STATE OF CALIFORNIA
AIR RESOURCES BOARD

MEETING OF THE
RESEARCH SCREENING COMMITTEE

February 13, 2026
10:00 a.m.

California Air Resources Board
Research Division
Cal/EPA Building
1001 I Street
Sacramento, CA 95814
(916) 445-0753

California Air Resources Board

Research Screening Committee Meeting
Cal/EPA Headquarters Building
1001 I Street
Sacramento, CA 95814
(916) 445-0753

February 13, 2026
10:00 A.M

Agenda

I. Approval of Minutes of Previous Meeting

December 1, 2025 *i-v*

II. Discussion of Draft Final Reports

1. "State of Zero Emission Vehicle Secondary Market and Accessibility Impacts in California's Underserved Communities," University of California, Davis, $500,000, Contract No. 22STC016 *1*
2. "Equitable Electrification of Existing Buildings: A Pathway to Decarbonization," University of California, Los Angeles, $1,049,073, Contract No. 21STC023 *6*
3. "Total Exposures to Air Pollutants and Noise in Disadvantaged Communities," University of California, Berkeley, $874,980, Contract No. 20RD012 *15*
4. "Impacts of Air Pollution on Life Expectancy Across Multiple Generations: Race, Ethnicity and Vulnerability Perspectives," University of California, Berkeley, $500,000, Contract No. 22RD011 *21*
5. "Impact of Air Pollutant Exposure on Metabolic Outcomes for California Residents," University of California, Berkeley, $525,000, Contract No. 22RD010 *27*
6. "Demonstration of Sensor Technologies for On-Road and Off-Road Heavy Duty Diesel Vehicles," University of California, Riverside, $750,000, Contract No. 21RD007 *34*
7. "Characterization of Tire-Wear and Brake-Wear PM Emissions Under On-Road Driving Conditions," Eastern Research Group, $649,993, Contract No. 22RD002 *38*

III. Other Business

1. Update on Research Planning

California Air Resources Board

Research Screening Committee Meeting
Cal/EPA Headquarters Building
1001 I Street
Sacramento, CA 95814
(916) 445-0753

December 1, 2025
10:00 A.M.

Minutes

Research Screening Committee Members in Attendance via Teleconference:

Dr. Aly Tawfik
Dr. Sam Silva
Dr. Bryan Hubbell
Dr. Michael Schmeltz
Dr. Thomas Bradley
Dr. Danae Hernandez-Cortez
Dr. Mary Johnson

I. Approval of Minutes of Previous Meeting

August 26, 2025

II. Discussion of a Contract Augmentation

1. "Using Integrated Observations and Modeling to Better Understand Current and Future Air Quality Impacts of Wildfires and Prescribed Burns," University of California, Davis, $70,000, Contract No. 23RD006

   One Research Screening Committee (RSC or Committee) member expressed that the approach appeared sound and would strengthen the original contract. However, it was noted that the characterization of how prescribed fires relate to future wildfires needs refinement. The proposal assumes that a wildfire will actually occur in the same area, which is far from certain. This uncertainty is critical when assessing the impacts on air quality from prescribed fires: prescribed burns generate definite smoke now, whereas wildfires produce uncertain smoke at unknown times. Evaluations should compare expected—not guaranteed—emissions, especially if the use of prescribed fire expands and potentially increases total smoke.

   The main recommendation was that the contractor should report the probability and timing of wildfires occurring in prescribed-burn areas to better inform tradeoffs between certain prescribed-burn emissions and possible future wildfire smoke.

Staff briefly responded to the comments and agreed to address these concerns in a revised version of the proposal.

Motion: Move to recommend that the California Air Resources Board (CARB) accept the contract augmentation, subject to the inclusion of revisions based on committee comments.

The Committee approved the motion.

2. "Validating Vehicle Choice Surveys," University of California, Davis, $50,000, Proposal No. 2891-317

A Committee member praised the project for its value despite the small budget. However, they requested clarification regarding a reference to a third party, the role of stakeholders versus a Technical Advisory Committee (TAC), and why the work was not done in-house, given its straightforward nature. The member also highlighted that the contractor had not fully defined the research question at the proposal stage. CARB staff clarified that the budget was small because several tasks would be performed by CARB staff. The budget was primarily for a post-doc to perform the tasks not completed by CARB. However, partnering with the University of California, Davis (UCD) was essential for access to survey data. Staff noted there was not a third party performing an analysis, but data would be obtained from the Department of Motor Vehicles, which may have caused confusion during the review. Staff explained that the TAC would be overseen by UCD and would provide methodological and interpretive guidance, while CARB staff act as stakeholders. Research questions would be specified in the project's first task, which is to create a pre-analysis plan (PAP). To uphold the integrity of the research, the PAP would be completed before analysis begins. A public commenter supported the project, citing the importance of addressing disparities in participation in incentive programs.

Motion: Move to recommend that CARB accept the proposal, subject to the inclusion of revisions based on comments from staff and the Committee.

The Committee voted to approve the motion.

III. Discussion of Draft Final Reports

1. "High Spatiotemporal Resolution PM2.5 Speciation Exposure Modeling in California," University of California, Irvine, $301,214, Contract No. 21RD006

   The contract manager gave a brief summary of 21RD006 and notes from CARB's evaluation of the draft final report (DFR). Overall, CARB staff did not find any red flags or areas of major concern in the DFR. The RSC reviewer had the following comments:

   - The Principal Investigator should have a public repository for the data.
   - The DFR should be approved as is.

   Motion: Move to recommend that CARB accept the draft final report.

   The Committee approved the motion.

2. "Understanding the Sources and Formation Regimes of Present-day PM2.5 to Mitigate Particulate Pollution in California," University of California, Riverside, $500,000, Contract No. 21RD010

   One Committee member acknowledged the extensive effort across four field campaigns in different locations and emphasized the importance of the study area, particularly for Environmental Justice analysis. They also noted the robustness of the analytical method and the value of the retrospective data analysis, with his main concern being the availability of data for sharing. Another member found the report well-written and the statistical methodology well-documented. They highlighted the finding regarding the role of ammonia in particulate matter (PM) formation presented in the DFR. Overall, the Committee supported this report, and a motion was made to approve it without further changes.

   Motion: Move to recommend that CARB accept the draft final report.

   The Committee approved the motion.

3. "Examining the Health Impacts of Short-Term Repeated Exposure to Wildfire Smoke," University of California, Irvine, $525,000, Contract No. 21RD003

   The Committee found the draft final report to contain extensive work and valuable, timely scientific evidence on the health impacts of wildfire smoke exposure. However, the Committee noted that the DFR read somewhat like a compilation of separate academic papers and encouraged greater narrative cohesion. The Committee recommended that CARB staff provide clearer guidance to

researchers on final report development and ensure inclusion of a layperson summary in future projects.

To strengthen this DFR, the Committee suggested adding more specific policy-relevant insights in the conclusion; clarifying methodological approaches for distinguishing wildfire smoke from other pollution sources; and addressing how interventions, such as N95 mask use, could be evaluated. The Committee also emphasized the need for clearer justification and consistency in the wildfire smoke exposure metrics used across health endpoints, recommending an integrated table summarizing metrics, their derivation, and interpretation; additional explanation of how non-wildfire PM was handled; expanded discussion of behavioral responses during smoke events; and clearer rationale for analyzing mental health outcomes separately across University of California healthcare systems. Finally, the Committee advised revising the conclusions about wildfire fine particulate matter (PM2.5) toxicity to avoid overstating differences relative to non-wildfire PM2.5, since stronger toxicity was not observed across all outcomes.

Below is a summary of the recommended edits:

- Add a technical abstract and executive summary.
- Develop a layperson summary for broader accessibility.
- Create an integrated exposure summary table listing all exposure metrics, derivation methods, and interpretation across endpoints.
- Provide clear justification for the use of different wildfire smoke exposure metrics across health outcomes.
- Standardize definitions (e.g., smoke waves) or clearly explain why differences are necessary.
- Clarify inconsistencies in the treatment of non-wildfire PM and provide rationale for each analytic approach.
- Expand discussion of methodological strategies for distinguishing wildfire PM2.5 from other pollution sources.
- Convert and report effect estimates per 1 μg/m3 increase in wildfire and non-wildfire PM2.5 and include these values in a consolidated key findings table.
- Expand the discussion on how smoke waves interact with behavioral responses and how these responses might explain data on exposure and health outcomes during smoke waves.

- Clarify the mental health analysis, including justification for analyzing healthcare systems separately and opportunities for combining compatible datasets to increase statistical power.
- Provide guidance on the relevance and potential future use of Pmax PM2.5 data.
- Add more specific, actionable recommendations to support policy development and future research needs.
- Discuss how interventions (e.g., N95 use, linguistically appropriate outreach) could be evaluated or tested.
- Revise conclusions on wildfire PM2.5 toxicity to match findings more closely and ensure they do not overstate differences relative to non-wildfire PM2.5, recognizing that stronger toxicity was not observed uniformly across outcomes.

Motion: Move to recommend that CARB accept the draft final report, subject to the inclusion of revisions based on comments from staff and the Committee.

The Committee approved the motion.

IV. Other Business

1. Update on Research Planning

   Staff provided Committee members with an update on ongoing research efforts. This item did not require a vote.

Item No.: II.1
Date: February 13, 2026
Contract No.: 22STC016

Staff Evaluation of a Draft Final Report

Title:	State of Zero-Emission Vehicle Secondary Market and Accessibility Impacts in California's Underserved Communities
Contractor:	University of California, Davis
Principal Investigators:	Gil Tal, Ph.D.
Budget:	$500,000
Contract Term:	33 Months

For further information, please contact Anna Wong at (279) 208-7203.

I. Summary

The California Air Resources Board (CARB) implements light-duty Zero Emission Vehicle (ZEV) regulations and incentive programs with the goal of increasing ZEV deployment to meet California air quality and climate change goals and ensure equitable access to clean vehicles for all Californians. As CARB continues to develop and refine light-duty vehicle regulations, a clear understanding of how policies influence the full ZEV market, including the secondary market, is essential. This project helps answer foundational questions about which policy levers are most effective in shaping the ZEV sector by examining who participates in the used ZEV market, how vehicles circulate within and beyond California, and how existing incentive programs affect affordability and access. These insights provide an empirical basis for designing future light-duty regulations and complementary programs that support market growth, consumer uptake, and equitable access to clean transportation.

Used vehicles account for approximately two-thirds of the vehicles purchased, making the secondary ZEV market a critical component of the California's ZEV deployment and retention efforts. This project advances our understanding of the state's used plug-in vehicle (PEV), meaning both battery electric vehicles (BEV) and plug-in hybrid electric vehicles market by assessing the socioeconomic, demographic, geographic and behavioral characteristics of used

PEV buyers, and comparing them with the purchasers of new PEVs and new and used internal combustion engine vehicles. Despite the growing importance of the used PEV market, there is limited existing research on this segment, as prior studies have largely focused on the early ZEV market characterized by shorter-range BEVs than those available today.

The objective of this contract was to assess the structure, performance, and equity implications of California's used PEV market and to identify barriers to market growth. The Principal Investigator (PI) conducted a literature review and administered a statewide survey to collect data on used PEV drivers, including demographic characteristics, charging behavior, and vehicle purchase decision-making factors. The analysis also examined whether used PEVs remain, or, are transferred out of California, and identified destination patterns in the case when vehicles leave the state. The results of this project will be used to inform state policies aimed at supporting market development, advancing equity, and achieving emission reduction goals.

Overall, key findings suggest that policies to expand access to home charging, reduce upfront costs through targeted incentives, and improve transparency around battery health could strengthen the used PEV market. Additionally, enhanced incentives and programs that support used PEV adoption may help retain vehicles within California, thereby maximizing the long-term climate benefits of state investments.

II. Technical Summary

Objective

Through analysis of socio-economic, demographic, geographic, and behavioral characteristics of used PEV drivers, the project answers several foundational questions needed to shape the PEV sector. Specifically, it evaluates how used and new PEV buyers differ, how used PEVs are driven and charged, the extent to which vehicle incentives affect both new and used markets, and how vehicles move into and out of California. These findings directly support policy discussions regarding whether hidden barriers may affect resale value, what regulatory or programmatic tools may be needed to guide the growth of the used PEV retail market, and how the secondary market contributes to (or limits) equitable access to clean mobility.

Background

The study integrates a literature review, analysis of vehicle registration and interstate movement data, and a statewide survey to assess differences between new and used PEV drivers. The approach provides a comprehensive understanding of the used PEV market and supports CARB's policy objectives by identifying key motivations, barriers, and decision-making factors influencing used PEV adoption. The analysis offers evidence on consumer behavior, market dynamics, and barriers to adoption that can inform policies and programs to expand equitable access to PEVs.

Project Summary

Methods:

The project was comprised of the following major components:

Literature Review: The literature review identified the reasons why people adopt used things, including Internal Combustion Engine vehicles and PEVs. The PI found 23 studies met their requirements for this project. Similar research projects used online surveys, surveys using vehicle registration data, and interviews. The literature review revealed that socio-demographic characteristics of used PEV owners are similar to new PEV owners. However, used PEV owners are more sensitive to upfront costs. New and used PEV drivers voiced concerns with battery performance and the availability of charging stations.

Survey: The survey served as the main research tool for this project, with the intent of understanding the behavior and motivations of vehicle owners, specifically those that own or have owned PEVs. The PI used the Department of Motor Vehicles (DMV) data set to inform the survey recruitment strategy and generalize the results of the sample survey to the broader population. The survey included open-ended questions, and optional questions. The survey was estimated to take 15 to 25 minutes and respondents could win a $40 Amazon gift card. The survey was distributed online to 50,000 vehicle buyers in California. The PI received 3,396 and after filtering the responses had 2,717 responses to analyze.

Understanding ZEV Movement across State Lines: The PI looked to understand the effect of state-level incentives for new PEVs on the number of used PEVs that leave California. The PI used S&P Global interstate transfer data from 2016 to 2023. The PI also used this analysis to identify

environmental implications, specifically the emission benefits California subsidized EVs once the vehicles leave the state.

Stakeholder Engagement Efforts: The PI along with researchers conducted regular progress updates with various state agencies throughout the contract. The PI drafted a final report summarizing all the completed work, including several policy recommendations. The policy recommendations centered around these key themes: 1) improving access to charging; 2) building confidence in the vehicle technology; and 3) incentives and education.

The analytical approach was based on econometric methods including descriptive statistics to document key trends and patterns, exploratory statistical analysis to identify relationships between variables, and modeling correlations between demographic, attitudinal, and behavior factors. The PI used two sets of DMV data, both from 2023. The second data set contains all 2023 model year vehicles and a subset of model year 2024 vehicles. The first data set was used for sampling for the survey.

Key Findings:

- Used PEV drivers resemble new internal combustion engine vehicle buyers but are more cost sensitive: Used PEV buyers are more likely to come from a low-income or disadvantaged community, with an income level similar to a new internal combustion engine vehicle buyer. However, used PEV drivers identified high upfront costs as one of the barriers to adoption. This finding aligns with previous research conducted on used PEV drivers.
- Used PEVs function similarly to new PEVs once adopted: Used PEVs have similar annual vehicle miles traveled as new PEVs. However, used PEV drivers typically have vehicles with a shorter range, meaning that they rely more on public charging and reported higher rates of driving limits due to charging constraints.
- Incentives drive both new and used PEV adoption equally: Incentives drive adoption. The PI conducted a survey experiment and results indicated about 21% of current PEV drivers, regardless of if the vehicle was new or used at the time of purchase, would not have selected a PEV without an incentive.

- Home charging access is essential, not optional: Respondents indicated that home charging is necessary, citing concerns about public charging availability, reliability and time to find functional chargers as barriers.
- Battery information gaps may suppress market development: About two thirds of buyers asked about battery health before purchasing the vehicle. Most relied on sellers or dashboard displays rather than third party testing. Most respondents indicated their battery was still under warranty when purchased, suggesting that warranty coverage may act as a deciding factor in purchasing a used PEV.
- California exports over 240,000 used PEVs to Other States: States with strong new PEV incentives import fewer used PEVs, suggesting that strong new PEV incentives may weaken demand for used PEVs. While most states receive some share of PEVs from California, Oregon, Arizona and Nevada received the largest share.

III. Staff Comments

This project enhances CARB's understanding of the secondary ZEV market and used ZEV buyers. Overall, the report provides empirical evidence on consumer behavior, interstate vehicle flows, and structural barriers affecting used ZEV adoption, offering actionable insights for state policymakers. Staff find the analysis to be well aligned with California's efforts to design effective, equitable light-duty vehicle policies. A similar project was completed in 2018, focusing on vehicles that were used from 2011 through 2015. Since then, the ZEV market has grown, with increasing ZEV sales, increased model availability, and improvements in the technology with advanced features and longer range BEVs. The changes in the ZEV landscape may have changed people's perceptions and opinions, particularly people that are more likely to purchase a used vehicle. Additionally, the technological improvements may have changed the demographics and behavior of used ZEV drivers since 2018. The added task of researching interstate trade of used ZEVs adds another layer of understanding of who is purchasing used ZEVs and where those vehicles are coming from into California.

In 2024, the PI provided staff with a separate literature review document. While completing other project task projects, the PI continued to update the literature review. Those updates have been incorporated into the draft final document. The PI sent over a draft final document, and staff

shared the draft final report with other CARB staff in Sustainable Transportation and Communities Division (STCD), Mobile Source Control Division (MSCD), Research Division (RD), California Energy Commission (CEC), and Department of Transportation (Caltrans) for comment. Staff are currently in the process of compiling comments for the PI to address.

The PI and CARB hosted quarterly meetings to discuss progress of the project. These meetings included discussions on survey data collection, hypothesis development, and methodology. Once the survey was distributed and the analysis of the survey began, the PI provided initial results on specific topics of their analysis (e.g., household fleet composition). CARB and other agency representatives asked questions on methodology and provided feedback on the initial results. These comments and questions have been incorporated into the draft final report. The PI worked with CARB and other agencies to refine the initial set of hypotheses. The refined hypotheses have been incorporated into the draft final report.

The PI noted that this report may reflect a higher degree of uncertainty than similar studies. Staff agree that the timing of the survey may have influenced the findings, as data collection occurred in 2025 during a period of heightened political and economic uncertainty. Under these conditions, survey respondent perceptions and attitudes toward ZEVs may have been more volatile than during a more stable period, potentially affecting survey responses. However, staff find that this context underscores the value of the report. Understanding consumer behavior and market dynamics during periods of uncertainty provides important insights into how resilient the used PEV market is to external pressures and how policy signals, incentives, and structural barriers influence adoption when conditions are less stable.

In addition, due to the very limited number of hydrogen fuel cell electric vehicles (FCEV) in the used vehicle market, the PI was unable to conduct meaningful analysis of used FCEV drivers. Should FCEVs become more prevalent in the future, staff recommend revisiting this research to assess the characteristics and experiences of used FCEV drivers.

IV. Staff Recommendation

Staff recommend that the RSC advise CARB to approve the report, contingent upon incorporating the additions and revisions identified by staff and the Committee.

Item No.: II.2
Date: February 13, 2026
Contract No.: 21STC023

Staff Evaluation of a Draft Final Report

Title:	Equitable Electrification of Existing Buildings: A Pathway to Decarbonization
Contractor:	University of California, Los Angeles
Principal Investigators:	Stephanie Pincetl, Ph.D..
Budget:	$1,049,073
Contract Term:	46 Months

For further information, please contact Dr. Melanie Zauscher at (279) 208-7951 or Dr. Patrick Wong at (916) 277-0690.

I. Summary

The 2022 Scoping Plan identified building electrification as the most technologically feasible path to reduce building related greenhouse gas emissions. However, statewide understanding about building decarbonization progress, costs and impacts, equity for underserved populations, and the norms, values and beliefs shaping building decarbonization decisions is limited. This study aimed to assess California's building decarbonization progress and equity gaps, evaluate electric service panel capacity and end user decision-making, and develop a prioritization framework for commercial buildings to guide equitable and feasible state investments through integrated quantitative and qualitative analysis. For residential buildings, the study used a mixed-method approach combining a novel bottom-up estimation of residential panel capacities from parcel and permit data, analysis of statewide incentive and adoption datasets, synthesis of decarbonization costs, and primary data collection through renter surveys and property owner interviews to assess trends, constraints, and equity in building decarbonization. The results show that disadvantaged communities (DAC) face undersized panels at four times the rate of non-DAC areas, while incentive-driven adoption remains minimal, as high installation costs, limited rebates, and strong cost sensitivity among renters and multifamily owners create significant economic barriers to decarbonization.

For commercial buildings, this study quantified metrics including emissions impacts, exposure, worker vulnerability, grid outage risk, and technology readiness, and conducted a detailed subsector feasibility assessment through property data analysis, stratified sampling, and stakeholder outreach. California's commercial building sector shows a sharp disconnect between abundant rebate resources and declining participation, and incentive inadequacy persists with decarbonization costs far exceeding available rebate levels. A seven-metric prioritization framework and an interactive web-based tool was developed, which can facilitate the selection of commercial building subsectors for decarbonization. The lodging subsector was selected for an in-depth analysis and its feasibility assessment revealed systemic outreach difficulties driven by structural barriers and chronic underinvestment. The evidence-based findings from this study will help CARB align policies and programs with the state's decarbonization and air quality goals and specifically inform the development of the Zero-Emission Space and Water Heater Standards.

II. Technical Summary

Objective

This study had three primary objectives: 1) to examine California's building decarbonization trends to date across several geographic and demographic dimensions to describe the gap between existing policy-supported decarbonization and the State's long-term goals; 2) to address building decarbonization barriers and knowledge gaps by quantifying electric service panel capacity constraints and understanding end user decision-making; and 3) to prioritize commercial building sectors for decarbonization efforts, by developing a prioritization framework and conducting an in-depth assessment of a selected commercial building subsector for decarbonization.

Background

California's homes and commercial buildings account for 12% of statewide greenhouse gas emissions, and 80% of these emissions are from space and water heating. In addition, direct emissions from space and water heaters emits criteria and toxic air pollutants, such as carbon monoxide, nitrogen oxides (NO_X), fine particles, and formaldehyde; many of these air pollutants have been linked with health risks such as respiratory illness, cardiovascular disease, and premature death. Increasing the adoption of zero-emission equipment in buildings can offer

energy savings, greenhouse gas reductions, and air quality and health co-benefits. Several studies have indicated that accelerated building decarbonization in the near-term is needed and is one of the most cost-effective strategies to help achieve carbon neutrality by 2045 for California.

Meeting California's climate and air quality goals requires not only regulating new construction via codes and standards, but also decarbonizing existing buildings. However, one of the largest and least understood barriers is the high cost and logistical challenge of upgrading electric service panels—especially in older homes. A lack of statewide electric service panel amperage data, wide variation in panel capacity, and disproportionate impacts on under-resourced communities, all of which complicate utility planning and equitable program design, require more detailed analysis.

Other challenges include limited access to trusted contractors, performance concerns, and the logistical effort required. Awareness of benefits—improved air quality, energy resilience, and safety—remains unclear, as does the influence of these factors on decision-making by households and building owners. Little is known about the relative strength of these barriers or the effectiveness of policy tools like incentives and rebates, making opinion research essential to inform strategies that address the most significant obstacles for under-resourced communities.

Additionally, more detailed analysis is required for commercial buildings, since there is a wide diversity of types of businesses in commercial buildings, and they use different types of greenhouse gas-emissive appliances at various sizes. Information regarding these end use mix in commercial buildings and emissions from these appliances is not available. While air quality and health impacts associated with use of these appliances has been studied, limited information is available on commercial buildings compared to other uses. Data are needed to understand the best strategies to achieve commercial building decarbonization, especially in impacted communities, assess the efficacy of these strategies to meet the State's climate goal and evaluate the co-benefits including health. A systematic, in-depth analysis on prioritization, feasibility, costs and benefits of existing commercial building decarbonization, with a focus on highly impacted areas, is needed to accelerate equitable decarbonization in California.

Project Summary

For residential buildings, statewide electric service panel capacities were estimated using permit data, parcel-level attributes, historical National Electrical Code requirements, and census-tract level probability functions. About half of single-family homes can support zero-emission space and water heating with minimal upgrades, compared to only one-third of multifamily units. A small share—around 3% of single-family and 10% of multifamily homes—have very low-capacity panels, disproportionally affecting DACs. Beyond panel size, other obstacles include limited indoor space for heat pump water heaters, outdoor siting challenges for heating, ventilation, and air conditioning units, and panel configuration issues such as insufficient breaker slots for 240V circuits, which often require sub-panels or full panel replacements. These technical and structural barriers, combined with equity concerns, complicate widespread residential building decarbonization.

Statewide incentive and adoption data, cost estimates and energy consumption trends were compiled from relevant databases, literature, and programs. The results showed that California's residential building decarbonization progress remains modest, and adoption remains uneven and far from mainstream. Despite over $550 million in combined California Energy Data and Reporting System and TECH Clean California funding allocated between 2021-2023, incentive-driven adoption is actually a small share of overall zero-emission heating adoption—representing less than only approximately 7% of the 600 thousand additional households that adopted electric space heating between 2015-2022. TECH program data reveal significant gaps between available incentives and actual project expenses: median costs for single-family ducted heat pump installations without panel upgrades reached nearly $20,000, while available incentives are around $1,350 per unit on average. These structural and financial barriers, fragmented program delivery, and equity gaps underscore the need for coordinated statewide strategies, streamlined incentive, and targeted support for low-income and multifamily households to accelerate comprehensive building decarbonization.

To assess equity and behavioral factors, a statewide survey of 807 renters in DAC and 15 interviews with multifamily property owners managing over 10,000 units were conducted. The results revealed strong interest among renters in adopting zero-emission appliances if costs remain neutral, driven by safety and environmental benefits. However, property owners

prioritize financial benefits over tenant or environmental considerations. Owners often pursue decarbonization only when it aligns with necessary repairs or reduces owner-paid expenses, and many cite inadequate incentives, complex application processes, costly electrical upgrades, and permitting and utility delays as major barriers. Both groups express concerns about affordability, tenant disruption, and utility delays, underscoring the need for streamlined programs and equitable funding.

For commercial buildings, incentive and adoption data, utility consumption records, and cost estimates were compiled to assess decarbonization feasibility. Despite significant funding, commercial building decarbonization faces major challenges. Incentive claims have dropped 88% since 2019 and uptake is concentrated in a few equipment categories like heat pump water heaters. Incentives are inadequate relative to high incremental costs: available incentives range from about $592 per unit for space heating/cooling to $17,500 per project for cooking equipment, and up to $10,000 for whole-building conversions, but restaurants face decarbonization costs of $60,000 to $124,000 per facility, offices $158,000, and schools and healthcare facilities similarly high costs. Electricity's share of commercial building energy use fell from 37% to 31% since 2006 due to overall increases in the volume of gas consumption and proportional declines in electricity usage, signaling persistent financial, technical, and structural barriers.

Spatial, quasi-spatial, and non-spatial data layers along with literature related to decarbonization were assembled for 12 commercial subsectors defined by the California Commercial End-Use Survey. Carbon dioxide (CO_2) and NO_X emissions for each subsector were calculated using the account-level gas consumption data, emission factors and control factors. A suite of other prioritization metrics, such as the impacts on exposures, worker vulnerability, decarbonization feasibility, and electric service reliability, were also quantified to develop a prioritization framework. The analysis showed that offices, restaurants, and health care facilities emerged as top contributors to total CO_2 and NO_X emissions, while colleges had the highest emissions per facility. Restaurants dominated indoor NO_X emissions and ranked highest for worker vulnerability due to low wages and large workforces. Miscellaneous (e.g., movie theaters and gymnasiums) and office subsectors pose the greatest exposure risk, and miscellaneous facilities also rank

highest for sensitive population impacts. Technology readiness varied, with lodging and offices scoring high, while process-heavy subsectors faced greater challenges.

Lodging was selected as the priority subsector for detailed feasibility analysis based on the prioritization framework, potential impacts to vulnerable communities, and potential learning returns (since other building types, such as restaurants, are often encompassed within lodging sector). The feasibility analysis included property-level analysis, stratified sampling of 100 hotels (half in DAC), and outreach through interviews and site visits. The lodging subsector, representing over 5% of California's commercial floor area and 6.7% of statewide gas use, faces significant decarbonization challenges due to high diversity of greenhouse gas-emissive end uses (e.g., water heating, cooking, laundry, pools) and aging infrastructure. Most hotels are small, old, independently operated, and located in DAC, with limited capital and staff capacity. While some hotel configurations show favorable economics, real-world costs often rise due to deferred maintenance and retrofits. Outreach efforts revealed systemic barriers—low owner engagement, time constraints, and skepticism about new technologies—underscoring the need for turnkey, vendor-led solutions, and integrated approaches addressing electrical upgrades and operational realities.

The study recommends that California should adopt a coordinated, statewide strategy to achieve zero-emission appliances, eliminate incentives for new greenhouse gas-emissive equipment, and expand financial support for decarbonization—especially for cooking, commercial retrofits, and panel upgrades—while ensuring equity and tenant protections. Programs must integrate tailored outreach, pre- and post-retrofit support, smart load management technologies, and transparent utility planning, alongside new energy tariffs and inclusion of health and societal benefits in evaluations. Improved data sharing, workforce training, and research on real-world energy use and costs are essential to guide policy and accelerate an affordable, equitable transition.

In summary, this research produced a comprehensive synthesis of data on the decarbonization of California's residential buildings, examining current trends, remaining gaps, electric panel capacity, and factors influencing end-user decision-making. In addition, the project delivered a prioritization framework and an interactive tool for commercial buildings, offering an accessible, evidence-based resource to guide decarbonization planning and investment across California. It

also generated a set of policy and research recommendations to support progress toward the State's climate goals.

III. Staff Comments

At every major stage of this research, robust public and expert inputs were incorporated through the Steering Committee (SC) meetings, the Technical Advisory Committee (TAC) meetings, and the quarterly progress update meetings to the public. The SC played a central role in guiding research decisions, ensuring that the perspectives and needs of marginalized communities directly shape the methods, analyses, and policy recommendations. The TAC—comprising of representatives from air districts, state agencies, industry groups, academia, and other expert organizations—provided specialized guidance on methodologies, findings, and helped refine conclusions, ensuring that the final recommendations reflect both rigorous technical input and meaningful community engagement.

A prior draft of this final report was distributed for review to CARB staff in RD and STCD, and externally to staff at CEC and the California Public Utilities Commission (CPUC). Overall, reviewers agreed that the report is a meaningful and impactful contribution to the literature that provides policy-relevant insights. The findings from the electric service panel analysis in particular have been shared with staff at CPUC and Bay Area Air District to inform their planning and policy work.

The major comments received and shared with the research team include: 1) to add more details about their methodology, including data collection instruments and modeling analysis; 2) to explain technical terminologies clearly to help non-technical readers understand and ensure consistent terminologies throughout the report; 3) to add more detailed analysis on the results presented in tables and figures to help understand the findings; 4) to confirm and update incentive availability analysis to note recent Federal changes; 5) to update greenhouse gas inventory figures to match CARB's most recent inventory; and 6) to not include any personally identifiable information, such as property addresses or photographs, without explicit written consent from the individuals or property owners involved in the lodging subsector survey, and revise the report to present the data in a more generalized format that protects privacy. The

current draft final report has addressed the comments from CARB staff, and the research work and content of the report meet the contract requirements.

IV. Staff Recommendation

Staff recommend that the RSC advise CARB to approve the report, contingent upon incorporating the additions and revisions identified by staff and the Committee.

Item No.: II.3
Date: February 13, 2026
Contract No.: 20RD012

Staff Evaluation of a Draft Final Report

Title:	Total Exposures to Air Pollutants and Noise in Disadvantaged Communities
Contractor:	University of California, Berkeley
Principal Investigators:	Betsey Noth, Ph.D. Asa Bradman, Ph.D.
Budget:	$874,980
Contract Term:	60 Months

For further information, please contact Dr. Pat Wong at (916) 277-0690.

I. Summary

Residents of communities in California's San Joaquin Valley (SJV) face elevated exposure to air pollutants and environmental noise, particularly near major transportation corridors like State Route 99. This study quantified indoor and outdoor exposures to fine particulate matter (PM2.5), black carbon (BC), Volatile Organic Compounds (VOC), formaldehyde, Polycyclic Aromatic Hydrocarbons (PAH), and noise across 64 households using real-time and passive monitoring, personal exposure tracking, and geospatial analysis. Results showed that indoor PM2.5 levels often exceeded outdoor levels. Mean 24-hour PM2.5 concentrations were higher indoors than outdoors, and the indoor-to-outdoor ratios (I/O) averaged 2.3, indicating that indoor concentrations were (on average) over double the outside concentrations. Household activities such as cooking, heating, smoking, burning candles, or the use of other combustion appliances likely contributed more to indoor PM2.5 levels than outdoor infiltration. Study homes in high CalEnviroScreen score (≥75th percentile) or Assembly Bill (AB) 617-designated communities had significantly greater PM2.5 and BC concentrations than those in lower-burden tracts. Homes near State Route-99 had significantly higher pollutant concentration exposures. Demographic analysis from this study group showed that renters, lower-income households (< $30,000 annual income), and Hispanic families experienced the highest indoor particulate and BC levels. Formaldehyde was detected in 81% of homes, frequently exceeding health-based thresholds and nearly all

indoor VOC levels measured exceeded outdoor levels 2 to 3-fold. Noise levels frequently surpassed limits associated with sleep disturbance and stress. These findings provide further insights into how exposure disparities in SJV communities observed with ambient air pollutant levels extend to disparities regarding indoor air quality as well and support CARB's efforts to better understand and address impacts in the most vulnerable areas.

II. Technical Summary

Objective

This objective of this study was to assess indoor and outdoor air pollutants and noise exposures of the participating communities to understand which exposure sources and pollutants have the largest impact on potential health risks and to better inform policies to protect the health of residents in these communities.

Background

Many California communities face disproportionate exposure to air pollution and noise, contributing to poorer health outcomes. This study assessed indoor and outdoor air pollutant and noise exposures primarily in overburdened communities in the SJV along with locations in lower-burdened areas with the goal of understanding possible disparities in exposure sources and potential health risks, and to inform strategies to reduce exposures in these overburdened communities. The project examined how factors like household behaviors (cooking, cleaning, smoking), building characteristics, and proximity to traffic affect resident's exposures to air pollutants and noise. It is among the first studies in California to measure indoor and outdoor noise levels alongside air quality, enabling a broader look at cumulative environmental exposures.

Methodology

A total of 64 households—each with at least one adult and one child aged 4–13—were recruited from Fresno and Stockton through partnerships with community organizations (Central California Asthma Collaborative and Little Manila Rising). Field monitoring was conducted between February and November 2023.

The research employed a multi-faceted environmental sampling approach to capture indoor, outdoor, and personal exposures over 24-hour periods. Real-time monitoring was performed using the Sensit RAMP platform to measure PM2.5, NO_2, CO, and ozone (O_3), while BC was assessed using Aerosol Black Carbon Detectors. VOCs were measured via active sampling using EPA TO-17 methods and analyzed by thermal desorption (TD) gas chromatography/mass spectrometry (GC/MS). Total VOCs (TVOC) were monitored in real time using Atmotube Pro sensors. Formaldehyde concentrations were measured using SKC UMEx-100 passive samplers analyzed by high-pressure liquid chromatography, and PAHs were collected using Harvard-type impactors and XAD4 sorbent tubes, followed by GC/MS analysis.

Noise exposure was quantified using Lutron DS-2013SD sound level meters placed indoors and outdoors, as well as personal monitors carried by adult participants. Passive PM samplers were deployed in selected homes to assess particle composition and size distribution using scanning electron microscopy and energy dispersive X-ray spectroscopy.

Participants completed detailed questionnaires on household characteristics, activities, and health outcomes. Geospatial data—including CalEnviroScreen 4.0 scores, traffic density, and proximity to State Route 99, a major transportation corridor through the SJV—were integrated using ArcGIS Pro and Google Earth. Air exchange rates were estimated using indoor/outdoor CO_2 measurements and home square footage data.

Statistical analyses were conducted using STATA and R, including Spearman correlations and non-parametric tests. Health risk characterization included hazard quotients for non-cancer risks and hazard ratios (HR) comparing estimated exposures to California's Proposition 65 No Significant Risk Levels (NSRL). This robust methodology enabled a comprehensive evaluation of environmental exposures and informed recommendations for mitigation strategies in vulnerable communities.

Results

This study found that residents in Fresno and Stockton communities experience elevated exposures to multiple environmental stressors, including air pollutants and noise. Across the 64 households in the study, indoor air quality was often worse than outdoor air quality, with significant disparities linked to proximity to traffic corridors and socioeconomic factors.

Air Pollution Findings:

- **PM2.5:** Indoor mean 24hour concentrations averaged 14.8 μg/m³, frequently exceeding outdoor levels (mean 11.9 μg/m³ [micrograms per cubic meter]), with the indoor-to-outdoor (I/O) ratio averaging 2.3. Maximum outdoor PM2.5 (36.9 μg/m³) exceeded the levels of both the United States Environmental Protection Agency (U.S. EPA) (35 μg/m³) and World Health Organization (15 μg/m³) standards.
- **BC:** Outdoor BC levels were higher than indoor, but homes in AB 617 designated communities had significantly elevated indoor BC (0.56 μg/m³ vs. 0.33 μg/m³), suggesting higher environmental burden in AB 617 communities.
- **VOCs:** Indoor VOC concentrations measured at 16 homes in Fresno were consistently higher than outdoor levels, with indoor-to-outdoor (I/O) ratios often ranging from 2 to 6 across compounds such as toluene, xylenes, and ethylbenzene. Benzene showed similar indoor and outdoor levels, suggesting infiltration was the primary indoor source.
- **Formaldehyde:** Formaldehyde was measured in 24 homes in Fresno using passive samplers. Formaldehyde was detected in 81% of samples collected from these homes, with a median concentration of 18 μg/m³—double the OEHHA and EPA chronic reference values (9 μg/m³).
- **PAHs:** Naphthalene was the most prevalent PAH, with indoor levels averaging 45 ng/m³, nearly double outdoor levels (26 ng/m³).

Noise Exposure Findings:

- Noise was monitored in 65 homes indoors, and 46 homes outdoors. There were 44 matched pairs.
- Average 24-hour noise levels were ~60 dBA, with daytime peaks >65 dBA and nighttime levels >50 dBA—thresholds linked to sleep disturbance and stress.
- Outdoor noise was significantly correlated with traffic volume within 100 meters; indoor noise showed no significant correlation with traffic.
- One-third of adults reported annoyance from indoor noise; over half were disturbed by outdoor noise heard indoors.
- Higher indoor noise levels were associated with increased reports of academic challenges and learning disabilities in children.

Health Risk Characterization:

- **Formaldehyde** exposure exceeded California's Proposition 65 cancer No Significant Risk Levels (NSRLs) for all groups, with median hazard ratios ranging from 5.6 to 7.1, and 95th percentile from 16.2 to 21.2.
- **Benzene** outdoor exposure exceeded NSRLs at the 95th percentile for both adults and children.
- **Naphthalene and ethylbenzene** exposures were below NSRLs.

Environmental Disparities:

- Homes in Assembly Bill (AB) 617-designated communities and those near State Route 99 had significantly higher pollutant levels.
- Lower-income, Hispanic, and renter households experienced disproportionately higher indoor PM2.5 and BC exposures.

These findings underscore the cumulative environmental burdens faced in San Joaquin Valley communities. Study authors recommended targeted interventions to reduce pollution exposures in communities such as accelerating measures to reduce heavy-duty truck and bus emissions, improving indoor air quality through filtration and ventilation improvements and low emission appliances, and mitigation of environmental noise. :

III. Staff Comments

CARB staff from RD and the Office of Community Air Protection, as well as external staff from the California Department of Public Health (CDPH) and Office of Environmental Health Hazard Assessment (OEHHA) reviewed the and provided comments on the draft final report which have been subsequently addressed.

The study faced several challenges that impacted its implementation and scope. There were significant delays in recruitment and data collection because of the COVID pandemic. There were also major supply chain issues during the study – again due to COVID – that delayed needed equipment and supplies. There were also unanticipated challenges that impacted staffing resources and time available from both the primary investigators and graduate student assistants. However, one of the most significant challenges was the inability to meet the original

recruitment goal of at least 90 households. 52 homes were enrolled in the Fresno community, but only 12 in the Stockton community due to unexpected staffing issues at the community organization involved in this study. This disruption reduced their ability to carry out tasks such as outreach and engagement efforts, scheduling visits to study homes and managing the monitoring equipment. The loss of much of the Stockton cohort reduced the geographic diversity and sample size of the study, reducing the statistical power and generalizability of some findings.

Although the study faced numerous setbacks, the research team was still able to collect a robust dataset and generate meaningful insights into exposure patterns. While the current data set may not necessarily represent the diversity of factors which may impact indoor air quality in households in the region, the results do provide insights for informing mitigation strategies as well as avenues for further research. In addition, the findings highlight exposure concerns and provide additional evidence that some residents of SJV communities disproportionately experience elevated pollutant exposures within the indoor space and are also subjected to consistently elevated noise levels

IV. Staff Recommendation

Staff recommend that the RSC advise CARB to approve the report, contingent upon incorporating the additions and revisions identified by staff and the Committee.

Item No.: II.4
Date: February 13, 2026
Contract No.: 22RD011

Staff Evaluation of a Draft Final Report

Title:	Impacts of Air Pollution on Life Expectancy Across Multiple Generations: Race, Ethnicity and Vulnerability Perspectives
Contractor:	University of California, Berkeley
Principal Investigators:	Guangquan (Jason) Su, Ph.D.
Budget:	$500,000
Contract Term:	34 Months

For further information, please contact Dr. Barbara Weller at (916) 324-4816.

I. Summary

Despite substantial improvement in air quality over the past two decades, PM2.5 remains a critical environmental health concern in California. Although many studies have estimated mortality risks from PM2.5, relatively few provide life-expectancy estimates, and limited studies have been conducted on how impacts differ across age and race-ethnicity groups. No prior study has also examined how the distribution of PM2.5 impacts changes over time. In this project, the researchers quantified PM2.5-attributable mortality and life-expectancy impacts for 2000–2010 (Period 1) and 2011–2021 (Period 2) in California, linking two decades of statewide mortality data to high-resolution exposure surfaces.

While long-term PM2.5 exposure remained a significant determinant of mortality in both decades (period 1 and 2), life-expectancy impacts statewide declined from 0.61 to 0.37 years, demonstrating that reductions in ambient PM2.5 resulted in significant reductions in mortality burden. The mortality and life expectancy findings in the study provide strong and robust results to support the health value of CARB's programs to reduce ambient PM2.5. Additional analysis was conducted to provide information across different race-ethnicity and age groups. When comparing the two periods, Black and Hispanic populations experienced the largest reductions in life-expectancy losses, approximately 0.59 and 0.57 years. Overall, in Period 1, older adults generally had higher PM2.5 impacts for most race-ethnicity groups. In Period 2, younger and

middle-aged groups had higher impacts. These higher impacts in younger and middle-aged groups are impacted by a demographic shift from increased population size and also show the influence of other occupational and community exposures. The exposure sources for these younger groups should be targeted to achieve equitable exposure and health impacts for all age groups in California.

Researchers also mapped these impacts to the Census Tract (CT) level throughout California. The results confirm that statewide progress reduced PM2.5-related death burdens but also showed persistent local disparities reflecting differences in sources and historically elevated exposure patterns in these areas. Together, these findings provide a clearer understanding of how PM2.5 mortality impacts have evolved in California, where policy progress achieved the largest gains, and where residual disparities remain. The results provide CARB with strong support for statewide regulatory strategies and the need for continued and targeted equity-focused interventions to address remaining PM2.5-related mortality risks.

II. Technical Summary

Objective

The objectives of this study were to quantify the mortality effects of long-term PM2.5 exposure in California, to translate those effects into life-expectancy impacts for two distinct time periods, and to evaluate how these impacts changed over time. Specifically, they include:

- Quantifying the mortality effects of long-term PM2.5 exposure for 2000-2010 and 2011-2021 in California.
- Calculation of life expectancy and the quantification of gains achieved between Period 1 and Period 2.
- Examining differences across race-ethnicity and age groups to assess subgroup-specific burdens and how these patterns changed over time.
- Identifying whether younger or older age groups had greater PM2.5-related burden to detect whether impacts were concentrated in younger, middle-aged, or older adults in each period.

- Assessing and visualizing PM2.5 exposure, PM2.5-attributable mortality, and life-expectancy impacts at the CT level across California.

Background

Even though PM2.5 concentrations have declined substantially over the past two decades because of regulatory and technological progress, PM2.5 continues to be a significant public-health burden in California. Long-term exposure to PM2.5 is well established as a contributor to premature mortality, but relatively few studies have quantified life-expectancy impacts, and fewer have examined how both mortality risks and life-expectancy losses evolve over multiple decades. Almost no prior research has evaluated how these impacts differ by age group and race-ethnicity, and whether effects are concentrated in younger or older adults. This study fills these gaps by assessing changes in mortality risks, life-expectancy impacts, age-distribution patterns, race-ethnicity disparities, and CT-level outcomes across two distinct decades in California.

Project Summary

Methods

The researchers linked individual-level mortality records from CDPH to high-resolution daily PM2.5 exposure estimates (100-meter resolution). For each decedent, long-term PM2.5 exposure was defined as the one-year rolling average preceding the date of death. All-cause and PM2.5-removed mortality rates were derived by first estimating age-specific mortality risks using conditional logistic regression models, where each model quantified the association between long-term PM2.5 exposure and mortality within each age group (and race-ethnicity group, when stratified). The observed all-cause mortality life expectancy was constructed directly from CDPH individual-level death records and corresponding population denominators. Counterfactual PM2.5-removed mortality was generated by applying the regression coefficients to predict mortality risks under a scenario in which PM2.5 exposure was set to zero, and the resulting observed vs. counterfactual mortality rates were then used to build life tables whose differences yielded life-expectancy impacts.

To characterize how PM2.5 impacts were distributed across age groups, the study applied a dual population-weighted and death-weighted framework, enabling identification of whether younger, middle-aged, or older adults contributed more to PM2.5-related losses.

CT-level life-expectancy impacts were generated by applying race-ethnicity and age-group specific PM2.5 effects to each tract's demographic composition, producing spatially resolved estimates for both Period 1 and Period 2. These results were visualized through a comprehensive set of maps, to examine CT-level life-expectancy impacts by annual average PM2.5 concentrations for 2010 and 2020 to illustrate long-term regulatory progress, and statewide maps of PM2.5-attributable mortality and life-expectancy loss stratified by race-ethnicity and vulnerability. Additional maps show differences in PM2.5 exposure and PM2.5-related life-expectancy loss between the two decades, overlaid with policy-relevant boundaries such as region, air districts, and goods-movement corridors to provide regulatory context.

Key Results

Across the whole population, PM2.5 remained a statistically significant determinant of mortality in both decades, but with risk estimates weaker in Period 2 (2011–2021) than in Period 1 (2000–2010), consistent with statewide improvements in air quality and the death-weighted life-expectancy impacts declined from 0.61 years to 0.37 years.

Age- and race-ethnicity-specific analyses revealed important disparities. In Period 1, older adults generally had larger PM2.5 impacts across most race-ethnicity groups. In Period 2, younger and middle-aged adults showed relatively more PM2.5 impacts, reflecting a shift in age distribution as overall pollution levels decreased. These increased impacts seen in younger and middle-aged adults are related to increased population size and the impacts from other exposures such as occupational and community. Asians were an exception: their population-weighted and death-weighted impacts were nearly identical in Period 1 indicating broad age distribution of impacts rather than concentration in younger or older groups. Black populations exhibited consistently low impacts among younger adults and higher impacts among older adults in both periods. Hispanic populations showed substantial PM2.5 impacts in Period 1 and continued to exhibit notable impacts in Period 2.

Using death-weighted changes to quantify policy gains, Black and Hispanic populations experienced the largest reductions between decades, approximately 0.59 and 0.57 years, indicating that regulatory progress yielded the greatest mortality reductions for these groups.

CT-level community mapping analyses confirmed statewide improvements but also revealed persistent geographic variability. Tract-level death-weighted life-expectancy impacts declined from 0.82 years to 0.61 years between decades, reflecting broad policy success. However, gains varied by neighborhood disadvantage: in the most disadvantaged tracts, mean impacts declined from 0.82 to 0.66 years, whereas in the most advantaged tracts, impacts declined from 0.81 to 0.57 years, yielding larger average policy benefits (0.25 years vs. 0.16 years). Spatial mapping highlighted hotspots in the SJV and Inland Empire, where some tracts continued to experience PM2.5-related life expectancy losses near 0.8 years, underscoring the persistence of environmental inequities despite overall improvements.

Conclusions

This study provides one of the most comprehensive evaluations to date of how PM2.5 affects mortality and life expectancy across age groups, race-ethnicity groups, and communities in California, and how these impacts have changed over two decades. The findings demonstrate that regulatory actions produced large reductions in PM2.5-related mortality, with substantial gains for Black and Hispanic populations. At the same time, residual impacts persist among race-ethnicity groups, age groups and in specific census tracts. The results show that PM2.5 control continues to yield public-health benefits, but achieving equitable protection for all Californians requires maintaining statewide emission reductions while also targeting local areas and demographic groups with remaining high impacts. Together, these findings underscore both the success of California's air-quality regulations and the ongoing need for focused policies to further reduce PM2.5-attributable mortality and address remaining disparities.

III. Staff Comments

The project included technical advisors, Dr. Pope, Dr. McConnell, and Dr. Lee, who reviewed initial and final results and provided significant advice on methodology throughout the project to ensure the most robust and consistent results. The contractor incorporated the recommendations of the advisors into the study and they are reflected in the final report.

Thorough reviews of the final report were provided by the project advisors, staff from OEHHA and CDPH as well as by CARB staff. Overall, reviewers agreed that the report presents scientifically rigorous and comprehensive work. However, reviewers had suggestions to add

information to the report to increase the clarity of the methods and discussion of results and conclusions. For example, the reviewers requested a table with the findings, separated into the strongest and the more informative. In response, the researchers provided ranking of the study findings from the strongest to those that are more informative in Table 8 of the final report. In addition, reviewers requested researchers provide updates to the GIS maps for the census tract level analysis to include clearer maps with proper legends and description in an Atlas format as an appendix in the report for public reference. CARB staff has additional suggestions for clarification in some sections of the report that have been provided to investigators.

Overall, the investigators produced a report that documents an impressive and timely contribution to understanding the long-term PM2.5 exposure impacts on mortality risk and life expectancy in California.

IV. Staff Recommendation

Staff recommend that the RSC advise CARB to approve the report, contingent upon incorporating the additions and revisions identified by staff and the Committee.

Item No.: II.5
Date: February 13, 2026
Contract No.: 22RD010

Staff Evaluation of a Draft Final Report

Title:	Impact of Air Pollution Exposure on Metabolic Outcomes for California Residents
Contractor:	University of California, Berkeley
Subcontractor:	University of California, Los Angeles
	Methodist Hospital Research Institute
Principal Investigators:	Jason Su, Ph.D. Timothy Brown, Ph.D.
Budget:	$525,000
Contract Term:	36 Months

For further information, please contact Dr. Pradeep Prathibha at (279) 216-0173.

I. Summary

This contract was developed to inform CARB's efforts to update and expand health endpoints used in the health impact analysis of CARB rulemakings and programs. CARB quantifies twelve adverse health endpoints associated with PM exposure. These health endpoints are premature death from cardiopulmonary disease, hospitalizations and emergency department (ED) visits for heart- and lung-related causes, asthma onset and symptoms/exacerbation, lung cancer incidence, nonfatal acute myocardial infarction, work loss days, Alzheimer's disease, and Parkinson's disease. Research has shown that numerous adverse health effects are associated with exposure to a variety of criteria pollutants and toxic air contaminants. In April 2020, CARB adopted Board Resolution 20-13 directing staff to expand their methodologies to include additional air pollutants and health endpoints. Per this resolution, this contract covered a study evaluating the effects of ambient air pollution on metabolic health endpoints.

This project used models to estimate statewide daily exposures to air pollutants, including nitrogen dioxide (NO_2), PM2.5, and O_3 at 30-m spatial resolution and the corresponding daily air pollution surfaces at 100-m for the years 2000-2021. Statewide concentration-response (C-R)

functions between these air pollutants and metabolic health endpoints (diabetes mellitus [type 2 diabetes]-related incidence, medication-use, hospitalizations, length of stay [LOS], ED visits, and mortality) and the associated economic benefits were also developed. This project identified C-R functions for not only the average statewide population, but also for race/ethnicity sub-groups. Additionally, exploratory air pollution models were developed to estimate statewide monthly exposure to selected air toxics, including benzene, total chromium, and nickel. The information gained through this contract will support CARB's ability to evaluate the effects of its policies and programs, including a wide range of public health benefits.

Regulatory/Policy Implications

This study developed California-specific quantitative estimates of associations between exposure to criteria air pollutants and metabolic health endpoints at high spatial resolution, with stratifications by race/ethnicity and socioeconomic status. These associations will inform CARB's regulatory health impact assessments by making the quantified public health benefits of CARB programs and rules more comprehensive, including in vulnerable communities. Additionally, this study identified gaps in demographic and exposure data for investigation in future research.

II. Technical Summary

Objective

The main objective of this study is to increase understanding of metabolic health effects in association with exposure to air pollutants throughout California. A specific aim is to develop California-specific C-R functions, including for low socio-economic status and racial/ethnic subgroups, between exposures to air pollutants and metabolic health endpoints.

Background

Epidemiological studies suggest that short- and long-term exposures to air pollution increase metabolic dysregulation, incidence of diabetes, and diabetes-related deaths. Those studies, however, largely focused on populations within a city or metropolitan area and used air pollution data with coarse spatial resolution. The U.S. EPA's 2019 Integrated Science Assessments (ISA) concluded that collective evidence is suggestive of, but not sufficient to infer, a causal relationship between long-term or short-term PM2.5 exposure and metabolic effects. However,

the ISA noted numerous epidemiological studies reporting positive associations with certain metabolic endpoints. Given the increasing number of studies linking the disease to air pollution, CARB considers diabetes an important health endpoint and aims to build upon emerging research in this area. Furthermore, based on the American Diabetes Association's report, approximately 10.5% of the adult population has been diagnosed with diabetes in California. However, an estimated 33.4% of the adult population has prediabetic conditions. Currently, there are no statewide population-based studies on metabolic health outcomes based on accurate air pollution exposures. This contract aimed to fill this gap. The results will help CARB better understand the relationship between air pollutants and their associated health impacts by providing new and important health analysis information to support its regulations, strategies, and programs.

Project Summary

Task 1: Literature Review

The researchers conducted a systematic literature review utilizing peer-reviewed journal papers on air pollution exposure and metabolic health outcomes, including incidence of diabetes, diabetes medication-use, diabetes mellitus-related ED visits, hospitalizations, and death. The researchers also examined literature on the lagged short- and long-term air pollution effects on these health endpoints.

Researchers identified 78 short-term exposure studies for review, consisting mostly of time-series/time-stratified case-crossover design with a few cross-sectional studies; several review studies were included for long-term exposures. Researchers concluded that, although available studies show significant associations between pollutants and metabolic health risk, many landmark studies predate major shifts in emissions sources, regulatory standards, and wildfire frequency increases. Additionally, researchers noted that studies were generally conducted on homogenous European cohorts or using older administrative data. Researchers also acknowledged that although evidence linking metabolic health risk to air pollution exposure is robust, studies lack evidence linking short-term fluctuations of air pollutant exposure to acute diabetes. They also noted that few studies explored metabolic health risk in association to robust air pollution data, including high-resolution exposure modeling with administrative data to

evaluate temporal lags, dose-response relationships, and the inclusion of modifiers such as temperature or wildfire smoke. In conclusion, the researchers stated that there is a need for updated data that explores more heterogeneous cohorts and short-term fluctuations of air pollution exposure on acute diabetes health outcomes.

Task 2: Develop Daily Air Pollution Models and Surfaces for Criteria Pollutants

Under CARB-funded contracts 19RD004, 20RD016, and 21RD004, researchers developed air pollution models for criteria air pollutants and identified impacts of various pollutant sources, such as on-road vehicle emissions, train/railway, and port pollution, for the years 1990-2019. They also extended previously modeled daily air pollution models and surfaces for pollutants to include the years 2020-2021. In this project, researchers utilized 2018-2021 Sentinel-SP NRTI (Near Real-Time) NO_2 and O_3 instruments of 12km daily NO_2, 7km spatial resolution and the 2010-2014 Berkeley High-Resolution instrument of 12km daily NO_2 measures to replace previously used O_3 Monitoring Instrument data to increase the spatial resolution to 30m and corresponding daily surface resolution to 100m, covering periods 2000-2021.

The models integrated multiple data sources, including traffic, land use, and meteorological conditions (adjusted R2 values of 84% for NO_2, 65% for PM2.5, and 92% for O_3). The longitudinal model results showed annual reductions in both NO_2 and PM2.5 related to regulatory shifts. However, for O_3, the results showed no significant annual trend.

Task 3: Develop Annual Air Pollution Models and Surfaces for Toxics

High-resolution annual air toxics models developed for benzene, 1,3-butadiene, chromium, nickel, lead, and zinc showed moderate to strong predictive performance (adjusted R2 = 0.59-0.90), with high model performance for benzene and zinc. There was substantially fewer monitoring data for toxics in comparison to other pollutant data, which led to significant limitations.

Task 4: Data Acquisition of Human Subject's Data for 2010-2019

In this task, researchers acquired and prepared health data sets to assess the effects of air pollution exposure on metabolic health outcomes. University of California Berkeley (UCB) researchers fulfilled all UCB and California Health and Human Services Internal Review Board

requirements, acquiring the necessary approvals for the study protocol and investigator authorization. Primary data acquisitions included the California Health Interview Survey (CHIS) data for diabetes incidence and medication use, which researchers highlighted as a unique endpoint to further understand the relationship between air pollution and metabolic health risk. Other primary data acquisitions included Healthcare Access and Information (HCAI) data for diabetes-related ED visits and hospitalizations, and CDPH Vital Records for mortality data. Following approval, the researchers adhered to strict requirements to maintain the privacy of human subject data. The acquired CHIS dataset was stored in the UCLA Center for Health Policy Research, and the HCAI and CDPH data was stored in the UCB (Secure Research Data Center to ensure Health Insurance Portability and Accountability Act (HIPAA) compliance.

Task 5: Identify Concentration-Response Relationships Between Air Pollution Exposures and Five Health Endpoints

This task comprehensively quantified associations between air pollutants and diabetes-related incidence, medication-use, hospitalizations, LOS, ED visits, and mortality. For the considered criteria pollutants (PM2.5, NO_2, and O_3), consistent positive relationships were seen for diabetes-related incidence and medication-use, with PM2.5 and O_3 showing a slight estimated increase over time for medication-use specifically. For all other O_3 estimates, results were mixed and inconsistent, likely due to the pollutant's complex spatiotemporal behavior and presence of the O_3 scavenger effect. For both NO_2 and PM2.5, statistically significant effects were shown for diabetes-related ED visits, with strongest effects seen in shorter lag times.

For diabetes-related hospitalizations, for both NO_2 and PM2.5, significant associations were shown for all lag periods, but more pronounced associations were seen in shorter lag times (0-1 days). Hospitalizations stratified by racial and ethnic groups showed overall positive associations with slight differences in affected groups and by lag times. For NO_2, short-term exposure had significant associations across all ethnic groups, with Asian and Other groups showing the strongest effects. For PM2.5, in contrast to NO_2, the strongest associations were persistently seen in Asian and Black groups.

Researchers also looked at LOS in association with pollutant exposure. For both PM2.5 and NO_2, elevated daily concentrations were significantly associated with longer hospital stays, with strongest effects at lag 0. Analysis by race and ethnicity showed that these associations remained

consistent, although for both pollutants, there were slight differences seen in temporal patterns among certain ethnic groups. For PM2.5, associations maintained statistical significance with slight variance among magnitude and temporal patterns among different ethnic groups. White individuals showed consistent and significant associations with long hospitalizations across all lags and Asians showed modest increases, whereas other ethnic groups showed distinct temporal patterns.

Results for Type 2 Diabetes-related mortality regarding exposure to PM2.5 and NO_2, showed that both pollutants showed consistent and increased effects, with PM2.5 having notably stronger and more robust effects.

Task 6: Estimate Economic Benefits from Reducing Air Pollution Exposures on Metabolic Health Outcomes

This task quantified direct (medical expenditures) and indirect (Value of Statistical Life) economic effects from reduced air pollution for type 2 diabetes. Researchers are updating analyses and drafting the corresponding chapter of the study report. CARB will review Task 6 when updated results are received and will provide comments to the committee at the RSC meeting.

III. Staff Comments

Dr. Su submitted the draft report titled, "Impact of Air Pollution Exposure on Metabolic Health Outcomes in California Residents." This report was reviewed by multiple staff members from CARB (RD, Air Quality Planning and Science Division [AQPSD], Transportation and Toxics Division), OEHHA, and one staff member from CDPH.

Reviewers requested clarification regarding methodology and discussion of uncertainties and noted small errors in terminology throughout the report. Reviewers also questioned the limited discussion of toxics in the literature report (Task 1) and the health analysis (Task 5). In Task 6, CARB and OEHHA staff noted inconsistencies with formatting with other sections of report, lack of explanation/justification for specific assumptions utilized in economic analyses, and missing abbreviation definitions and years of the estimated air pollution levels. Researchers addressed most comments and provided detailed responses to reviewers.

After the revision, the toxics portion of the literature review remains quite brief and requires expansion. Furthermore, for the long-term review studies section, the researchers did not report the number of studies reviewed or provide a flow chart explaining the exclusion and inclusion process for the identified studies. CARB requests that researchers expand upon the toxics literature, including a study breakdown with number of studies in total, the number of various study designs, and a diagram presenting how inclusion and exclusion criteria were determined to provide essential context for future work. Aside from these factors, the report generally satisfied contract criteria.

IV. Staff Recommendation

Staff recommend that the RSC advise CARB to approve the report, contingent upon incorporating the additions and revisions identified by staff and the Committee.

Item No.: II.6
Date: February 13, 2026
Contract No.: 21RD007

Staff Evaluation of a Draft Final Report

Title:	Demonstration of Sensor Technologies for On-Road and Off-Road Heavy-Duty Diesel Vehicles
Contractor:	University of California, Riverside
Principal Investigators:	Kent C. Johnson, Ph.D.
Budget:	$750,000
Contract Term:	48 Months

For further information, please contact Dr. Kerri Steenwerth at (279) 208-7842.

I. Summary

CARB continues to pursue strategies to reduce emissions from heavy-duty vehicles (HDDV) and large off-road diesel engines (ORDE) to meet stringent air quality and greenhouse gas goals. While significant progress has been made, further reductions in NO_X remain critical in California. Accurate, real-time monitoring of NO_X, PM, and CO_2 emissions using advanced sensor technologies is essential to support tighter certification standards and regulatory programs.

This project evaluated the feasibility of state-of-the-art sensor technologies in meeting the emissions monitoring needs for recently implemented and future regulatory programs. The contractor developed and tested an integrated on-board sensing system capable of measuring emissions and key engine parameters under real-world operating conditions. Laboratory and field evaluations demonstrated the potential of these systems to provide reliable, continuous emissions data.

The findings support CARB's existing and future monitoring efforts and provide valuable data for programs such as Clean Turck Check (CTC), emission inventories, in-use compliance, on-board diagnostics (OBD), certification, and air quality planning.

II. Technical Summary

Objective

The objective of this research is to evaluate the feasibility of using state-of-the-art and innovative sensor technologies to support the successful implementation of existing and future regulatory programs. This includes the use of on-board sensors to monitor NO_X, PM, and CO_2 emissions from on-road HDDVs and large ORDEs. The study characterizes the accuracy, stability, durability, and operational limitations of different types of on-board sensors - primarily focusing on NO_X sensors - in measuring real-time real-world diesel emissions. Additionally, the research aims to utilize large real-time datasets collected from both HDDVs and ORDEs to characterize emissions and activity patterns. These datasets will be used to inform regulatory programs, improve emission inventories, and identify advantages and limitations of sensors-based monitoring.

Background

Reducing emissions from mobile sources remains one of California's most significant environmental challenges in the near term and over the coming decades. CARB has been developing and implementing a range of different regulatory programs to reduce air pollutants and GHG of concern, such as NO_X, PM, and CO_2 emissions. Although considerable progress has been made in reducing vehicle emissions and improving air quality, further reductions in NO_X emissions are still needed to achieve air quality goals in California, as HDDVs remain major sources of diesel PM and NO_X. Sensor-based monitoring of emissions from HDDVs and ORDEs offers cost-effective opportunities to enhance current programs and streamline future efforts aimed at achieving sharp reductions in NO_X. As engine certification limits drop to 0.05 g/bhp-hr and below for NO_X, improvements in NO_X sensor technology will be critical to address the challenges of monitoring emissions such low levels across the full range of vehicle operations. Additionally, monitoring real fuel consumption to characterize in-use CO_2 emissions will be necessary as California's Phase 2 greenhouse gas standards for medium- and heavy-duty vehicles are phased in from 2018 to 2027.

Project Summary

The project included a comprehensive literature review and leveraged resources such as industry partners to access current sensor technologies for NO_X, PM, ammonia (NH_3), CO_2 and other sensors such as nitrous oxide. The review covered operating principles, commercial availability, and performance to identify potential advantages of using on-board sensors compared to other technologies for different emission characterization metrics for HDDVs and ORDEs. The contractor developed an on-board sensing, analysis, and reporting (OSAR) system by integrating a NO_X sensor, PM sensor, GPS, an ECM data logger connected to the vehicles OBD system, and a cellular connection for real-time data reporting. Sensor performance was evaluated on a laboratory test bench and deployed for field testing with selected HDDV and ORDE fleets for one month per vehicle.

Key findings from field testing, primarily focusing on NO_X measurements

- On a g/bhp-hr basis, average NO_X emissions across the fleets ranged from < 0.02 to ~0.82 g/bhp-hr, with substantial variability among individual vehicles.
- About 64% of vehicles showed average NO_X emissions below 0.2 g/bhp-hr (in-use emissions standard). However, daily data revealed a broader distribution, with several days exceeding 1 g/bhp-hr.
- Five vehicles (~0.09%) exhibited average NO_X emissions greater than 0.4 g/bhp-hr.
- In general, higher NO_X emissions were associated with aftertreatment temperatures near 200°C or lower. A Fleet operating primarily at highway speeds (average 52 mph) exhibited the lowest NO_X emissions and the highest aftertreatment temperatures, while a fleet with lower operating speeds (average 11 mph) showed the highest average NO_X emissions and aftertreatment temperature near 200°C.
- One of the key advantages of the OSAR system is its ability to capture cold start emissions.
- Additional analyses were conducted for the EPA 2-Bin method and CARB Real Emissions Assessment Logging (REAL) emission bins. The CARB REAL bins showed that NO_X

emissions decrease significantly with engine loads above 25%, where average emission rates were comparable to or below 0.2 g/bhp-hr.

III. Staff Comments

The draft final report was reviewed by staff from RD, MSCD, Mobile Source Laboratory Division (MSLD), AQPSD, Enforcement Division, and Emission Certification and Compliance Division. The project demonstrated the feasibility and importance of real-world tailpipe emissions monitoring using on-board sensing systems that provide continuous, reliable measurements to support next-generation monitoring for HDDVs and OREDs. The on-board sensing system successfully measured NO_X, PM, and CO2 emissions during the one-month field deployment on selected fleets. These data and findings from the project will support multiple CARB programs, including CTC, on-road and off-road emission inventories, in-use compliance, OBD, engine/vehicle certification, and air quality planning.

IV. Staff Recommendation

Staff recommend that the RSC advise CARB to approve the report, contingent upon incorporating the additions and revisions identified by staff and the Committee.

Item No.: II.7
Date: February 13, 2026
Contract No.: 22RD002

Staff Evaluation of a Draft Final Report

Title:	Characterization of Tire-Wear and Brake-Wear PM Emissions Under On-Road Driving Conditions
Contractor:	Eastern Research Group
Principal Investigator:	Sandeep Kishan
Budget:	$649,993
Contract Term:	36 Months

For further information, please contact Dr. Seungju Yoon at (279) 842-9159 or Seungju.Yoon@arb.ca.gov.

I. Summary

Characterizing non-exhaust emissions from brake-wear and tire-wear is becoming increasingly important as tailpipe emissions continue to decrease. These emissions have the potential to adversely impact health and communities near roads disproportionately burdened by air pollution. The objective of this study is to develop novel on-vehicle sampling systems for measuring brake-wear and tire-wear PM emissions under real-world driving conditions. A light-duty truck was instrumented with these sampling systems, equipped with a suite of particle measurement instruments, and operated over various test routes in Southern California to encompass a range of driving conditions. Data collected for brake-wear emissions was analyzed to identify gaps between emissions previously measured in laboratory experiments with established methods, which currently inform the On-Road Mobile Source Emissions Inventory (EMFAC) model, and emissions under real-world driving conditions. Chemical composition analysis and source apportionment modeling were used to help estimate tire-wear emissions from on-road measurements. Key findings from this report provide valuable insight regarding on-road brake-wear and tire-wear emissions measurement methodology and updating CARB's on-road emissions inventory, mobile source programs, and air quality planning strategies.

II. Technical Summary

Objective

The objectives of this study are to measure and analyze real-world brake-wear and tire-wear PM emissions by developing innovative methods to measure on-vehicle particle mass concentrations, particle number concentrations, and particle size distributions. Novel brake-wear and tire-wear sampling systems developed in this study will be characterized. Brake-wear emission measurement uncertainties from previously conducted laboratory testing will be investigated by comparing the test results to real-world results measured in this study. The results of this study will inform relevant mobile source programs, including the on-road emissions inventory.

Background

Tailpipe PM emissions from on-road vehicles have decreased significantly over time due to regulatory and incentive programs in California, resulting in air quality improvements for communities near roads. Non-exhaust PM emissions from brake-wear and tire-wear remain on roads and are projected to increase with transportation vehicle miles traveled. These emissions are known to contain heavy metals that potentially cause adverse health effects. Brake and tire materials, driving behaviors, and roadway conditions (speed, traffic, road geometry, and pavement types) can affect chemical and physical characteristics of brake- and tire-wear PM emissions. Previously, laboratory test methods were established for measuring brake-wear PM emissions and were implemented to update CARB's on-road emissions inventory. However, the limitations of these laboratory methods should be addressed by comparing previous results to brake-wear PM emissions measured during real-world on-road driving conditions. No standardized test method currently exists for measuring PM emissions from tire-wear. It is necessary to develop a test method for measuring airborne PM emissions in real-world driving conditions that reflect important variables such as tire types, traffic conditions, pavement types and materials.

Project Summary

For this study, researchers developed novel on-vehicle PM sampling systems for measuring brake-wear and tire-wear PM emissions after conducting an extensive literature review and consulting with technical experts. The researchers demonstrated the feasibility of on-board measurements in real-world conditions through comprehensive characterization of the sampling systems. These systems were instrumented on a light-duty truck and equipped with instruments for measuring particle number, mass, size and chemical composition. Measurements were conducted across various test routes in Southern California to capture a mix of driving conditions and roadway types, including city, highway, asphalt and concrete roads.

A testing matrix was developed to assess the impacts of brake friction materials (ceramic, non-asbestos organic, semi-metallic), payload, and driving conditions on emissions. Brake-wear emissions depended on friction material, with ceramic brakes producing the most PM. Additionally, emissions were highest on the city route and lowest on highways, correlating with braking intensity. On-road brake-wear mass emissions and size distributions compare well with previous laboratory results for similar braking intensities after accounting for differences in vehicle weight, but PM emission factors for city driving were higher than previous laboratory results, due to higher on-road braking intensities.

The tire testing matrix covered six major brands and one budget brand under varied conditions. Observed tire-wear emissions varied between routes, with city routes generating higher PM mass than highway routes. Chemical analysis and positive matrix factorization modeling were used to estimate the contribution of tire-wear emissions total on-road emissions, but some uncertainty from the influence of road dust and environmental PM sources remains. Analysis was conducted for scaling emissions from single tires to full vehicles and extending to fleet-level emissions.

III. Staff Comments

The draft final report was reviewed by CARB staff in RD, AQPSD, MSCD, MSLD, and the Emission Certification and Compliance Division. The report demonstrated the feasibility of implementing on-vehicle sampling systems developed in this study for measuring brake-wear and tire-wear PM emissions under real-world driving conditions in California. The results provided key scientific insight to help bridge gaps between laboratory and on-road brake-wear emissions testing

methods. Conclusions from this report will support CARB's on-road emissions inventory and help inform air quality planning efforts.

IV. Staff Recommendation

Staff recommend that the RSC advise CARB to approve the report, contingent upon incorporating the additions and revisions identified by staff and the Committee.