.5 speciation, CARB is enhancing its ability to identify major pollution sources and quantify their contributions to air quality challenges in the San Joaquin Valley.

Figure 1: Photograph of proton-transfer reaction mass spectrometer operating at the Fresno-Garland supersite.

Re-Evaluating the Chemistry of Air Pollutants in California

As part of the 2021 Re-Evaluating the Chemistry of Air Pollutants in California (RECAP-CA) field campaign, CARB deployed two mobile research platforms (Figure 2) in Redlands and Pasadena to conduct multi-month air quality monitoring. These platforms collected high-resolution measurements of key air pollutants, including nitrogen oxides (NOx), HCHO, and various VOCs, such as ethanol, acetonitrile, acetone, isoprene, benzene, and m-xylene. The resulting high-quality, time-resolved significantly improved source identification and enabled more accurate quantification of contributions from various pollution sources, advancing the scientific understanding of regional air pollution dynamics.[1, 2]

Figure 2: Mobile platform used during the RECAP-CA campaign.

[1] *Wu, Shenglun, et al. "Source apportionment of Volatile Organic Compounds (VOCs) in the South Coast Air Basin (SoCAB) During RECAP-CA." Atmospheric Environment 338 (2024): 120847.*

[2] *Wu, Shenglun, et al. "O3 Sensitivity to NO x and VOC During RECAP-CA: Implication for Emissions Control Strategies." ACS ES&T Air 1.6 (2024): 536-546.*