Air Resources Board

Mary D. Nichols, Chair
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Matthew Rodriquez
Secretary for Environmental Protection

Edmund G. Brown Jr.
Governor

May 16, 2017

Dear UC/CSU Researchers:

The California Air Resources Board (ARB or Board) is soliciting draft research proposals from California public universities and colleges to implement the development of the Fiscal Year 2017-18 Annual Research Plan https://www.arb.ca.gov/research/apr/plan/fy17-18/2017-18_arb_draft_research_plan.pdf. The enclosed solicitation provides greater detail on ARB's priority research topics for the Plan.

If you are interested in submitting a draft proposal for the research project described in this solicitation, please send an email that indicates your intent to submit a proposal and identifies the tasks to which you plan to respond, to Sarah Pittiglio by **May 30, 2017**. Draft proposals will then be due no later than **June 21, 2017**. Eligible applicants may submit their draft proposal through our proposal solicitation website at: http://researchplanning.arb.wagn.org/. The website will be open to receive submissions by May 22, 2017. Guidelines for developing your draft proposal are also included in this solicitation package and available at the solicitation website.

Guidelines for developing your draft proposal are included in this solicitation package. Projects that provide co-funding or other leveraging will be evaluated more favorably. Please note that the amount of money allocated for each project is an estimated cost, and the actual cost for submitted proposals may vary. Projects that provide co-funding or other leveraging will be evaluated more favorably.

We expect to select a proposal by July 14, 2017. A final proposal incorporating comments by ARB staff will be needed by July 26, 2017 for further review and refinement by the Board's Research Screening Committee in August. Final proposals would be needed by early September for a final decision by the Board and our target of executed contracts by December 2017.

Prospective investigators are encouraged to contact Sarah Pittiglio at (916) 324-0627 or sarah.pittiglio@arb.ca.gov for any clarification on these topics.

Sincerely,

/s/

Bart Croes, P.E.
Chief, Research Division

Enclosure

cc: See next page

cc: Jorn Herner, Research Division
Sarah Pittiglio, Research Division
Annalisa Schilla, Research Division

CALIFORNIA AIR RESOURCES BOARD
FISCAL YEAR 2017-18 ANNUAL RESEARCH PLAN

SOLICITATION OF DRAFT RESEARCH PROPOSALS FROM CALIFORNIA PUBLIC UNIVERSITIES AND COLLEGES

Table of Contents

Geofencing as a strategy to lower emissions in disadvantaged communities

I. Objective

The objective of this research is to evaluate strategies in the heavy-duty sector that could lower emissions through the use of geofencing in disadvantaged communities, during certain times, or in areas of poor air quality.

II. Background

ARB's research program is committed to monitoring levels of harmful pollutants, and determining strategies to reduce exposure, particularly in disadvantaged communities (DACs). Current in-house research is focused on comparing the trends in pollutant concentrations in high and low socioeconomic status communities. This work allows ARB to track the effectiveness of current rules and regulations to reduce traffic-related pollutants, as well as to quantify their impact on specific vulnerable communities to ensure that California's DACs benefit equitably from California's air pollution control programs. Results indicate that diesel PM and other primary pollutants are decreasing everywhere, especially in the most impacted communities. PM2.5 is also going down everywhere, but the disparity between the most and least DACs persists. ARB is initiating research to identify sources of PM2.5 in DACs, but additional research is needed to develop strategies that reduce exposure to traffic-related sources of PM2.5. Geofencing is a promising new strategy to reduce such exposures.

Geofencing allows a user to define virtual boundaries on top of a real-world view of a specific geographical area. In order to reduce harmful effects of mobile sources within predetermined areas, a device can be mounted to emitters, such as heavy-duty vehicles, which alerts both the user and a geofence operator when the vehicle crosses the geofenced perimeter. These triggers can be designed to provide specific instructions for the user to modify his or her current activities, or to employ strategies that would lower pollutant emissions in a specified area.

Geofencing is already being used by today's heavy-duty fleets to provide real-time vehicle location information that can be used to optimize productivity, security, and cost efficiency. The real-time data also facilitates route optimization and better fleet management. Geofencing capabilities are currently being tested to lower emissions in high traffic areas using Class 8 drayage trucks as part of a South Coast Air Quality Management District (SCAQMD) project, in coordination with ARB and is being funded by a $23.6 million grant from the State of California. When a truck enters the zero-emission geofenced area, which is typically a location with heavy freight traffic, such as a port, the truck operates in pure electric mode. When outside the zero-emission area, such as on the way to a rail yard or distribution center, the diesel engine is enabled, allowing for hybrid operation and recharging of the batteries. The drayage trucks in the SCAQMD/ARB project are using geofencing to switch between zero-emission and conventional hybrid operating modes in DACs, as well as railyards, ports, and warehouse districts. The data collection and analysis contract, which the drayage project is part of, is being finalized right now, and will be a great source of data for this geofencing project.

Researchers will also leverage data being collected by a current ARB research project with UC Irvine that aims to quantify the potential reductions in the emission of GHGs and criteria pollutants through the use of a broad range of connected and automated technologies and efficiency upgrades in the heavy duty sector. Some of the connected and automated technologies being assessed in this project, such as platooning, could be used to reduce the emission of harmful pollutants in geofenced areas. This project is also examining potential unintended consequences that could be caused by the use of connected and automated technologies in the heavy-duty sector on California's DACs. For example, real-time alternate route information could direct truck traffic through DACs instead of nearby truck routes in order to avoid traffic, thereby increasing the exposure to pollutants in these communities. More information about this project can be found here: https://www.arb.ca.gov/research/apr/plan/fy16-17/research_plan_2016-2017_approved.pdf.

III. SCOPE OF WORK

The investigators will examine the potential for geofencing strategies to reduce the emissions of toxic air contaminants, criteria pollutants and greenhouse gases. The project will estimate emission impacts through modeling that simulates traffic and emissions using existing emissions data. The project will consider which vehicles, and which areas in California, are the best candidates for this technology, and would experience the greatest reduction in exposure to heavy-duty related emissions to protect California's most vulnerable populations.

Emission reductions will be estimated by modeling the implementation of these strategies in regions of California where heavy-duty transportation has the greatest impact on DACs. These areas should be identified using CalEnviroScreen, and may be refined through discussions with environmental justice community representatives.

Recommended Tasks

Task 1. Identify Technical Advisory Committee

A committee of technical experts should be identified to provide guidance at quarterly meetings and review the final report. Technical experts can include representatives from other research institutions conducting similar research, or those that would benefit from research results, such as academics, community representatives, and staff from state and federal agencies and California air districts.

Task 2. Literature review

a) Emission reduction strategies – Compile information on strategies to reduce exposure of harmful diesel particulate matter and PM2.5 could include, but are not limited to, reduced acceleration rates, lowering maximum speeds, switching to electric mode in hybrid vehicles, changing engine calibration, and emission control operation. Information should also be gathered on softer boundary restrictions based on economic drivers that lead to truck exclusion. These strategies may include mileage fees, entry fees, registration discounts, restricted hours, and preferential lanes/gates. Results from the literature review will help to identify the strategies with the greatest potential to reduce harmful pollutants. The strategies with the greatest potential should be included in the modeling assessment.

b) Emission reductions associated with strategies – Review the literature for information on criteria pollutant, greenhouse gas and toxic air contaminants emission reductions associated with emission reduction strategies identified in the subtask above. Criteria pollutants that should be considered include NOx, ozone, diesel PM, PM 2.5, and carbon monoxide.
c) Economic impacts of emission reduction strategies – Literature discussing potential economic impacts suggested strategies should be summarized. For example, some strategies may require re-routing trucks to reduce exposure, which could impact the local economy, while changes to fuel economy in heavy- duty vehicles could impact small businesses.

Task 3. Identify study areas

This task will identify the areas that are the best candidates for the specified technologies, and would experience the greatest reduction in exposure to heavy-duty related emissions to protect California's most vulnerable populations. This task should be coordinated with the technical advisory committee.

Task 4. Model emission reductions in study areas

Use a traffic simulation model to examine emission reductions associated with the implementation of geofencing strategies relative to a baseline scenario. Multiple scenarios should determine emission reductions from the implementation of individual, as well as mixes of strategies in geofenced areas of varying size. The model should use the predicted heavy-duty fleet mix for one or more future calendar years, which will be provided by ARB staff. The analysis should use dispersion modeling to not only assess emissions in DACs, but also the impacts of emissions in these communities that may be upwind of areas where harmful pollutants are released from heavy-duty traffic. Proposals should indicate the specific pollutants they intend to model and the year and vehicle weight classes within the heavy-duty sector that they intend to focus on. Some strategies may be most applicable to specific weight classes or uses.

Task 5. Final report

Assess the model results to provide recommendations for the use of geofencing to reduce exposure of harmful pollutants in DACs.

The results will identify strategies that the freight industry might employ using geofencing strategies to mitigate near roadway impacts and to quantify the cumulative effect of multiple mitigation measures. These results could be used to inform the use of incentive funding and the development of strategies that reduce pollutant emissions in DACs.

IV. Deliverables

- Quarterly Progress Reports and conference calls;
- All data and analyses generated through the course of this project;
- Final Report;
- Research seminar in Sacramento;
- Peer-reviewed publication(s), as appropriate;
- Additional deliverables to be determined in consultation with ARB staff.

V. Timeline

It is anticipated this project will be completed in 24 months from the start date. This allows 18 months for completion of all work through delivery of a draft final report. The last 6 months are for review of the draft final report by ARB staff and the Research Screening Committee (RSC), modification of the report by the contractor in response to ARB staff and RSC comments, and delivery of a revised final report and data files to the ARB. The estimated budget for this project is $300,000.

Activity data of off-road engines in construction

I. Objective

The objective of this research is to characterize the activity profiles (e.g. operation duration on an average working day, load factor variation during operation, and exhaust temperature) for heavy-duty off-road diesel vehicles and engines used for construction purposes. The research should also put these results in context of the emission certification test cycles, and provide an analysis of the representativeness of the certification cycles to real-world emissions of NOx for the types of off-road vehicles and engines considered.

IV. Background

Considerable reductions in NOx emissions are needed for the State of California to meet the upcoming National Ambient Air Quality Standards (NAAQS) requirements for ambient particulate matter and ozone. Construction and agricultural equipment is estimated to contribute about 8% of the NOx emissions in the State in 2016; and this relative contribution is expected to increase as the heavy-duty on-road fleet gets cleaner in response to increasingly stringent emission standards and in-use compliance measures for the on-road sector. The design of effective emission control measures requires accurate emission inventory and realistic certification cycles, both of which require proper characterization of the activity profiles. However, the activity values in the California OFFROAD model were derived from survey data prior to 2010. In addition, much of the OFFROAD data are not specific to California fleets. New activity data should be collected to reflect the changes in the construction sector.

In sharp contrast with the 8-mode steady-state engine dynamometer certification test cycle for new off-road diesel engines, real-world engine/equipment operation is highly transient, with rapid and repeated changes in engine speed and load. In addition, the average engine "load factors" can be different than the certification test cycle load factor. In a previous ARB-sponsored study (Durbin et al., 2013), the tailpipe emissions of 27 pieces of construction equipment were measured, along with their activity profiles. The current study will expand on that study by focusing on the activity data collection that will cover a comprehensive array of equipment types and engine power ratings for construction equipment, and later extending the collection to agricultural equipment. Construction and agricultural equipment are the two most significant sources of NOx emissions in the heavy-duty off-road vehicle/engine sector.

III. Scope of Work

The contractor should create a fully developed research plan and perform all tasks as described below.

Task 1. Identify the matrix of equipment types and engine power rating ranges for the activity data collection for construction and agricultural equipment

The OFFROAD model includes 19 types of construction equipment.

- Bore/Drill Rigs
- Cranes
- Crawler Tractors
- Excavators
- Graders
- Off-Highway Tractors
- Off-Highway Trucks
- Other Construction Equipment
- Pavers
- Paving Equipment
- Rollers
- Rough Terrain Forklifts
- Rubber Tired Dozers
- Rubber Tired Loaders
- Scrapers
- Skid Steer Loaders
- Surfacing Equipment
- Tractors/Loaders/Backhoes
- Trenchers

Conduct a comprehensive review of the current inventory, and evaluate new information about equipment population, hours of use, load factors and growth forecasts. Work with ARB to identify 10 types of construction equipment that are the most significant NOx emission contributors. Based on this selection, Tasks 2 and 3 will be conducted.

Task 2. Develop a test procedures including an equipment survey form and data logging protocols

Develop an equipment survey form to collect engine and vehicle information such as equipment type, vocational use, engine maker, engine size, engine model, engine model year, after treatment configuration, typical shift start and end time, and other information recommended by the contractor.

Work with ARB staff to determine the target parameters to be logged, and the minimum number of days/hours to be logged for each piece of equipment. Instantaneous engine operation data can be acquired by engine control unit (ECU) or on-board diagnostic (OBD) data loggers. Desired target parameters include but are not limited to engine, engine rpm, fuel rate, actual engine percentage torque, friction torque, engine reference torque, engine load, exhaust temperature, aftertreatment device status, pedal and other operator control positions. In addition to ECU/OBD data it is desired to collect equipment position data by global positioning system (GPS), time-synchronized with ECU/OBD data.

Task 3. Recruit vehicles and collect data

Recruit no less than 10 pieces of equipment, representing a range of horsepower, for each equipment type identified in Task 1. Because activity should be similar for older (non-OBD) and newer equipment, it should be adequate to selecting only newer ECU/OBD equipped vehicles for data logging, but contractor recommendations are welcome.

Complete the equipment survey data form developed in Task 2 for each piece of equipment recruited.

Complete the activity data logging protocol developed in Task 2 for piece of equipment recruited.

Task 4. Field data QA/QC
Field data collected in Task 3 should be reviewed to exclude erroneous recording and false engine start due to lost connection. Data should be screened to confirm that data values and rates of change fall within reasonable ranges. ECU data should be crossed checked where possible such as fuel rate versus engine load. The contractor should also verify that the equipment operate normally during the study. Data points from uncommon activities or malfunctioning equipment should be excluded.

Task 5. Data analysis
Provide summary statistics including number of engine starts per day and distribution of soak times, as well as statistics and distributions of durations, load factors, and exhaust temperatures for each vocational use. Analyze the results to assess the representativeness of existing engine certification cycles and to assess suitability for effective NOx control by SCR. Recommend whether new cycles are needed or existing cycles are adequate for assessing NOx emissions from different construction equipment. If new cycles are needed, develop duty cycles that can better represent equipment activities by vocational use.

Task 6 Reporting and data delivery
Provide monthly status phone calls. Provide quarterly progress reports, a technical summary report for each task, draft final report, and final report. Present a seminar in Sacramento at the conclusion of the project. Delivery all raw activity data, QA/QC'd activity data, and tables of summary statistics in electronic format. Prepare a peer reviewed journal article as appropriate.

IV. Deliverables

- Monthly project team meetings
- Quarterly progress reports
- Interim report for each task
- Draft and final reports
- Peer-reviewed journal articles, as appropriate
- All data and analyses generated through the course of this project

V. Timeline

It is anticipated that this project will be completed in 24 months from the start date. This allows 18 months for completion of all work through delivery of a draft final report. The last 6 months are for review of the draft final report by ARB staff and the Research Screening Committee (RSC), modification of the draft final report by the contractor in response to ARB staff and RSC comments, and delivery of a revised final report and data files to ARB. Total cost should not exceed $200,000.

Policy, planning and program frameworks for zero-net carbon communities

I. Objective

The objective of this research is to leverage an existing zero net energy (ZNE) project that will fund the planning, permitting, and design of low-income ZNE housing to create a benchmarking framework for zero net carbon (ZNC) communities. A pilot study will be conducted to build upon the zero carbon building research underway and expand the focus to evaluate GHG emission reduction strategies that can be implemented at the community level by municipalities.

II. Background

California passed landmark legislation in 2006 (Assembly Bill 32) to reduce GHG emissions to 1990 levels by 2020. Ten years later, Senate Bill 32 was passed in 2016 to reduce GHG emissions 40% below 1990 levels by 2030. As a long term climate goal, Governor Brown directed California to reduce GHG emissions 80% below 1990 levels by 2050. The First Update to the Climate Change Scoping Plan recognized that zero carbon buildings will contribute significantly to achieving 2050 climate goals. ARB funded a research study to explore the technical feasibility of developing a statewide policy for zero carbon buildings. This zero-net carbon community research study will build upon the zero carbon building research project and leverage a $2.6 M project funded by the California Energy Commission (CEC).

At the end of 2016, the CEC released a competitive solicitation titled “The EPIC Challenge: Accelerating the Deployment of Advanced Energy Communities” under the Electric Program Investment Charge (EPIC) Program. Thirteen projects were awarded through the solicitation. The purpose of the solicitation was to fund a competition that would challenge project teams comprised of building developers, local governments, technology developers, researchers, utilities, and other project partners to develop innovative and replicable approaches for accelerating the deployment of Advanced Energy Communities (AECs), which the CEC defines as “community-scale developments based on systems integration in which energy efficiency, renewable energy, and storage technologies meet the energy supply and demand needs of its residents and supports local grid reliability and safety.” The initial phase of the solicitation was focused on researching barriers and opportunities, designing frameworks and master plans, and developing models and tools for target pilot communities. The projects are eligible for a second phase, which will focus on developing specific projects in the pilot communities, most of which aim to develop microgrids or advance zero net energy implementation.

The program, which is intended to create replicable models of energy systems of the future, is the perfect starting point to broaden the scope of goals beyond GHG emission reductions in energy use in buildings, to include community-level land use, transportation, water, and waste GHG reduction strategies.

III. Scope of Work

Research is underway to evaluate the technical feasibility of zero carbon buildings. However, it is unclear if there are additional strategies that should be implemented by municipalities at the community scale to help contribute to broader zero carbon community performance. This study will identify how zero carbon communities are different from zero carbon buildings and what strategies and policies can be implemented at the municipal scale that cannot be implemented at the building scale to achieve zero carbon community performance.

The investigators will develop and implement a zero carbon community-scale framework for evaluating community-level GHG emission reduction strategies that may otherwise not be accounted for in a ZNE framework. The framework will be used to conduct a pilot study to determine if the policies and strategies result in zero carbon community-scale performance. As a starting point, the framework will 1) develop methods to calculate baseline current emissions – energy used by transport, buildings, other commerce and industry, plus emissions from waste and land use (including negative emissions); 2) evaluate mitigation strategies in the community and model the potential to reduce emissions, and; 3) apply these methods to Richmond's AEC policy and program development and provide a template for other municipalities to adopt strategies within the framework of a Climate Action Plan.

The research team will develop a pilot implementation plan to identify which innovative strategies and policies in the framework can be adopted by the City of Richmond and replicated by other jurisdictions to achieve zero carbon community performance. The investigators will conduct the pilot study and work with the City to implement change. The research team will support and monitor the pilot study to provide guidance when problems arise and ensure that performance is tracked throughout the pilot effort. Investigators will evaluate the pilot results to measure success. They will compile GHG emission reductions of various strategies and policies; identify lessons learned and suggestions for improvement. The research team will conduct statistical analyses to validate the magnitude of improvement and zero carbon community performance, which will include a comparison of baseline emissions, compared to the measured zero carbon community-scale performance. Lastly, the research team will prepare a report, which includes the framework and pilot study summary with recommendations for other municipalities to achieve zero carbon community performance.

The investigators will leverage the City of Richmond Advanced Energy Community Project (Richmond AEC Project) that has been awarded $2. 6M from the California Energy Commission EPIC challenge for disadvantaged communities. The current scope of the project, ending in early 2018, includes the development of a ZNE reach code and zoning ordinance, a building energy use benchmarking ordinance, the planning and permitting of 20 affordable ZNE homes, incentive program design for early ZNE adopters and low-income ZNE housing, and development of an EV Action Plan.

This research project will serve as a pilot program to demonstrate how other municipalities can achieve zero carbon community-scale performance. The results of this study will be useful in the development of a GHG baseline to quantify additional non-energy GHG reductions of California ZNE communities that are needed to achieve the 2050 target.

IV. Deliverables

- Quarterly progress reports and conference calls;
- Zero carbon community-scale framework
- Pilot study implementation plan
- Conduct the pilot study
- Support and monitor the pilot study
- Evaluate pilot results
- Conduct statistical analyses to validate pilot results
- Make recommendations for other jurisdictions
- Draft final report;
- Peer-reviewed publication(s), as appropriate;
- Final report and research seminar in Sacramento;
- All data and analyses generated through the course of this project;
- Additional deliverables to be determined in consultation with ARB staff.

V. Timeline and Budget

It is anticipated this project will be completed in 24 months from the start date. This allows 18 months for completion of all work through delivery of a draft final report. The last 6 months are for review of the draft final report by ARB staff and the Research Screening Committee (RSC), modification of the report by the contractor in response to ARB staff and RSC comments, and delivery of a revised final report and data files to the ARB. The estimated budget for this project is $250,000.

Small commercial stationary refrigeration equipment inventory and f-gas emissions estimates

I. Objective

The objective of this research is two-fold: 1) To develop an equipment inventory and estimates of the current fluorinated gas (F-gas) emissions in California from non-residential, commercial or industrial stationary refrigeration equipment using less than 50 pounds of refrigerant; and 2) to research and assess the cost, feasibility, and energy efficiency of using low-GWP alternative refrigerants for these smaller refrigeration systems. To estimate F-gas emissions accurately, it will be necessary to determine the types of equipment and the number of each type used by each end-use sector, including their refrigerant charge sizes (amount of refrigerant used in the equipment), the type of refrigerant used, the average annual leak rates, and the average end-of-life loss rate of the refrigerant.

The results will be used to improve current ARB F-gas emissions estimates and will also be used to inform policy decisions regarding the impacts and potential mitigations of greenhouse gas emissions from the stationary refrigeration equipment using less than 50 pounds of high-GWP refrigerant.

II. Background

California Senate Bill (SB) 1383, Lara, 2016 requires a 40 percent reduction in hydrofluorocarbon (HFC) emissions below 2013 levels by 2030. In order to achieve these reductions, ARB must estimate HFC emissions from each equipment type and business sector that uses HFCs. Currently, ARB is lacking good data for California on the numbers and types of stationary refrigeration equipment using less than 50 pounds of refrigerant. A comprehensive equipment inventory is a necessary first step towards estimating F-gas emissions from this sector. Although the ARB Refrigerant Management Program (RMP) requires registration and reporting from facilities using at least one stationary refrigeration system that uses 50 pounds or more of high-GWP refrigerant, facilities with refrigeration systems using less than 50 pounds of high-GWP refrigerant are specifically exempted from the RMP registration and reporting requirements. This exemption has led to a lack of equipment data on these smaller refrigeration systems.

The transition to low-GWP refrigerants has been slower for the smaller stationary refrigeration systems that use more than 150 grams of refrigerant, but less than 50 pounds of refrigerant (systems using less than 150 grams of refrigerant are allowed to use flammable hydrocarbons, which have known energy efficiencies, and these systems will not be the focus of the feasibility research). The feasibility of low-GWP refrigeration for walk-in coolers and remote condensing units, commonly used in grocery stores and convenience stores, is less well-known.

ARB estimates that most of the smaller refrigeration systems are used in small grocery stores, convenience stores, and food service facilities (restaurants, fast-food establishments, commercial kitchens, etc.). Many of the smaller refrigeration systems may be used by businesses that also use larger refrigeration systems and are currently reporting, or should be reporting with the ARB Refrigerant Management Program. Additional industries that use smaller refrigeration systems may include food storage, handling, processing, preparation, and distribution; pharmacies; and industrial processes.

III. Scope of Work

The contractor will create a fully developed research plan and perform all tasks as described below.

Task 1. Conduct a literature review and preliminary market report review

The literature review may include not only peer-reviewed papers and reports, but government and business studies, market reports, and refrigeration equipment inventories and analyses from the U.S. and other countries.

Task 2. Conduct surveys, site visits, interviews, market research, and use other methods to complete an equipment inventory

Industry and business types likely to use refrigeration equipment must be identified. After business types have been identified, an inventory of refrigeration equipment is completed. The refrigeration equipment should be inventoried by basic type of equipment (ice maker, remote condensing unit, etc.); sub-category of equipment (based on charge size or type of usage); type of refrigerant used; and charge size of refrigerant. Refrigeration equipment using low-GWP refrigerants should also be included in the inventory. Low-GWP refrigerants include carbon dioxide, ammonia, hydrocarbons, and pure hydrofluoro-olefins (HFOs). To the greatest extent possible, the inventory should employ a bottom-up approach specific to California, and not rely on scaling national data to the state level, nor rely on using data from other countries and correlating to California.

Task 3. Estimate statewide F-gas emissions from stationary refrigeration equipment using less than 50 pounds of refrigerant

Estimate by business type and equipment type, the annual F-gas emissions by type of refrigerant, pounds, and metric tonnes of CO_2-equivalents (use 100-year GWP values according to the 2007 Fourth Assessment Report from the IPCC). Annual refrigerant leak rates may be unknown by equipment operators and owners, although service technicians generally keep records of how much refrigerant is added to equipment. End-of-life loss rates tend to be underestimated because intentional venting is illegal.

Task 4. Research and assess the cost, feasibility, and energy-efficiency of low-GWP refrigeration for equipment using more than 150 grams refrigerant and less than 50 pounds of refrigerant

In addition to the literature review, completing this task may involve equipment manufacturer surveys and interviews, site visits to facilities using smaller charge low-GWP equipment, and discussions with experts and end-users outside California or the U.S. familiar with the equipment of concern.

Task 5. Reports to ARB
Quarterly reports will be submitted. A Draft Report is due 18 months after contract start, and a Final Report is due 24 months after contract start.

Proposal submissions must provide the following elements:

- Description of the approach(es) that will be used to 1) identify business types using the equipment of interest; the types of systems and number of each type of system currently operating in California, the types and amounts of refrigerant used by each type of equipment, and the average annual leak rates and end-of-life loss rates of refrigerants; and 2) determine the cost, feasibility, and energy efficiency of using low-GWP alternative refrigerants to replace these types of smaller refrigeration systems.
- Description of the types of data sources that will be used to identify and determine the above.
- Description of business surveys/interviews/outreach to be used, site visits to be conducted; refrigeration equipment technician surveys/interviews/outreach; and equipment manufacturer data.
- Description of statistical methodologies to be used to extrapolate from dataset to statewide estimates, all the following: survey data, site visit data, technician data and interviews, and equipment manufacturer data.
- Description of how all findings will be summarized and applied to the statewide level of California.

Note that the following refrigeration equipment sectors do not require additional research, and are not part of the scope of work:

- Residential appliances, including residential-type refrigerator-freezers used in businesses,
- Refrigerated vending machines,
- Air-conditioning equipment and heat pumps used only for comfort cooling, and
- Any mobile refrigeration, including transport refrigeration units, refrigerated shipping containers, and rail and train refrigeration.

IV. Deliverables

- Literature survey and preliminary market survey,
- Quarterly progress reports,
- Draft report, Final report, and

- All data, literature, and analyses collected or generated through the course of this project

V. TIMELINE

It is anticipated this project will be completed in 24 months from the start date. Note that this allows 18 months for completion of all work through delivery of a draft final report; the last 6 months are for ARB and RSC review of the draft final report and delivery of a revised final report and data files to the ARB. The estimated budget for this project is $250,000.

Vehicle brake and tire wear emissions

I. Objective

The main objectives of this proposed study are to measure and analyze brake wear data to update emission factors in EMFAC, to support generation of speed-dependent emission factors, and to support source apportionment and health impact studies. The focus is on brake wear emissions because they comprise the largest portion of non-exhaust PM emissions overall. If funding and time allows, tire wear emissions will also be characterized. The plan will prioritize LDVs since they comprise the largest source of emissions, but if time and funding allows, HDVs will also be tested and characterized.

V. Background

Vehicles emit inhalable particulates from two major sources: the exhaust system, which has been extensively characterized and regulated; and non-exhaust sources including brake wear, tire and road wear, clutch wear and road dust resuspension. The non-exhaust sources have not been regulated because they are difficult to measure and control. However, with increasingly stringent standards for exhaust emissions, the non-exhaust fraction has become increasingly important. Model predictions (both MOVES and EMFAC) suggest that traffic-related emissions of both $PM_{2.5}$ and PM_{10} will eventually be dominated by non-exhaust sources (Reid, et al. 2016)[1]. Additionally, there is concern that exposure to these particles may increase in CA because proposed regional land use and transportation plans may lead to denser cities and a higher proximity of people to major roadways. Given the increased relevance of non-exhaust emissions, new studies are needed to better estimate the magnitude of these emissions and to assess the potential to control these emissions. But before an effective method to control these emissions can be devised, a greater understanding of their physical and compositional characteristics as well as overall emissions is needed. The available data and emission factors currently used in models such as MOVES and EMFAC are out of date and do not reflect new technology changes and future vehicle fleet characteristics. Further, the emission factors used in EMFAC are not speed dependent. These factors are based on two studies published in 2000-2003 (Garg, B., et al. 2000[2], Sanders, P., et al. 2003[3]) which consisted of laboratory and real-world emissions sampling. However their methods differed in their approach for simulating braking behavior and their results were inconsistent. Only recently has there been a concerted effort to devise standardized methods for brake wear or tire wear emissions sampling. These efforts are being led by the European Particle Measurement Program (PMP) under the direction of the Joint Research Council (JRC) and their results are preliminary. This work plan will specify the necessary next steps that will help improve EMFAC reliability in modeling non-exhaust emissions.

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[1] Reid, S., et al.; Emissions Modeling with MOVES and EMFAC to Assess the Potential for a Transportation Project to Create Particulate Matter Hot Spots; *Transportation Research Record: Journal of the Transportation Research Board, No. 2570,* Transportation Research Board, Washington, D.C., 2016, pp. 12–20. DOI: 10.3141/2570-02

[2] Garg, B. et al.; Brake Wear Particulate Matter Emissions; *Environmental Science and Technology*; 34.21 (2000): 4463-4469, DOI: 10.1021/es001108h

[3] Sanders, P.G., et al.; Airborne Brake Wear Debris: Size Distributions, Composition, and a Comparison of Dynamometer and Vehicle Tests; *Environmental Science and Technology;* 2003, 37, 4060-4069; DOI: 10.1021/es034145s

III. Scope of Work

In particular, this study should address the following objectives.

- Improving the “representativeness” of drive cycles and testing standards to reflect brake wear emissions in the “typical” driving conditions selected to reflect real-world fleet characteristics and behaviors
- Determining brake wear emissions as a function of driving mode and/or braking power
- Determining brake wear emissions as a function of brake technology and friction materials so that average brake wear emission factors can reasonably reflect the in-use fleet
- Measuring the emission factors of brake wear $PM_{2.5}$ and PM_{10} for LDVs, both conventional and those with newer technologies such as regenerative braking, and HDVs.
- Characterizing size distributions and emission rates of ultrafine particles (UFP) in non-exhaust emissions.
- Determining the composition and unique tracers of non-exhaust emissions for source apportionment

Task 1. Gather information through literature review and data mining and acquire braking activity data

Starting from information and data compiled by ARB, this project will continue with an extensive information gathering effort. The literature will be mined for all EF information acquired by all methods including laboratory, real-world and source apportionment methods. Since a main objective is to devise effective standardized methods for testing brake and tire wear, appropriate braking activity data is needed to properly design test cycles which reflect real-world driving behaviors. If possible CA data is preferred. If recent braking activity data is not available, then the contractor must either collect braking activity data or work with a subcontractor capable of collecting this data. This data will include statistical information on braking frequency, brake assembly temperatures, braking power and associated vehicle speeds. Braking emission PM size and composition has been shown to be dependent on brake pad materials therefore a distribution within CA of brake pad products being used on-road will be compiled.

Task 2. Analyze activity data and choose/design representative test cycles

Using the activity data found in task 1, the current test cycles will be evaluated for applicability to real-world driving behavior that would effectively capture real-world braking and tire wear emissions. To accomplish this, a comparison of the statistical distribution of braking frequency and force between the activity data from task 1 and current drive cycles will be performed. Based on this evaluation a recommendation will be made on whether or not to use existing cycles or whether a new cycle would need to be developed where test cycles need to represent average braking behavior and braking force. A final driving cycle will be chosen for use in subsequent tasks.

Task 3. Identify, upgrade, or design and build a lab grade testing facility that allows testing for PM brake wear emissions using cycles developed/recommended under task 2

Currently dynamometer systems are designed specifically to sample tailpipe emissions thus a new system will be developed which enables the measurement of non-exhaust emissions. Some currently existing facilities may be either retrofitted or enhanced based on cost-benefit considerations. Facilities, either new or existing, will be required to simulate real-world braking with respect to vehicle mass and vehicle weight distribution. If single brake assemblies are used, then consideration needs to be given toward weight distribution differences among front or rear brakes. The test facility will implement the drive cycle chosen from task 2. The sampling method will be designed to either collect PM over an entire cycle of driving (e.g., per mile) or modally (e.g., per braking event). This may depend upon the needs of the model to take vehicle speed under consideration. The sampling method should also include real-time measures of particle number and mass. Brake pads will be exposed to dynamic airflow and experience temperatures corresponding to the speeds they are driven.

Task 4. Develop a work plan that describes selection of materials and vehicles

Based on task 1 results, vehicle load parameters will be chosen which are representative of on-road vehicles including some or all of the following: LDVs, MDVs, and HDVs as well as hybrid, EVs and PHEVs. For HDVs a range of representative payloads will be simulated since payload can have a significant impact on brake-wear emissions. Additionally, brake systems will be chosen to reflect current in-use inventories and may include disc brakes, drum brakes and regenerative brakes. Braking configurations tested will include relevant materials found in task 1 and may include semi-metallic, non-asbestos organic, low-metallic and ceramic. Finally, the work plan will include the representative test cycles chosen from task 2. This may require separate test cycles for passenger vehicles, long-haul HDVs and vocational HDVs. The work plan must be approved by ARB before proceeding to Task 5.

Task 5. Collect PM brake wear emissions using variables determined under task 4

The contractor will devise a plan to collect PM samples from each of the various materials and vehicle scenarios determined in task 4. Instrumentation capable of analyzing the full size distribution of particles likely to be emitted under each test scenario will be chosen and be capable of characterizing both $PM_{2.5}$ and PM_{10} and possibly UFP. Filter analysis which captures total mass per drive cycle will still be recommended for mass closure purposes. Measurement of particle counts and size distributions are recommended, in part, to better understand toxicity and airborne fraction. Filter samples should be collected for determination of PM mass emissions. Samples should also be collected for offline compositional analysis using instruments such as XRF and ICP-MS to be funded separately, or to be performed in-house by ARB. This would be useful for identifying key markers.

Task 6. Analyze collected data for use in the EMFAC model

The results from task 5 should provide ample information regarding emissions as a function of braking events and corresponding vehicle speed and total brake power. They should also provide overall brake-wear PM emission rates in units of g/mi for the test cycles performed under task 5. This information will be critical in providing speed correction factors in the EMFAC model. Additional corrections to the model can include impact of payload, road type, weather conditions, and regenerative braking.

IV. Deliverables

- Monthly project team meetings
- Quarterly progress reports
- Interim report for each task
    - Synthesis of literature review, brake material distribution
    - Results from activity data analysis and new drive cycles
    - Plans for facility design or modifications and PM sampling plans
    - Detailed work plan matrix including vehicle parameters, brake types and brake materials and corresponding drive cycles
    - Summary of preliminary analysis of PM real-time data, delivery of filters for offline analysis
- Draft and final reports
- Peer-reviewed journal articles, as appropriate

V. Timeline

It is anticipated this project will be completed in 24 months from the start date. The estimated budget for this project is $350,000.

Emissions impact of connected and automated vehicle deployment in California

I. Objective

Determine the range of projected impacts of varying penetration levels of light-duty connected and automated vehicles (CAV) on energy usage, vehicle miles traveled (VMT), and greenhouse gas (GHG) and criteria pollutant emissions at the transportation system-level in California through 2050. California-specific CAV deployment scenarios will be developed that take into account various market, consumer, and policy developments and interactions.

II. Background

The transportation sector is undergoing a rapid transformation towards fully connected and automated vehicles (SAE level 4 & 5), which could increase light-duty vehicle miles traveled (VMT) by making them easier, cheaper, and more appealing to use, by leading to more disperse land use patterns and thereby increasing travel distances and auto-reliance, and also by enabling zero occupancy or dead-heading travel. However, increases in vehicle travel could be contained by deploying automated vehicles as shared-use vehicles, promoting and facilitating widespread carpooling, and ensuring they provide first- and last-mile service to line-haul transit rather than replacing it. Emissions resulting from increases in VMT could be counteracted by increased vehicle and system efficiencies through eco-driving, vehicle right-sizing, vehicle light-weighting, decreased traffic congestion, and deployment as zero emissions vehicles. Recent research shows that CAVs have the potential to greatly increase or decrease overall energy usage, VMT, and GHG emissions, depending on the factors listed above. Previous work has not quantified air quality impacts of CAVs nor focused on California specific CAV deployment scenarios.

An accurate assessment of the range of potential energy usage, VMT, GHG and criteria pollutant emissions from CAVs at the transportation system-level in California through 2050 will help ensure policies can be developed such that we can still meet our future climate and air quality goals without unintended consequences. The results of this study will inform the next generation of Advanced Clean Cars regulations and Sustainable Community Strategies by quantifying the emissions and VMT impacts of this emerging technology.

This project should leverage ongoing CAV and smart infrastructure efforts at various federal and state agencies, local jurisdictions, research institutions, etc. For example, relevant datasets collected as part of CAV pilot projects (available through https://www.its-rde.net) could be analyzed for this project. This study should also take advantage of CAV, new mobility services, and related existing and underway reports and peer-reviewed publications, including literature reviews (such as those funded by the California Department of Transportation (Caltrans), the California Department of Public Health (CDPH), the National Center for Sustainable Transportation (NCST)), and the Transportation Research Board (TRB), and update these as necessary. Timely results from the ARB-sponsored project "*VMT, Household Vehicle Ownership, GHG, and Policy Implications of Ridesourcing, Ridesharing, and CAV*" should also be leveraged.

III. Scope of Work

Task 1. Determine California specific CAV deployment scenarios

The primary focus of this task is to develop CAV deployment scenarios based on a matrix of possible different outcomes including:

a) range of connectivity vs automation of vehicles: connected conventional vehicles, fully automated vehicles (SAE level 4/5) with no connectivity, and connected automated vehicles

b) different ownership profiles: ranging from conventional, individually-owned vehicles used exclusively by the individual's household, to shared or fleet-based ownership dominated by shared-use and shared-ride vehicles

c) different vehicle occupancy profiles, reflecting scenarios with increases in zero occupancy vehicles and scenarios with increased carpooling

d) various powertrains: from zero emission vehicles to internal combustion vehicles

e) varied smart infrastructure diffusion: across the state in urban, suburban and rural areas and between now and 2050

f) range of CAV penetration rates among the California light-duty vehicle fleet: based on aggressive and conservative market introduction and growth and different fleet turnover projections

g) variety of potential interactions with the overall transportation system, such as the effects on transit systems and usage, active transportation rates and infrastructure, and resulting effects on VMT, GHG, and land use patterns

h) consideration of travel costs that take into account the costs of the vehicle, energy used, time of driver (for baseline case) and time of travel, etc.

i) statewide policies:

   i. ZEV deployment in CAVs to reach 40% GHG reductions from 1990 levels by 2030 as set by Senate Bill 32

   ii. Level of shared fleet required to reach the updated Senate Bill 375 VMT targets for 2035

   iii. Statewide per mile road-fees are implemented or other pricing schemes to encourage shared vehicle occupancy, mode shift to transit and active modes, shorter trips, more compact land use, and more efficient use of roadway capacity.

This task will require the researchers to work in coordination with ARB staff to refine and limit the number of scenarios. The different scenarios should be at 5 year intervals and in a format compatible with ARB's Vision and EMFAC models.

Task 2. **Quantify the impacts of CAVs on VMT and improvements in efficiency at the transportation system-wide level in California, and on GHG and criteria pollutant emissions**

This task will draw upon available literature and use various simulations and modeling tools to estimate the range of potential changes in VMT and transportation system efficiency improvements from 2020 to 2050 for each CAV deployment scenario. The VMT analysis will be based on projected travel behavior and costs, as well as outlined statewide policies, and collaboration with ARB staff. The efficiency improvement projections will be based on known and projected changes in the vehicle and transportation system level among them eco-driving, vehicle right-sizing, vehicle light-weighting, increased vehicle occupancy, and changes in traffic congestion. Furthermore, the impacts of connectivity on efficiency, in particular impacts on roadway capacity, will also be explored. Finally, the interactions between these two effects, for example the VMT rebound effect, will also be examined.

In order to estimate the range of potential energy usage, GHG and criteria pollutant emissions from 2020 to 2050 for each CAV deployment scenario, the research team should work closely with ARB staff to use the most up-to-date version of ARB's Vision and EMFAC models to quantify the GHG and criteria pollutant emissions of each scenario from Task 1. Specifically, the GHG emissions of interest include, but are not limited to, carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), while those of criteria pollutant emissions are nitrogen oxides (NOx), particulate matter smaller than 2.5 microns (PM2.5), and volatile organic compounds (VOCs). Available literature will also be utilized for this task. The researchers will work with ARB staff to determine the share and emissions of California's 2020-2050 fuel types and electrical grid (based on CAV powertrain scenarios) that will be incorporated into the analysis.

Task 3. **Assess CAV-related policies based on projected energy usage and emissions of the various scenarios**

Based on the results from tasks 2 and 3, describe the implications of selected CAV scenarios for ARB policies, and climate and air quality goals. Examine CAV policies that could be implemented to help meet our climate and air quality goals or minimize the climate and air quality impacts of CAVs. Examine which strategies can be implemented at different scales (local, regional, statewide, etc.). Analyses will consider changes in costs over time and potential barriers (and ways to overcome these) to implementing the most promising policies.

IV. **Deliverables**

- Quarterly progress reports and conference calls;

- Interim report;
- Draft final report;
- Peer-reviewed publication(s), as appropriate;
- Final report and research seminar in Sacramento;
- All data, analyses and analytical tools generated through the course of this project;
- Additional deliverables to be determined in consultation with ARB staff.

V. **Timeline**

It is anticipated this project will be completed in 24 months from the start date. This schedule allows 18 months for the completion of all work through delivery of a draft final report; the last 6 months are for ARB review of the draft final report and the delivery of a revised final report and data files to ARB. The estimated budget for this project is $220,000.

Strategies to reduce methane emissions from enteric and lagoon sources

I. Objective

The objective of this research is to determine the economic and logistical feasibility of strategies to inhibit methane (CH_4) production from enteric fermentation and anaerobic manure storage lagoon sources at California dairy and beef operations.

VI. Background

The Short-Lived Climate Pollutant Reduction Strategy, in conjunction with AB 32 and SB 1383, aims to decrease CH_4 emissions from dairy and livestock manure management by 2030. Additionally, per SB 1383, voluntary reductions will be pursued for CH_4 reductions from enteric fermentation, with potential regulatory mandates if certain specific findings outlined in SB 1383 are reached. Enteric fermentation and manure management emissions from California's 1.8 million dairy cows contribute approximately half of California's total CH_4 emissions, making achieving significant CH_4 emission reductions from these sources critical for meeting the goals of SB 1383 and ARB's broader climate change policies.

Several products have recently been identified as additives that may reduce CH_4 emissions from California dairy operations. These products fall into two categories: feed additives focused on enteric fermentation emission reductions, and anaerobic manure storage lagoon additives to lower emissions from manure storage.

While many of these products have been assessed for potential CH_4 emission reductions in generic dairy of beef operations, none have been examined under California-specific dairy and beef operations or conditions. The logistical and economic feasibility of using these products in California needs to be examined to determine the potential for these products to reduce emissions. For example, certain modifications to feed delivery systems and feeding schedules have been shown to achieve CH_4 emission reductions from enteric fermentation, but the impact of these strategies remains unclear for California dairy operations. In addition, the optimal introduction rate for feed or lagoon additives under California-specific conditions has not been investigated sufficiently for any of the proposed project, and should be evaluated further. The willingness of facility operators, trade groups, and retail groups to use or purchase product that may contain these additives remains unclear and needs to be investigated.

III. Scope of Work

This study aims to identify CH_4 reduction strategies that are effective, economically viable, and have no impact to meat or milk quality and production. Effective strategies to reduce CH_4 emissions from enteric and lagoon sources can provide significant greenhouse gas and short-lived climate pollutant emission reductions from the California dairy and livestock sector. These important emission reductions can help the State achieve its climate change goals while ensuring there are no adverse effects on animal health and productivity or the environment. The priority for this study is to focus on California dairy operations, since the majority of CH_4

emissions come from this source, however, beef and other livestock operations in California are also of interest, and should be included in the investigation if it is feasible.

Recommended Tasks

Task 1. Literature review - Researchers will perform a literature review on identified emission reductions strategies from enteric and lagoon sources that are currently available to reduce CH_4 emissions from dairy and livestock sources. The analysis will help determine the potential feasibility of these strategies for use at California dairy and livestock operations, and inform the need for further investigation of these strategies. The literature review will include review of impacts on animal welfare and performance, estimated emission reductions, cost analyses, and barriers to implementation.

Task 2. Industry survey – Survey members of California's dairy and beef industry to determine willingness to use food or lagoon additives in their operations. The survey should also focus on the logistical feasibility of adding the additives to these operations, and concerns about the use of additives that should be addressed in future research. The survey should also be conducted on members of trade and retail groups to determine the willingness of customers to buy products that have used additives in their operations.

Task 3. Research roadmap – Develop a prioritized list of research gaps associated with the use and effectiveness of additives to reduce CH_4 emissions from enteric and lagoon sources in California. This roadmap will be used to guide future research within the State to maximize the effectiveness of additives and ensure that there are no unintended impacts from their use.

Task 4. Final report – The final report should summarize the findings of the literature review, industry survey and research roadmap. Barriers to the use of these strategies in California should be assessed, including limitations due to cost. The barrier analysis should conclude with specific recommendations to overcome these barriers.

IV. Deliverables

- Quarterly Progress Reports and conference calls;
- Final Report;
- Research seminar in Sacramento;
- Peer-reviewed publication(s), as appropriate;
- Additional deliverables to be determined in consultation with ARB staff.

V. Timeline

It is anticipated this project will be completed in 24 months from the start date. This allows 18 months for completion of all work through delivery of a draft final report. The last 6 months are for review of the draft final report by ARB staff and the Research Screening Committee (RSC), modification of the report by the contractor in response to ARB staff and RSC comments, and delivery of a revised final report and data files to the ARB. The estimated budget for this project is $150,000