EXHIBIT A

SCOPE OF WORK

☒ Contract ☐ Grant

Does this project include Research (as defined in the UTC)? ☐ Yes ☒ No

PI Name: Georgios Karavalakis

Project Title: Characterization of Train Brake-Wear and Wheel/Rail-Wear PM Emissions

Project Summary/Abstract

Exhaust particulate matter (PM) emissions for both on-road and off-road equipment have decreased significantly over time due to stricter regulations, incentive programs, and advanced technology. Conversely, non-exhaust PM emissions (e.g., brake- and tire-wear PM) have increased and are projected to surpass the exhaust PM emissions multiple times in 2030. Non-exhaust PM emissions have become a concern due to their increased contribution to regional PM emissions and exposure in communities near traffic and freight corridors. The California Air Resources Board (CARB) and other government agencies and research institutes have investigated the impact of non-exhaust PM emissions to inform relevant programs and policies. However, current non-exhaust research characterizing emission factors (EF), PM compositions, and related potential health effects (CARB contract #17RD012, #17RD016, and #18RD017, and Caltrans contract #65A0703) has focused only on on-road vehicles. There is a need to expand this work to include other non-road sectors such as rail.

California has 4,981 miles of freight rail tracks and carries the second-largest freight rail carloads in the nation. CARB is currently proposing an In-Use Locomotive Regulation (title 13, California Code of Regulations, sections 2478 through 2478.16) to reduce exhaust emissions, including diesel particulate matter), oxides of nitrogen (NOx) and greenhouse gas (GHG), by replacing old locomotive engines with newer cleaner models. With the expected significant reduction of the exhaust emissions from the trains, brake-wear and wheel/rail-wear particles are expected to become the dominant sources of PM emissions from trains, similar to the projections for on-road vehicles. The extent of research on (BWWW) PM emissions from trains and their potential health risks in near railroad communities is limited and needs to be improved for emission inventory development and health impact assessments. BWWW PM emissions from trains are not yet included in CARB's train emission inventory. Therefore, characterizing the BWWW PM emissions and train activity patterns can inform the development of BWWW PM emissions inventories and provide opportunities to assess near-railroad community exposure to these emissions.

The increased knowledge developed by the transportation industry in preparation for the upcoming Euro 7 regulation for brakes and tires is of utmost importance to support this development. Several partners in the University of California, Riverside (UCR) team have been engaged since the inception of the different Task Forces of the Informal Working Group within the Particulate Measurement Programme of the United Nations Economic Commission for Europe (UNECE). Additionally, the UCR team includes members of the ISO Technical Committee TC269 charter to develop a laboratory method for measuring brake emissions for rail brake systems. Lastly, recent announcements from the Federal Government related to funds earmarked to support public transport seek to strengthen the rail infrastructure and enhance the quality and reliability of

public transportation services. As the rail infrastructure and service expand, this project enables the assessment of potential health impacts and guides mitigation strategies. Ultimately, the project helps reduce the exposure of vulnerable communities or users, including train operating personnel and rail yard staffing.

If Third-Party Confidential Information is to be provided by the State:

☐ Performance of the Scope of Work is anticipated to involve the use of third-party Confidential Information and is subject to the terms of this Agreement; ***OR***

☐ A separate CNDA between the University and third-party is required by the third-party and is incorporated in this Agreement as Exhibit A7.

Scope of Work

For this project, a team of university and industry researchers with extensive experience and expertise in measuring non-exhaust emissions from mobile sources, emissions physicochemical characterization, aerosol sampling and instrumentation development, emissions and air quality modeling, and emissions exposure and epidemiology modeling will undertake the efforts to execute a comprehensive test campaign for the better characterization of BWWW PM emissions. UCR will lead this project with the support of Link, the University of California, Irvine (UCI), San Diego State University (SDSU), and Eastern Research Group (ERG). Technical support and technical advisory will be provided by Deutsche Bahn Systemtechnik (Germany). The project team will collect activity data during real-world train operations and design a test method to measure BWWW PM emissions for California representative types of trains: line-hauls, switchers, and passenger trains. In developing the test method, factors potentially correlated with the BWWW emissions will be accounted for, such as locomotive and car weights, train speed, brake and wheel/rail materials, brake and wheel technologies, etc. Real-time PM2.5 and PM10 mass, particle number, and size distribution will be measured, and PM2.5 and PM10 filter samples for both gravimetric and composition/chemical analyses will be collected. Since BWWW PM emissions may have different physical and chemical properties depending on the specific brake and wheel systems, the project team will conduct a suite of chemical, metal, and oxidative stress analyses using the PM filter samples. The project team will develop train type-specific EF and chemical profiles for BW PM and WW PM emissions. Next, to address the environmental equity of near-railroad communities, the project team will assess current community air protection programs and policies based on the results from this study. The project team will consult environmental justice experts or proceed via other proposed methods to understand community exposure and potential community concerns about BWWW PM emissions and suggest relevant future steps and programs.

Three critical dimensions the UCR team will keep in perspective throughout the project include:

a. The different designs and contraptions of the friction couples, their influence on emissions factors, and their related parameters (torque, control pressure, and temperatures). Of particular interest to the UCR team are the considerations when designing and building the PM sampling devices, as exemplified in Figure 1.

		
Legacy disc brake	Compact disc brake	Compact tread brake

Figure 1 Different designs of brake actuators for disc and tread brakes[1]

b. Depending upon the type of train (e.g., line-haul, switcher, short-line, passenger), manufacturer, and year of manufacture, the embodiment of the bogies and the rolling stock can have different control technologies and components. These influence the brake work distribution (including reaction times) during regular operation. See Figure 2 for two examples of braking circuit layouts.

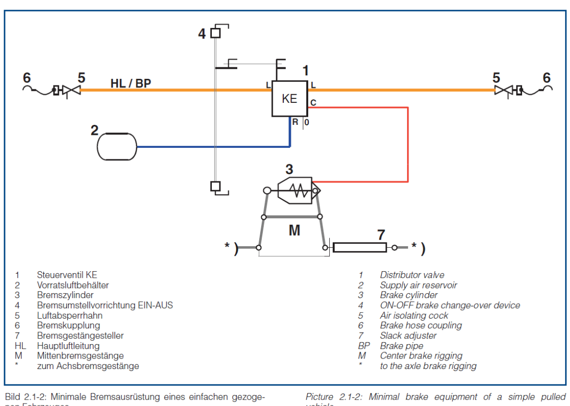
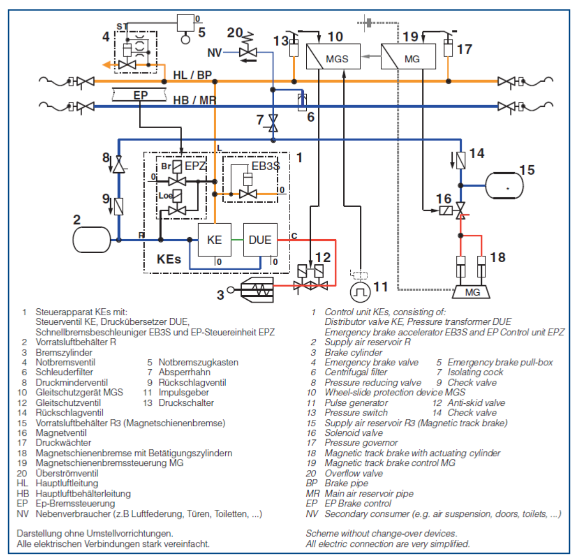
	
Manual brake of a simple pulled vehicle	Brake equipment for a passenger car

Figure 2 Different braking circuit layouts for different types of trains[2]

c. The on-rail measurement systems need to collect activity data sufficient to characterize non-frictional dynamic torques (electric or regenerative) that decelerate the train and influence the kinetic energy of the brakes on the bogie to dissipate. This behavior determines the tribology (pressure, speed during friction braking, and interface temperatures) and its effect on the emissions levels. Figure 3 illustrates

[1] *Grundlagen der Bremstechnik – Basics of Brake Technology*. KNORR-BREMSE
[2] See Footnote 2.

regenerative brake blending, which has been used for train brakes for decades. The brake dynamometer testing will approximate the regenerative braking for powered axles.

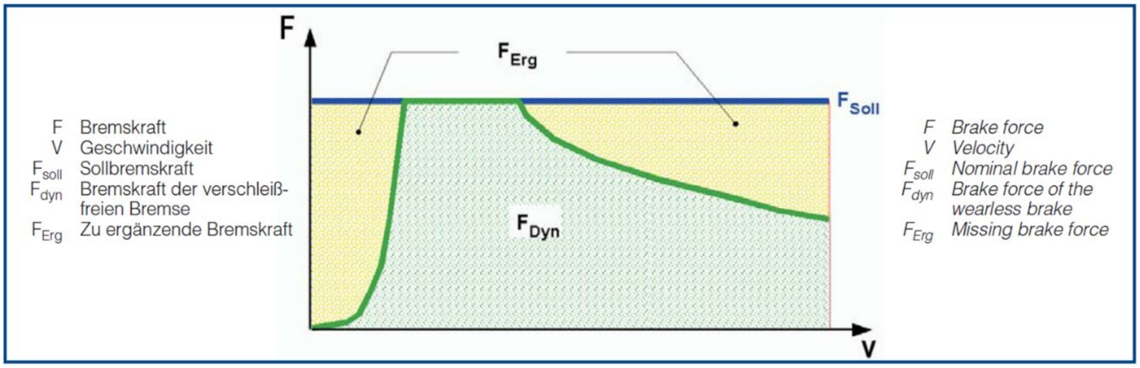


Bild 3.2-11: Beispiel für Blending

Picture 3.2-11: Example of blending

Figure 3 Electric or regenerative braking[1]

The UCR team for this proposal will include:

	University of California, Riverside College of Engineering's Center for Environmental Research and Technology (CE-CERT)
	LINK Engineering Company (LINK)
	Eastern Research Group, Inc. (ERG)
	University of California, Irvine
	San Diego State University

The following sections discuss the methodology for each task, with specific tasks led by different project team members.

[1] See Footnote 2.

Project Tasks

Task 1: Literature Review (lead UCR, support UCI, LINK)

Task 1a: Review of Train Duty Cycles and Non-Exhaust Emission Test Methods

UCR, in collaboration with UCI and Link, will conduct a comprehensive literature review on currently available train BWWW PM measurement practices, train duty cycles reflecting real-world operations, and the latest technologies of braking systems, brake friction materials, and wheel and rail materials, along with their propulsion systems. The project team is well-versed in the available literature involving train PM measurements. The project team will conduct a comparative analysis for potential on-rail and in-laboratory test methods. Based on the available literature, the project team will identify a few testing configurations designed to measure BWWW PM emissions separately, either on-rail or in the laboratory. This analysis will determine the advantages and disadvantages of each method regarding the repeatability of emission measurements and the reproduction of real-world brake and wheel abrasion activities. The project team will also obtain information about currently existing duty cycles for trains and investigate whether these duty cycles can reflect real-world train operations, such as engine load, braking frequency, and acceleration and deceleration behaviors. The project team will review and summarize conventional and advanced technologies on train engines, brake technologies, and wheel systems. The project team will evaluate the availability, feasibility, and influence on BWWW PM emissions of advanced technologies shortly.

Many studies have identified the importance of measuring and characterizing PM emissions from trains (Cha et al., 2018; Lee et al., 2018; Sundh et al., 2009; Lee, 2020). The sources of PM emissions in rail traffic systems include wear from the wheel-rail contact, brake system contact, and electrical power systems, as well as the resuspension of particles caused by the movements of trains. The composition of these particles contains a significant amount of metals and minerals, including hexavalent chromium (Cr(VI)), which is regarded as a carcinogen, according to the International Agency for Research in Cancer. Studies have shown that transition metals such as Ni, Fe, and CrVI often result from the friction-induced wear of railway components, especially steel rails and cables (Lovett et al., 2018; Seaton et al., 2005). Previous studies have assumed that all Cr detected in train brake wear is CrVI due to the high temperatures in which railway dust is formed (Lovett et al., 2018; Chillrud et al., 2004).

Burkhardt et al. (2008) estimated the PM emissions from trains from 7,200 km of tracks in Switzerland based on the material losses from brakes and wheels and found that annually, some 1,912 tones of PM are generated by brakes, 550 tones from rails, 124 tones from wheels, and 38 tones from contact lines. Burkhardt et al. also reported that wheel-rail contact was a source of Fe, Mn, Cr, Ni, and VA emissions. Fridell et al. (2010) showed average PM emissions of 2.9 g/train-km for freight trains, 0.48 grams(g)/train-kilometers (km) for commuter trains, and 0.24 g/train-km for regional trains. Fridell et al. (2011) performed on-board emission measurements on a passenger train and found elevated particle emissions during braking events. A recent study by Fruhwirt et al. (2023) found that the cumulative PM10 emissions of the wheel-rail contact ranged from 0.33 to 5.57 g/km. Fruhwirt et al. also showed that the average proportions of PM2.5 and PM1 in the PM10 emissions were 87.5 percent and 68.46 percent, respectively. Lee et al. (2018) investigated the effect of train speed on particle emissions. Lee et al. found increased particle emissions during rolling/sliding contact and decreased particle emissions during sliding contact at 45 and 90 km/h. Overall, Lee et al. found higher particle emissions with increased train velocity and particles with larger sizes with increased train velocity. Abbasi et al. (2011) found an ultrafine peak for particles at around 100 (nm), a dominant fine peak for particles at around 350 nm, and a coarse peak with a size of 3-7 µm. They also showed that these particles comprised Fe, Cu, Al, Cr, Co, Zn, and Sb. Octau et al. (2020) found high concentrations of ultrafine particles (<100 nm) during braking and at temperatures higher than 180 °Celsius. Octau et al. also showed that fine particles with a diameter of around 500 nm were unaffected by temperature changes and contact pressure variations. Abbasi et al. (2012) found that during braking, there were three speed/temperature-dependent particle peaks in the fine region, representing particles with 280 nm, 350 nm, and 600 nm in diameter. Abbasi et al. also found a coarse region with a three – six µm diameter peak. Abbasi et a showed that particle peaks increased with increasing temperature and that electrical braking significantly reduced airborne particle numbers.

The project team will continue reviewing the latest available literature at the time of project initiation. The team will develop a list of the leading methods for train brake PM measurements and the advantages and disadvantages of each in terms of repeatable emission measurement capability and reproduction of real-world emission rates. The team will also develop comparisons outlining the advantages and disadvantages of laboratory methods compared to in-use sampling methods evaluated and implemented as part of this project.

Task 1b Review of Train-Related Exposure Studies, Research on Potential Health Impacts on the Near-Railroad Communities

The project team will conduct a comprehensive literature review on currently available studies on exposure to train emissions, both exhaust and non-exhaust emissions, and their potential health impacts on near-railroad communities. The literature search will cover literature in English published from January 2000 to the time the review is conducted (e.g., December 2024). We will search common databases (e.g., Web of Science, Scopus, MEDLINE, PubMed, Google Scholar) to identify relevant studies on 1) train emissions, 2) air pollutant concentrations or human exposures to train emissions, and 3) potential human health impacts on the near-railroad communities. In the search, we will use terms such as train/railroad/freight/locomotive, emission/brake and wheel wear/air pollution/health impact/community concern. The titles and abstracts of the entire list of studies identified by the search will be screened to select those that fulfill the selection criteria. After the initial appraisal, we will retrieve the full text of the selected titles. Full texts will be appraised and reviewed. We will also review reference lists of the retrieved articles and previous systematic reviews for additional publications. In addition, we will contact CARB staff and other experts in the field to identify additional references that should be considered. Selection criteria, study selection procedures, data extraction, and quality assessment will be explicitly documented. We will summarize the existing studies and identify data gaps for our proposed research.

Further, the project team will extract and study the literature on sociodemographic characteristics, disproportional exposures, risks of adverse health outcomes, and concerns and needs related to train emissions for both exhaust and BWWW PM among residents living in communities adjacent to railroads. We will focus on the studies in California but will expand the literature to the U.S. or even globally if such information is scarce in California. Since we expect that most of the near-railroad neighborhoods are disadvantaged communities, we will pay particular attention to the literature related to environmental injustice issues associated with train and railroad impacts, e.g., short-term and long-term concerns of communities, civic engagement, and community mobilization to address the problems, and existing mitigation strategies.

The project team will conduct a comprehensive literature review on currently available studies on exposure to train emissions, both exhaust and non-exhaust emissions, and their potential health impacts on near-railroad communities. The project team could consult environmental justice experts or use other proposed methods to understand near-railroad community concerns about train emissions for both exhaust and BWWW PM. UCI's Professor Wu will address the potential health effects on near-railroad and disadvantaged communities and engage with community groups regarding air pollution from trains.

Deliverable:

This report reviews train emissions research and studies, existing operation duty cycles, conventional and advanced engines, and brake and wheel technologies. It shall also include reviews of recent studies of the health impact of train emissions on near-railroad communities, potential health effects, community concerns for air pollution exposure, possible health effects, community concerns, and existing mitigation strategies.

Task 2 Identify Test Train Types and Associated Materials and Routes

Task 2a Assemble a Project Workgroup

The UCR team will organize a project workgroup (Workgroup) in consultation with CARB staff. Candidates for the Workgroup will be identified and recruited drawing from our team's broad connections with stakeholders, including federal agencies, rail and brake system manufacturers (with knowledge in braking systems, tribology, and wear), PM researchers, local air districts, and international bodies conducting similar research. This would include a presentation of candidate members, their expertise and interests, and how they complement the Workgroup with multiple perspectives for the study. When candidate commitments are in place, we will convene the Workgroup to present and discuss designs and plans and solicit input on the remaining elements of Task 2, including the market survey, locomotive and railcars selection, track and route prioritization, and designing of the on-rail and in-laboratory emission sampling methods and testing. We assume the cost proposal can be covered in four Workgroup meetings agreed upon with CARB (e.g., within three months, 12-15 months, and 24-27 months from the date the work begins, and within three months before the commencing Task 9. We will compile a report for CARB summarizing Workgroup input, including written comments, and present it during the regular reporting meetings. Our team will meet with CARB to discuss the Workgroup input and recommendations for incorporating it into plans for subsequent tasks.

In addition to the stakeholders from California, the UCR team considers some of the following could strengthen the Workgroup:

- Federal Railroad Administration (FRA) from the DOT,
- The Office of Environmental Justice (OEJ) within the Federal Department of Justice
- American Association of State Highway & Transportation Officials (AASHTO),
- American Public Transportation Association (APTA),
- American Short Line and Regional Railroad Association (ASLRRA),
- National Passenger Railroad Corporation (Amtrak),
- Association of American Railroads (AAR),
- Health Effects Institute (HEI),
- Foreign authorities dealing with rail transport and health effects (e.g., EU HORIZON, UIC, European Commission)

Task 2b Market Survey of Brake, Wheel, and Rail Materials and Identify Representative Trains by Operation Types in California

BWWW PM sizes and compositions largely depend on their materials and the tribology at the contact areas (between the brake pad and brake disc, tread brake block and wheel, and wheel and rail). The UCR team will conduct market surveys of brake, wheel, and rail materials and find their market shares by material type for train types in California. The UCR team will structure a survey and interviews to collect information on the wheel and brake replacement frequencies and brake, wheel, and rail materials, technologies, and maintenance protocols/practices. The survey will include three main phases:

The UCR team will develop a comprehensive list of California representative train models with associated wheel and brake materials and technologies using the survey results by conducting surveys, exchange sessions, and interviews. The train models in the list should be characterized by train weight (locomotive and car weights separately) and type, commodity weight and types, and daily operation miles and frequencies. When applicable, the taxonomy of locomotives and trains will follow the CARB Fact Sheet:

In-Use Locomotive Emissions Inventory: Regulations Proposal and Scenarios.[1] Out of the list, the Contractor shall identify the train types most prevalent in California and nominate them for activity data collection and emissions testing. Before proceeding to the next task, these nominated train types should be discussed with the Workgroup. To ensure the alignment with environmental justice criteria, the Market Survey criteria will include some aspects related to the demographics and other relevant socio-economic factors.

The Market Survey should rely as much as possible on classifications from recent CARB inventories.[2,3] The structure below allows the integration of other survey information with other CARB initiatives to reduce overall rail emissions and provide the high-level classification of railcars and their associated braking systems.

- Class I Line haul locomotives typically move freight across State and country borders. They comprise two to four locomotives that push or pull a single line of freight railcars that can be miles long.
- Class I Switchers operate in rail yards to move individual railcars or segments of trains, typically to build a line of railcars that line haul locomotives will pull.
- Short-line rail is limited to smaller regional operations, usually owning a few locomotives.
- Passenger rail includes inter-city, intrastate (within the State), and interstate (exiting the State) passenger operations such as Amtrak, Metrolink, and others. Similar to the regulatory activities, any Passenger rail exiting the State is excluded from the analysis
- The industrial locomotive category includes approximately 39 California industrial operators that typically conduct short-range goods movement within and around their facilities.

The Market Survey will use categories as needed to ensure proper classification of locomotives and railcars concerning variables influencing emissions factors (e.g., kinetic energy for acceleration and braking, power during constant speed and uphill/downhill, brake type and formulation, wheel type and material, rail type and material, and brake controls systems). Table 1 illustrates the high-level tabulation of findings of the Markey Survey to support future work to understand the variations among parameters and configurations for locomotives and railcars and pursue the aggregation of brakes and wheels for future assessments, measurements, and testing campaign design.

Table 1 Locomotive and railcar types and selected parameters for each locomotive and railcar type

Locomotive and railcar types	Parameter for each locomotive and railcar type

[1] CARB, 2021 Class I Line Haul Locomotive Emission Inventory, February, 2021 (weblink: https://ww2.arb.ca.gov/sites/default/files/2022-07/2021%20Line-Haul%20Locomotive%20Emission%20Inventory%20%28Final%29%202022%20July%20Update.pdf

[2] CARB's 2022 Switcher Rail Yard Emission Inventory, July 2022. (weblink: https://ww2.arb.ca.gov/sites/default/files/2022-07/2022%20Class%20I%20Switcher%20Emission%20Inventory%20technical%20document%2007112022.pdf

[3] CARB, 2017 Passenger Rail Emissions Model, June 2017. (weblink: https://ww3.arb.ca.gov/msei/ordiesel/locopassenger2017ei.docx)

Locomotive – tier 0 – tier 1 – tier 2 – tier 3 – tier 4 Switcher – tier 0 – tier 1 – tier 2 – tier 3 – tier 4 Line-haul railcar – Autorack – Gondola – Boxcar – Flatcar – Tank car – Covered hopper – Open-top hopper – … Passenger – Amtrak – Metrolink – … Industrial – … – …	– Quantity (in normal operation) – Weight, tare/tons – Weight, avg. / tons – Weight, max/tons – (not for railcars) Engine type (elect./diesel) – (not for railcars) Engine power / kW – Max speed/mph – Wheel size/inch – Track, rail profile / … – # Axles/unit – # Brakes/axle – Tread/Disc – Wheel/Disc material – Actuation Air/Hyd. – Brake size / (disc diam x pad area), (wheel diam x block length) – Friction type / (composite/sintered) – Non-µ braking methods

The Markey Survey comprises three main subtasks:

- Task 2b.1. – Structuring the Market Survey: with data entries (listing of parameters to survey), data type (numeric, text, categorical or listing), format, and overall approach for data processing
- Task 2b.2. – Executing the Market Survey: distributing, collecting, and providing support to stakeholders filling out the survey
- Task 2b.3. – Analyzing the Market Survey: compiling, curating, summarizing, and analyzing results and findings. This task includes appropriately adjusting the results to reflect the locomotive tier phase-in and phase-out projection as part of the Zero Emissions initiatives with the 2050 horizon, as illustrated in Figure 4. The project team will follow CARB's official locomotive inventory that reflects the In-Use Locomotive Regulation. By using the CARB inventory, the project can also ensure that the taxonomy of locomotives, railcars, and other meaningful parameters are aligned.

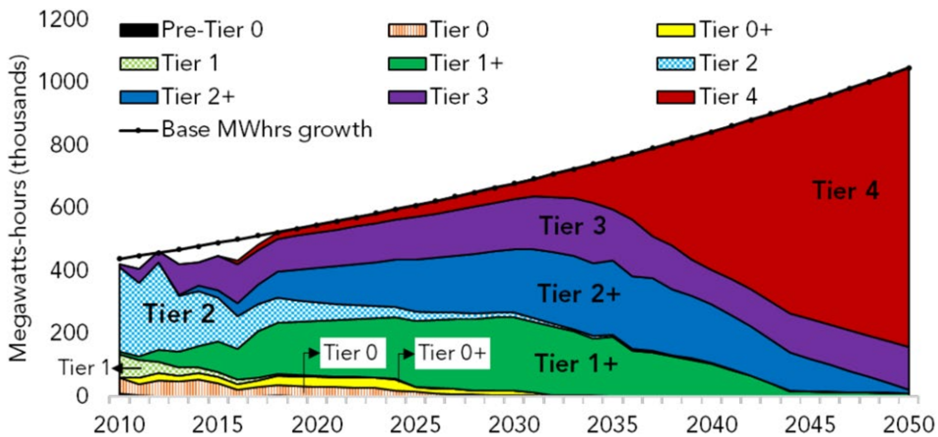


Figure 4 Business-As-Usual (BAU) Scenario Tier Distribution

Deliverable:

A report describing brake, wheel, rail, and associated technologies used for different types of trains in California. The Contractor will submit this in a mutually agreed-upon format.

Task 2b Characterize California Train Operations

Depending upon the rolling stock technology and controls, wheel/rail-wear PM will be generated during train acceleration, hill ascent/descent, deceleration, and cruising due to the friction between wheels and rails, and brake-wear PM will be generated during deceleration to slow and stop trains due to the friction between brakes and wheels. Those PM emissions will vary depending on train operation characteristics by commodity type and weights, locomotive configuration and engine power, railcar types, number of railcars and weight, rail track configurations and geometry, and non-frictional control technology. The UCR team starts this task by collecting and summarizing the existing California rail operation data and estimating daily, monthly, and annual activity by train types.

Several data sources would be required to provide sufficient data granularity for calculations to support activity profile development for California's rail system. This effort could include a different look at available CARB data, such as operations data collected to support the development and evaluation of CARB's In-Use Locomotive Regulation and other state or local initiatives. State—and locally-derived data will likely contain this effort's most accurate and refined data.

If and where local data are unavailable or insufficient for this project, alternative data sources may be obtained, including publicly accessible and proprietary/paid data. The Federal Railroad Administration collects annual Class I MGT data at the rail network segment level for Class I rail activity. While some of this information is available publicly, consent is required for FRA to share CBI for this effort. The Association of American Railroads[1] also collects and provides statistics and operations information on Class I rail at the national and state levels, as shown in Figure 5.

[1] https://www.aar.org/data-center/rail-traffic-data/

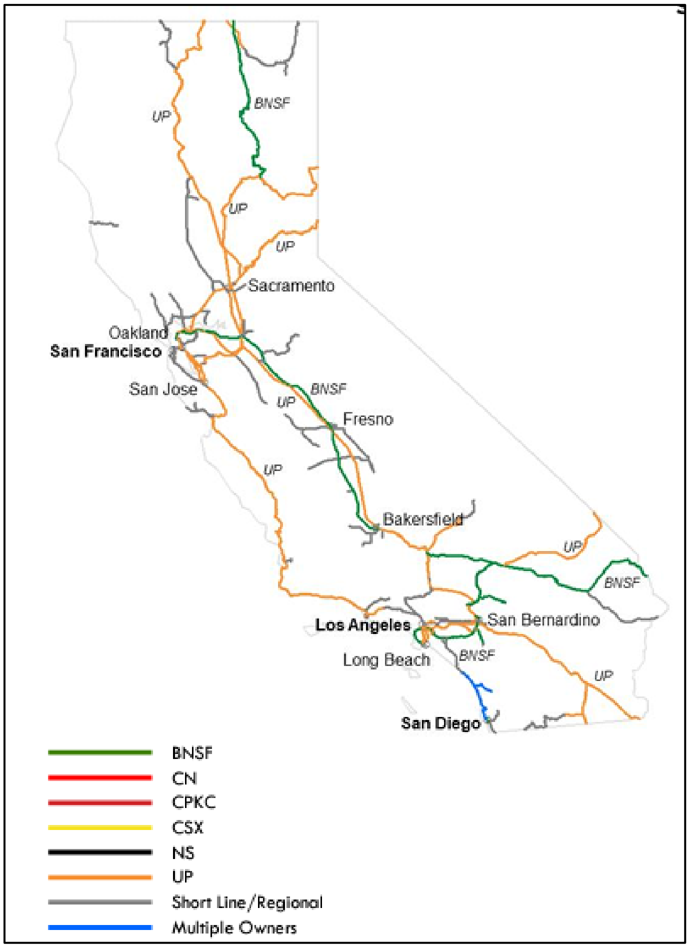


Figure 5 California Freight Railroad Network (Source: AAR)

Short-line rail data can typically be obtained from trade associations such as the American Short Line and Regional Rail Association (ASLRA)[1], California Short Line Railroad Association (CSLRA)[2], or railroad communications. For passenger rail, Amtrak[3] data is available directly and via the Rail Passengers Association, and the National Transportation Database includes fuel usage for commuters and other passenger lines in California. Yard operations are historically underrepresented in inventory efforts, but all potential data sources will be investigated. These could include fuel usage from R-1 reports, CARB's 2022 Class I Switcher Rail Yard Emission Inventory, and switch activity from the U.S. EPA's latest National Emissions Inventory.[4]

Commuter rail, both electrified and fossil fuel propelled, in California's urban (e.g., MetroLink, Caltrain, Coaster) and regional/inter-state areas (e.g., Armtrak) is expected to contribute significantly to BWWW emissions exposure due to the frequency of stops coupled with travel in densely populated areas (see figure below) and near-railway communities. Data on locomotive and passenger car fleets published by the individual rail authorities will serve as the starting point for characterizing these trains, with follow-up as needed to fill in details required for this task. The project considers the main routes in California as shown in Figure 6 to derive metrics related to operations and to select the actual routes in which to measure.

---

[1] https://www.aslrra.org/ASLRRA/document-server/?cfp=ASLRRA/assets/File/public/about/Facts_and_Figures_eVersion.pdf

[2] https://ww2.arb.ca.gov/sites/default/files/2022-07/2022%20Class%20I%20Switcher%20Emission%20Inventory%20technical%20document%2007112022.pdf

[3] https://www.amtrak.com/content/dam/projects/dotcom/english/public/documents/corporate/statefactsheets/CALIFORNIA22.pdf

[4] https://www.epa.gov/air-emissions-inventories/national-emissions-inventory-nei

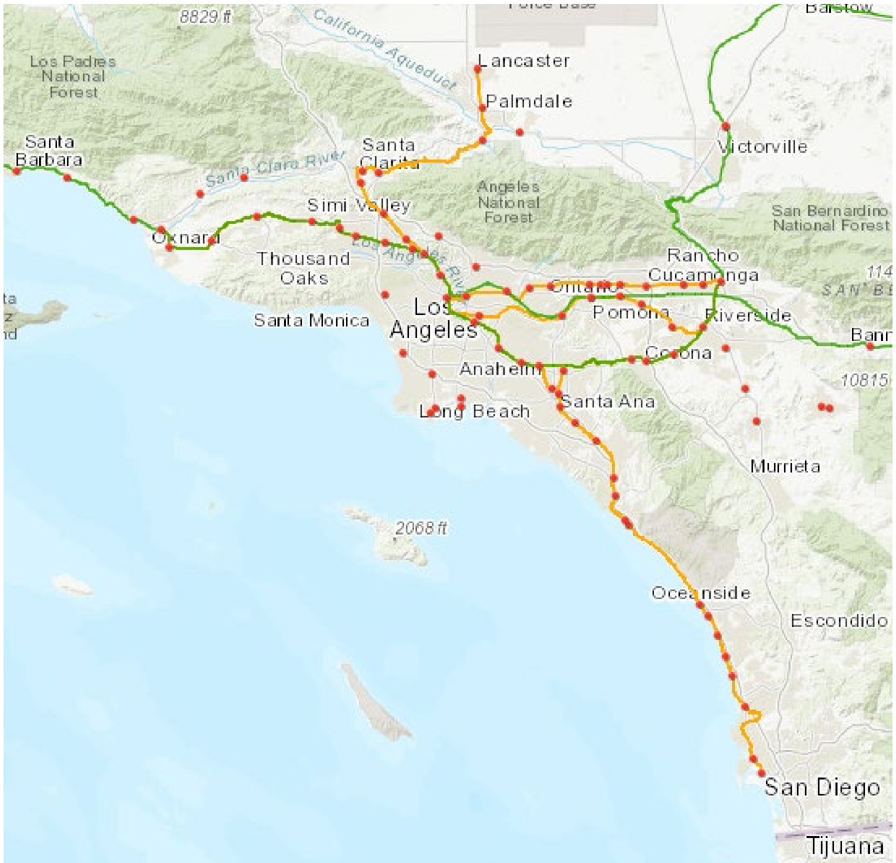


Figure 6 Passenger & Commuter Rail Network in Southern California (Source: Caltrans)

Data collection efforts will focus on the most refined temporal and spatial data available and include various units of measure to provide maximum flexibility in emissions calculations. Train counts, car counts, freight weight, and the number of trips and stops will be researched. Where data elements are unavailable, a literature review would inform proxy development to fill data gaps.

The UCR team will then identify train operation factors influencing the BWWW PM emissions and discuss them with the Workgroup before conducting the next task. To ensure the alignment with environmental justice criteria, the UCR team will include some aspects related to the demographics and other relevant socio-economic factors.

The UCR team will structure an extension to the Markey Survey from Task 2b to document the parameters for each of the main types of locomotives, railcars, and segmented routes. The primary sources of information would be databases and logs from the network operator, sample ECU data made available to the project, manuals of operation, safety requirements, and regulations for at least the following factors:

- train operation hours per period (including seasonality),
- complete stops (e.g., at stations or rail yards) per period
- partial decelerations (e.g., at the railroad crossing, at specific parts of the route, approaching curves) per period and typical changes in speed
- average speed during cruising, curves, uphill, downhill, and rail yard operation
- travel miles per period
- average and median values per period (including seasonality) for the number of trips, number of railcars hauled per trip, number of locomotives in the train, average cargo weight per trip, and operation frequencies by routes in California.

To complete the characterization of the California rail operations, the UCR team will combine the results from the operational survey with socioeconomic factors (e.g., ethnicity, income, education, age distribution, population density at a certain distance from the railroad tracks or rail yard) to weigh the relative importance of a particular combination of locomotives, railcars, traffic, Rail x Miles x tons metrics, and energy dissipation, to target specific routes and regions during Tasks 3 and 5. Data readily available [X1, X5] can support this assessment. The UCR team will dedicate a particular section during the execution of this task to estimate the interaction with vulnerable rail users (rail passengers and rail yard staff) to influence the mix of locations and test cycles, combining Train routes with demographics as shown in Figure 7.

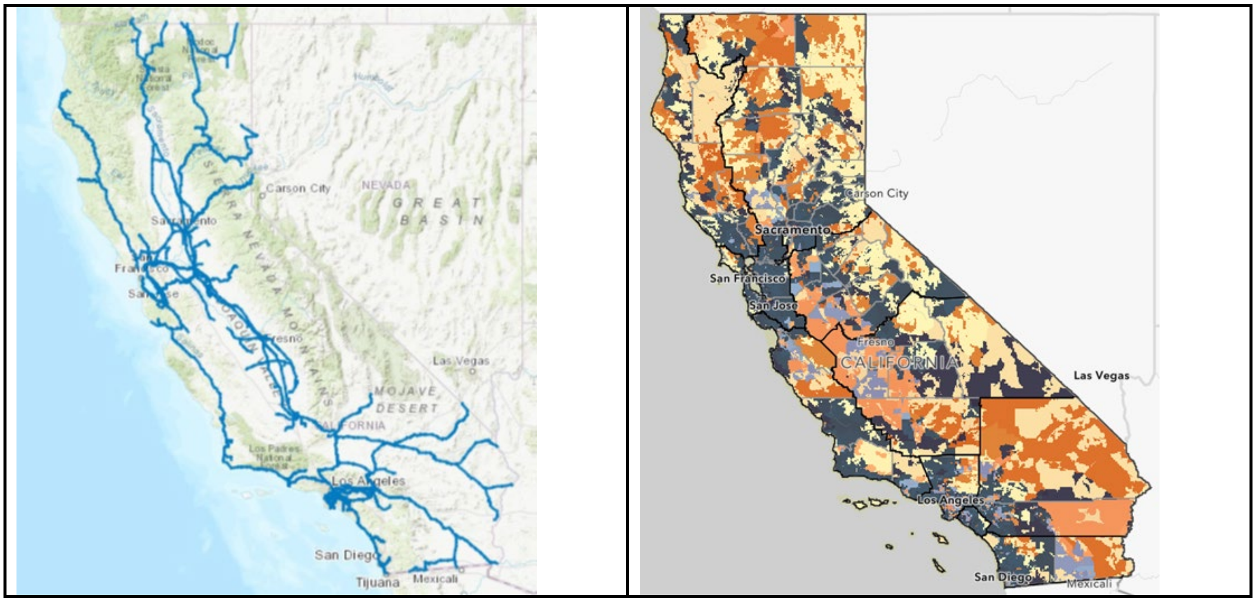


Figure 7 Left – California rail network [X1]. Right – California 2020 Census, mail contact strategies, and Hard-to-Count (CA-HTC) Index as a surrogate for population vulnerability [X5]

Deliverable:

A report describing operations for representative types of trains in California. The Contractor will submit this in a mutually agreed-upon format.

Task 3: Collect Train Activity Data and Develop California BWWW Testing Cycles by Train Type

Various factors will affect the BWWW PM emissions, such as train speed, train weight, train vocation, rail geometry, rail and wheel materials, brake friction materials, braking systems, and environmental factors (e.g., season, temperature, humidity, and precipitation). The UCR team will develop a plan for collecting activity data from California fleet representative trains or existing in-use activity data that can be used to characterize activity patterns and build BWWW testing cycles. This task will require significant input from Task 2 to determine the specific trains, routes, and configurations that are more relevant to this task and subsequent measurements of brake and wheel-rail emissions (both on-rail and in-laboratory). This task will leverage prior testing campaigns using in-vehicle data acquisition systems for Road Load Data Acquisition (RLDA) conducted by LINK for tractor-trailers with over 200 sensors for vehicle dynamics and chassis stresses. Also, the project can implement some of the elements used during driving cycle measurements in city buses in Valladolid (Spain) and Ancona (Italy) within the AeroSolfd to assess passive filtration systems to reduce PM in city dwellings.

Deliverable:

Upon completion of Task 3, the Contractor will submit Interim Report #1, which includes all the results and information collected from Tasks 1-3.

Task 3a: Collect Train Activity Data

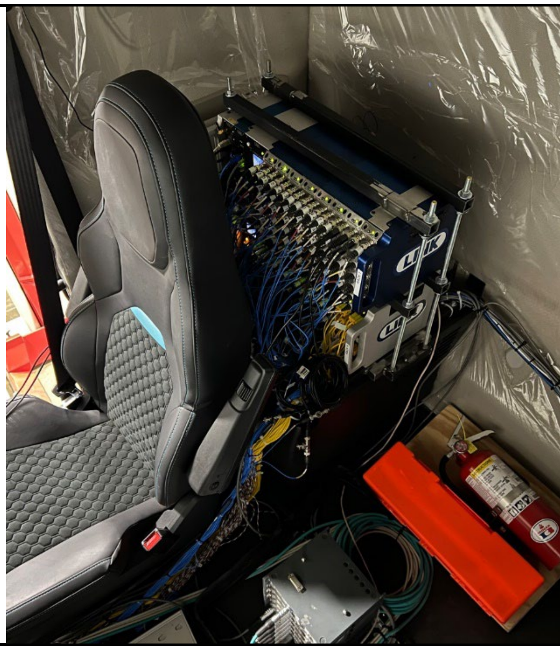
The project team will develop an activity data collection plan for braking activity and operation data. In consultation with the Workgroup, the project team will identify at least one train from each train type of line haul, short-line, and passenger trains for collecting its activity data. This train activity data collection establishes relationships between the operation, including engine status, route geography, train speed, braking activity, and wheel-rail contact forces (including lateral accelerations). The latter will be helpful during the development of test cycles for in-rail and in-laboratory wheel-rail wear and emissions measurements.

The project team will work closely with the rail operators, railyard, and scheduling teams to implement a three-pronged strategy. The project will include a similar plan with transit authorities for passenger trains (Amtrak and METROLINK).

a) The starting source of train activity data will be the in-use CARB official locomotive inventory that reflects the In-Use Locomotive Regulation.
b) Use rail operators' logs and reports to document the trains selected related to train weight in real-world operations using freight and passenger logs, estimated records, or electronic weight sensors. The UCR team will verify that the train and commodity weights are recorded correctly by conducting random visual verifications on the train. To qualify the data and findings, the UCR team will consider the feasibility of obtaining statistical and historical reports on traffic (e.g., trains, railcars, cargo).
c) Access data files directly from rail event recorders (CFR 49 Ch II 229.5), designed to resist tampering, that monitor and record data on train speed, the direction of motion, time, distance, throttle position, brake applications and operations (including train brake, independent brake, and, if so equipped, dynamic brake applications and operations) and, where the locomotive is so equipped, cab signal aspect(s), over the most recent 48 hours of operation of the electrical system of the locomotive on which it is installed[1]. This approach will maximize the use of the native data collection system fully integrated with the train, reduce the effort and complexity of measuring key outputs related to the train operation, and simplify the interaction with the rail operator and train crews. Even though the task may not yield an extensive array of outputs, with this Minimum Viable Process (MVP) approach, the project can extend to multiple trains in multiple routes with minimal effort to collect meaningful data for braking and wheel-rail operating conditions. When available directly from the event recorder, the project will target collecting the desired ECU parameters, including but not limited to engine model and make, engine rpm, fuel rate, actual engine percentage torque, friction torque, engine reference torque, engine load, exhaust temperature, speed, and other operator control positions.
d) For those locomotives or railcars without the possibility of a direct data interface (via an in-locomotive event recorder) or for channels not directly connected to the same event recording, the UCR team can install dedicated data acquisition systems (e.g., LINK V-Max 4000) to collect brake pressures, brake temperatures, and train GPS position. Unless the event recorder on the locomotive provides all three measurements, the direct approach enables three critical dimensions of the on-rail measurements:
    i. Direct brake pressure at the tread or disc brake, brake line pressure (feeding multiple railcars and transmitting the brake signal) to later determine control levels and control strategies (e.g., regenerative braking or exponential pressure buildup times) during in-laboratory testing.
    ii. brake and wheel temperatures using non-invasive sensors (e.g., sliding thermocouples or infrared sensors) to develop a reasonable and practical brake cooling strategy and to validate the amount of energy dissipated during the in-laboratory testing for brakes and wheel (since temperature is a principal component in most wear models).
    iii. By default, the V-Max 4000 system includes Global Positioning System (GPS) signals for calculating instantaneous train speed, lateral and longitudinal accelerations, and position. The UCR team can later validate the curve radius and track incline with rail track specifications and railroad track maps by processing

[1] CRF 49 Ch II 229.5 requires data collection for Emergency brake applications initiated by the engineer or by an onboard computer; A loss of communications from the EOT (End of Train) device; Messages related to the ECP (electronic controlled pneumatic) braking system; EOT messages relating to ''ready status,'' an emergency brake command, and an emergency brake application, valve failure indication, end-of-train brake pipe pressure, the ''in motion'' signal, the marker light status, and low battery status; The position of the switches for headlights and for the auxiliary lights on the lead locomotive; Activation of the horn control; The locomotive number; The automatic brake valve cut in; The locomotive position (lead or trail); Tractive effort; The activation of the cruise control; Safety-critical train control display elements with which the engineer is required to comply.

the GPS signals. These assessments help to determine lateral forces (meaningful to the wheel-rail contact Hertzian stresses, wear, and consequent emissions) and longitudinal forces due to gravity in addition to frictional or accelerating/decelerating forces (meaningful for both brakes and wheel-rail), respectively. Figure 8 illustrates a unique setup to measure close to 300 channels for microstrain, brake activity, and vehicle dynamics for a full electric tractor-trailer, using an array of LINK V-Max 4000 units. In this example, the data was analyzed with a software process adhering to the methodology utilized by the European Commission to derive the Worldwide Harmonised Light Vehicles Test Procedure (WLTP) brake cycle.



Installation with ~300 channels on a battery electric commercial vehicle

Intermittent Power Backup	Internal Super Capacitors, 3 seconds
Module types	Analog input, Differential analog input, Analog output, Temperature, NVH, Pulse, CAN, Digital input/output, Power module, Power distribution module, POE Ethernet, Video, CPU
Operating Temperature Range	-30 °C to +55 °C (-22 °F to +131 °F)
Operating Relative Humidity	5% to 95% Non-Condensing
Protection	IP 31
Approvals	CE Mark
Input Voltage	9 Vdc to 27 Vdc
Sample Rate	up to 51.2 kHz (depending on channel type)
Total # of channels	up to 1000

Main specifications

Figure 8 LINK V-Max 4000 and signal conditioning modules

In all cases, the project team will:

1. Collect data for at least four weeks on each train.
2. Collect train operation data (aligned with Task 5), including but not limited to train weight (with the locomotive(s) and car weights separately), locomotive type (line-haul/switcher), number of locomotives and railcars per train, the mix of railcars, brake and wheel material and type, train weight, axle load, vocation, railcar type, cargo type and weight, engine make, size, model and model year, actual and typical hours of use, commodity weight and types, daily operation miles and frequencies, rail geometry, rail and wheel materials, brake friction materials, and braking activities (to correlate later to the inventory developed during Task 2).
3. Make provisions for sampling different types of railcars, prioritizing (in close coordination with the operator) covered hoppers, tanks, intermodal, and gondolas. See Figure 9 for national distribution [X6]

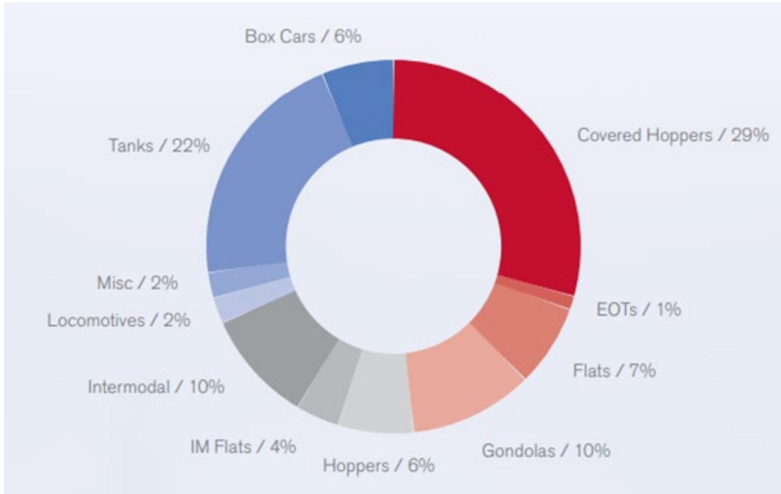


Figure 9 Railinc's Umler equipment index by segment through the fourth quarter of 2022[10]

4. Exercise due diligence to document (e.g., train logs, video, counting) changes in the train loading and length (e.g., passenger load, cargo cars loading/unloading, railcar coupling/decoupling, number of locomotives per train), which can influence the wear rates and the emission factors for both friction couples (brakes and wheel-rail).
5. Exercise due diligence to record any abnormalities supporting subsequent analysis for data stragglers or outliers.
6. Exercise due diligence to document general geographic or location-based features of the route that can be meaningful for future analysis (e.g., urban areas, tunnels, railroad crossings) using observational data or map-based documentation
7. Conduct a limited-scope survey of brake wear and rail track profiles relying primarily on data readily available from the rail operator.
   Special considerations

   The project team will need to consider the following items during the planning and execution of this task, which involves fieldwork:

1. Operator safety requirements and California workplace regulations can directly limit or determine the amount of work or interventions the project staff makes in the train braking systems.
2. The availability of a power supply to energize the data acquisition systems and sensors, especially regarding using multiple systems on the same train to collect activity from the locomotive(s) and several railcars.
3. Scheduling and logistics with the rail operator to minimize disruptions, ensure proper and safe installation of the data acquisition systems, duration of the measurement campaign when operating with batteries, and coordinate the retrieval of external memory devices and the removal of data acquisition systems for trains not returning to the start point or traveling out of the state.

Deliverable:

Operating activity data was collected for California representative train types.

Task 3b Characterize Train Activity Patterns

The project team, especially UCR and Link, will develop a quality assurance/quality control (QA/QC) plan for analyzing the train and engine information and data collected from Task 2 and Task 3a. The project team will characterize train activity patterns for each train type based on the data collected from earlier Tasks. Activity patterns shall represent operation hours, miles, speed, longitudinal accelerations/decelerations, lateral accelerations, braking events level, durations, and stops per trip for each train type. The UCR team will collect environmental factors from direct measurements or nearby weather stations. Environmental factors complement the data to characterize typical train operation conditions in California, e.g., season, temperature, humidity, and wind speed (including prevailing direction), which all can play a role in airborne PM emissions and their fate.

1. Work with data readily available from nearby weather stations to obtain measurements for ambient temperature, humidity, air pressure, and airspeed (level, variation, and prevalent direction) near the railroad tracks or the rail yards. These measurements prioritize route segments or railroad tracks near high-exposure or high-emitting areas (e.g., service yards, train depots, large passenger stations, tunnels, high-speed segments for wheel-rail wear, and populated areas).

2. Work with the Assess the feasibility of conducting or accessing data from near-railroad stationary measurements (from other air quality monitoring programs) for PM, metals, and other meaningful pollutants during four measurement campaigns (about one week each) to include variation due to seasonality (weather conditions and possibly rail traffic).

3. Conduct Principal Component Analysis (PCA) and multi-regression to determine the minimum variables required to plan future work from Tasks 3b forward (test plan, emission factors, emissions simulations, and health risks).

As part of this work, the UCR team will implement a quality assurance/quality control (QA/QC) plan using the measurements and criteria outlined in Table 2:

Table 2 Planned QA Assessment Procedures

Measurement Parameter	Instrumentation	Daily Assessment Method
Train speed and accelerations (longitudinal and lateral)	V-MAX 4000 GPS or train event recorder	Verify zero levels with the train standing still
All signals in the event recorder (when available)	In-train event recorder	Per event recorder protocol and standard verification procedure
Brake temperature	V-MAX 4000 temperature channel	Zero and span voltage for analog signals Reading of ambient temperature before the start of train activity after cooldown
Brake pressure	V-MAX 4000 brake pressure channel or train event recorder	Zero and span voltage for analog signals Zero pressure with the train stationary and brakes disengaged
PM sampling system	TBD	Airflow level v nominal Cyclone and sampling train assembled and secure No fault signals or error messages
PN measurement system	Dekati high-resolution ELPI+	Airflow level v nominal No fault signals or error messages (weekly) PN concentration below 0.5 #/cm with putting a HEPA 13 filter and returning to a higher level with the filter removed
Toxic metal aerosol analyzer	TARTA	Blank experiments by sampling filtered air

		> ten sparks to clean off the deposited particles after each experiment
Logs and operational information	Records	All records from previous field measurements are complete All initial records for the upcoming field measurements are complete

Task 3c Decide BWWW Testing Approach and Develop California BWWW Test Cycles for each Train Type

The UCR team will propose a BWWW testing approach to the Workgroup based on the knowledge gained from the previous tasks. In consultation with the Workgroup, the project team will identify a BWWW testing approach that can be employed for linehaul, short-line, and passenger trains.

Based on the data and activity patterns characterized by Tasks 2 and 3, the UCR team will develop representative BWWW testing cycles for typical train types in California to implement the plan above. Each BWWW testing cycle shall reflect the real-world operation characteristics of the corresponding train type, including travel duration, acceleration, deceleration profiles, stops, braking events and durations, brake pad and wheel temperature profiles, and environmental factors. Multiple test cycles can be developed for each train type if they are designed to represent portions of real-world activity patterns characterized by average cycle speed, engine horsepower, or something else.

The UCR team proposes two primary approaches to developing the test cycle. Both methods use the micro-trip method used by Steven et al. for the development of the WLTC cycle and the WLTP-Brake cycle within the Euro 7 framework and implemented in the Global Technical Regulation (GTR) 24 document. The main criteria for assessing the representativeness of the cycle selected is the alignment of the speed and the acceleration of the Cumulative Density Functions (CDF). A third criterion for brakes includes comparing the temperature regimes, which is also crucial in determining the BWWW emissions (tribomechanics at the friction layer). For wheel-rail emissions, the project team (UCR and Link) working closely with consultants and experts on wheel-rail wear and fatigue will consider the correspondence of Hertzian contact stresses (which include longitudinal and lateral forces on the wheel).

For on-rail testing, select a predefined (regular operation) route and segment representing the speed and acceleration CDFs for the train's vocation without altering the path or the train's schedule.

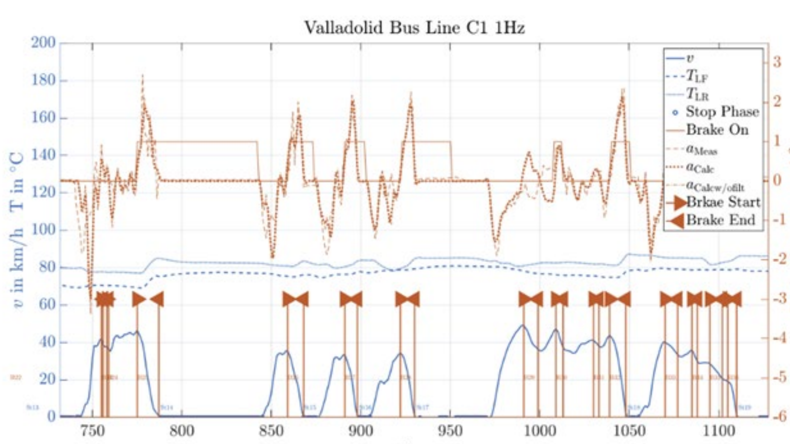
Design an engineered cycle for each primary train type for in-laboratory testing, meeting the speed and acceleration CDFs by verifying the brake temperatures or the wheel Hertzian contact stresses. Figure 10 shows the AeroSolfd project sample GPS routes with elevation data, time-resolved speed profiles, and the CDF comparisons between the candidate route and the collective vehicle activity for an urban city bus in Valladolid.

The UCR team will propose to the Workgroup two approaches to the test cycles:

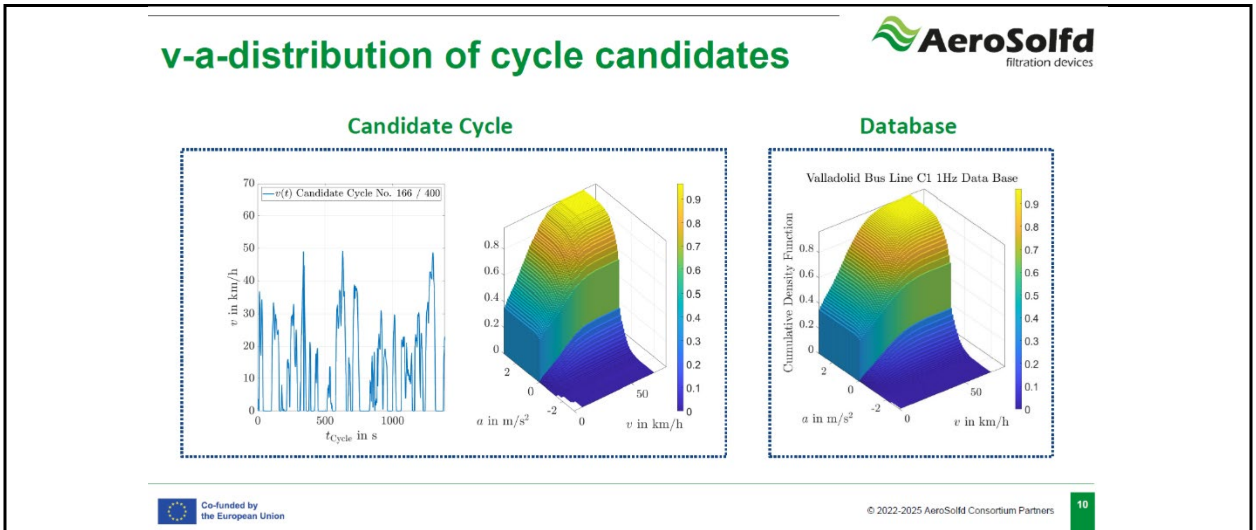
- Combining brake and wheel cycles into one for on-rail testing
- Separate test cycles for brakes and wheels for in-laboratory testing

a – Original GPS signal for regular route

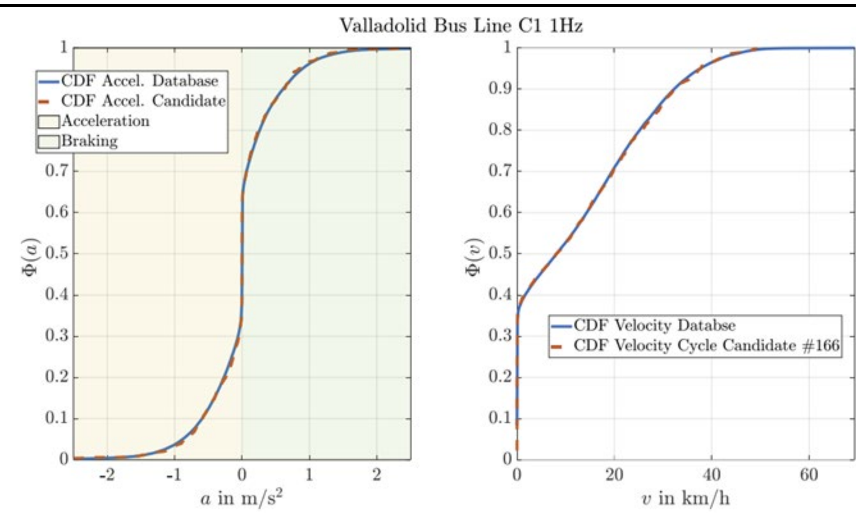
b – minimally intrusive setup for data acquisition during regular bus operation



c – Time-resolved speed, acceleration, and brake-on signal



d – Speed and acceleration distribution for the candidate cycle for dynamometer tests



e – Cumulative Density Functions (CDF) for accelerations and speed

Figure 10 Setup and outcomes of driving cycle development for city buses

(source: HORIZON 2020 AeroSolfd)

Deliverable:

BWWW testing cycles for each California representative train type. The Contractor will submit this in a format that is mutually agreed upon.

Task 4 Develop a BWWW PM Emission Sampling System and a Test Plan

The BWWW PM Emission Sampling System Development project aims to create a robust system capable of separately measuring brake-wear (BW) and wheel-wear (WW) emissions in train systems. Task 4a focuses on developing this sampling system, considering factors such as separation of emissions, collection efficiency, operational impact, and versatility across train types. The proposed system utilizes an onboard sampling tunnel with dedicated brake-wear and wheel-wear emissions sampling components. Real-time and gravimetric off-line sampling methods will be employed for comprehensive PM measurements and PM chemical characterization, with considerations for power requirements and background PM correction.

As outlined in Task 4b, pilot tests will validate the proposed sampling system for collecting brake-wear and wheel-wear emissions separately, with results informing adjustments based on Workgroup feedback. Task 4c emphasizes the development of a chemical analysis plan for PM samples, encompassing methods such as XRF for metals analysis, EC/OC analysis, PAH analysis, hexavalent chromium analysis, and reactive oxygen species (ROS) assays. Task 4d involves the development of a comprehensive, complete test plan for California's prevalent train types, incorporating low-speed, uphill-downhill, and high-speed routes for background and brake system testing. The testing regimen will include train types such as Line Haul, Short-line, and Passenger-train.

This project aims to thoroughly understand BWWW PM emissions in train systems, enabling informed decision-making for emission reduction strategies and environmental protection efforts.

Task 4a: Develop a BWWW PM Emission Sampling System

The project team, especially UCR and Link, will develop an emission sampling system according to the testing approach identified under Task 3c to measure train brake-wear PM and wheel-wear PM emissions separately. The project team will provide detailed information to the Workgroup about the sampling system design, including PM mass and PN sampling device choices, instrumentation setups, and data collection. This sampling system will measure real-time BW and WW PM2.5 and PM10 mass, real-time BW and WW PN by size, real-time BW and WW PM2.5 and PM10 trace metals, BW and WW PM2.5 and PM10 gravimetric filter samples, and real-time gaseous emissions. The project team will report PM and PN sample collection efficiencies at various train operating conditions for each test. Determination of collection efficiency will be evaluated based on the CO_2 trace gas method by injecting CO_2 of a predefined concentration in the front of the the wheel/brake system. Due to potential limitations and availability of locomotives and railcars, the collection efficiency study will be performed under laboratory conditions only. The sampling system will be suitable or easily adjustable for selected test subjects. The sampling system will be able to measure both locomotive and railcar BWWW PM emissions.

Before the development of the BWWW PM Emission Sampling System, a detailed analysis of the brake systems, as described in Task 2, will be carried out. Brake system variations under different train types will be essential for designing and evaluating the sampling system. It is expected, based on train type, there are five main brake types:

1. Air Brakes: This is the most common type of brake system used in trains. It operates using compressed air to control the braking force. When the engineer applies the brake, air pressure is released from the brake pipe, causing the brake shoes to press against the wheels, slowing down or stopping the train. There are two main types of air brakes:
   a. Automatic Air Brakes: In this system, the brake pressure is automatically adjusted based on the length and weight of the train. It ensures uniform braking across all cars.
   b. Electropneumatic Brakes: These are a type of air brake where the application of brakes is controlled electronically rather than pneumatically.
2. Dynamic Brakes: Dynamic brakes slow a train by converting kinetic energy into electrical energy. The system uses the traction motors as generators, generating electricity as the train slows down. This electrical energy is dissipated as heat through resistors or grids mounted on the locomotive's roof.
3. Regenerative Brakes: Like dynamic brakes, regenerative brakes convert kinetic energy into electrical energy. However, they feed it back into the power grid instead of dissipating it as heat. This can improve energy efficiency and reduce wear on braking components.
4. Electro-Dynamic Brakes: This braking system generates braking force by interacting between the locomotive's traction motors and the rails. By controlling the electrical current in the motors, the system can slow down or stop the train.
5. Friction Brakes: Friction brakes, like those used in automobiles, are sometimes used in conjunction with other braking systems or as emergency brakes. They typically involve brake shoes pressing against the wheels to create friction and slow down the train.

Each brake system type has advantages and limitations, and the system choice depends on factors such as the type of train, speed requirements, and operational considerations. Figure 11 illustrates a disc brake system which will require a sampling system to characterize brake emissions as close as feasible to the source as possible (after considering constraints related to logistics for installation, safety requirements from the rail operator, and the physical embodiment of the truck).

Figure 11 An example of an air brake and friction brake system that is commonly used.

The most common type of braking in cargo trains is the air brake system, particularly the automatic one. This system is widely used due to its reliability, effectiveness, and ability to provide uniform braking force across all cars in the train. Automatic air brakes are well-suited for freight trains because they can handle varying train lengths and weights, providing consistent braking performance regardless of the cargo being transported.

Additionally, dynamic brakes are frequently used in cargo trains, especially when descending steep grades or additional braking force is needed to supplement the air brakes. Dynamic brakes help control the train's speed by converting kinetic energy into electrical energy, reducing wear on the mechanical braking components, and improving overall braking efficiency.

While other braking systems, such as regenerative and electro-dynamic brakes, are gaining attention for their energy-saving capabilities, they are less common in cargo trains compared to air and dynamic brakes. These systems are often used in passenger trains or mixed-traffic applications where energy efficiency is a significant concern.

Additionally, friction braking is used for non-normal conditions such as:

1. Emergency Braking: Friction brakes are often designed as emergency brakes. In situations where the train suddenly needs to stop, such as an unexpected obstacle on the tracks or a malfunction in the primary braking system, friction brakes can bring the train to a halt as quickly as possible.
2. Parking Brakes: Friction brakes may be used as parking brakes when the train is stationary. This helps to prevent unintended movement while the train is parked, especially on inclines or uneven terrain.
3. Supplementary Braking: In some cases, friction brakes may be used with other braking systems to provide additional force, particularly during heavy braking or in challenging conditions like slippery rails.

The previous parameters will be included in the design and development of the BWWW PM Emission Sampling System under Task 4a. In particular, the UCR team design considerations will be centered around developing an efficient and effective sampling system that measures brake- and wheel-wear emissions separately while concurrently sampling for background/ambient PM, including ambient dust. Several vital objectives guide the design process:

1. The project team will build two sampling systems that will be used concurrently on each train type and for both the locomotive and railcars. The first sampling system will be dedicated to measuring emissions, either rail-wear or brake-wear, and the second system will measure background emissions.
2. Separation of BW and WW Emissions: The sampling system must differentiate between brake and wheel-wear emissions. This involves designing independent sampling inlets for each emission type to minimize contamination between the two. To avoid potential contamination from previous BW or WW tests, the on-rail testing protocol will include a purging sequence in between brake and wheel measurement cycles with a short background check on the BW and WW sampling tunnel. Tentatively, the sampling time will be split evenly between the two. At the time of planning the actual measurement campaigns, the project team will coordinate the most useful split and schedule (e.g., schedule of train load with railcars counts and railcar cargo, actual route split for curvy vs. straight, flat vs. incline, long vs. short intervals) between stations.
3. Maximization of Collection Efficiency: The system should have high collection efficiency for emitted particles and minimize particle losses throughout the sample train. Computational simulations and laboratory testing will inform decisions on sampling line material, inlet positioning, and transport efficiency.
4. Minimization of Operational Impact: The measurement system should not impact the vehicle's operational characteristics. This includes considerations for airflow rates, cooling of brake systems, and integration with vehicle components.
5. Versatility Across Train Types: The sampling system should be adaptable to various train types with minimal alterations.
6. Measurement Methodologies: The system will utilize real-time and gravimetric sampling methods for PM measurement and concurrently measure chemical speciation. Instruments will be selected based on their ability to provide accurate and comprehensive data on PM mass, particle number, particle size distributions, and chemical composition.

Based on these considerations, the UCR team plans to implement an onboard sampling tunnel using a constant volume sampling (CVS) concept. Sample flow from brake and wheel-wear sampling systems will be directed to the tunnel in a non-concurrent manner, where flow stabilization occurs before further sampling by individual lines to instruments or filter holders. Similarly, the team will develop a system based on an inlet probe mounted behind the wheel/rail interface for wheel-wear sampling. Considerations will be made for mounting, probe design, and flow rate adjustments to maintain isokinetic sampling.

The CVS tunnel will be made from smooth-walled stainless-steel tubing with multiple ports directing flow to each instrument. The project team will determine the appropriate dimensions of the tunnel based on the total instrument sample flows and expected loading. A pump will be mounted downstream of all sample ports to draw flow through the system at a constant volumetric flow rate and exhaust it outside the test train. The team expects the same sampling tunnel to be used for both BW and WW applications, as well as all test conditions (on-rail and laboratory) and train types. However, multiple funnel sample probes may need to be fabricated to accommodate different brake/wheel and train types.

The physical characterization of BW and WW PM emission will include gravimetric mass, particle number, and particle size distributions. The online analysis of PM-bound metals will explain the nature of the particles that will be further characterized during the offline chemical PM speciation. TPN (total particle number, i.e., volatile and non-volatile particles) measurement configuration will be utilized to investigate particle number, sizing, and particle mass, as shown in the conceptual schematic presented in Figure 12. Figure 13 illustrates the concept for the sampling train. Due to its design, the sampling system will focus on characterizing particle size distribution and time-resolved particulate mass, not so much on quantifying emissions factors due to the sampling and transport losses associated with open sampling systems.

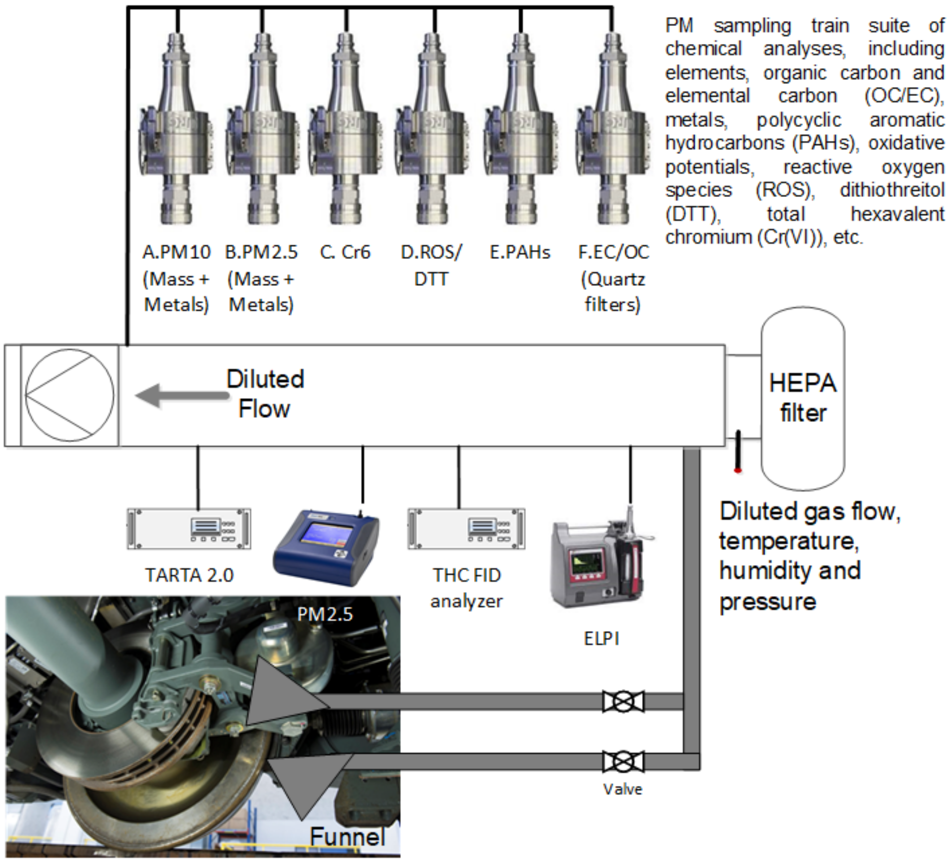


Figure 12 Potential measurement schematic for BWWW emissions showing PM2.5, PM10, real-time PM2.5, real-time PN, size distributions, near-real-time metals, and THC emissions.

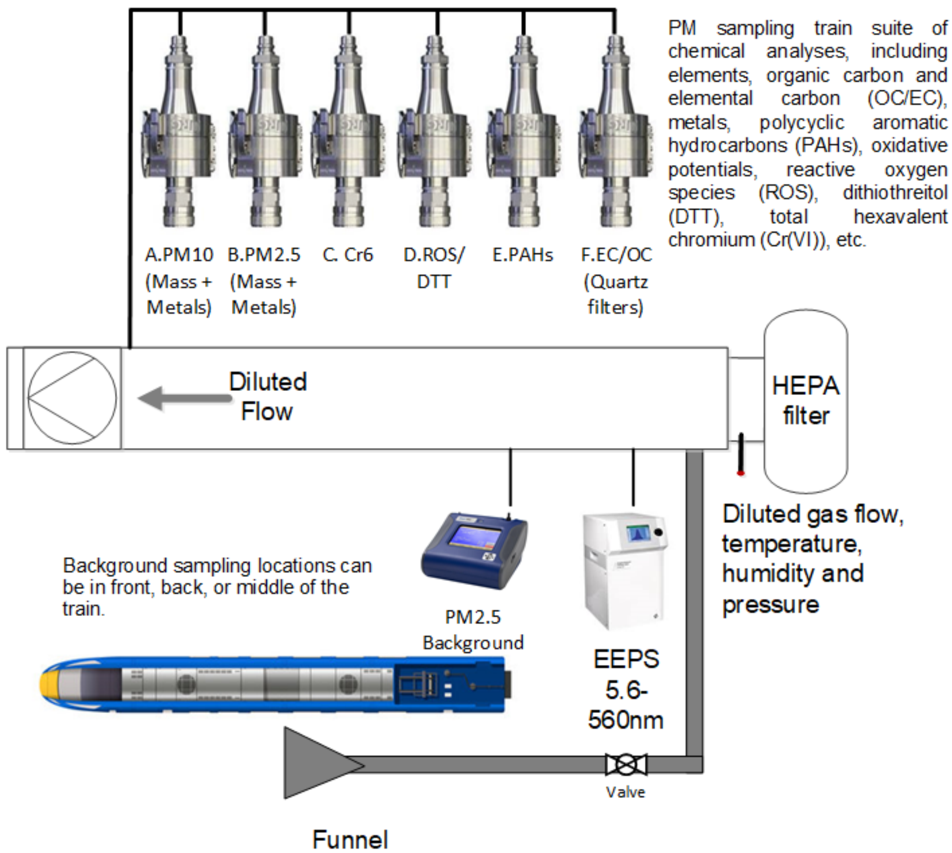


Figure 13 shows a Potential measurement schematic for BWWW emissions, which is dedicated to background measurements, showing real-time PM2.5, real-time PN, and size distributions

Sample probes for each PM measurement instrument will be sized to draw flow from the tunnel with the goal of being ±10% isokinetic with the flow through the tunnel. It is likely that the tunnel can be sized such that no dilution is necessary (i.e., a full-flow tunnel), but dilution may be considered if, during the design process, the project team identifies the potential for exceedance of various instrument ranges.

A sample will be drawn from the funnel probe to the sampling tunnel using conductive silicone tubing and/or stainless-steel piping. The tubing will be routed to minimize bend radii and package lines and equipment as tightly as possible to the vehicle body. The sampling line will be constructed so that no dust samples are accumulated inside to skew the measurements.

The UCR team will also develop a method to measure and account for background PM. For this project, one sampling system will be dedicated to collecting either BW or WW emissions, and the other sampling system will concurrently collect background emissions. The project team expects to collect background PM measurements of PM2.5 and PM10 mass, particle number and sizing, gaseous emissions, and filter samples for chemical speciation of metals, PAHs, hexavalent chromium, and ROS. For each train type/route combination, the project team will dedicate several testing days to the simultaneous collection of BW and background emissions and several testing days for the simultaneous collection of WW and background emissions.

Real-time instruments will measure the number, concentration, and size distribution of particles directly emitted by BW and WW. Due to instrument availability, it is expected that each sampling system will likely have different real-time particle instruments. Total particle number and particle size distributions will be measured with a Dekati high-resolution ELPI+ and a TSI Aerodynamic Particle Sizer (APS) 3321. Depending on instrument availability, the UCR team will also employ condensation particle counters (CPCs) at different cutoff sizes to measure particle number emissions. Two TSI DustTrak DRX aerosol monitor 8533 units will be used for each sampling system to measure real-time PM mass. Gaseous total hydrocarbon (THC) emissions will be measured continuously using a heated flame ionization detector (FID) THC analyzer. UCR will use two FID THC analyzers for each sampling system (for either BW or WW emissions and background measurements).

The BWWW sampling system will have provisions for online real-time analysis of PM-bound metal. SDSU and UCR will use a metal monitor (Toxic-metal Aerosol Real Time Analyzer or TARTA) developed by Dr. Hanyang Li and Dr. Wexler, funded by the California Air Resources Board (contract 17RD022)). This unit will be used for near-real-time analysis of PM-bound metals. Unlike traditional metal measurement techniques such as X-ray fluorescence (XRF) and Inductively Coupled Plasma Mass Spectrometry (ICP/MS), which provide integrated concentration over some time by collecting PM on filters or impactor stages, the TARTA instrument offers near-real-time analysis, enabling the identification of metals associated with various train operation and braking activities instantly. A comparison of TARTA's detection limits against those of Xact-625 and the Horiba PX-375 is summarized in Table 3.

Table 3 Comparison of limits of detection (LODs) of TARTA and commercial real-time metal monitors (ng m-3). The presented results are based on a 15-minute sampling time.

Element	TARTA (1σ)	TARTA (2σ)	Commercial instruments	
			Xact (1σ)	PX-375 (2σ)
Aluminum (Al)	28.8	57.6	680	-
Beryllium (Be)	23.2	46.4	-	-
Cadmium (Cd)	29.6	59.6	17.6	43.2
Carbon Monoxide (Co)	13.6	27.6	0.8	-
Chromium (Cr)	13.6	27.6	0.8	16.8
Copper (Cu)	14.4	28.4	0.4	7.2
Iron (Fe)	24	48	1.2	-
Mercury (Hg)	33.6	67.2	0.8	9.6
Manganese (Mg)	28.8	57.6	-	-
Molybdenum (Mn)	22.4	44.8	1.2	7.2
Nickel (Ni)	15.2	30.4	0.8	-
Lead (Pb)	28	55.6	0.8	6
Vanadium (V)	8.8	17.2	0.8	-
Zinc (Zn)	15.2	30.4	0.4	3.6

The SDSU team has demonstrated TARTA's reliability in real-time atmospheric monitoring by co-deploying a TARTA and a Xact625 at the Pico Rivera site in Los Angeles within the Atmospheric Science and Chemistry Measurement Network (ASCENT). As seen in Figure 14, the concentration of Fe measured by both metal analyzers tracks PM2.5 trends closely most of the time over one month of the sampling. What makes the result more outstanding is that TARTA has a more significant correlation with PM2.5 than Xact625 (R^2 = 0.56 (TARTA) and 0.44 (Xact)).

Moreover, TARTA has been used for on-road monitoring of traffic-related metal emissions in the Sacramento Environmental Justice Community Air Monitoring Project, funded by the State of California - Department of Justice and led by Dr. Wayne Linklater from Sacramento State University. Using TARTA on a mobile monitoring platform, the research team conducted over 100 experiments by driving through different areas of Sacramento at various times between March and November 2023. Table 4 presents the elemental concentration results obtained by TARTA during this mobile study, compared to the stationary measurements using TARTA near downtown Sacramento. The greater elemental concentrations measured during the mobile research (e.g., Cu, Fe, Zn, Ni, Mn, and Al) are probably associated with non-exhaust traffic-related emissions, such as brake and tire wear PM.

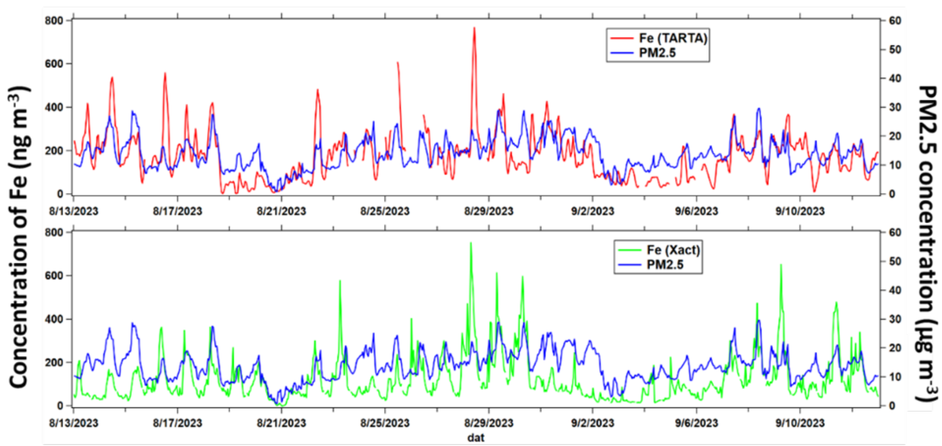


Figure 14 Time series of Fe measured by TARTA and Xact (left) and PM2.5 concentration (right) over the sampling period at the ASCENT site.

Table 4 Comparison of averaged elemental concentrations (ng m-3) from the mobile and stationary studies in Sacramento, CA.

	Cu	Fe	Mg	Zn	Ni	Mn	Al
Mobile study	52.5	255.5	86.2	11.4	8.6	41.9	21.2
Stationary study	10.57	60.45	112.81	9.73	6.58	26.90	12.75

In this project, two upgraded TARTA (TARTA2.0) versions will be deployed at the BWWW sampling system, one for PM2.5 analysis and the other for PM10 analysis. Each TARTA will feature a cyclone to eliminate large particles exceeding PM2.5 or PM10. TARTA2.0 is more compact and lightweight (8*10*6 in) than the original version of TARTA. It is also equipped with an EZ-swap nozzle/optics cartridge to eliminate the need for intricate maintenance procedures (Figure 15). Furthermore, it has a user interface compatible with small computing devices (SCDs). In each TARTA experiment, particles are sampled at a flow rate of 16.7 L/min and directed onto the ground electrode. The sampling duration ranges from 10 to 30 minutes, depending on the pollution concentration. This is followed by ten high-voltage sparks to detect and dislodge the deposited particles. A pump with a greater flow rate can be utilized if a higher time resolution is necessary.

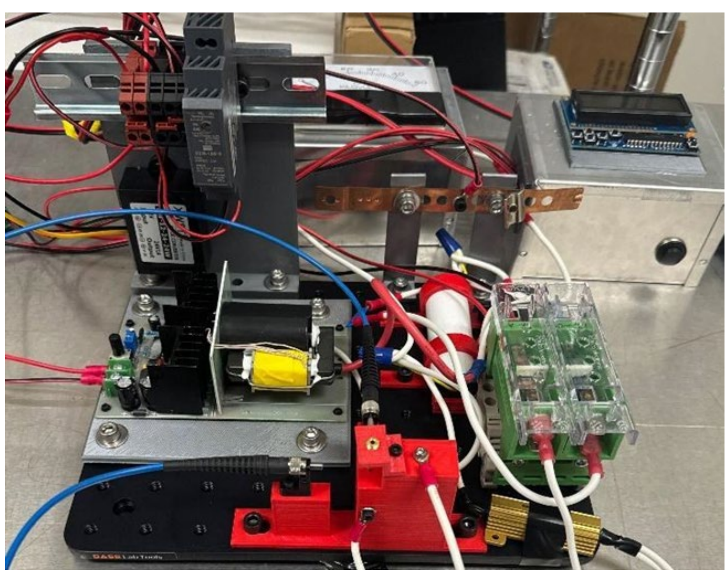


Figure 15 A photograph of the improved central part of TARTA2.0.

Deliverable:

A sampling system for measuring train BWWW PM emissions separately.

Task 4b Conduct Pilot Tests

UCR and Link will perform pilot tests using the proposed sampling system, the developed BWWW testing cycle, and sample analysis protocols. The project team will create a pilot test plan and consult with the Workgroup before conducting plan tests. The project team will present the Workgroup with the pilot test results and demonstrate the feasibility of a full-scale BWWW test along with the developed test cycles, the proposed BWWW PM sampling method, and the sample analysis plan. If the Workgroup requests, the project team will modify test cycles and the proposed sampling method.

The on-rail proposed sampling system will be tested under braking and wheel-rail laboratory conditions. One of the three selected train types will be utilized depending on availability. The BWWW sampling systems will be tested under transient and steady-state testing conditions. Pilot testing will include the complete suite of instruments as proposed in Task 4a. Several braking events will be tested, and emission test results will be submitted to CARB for evaluation. Following the pilot tests, the team will present the Workgroup with the results to demonstrate the feasibility of a full-scale BWWW test. Any necessary adjustments or modifications to the test cycles and sampling methods will be made based on feedback from the Workgroup. Similar to on-rail sampling system, lab-based sampling system will be evaluated under transient and steady-state BWWW conditions. The type and the number of tests for on-rail and lab-based pilot testing are presented in Table 6.

Through these pilot tests, UCR and Link aim to validate the effectiveness of the BWWW PM Emission Sampling System in accurately measuring brake-wear and wheel-wear emissions separately in train systems. The data collected during the pilot tests will provide valuable insights into the system's performance under real-world conditions and its compatibility with different types of trains and operating scenarios. By addressing any potential issues or limitations identified during the pilot testing phase, the project team will ensure that the sampling system meets the requirements for conducting a full-scale BWWW test and informing emission reduction strategies and environmental protection efforts.

LINK will use technical advisors and testing facilities with access to wheel-rail test rigs and the appropriate engineering expertise in rail wheel wear, fatigue, and emissions (e.g., Deutsche Bahn Systemtechnik).

Deliverable:

Pilot test results. The Contractor will submit this data in a mutually agreed-upon format.

Task 4c: Develop a Chemical Analysis Plan for PM Samples

Brake-wear, wheel/rail-wear, and background PM emissions differ regarding chemical properties, compositions, and size distributions. The project team will develop a chemical analysis plan for analyzing the collected gravimetric PM2.5 and PM10 samples, as outlined below:

- Teflon filters will be collected for PM2.5 and PM10. The filters will be used for gravimetric analysis, metals analysis, and trace element analysis. Metals analysis will use an XRF (X-ray fluorescence) technique according to EPA Method IO-3.3.
- QAT Tissuquartz quartz-fiber PM2.5 filters will be collected for EC/OC analysis using a Thermal/Optical Carbon Aerosol Analyzer (Sunset et al., OR) according to NIOSH (National Institute of Occupational Safety and Health) Method 5040.
- Separate PM2.5 Teflon filters will be used for PAH analysis employing gas chromatography-mass spectrometry (GC-MS) techniques.
- Oxidative stress will be measured using the DTT and ROS assays from the same PM2.5 Teflon filter.

- PM2.5 sodium bicarbonate-impregnated cellulose filters will be used for a subset of samples for CrVI analysis. The analysis will be performed by ion chromatography (IC).

Detailed descriptions of the analytical methods and protocols are discussed in Task 6b.

Deliverable:

A sample analysis plan includes testing protocols and procedures. The project team will submit this data in a mutually agreed-upon format.

Task 4d Develop a Full Test Plan

The project team will develop a complete test plan for California's prevalent train types (including at least one line haul, short-line, and passenger trains), the testing cycles (Task 3c), and the sampling system (Task 4a). Each subject will be tested for at least three corresponding BWWW testing cycles. The project team will also periodically check all the instrumentations to ensure the sampling quality. Based on the pilot test results (Task 4b), the proposed full test plan is subject to change for test methods (on-rail vs. in-lab), sampling methods, and sample sizes, and for the subsequent tasks: emission factor and chemical analyses and exposure risk assessment. The UCR team will demonstrate if each PM sample provides sufficient mass for chemical analyses outlined in Task 4c.

Based on the train activity data collected in Task 3a, the characterization of train activity patterns for each train type in Task 3b, and lastly, the selected routes for each train type, a development of a complete test plan will be provided in Task 4d. To minimize potential measurement variability and the measurement /train utilization cost, a dual measurement plan will be adopted that contains:

- Background ambient and WW testing: The proposed sampling system for PM2.5, PM10, gaseous emissions (THC), real-time PN, and PM sampling for chemical speciation will be utilized for WW testing along with background emission testing.
- Background ambient and BW testing: The proposed sampling system for PM2.5, PM10, gaseous emissions (THC), real-time PN, and PM sampling for chemical speciation will be utilized for BW and background emission testing.

Based on the findings of Task 3, the project team will propose a representative train route corresponding to the speed, acceleration, temperature, and wheel force collectives. The proposed test plan consists of more than <u>400 days</u> of testing, as shown in Table 6

For Task 5, the project team will conduct comprehensive testing on various train configurations to evaluate emissions and performance across different operational conditions. This includes testing on one line-haul train, one short-line train, and one passenger train. Emissions testing will be performed on one locomotive and one railcar for each train type. The testing will occur during the trains' normal daily operations, without the need for designing dedicated routes, ensuring real-world conditions are reflected in the assessment.

The project team will use the same configurations for brake and wheel testing for tread brakes (brake block on wheel). Sharing the same wheel allows the project to maximize the utilization of test hardware. It also enables assessing the total wheel behavior, including braking and rail contact on the same set. The test plan assumes no test trains or railcars are available for the project, which could be scheduled independently of normal rail operations. The approach to testing locomotives and railcars in normal operations enables CARB to replicate or conduct future measurement campaigns following a similar scheme and methods. The project team will consider combining the representative locomotive and railcars on the same train for on-rail testing to optimize testing and engineering resources and reduce the total test duration. This approach must consider the availability of PM, PN, particle size distribution instruments, power supplies, and the rail operator's logistics. For in-laboratory testing of brakes, the setup needs to consider in detail the embodiment of the fixture and the brake enclosure to enable the replication of train operation, as the train travels in both directions in many routes, with approximately 50% of the distance traveled in each direction. For in-laboratory testing for brakes and wheels, LINK will contact independent technical services and advisors (Deutsche et al.) with testing capabilities and expertise unavailable within LINK.

1. Below is the detailed structure of Task 5, which includes: On-rail braking testing: The project team anticipates 27 testing days for BW and background measurements performed in parallel for two locomotives and two railcars for each train type (3 train types total).
2. On-rail wheel-rail testing: We also project 27 testing days for WW and background measurements performed in parallel for two locomotives and two railcars for each train type (3 train types in total). To get statistically meaningful background filter samples, on-rail testing will include about 24 background filter samples collected evenly during on-rail BW and WW testing.
3. In-laboratory brake dynamometer testing under braking conditions: The project team anticipates about 72 testing days for BW including 2 brake types, 2 repeats per brake type for each train type (4 train types in total). In the BW dynamometer testing two types of brake-friction materials will be investigated. Since the laboratory environment is fully controlled, no background emissions will be collected.
4. In-laboratory testing under wheel-rail conditions: The project team anticipates 18 days for WW. A dedicated wheel-material will be investigated in the WW dynamometer testing under different loads and dyno cycles. Since the laboratory environment is fully controlled, no background emissions will be collected. Even though the chemical composition is fairly standard, it should be noted that wheel material is different based on the forging technology. It can be either forged steel or cast iron. The latter is a naturally occurring element, while the former is an alloy of iron and carbon. Steel alloy wheels are stronger than iron ones in yield and tensile strength domains. Hence, steel alloy wheels are primarily expected in locomotives, where braking power and load are significantly higher than in railcars. Due to the budget limitations, acquisition considerations, and additional logistic limitations, (e.g., significantly higher price of locomotive wheels, difficulty purchasing individual components from suppliers, wheels are typically sold as axle-sets with two wheels mounted on the truck shaft), the team will focus on a single wheel type under different loads per cycle during the WW laboratory testing. The project will rely on Hertzian contact stresses and wear modeling to develop scaling factors (e.g., wheel diameter, wheel profile, train speed, axle load, curve radius) to allow the use of a single wheel as a surrogate for the other applications.

The on-rail BW and background filters that will be included for gravimetric measurements and chemical speciation are the following: PM2.5 filters for gravimetric PM mass and metals analysis, PM10 filters for gravimetric PM mass and metals analysis, filters for EC/OC analysis, filters for PAHs, filters for DTT/ROS analysis, and filters for CrVI analysis. For the WW samples, the project team will include in the analysis the PM2.5 filters for gravimetric PM mass and metals analysis, PM10 filters for gravimetric PM mass and metals analysis, and the filters for CrVI analysis. Depending on budget constraints, the number of filters can be increased. The following Table 5 indicates the types of PM filters that will be utilized for the different sampling locations under on-rail and laboratory testing. To minimize potential high PM filter concentration variability under on-rail testing, the analysis will be limited to PM2.5 gravimetric analysis along with metal XRF analysis.

Table 5 Proposed selection of PM filters per sampling location for each test

Selection of filters	PM2.5	PM10	Metals	PAH	EC/OC	DTT	ROS	Cr6
On-rail BW	√		√					
On- rail WW	√		√					
Lab BW	√	√	√			√	√	√
Lab WW	√	√	√	√	√	√	√	√
Background	√	√	√	√	√	√	√	√

In addition to the filter samples, each measurement day will include real-time PM and PN measurements, near-real-time metals measurements, and real-time THC emissions measurements. For the in-laboratory testing, the project team, especially Link, will test a single locomotive and railcar for each condition (i.e., BW and WW) for three train types. Measurements will be performed in triplicate. Emphasis will be given on PM2.5 and PM10 collection for gravimetric PM mass and metals analysis. Background samples will also be collected during laboratory testing. The project team does not anticipate performing detailed chemical/toxicological analyses for the laboratory samples. However, each measurement configuration will include real-time PM and PN measurements, near-real-time metals measurements, and real-time THC emissions measurements. For tread brakes (brake block on wheel), use the same configuration for brake and wheel testing.

Table 6 Proposed complete development test plan

Task	Test type	System	Duration per test	Number of tests	Total test campaign/days	Total number of non-exhaust filters	Number of background filters	Train type (note 1)			
								Line-haul (tread brake)	Short-line (tread brake)	Passenger (disc brake) electric	Passenger (disc brake) Conventional
3a. Collect Train Activity Data	On-rail	Both	48 weeks	4 trains * 3 types for each train * 4 weeks/each	240	Activity data collection only		3 Locos + 3 Railcars	3 Locos + 3 Railcars	3 Locos + 3 Railcars	3 Locos + 3 Railcars
4b. Conduct Pilot Tests	On-rail	Braking	2 weeks	2 trains, 7 days on each train plus 4 total days for setup preparation	18	Evaluation study of PM study will be carried out		2 sample trains with worst-case for sampling from Task 3a (note 8)			
		Wheel-rail									
4b. Conduct Pilot Tests	In-Lab	Braking	2 weeks	Elements of the Task 5 plan will be conducted under the Task 4 pilot study	5			One disc brake assembly			
		Wheel-rail			5			Wheel 1 / Load TBD, Cycle TDB			
5. conduct Train BWWW Emissions Measurements	On-rail	Braking	~ 1.5 days	3 train types * 2 types each * 1.5 days * 3 repetitions	27	27	6	1 Locos & 1 Railcars		2 Locos & 2 Railcars	
	On-rail	Wheel-rail	~ 1.5 days		27	27	6				
	In-Lab (brake dynamometer)	Braking	~ 3 days	(4 brakes * 2 materials each * 2 repeats * 2days * 2 load levels + 8 setup days)	72	211	0	Wheel 1 / (1 Brake with Material A & B)	Wheel 2 / (1 Brake with Material A & B)	1 Brake disk with Material A & B	1 Brake disk with Material A & B
	In-Lab (wheel-rail bench)	Wheel-rail	~ 3 days/wheel	(1 wheels * 4 load cycles per wheel application (including load change) * 2 repeats * 2 days per cycle/wheel + 2 setup preparation)	18	211	0	Wheel 1 / Load A, Cycle A	Wheel 1 / Load B, Cycle B	Wheel 1 / Load C, Cycle C	Wheel 1 / Load D, Cycle D

Deliverable:

A complete test plan. The project team will submit this data in a mutually agreed-upon format.

Task 5: Conduct Train BWWW Emission Measurements

The UCR team will instrument all the test articles with sampling analyzers and conduct emissions measurements along with the test plan developed under Task 4d. For each test article instrumented, the project team will collect information such as BWWW test cycle used, train type, brake and wheel material and type, train weight, vocation, railcar type, cargo type and weight, engine make, size, model and model year, and typical hours of use.

The testing will include several subcontractors for different tasks:

a. UCR and LINK will coordinate the test plan and schedule with the rail operators and the test facilities
b. UCR, LINK, and SDSU will coordinate the logistics for data collection systems, sampling devices, and instruments for particle mass (gravitational and real-time), particle number, particle size distribution, and particulate metals
c. UCR and LINK will coordinate the logistics and planning of in-laboratory testing beyond LINK's in-house testing capabilities (e.g., beyond the test inertia for brakes or wheel-rail testing rigs) using independent testing facilities and engineering support and consulting from Deutsche Bahn Systemtechnik.

The UCR team and the testing contractor will perform each measurement for triplicate valid samples. The test plan considered by the URC team includes the steps outlined in Table 7:

Table 7 On-rail and In-laboratory test planning

− On-rail	− In-laboratory
Test planning	
Select loco/railcar combination Agree on data acquisition system and strategy Determine test materials and sourcing Select test route(s) or cycle(s) with operator Detailed sampling systems design and fabrication Rail operator planning and train earmarking	Select loco/railcar combination Determine test materials and sourcing Agree on test cycle(s) Detailed sampling systems design and fabrication Agree on the timeline for lab readiness
Test staging	
Secure data collection and sensors Secure sampling systems Agree on train parameters Agree with the operator on timing, permits, and logistics	Secure data collection and sampling systems Secure sampling systems Agree on train parameters Agree on the timeline for test setup and hardware availability
testing/measurement setup	
Bring all test instrumentation and data acquisition to the test site Secure railyard personnel and resources Install power and systems on the train Perform short operational test	Bring all test instrumentation and data acquisition to the test site Secure railyard personnel and resources Install power and systems on the train Perform short operational test
Setup verification	
Verify output, stability, and noise for all sensors	Verify output, stability, and noise for all sensors

Verify outputs from the event recorder(s) (if available) Verify the entire operation of all sampling systems	Verify outputs from the event recorder(s) (if available) Verify the entire operation of all sampling systems
Main testing	
Execute the test plan, including inspections and retrieval from logs and rail records Monitor data acquisition and instrumentation	Execute the test plan, including inspections and changeovers for test parameters or cycles Monitor data acquisition and instrumentation
Test teardown	
Perform complete test down Inspect parts and hardware Measure wear and document with pictures	Perform complete test down Inspect parts and hardware Measure wear and document with pictures
Test reporting	
Generate the minimum set of variables agreed with the CARB Workgroup	Generate the minimum set of variables agreed with the CARB Workgroup

The laboratory test using a brake dynamometer considers two possible locations. Depending upon the test conditions (e.g., brake and fixture layout and size, brake torque, test inertia), the LINK Testing Facility uses a heavy-duty system. It is equipped with brake emissions measurement according to GTR 24 (PM, Total and Solid PN, isokinetic sampling tunnel, and conditioned cooling air) plus additional devices for particle size distribution and metals particulate. The LINK dynamometer is limited in its ability to accommodate certain brake sizes. Alternatively, LINK can access a full-scale brake dynamometer at the Deutsche Bahn Systemtechnik (DB) Technical Center in Minden, Germany. Figure 16 illustrates both options. The UCR team would present options to the Workgroup for consideration when defining the test plan.

A standard set of test conditions which both dynamometers can meet are:

- 575 revolutions per minute for a 920-mm wheel at 100 km/h
- 3200 kg·m² of test inertia for a 15 000 kg wheel load for the same wheel size
- 25 kN·m of frictional braking torque
- Disc brakes

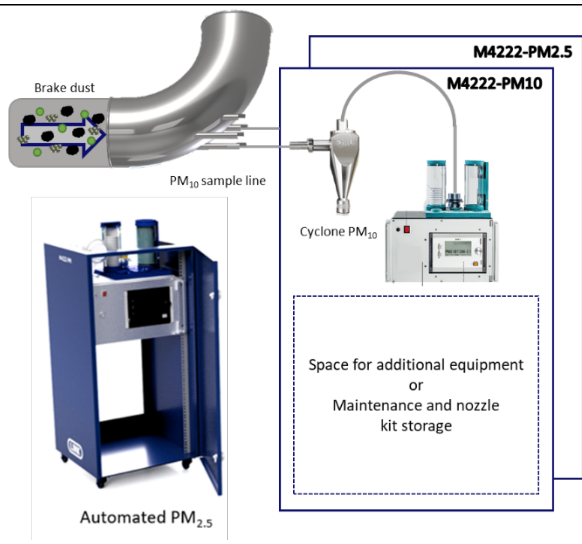
The primary capabilities the DB dyno offers above the ones listed above are:

- Maximum rotational speed of 2200 RPM
- Test inertia up to 5000 kg·m²
- Ability to accommodate rail wheels for tread brakes up to 1400 mm diameter

<table>
<tr><td></td><td></td></tr>
<tr><td>LINK’s Commercial vehicle brake dynamometer with brake emissions measurement system (Limburg, Germany)</td><td>DB’s full-scale brake dynamometer, with limited adaptability to measure brake emissions (Minden, Germany)</td></tr>
</table>

Figure 16 Brake dynamometer candidates for in-laboratory testing

The minimum setup for measuring brake emissions during in-laboratory testing includes the elements shown in Figure 17. The two primary systems enable the measurement of PM using filter holders, and PN measurement using Condensation Particle Counters for total and solid particles according to the GTR 24.

<table>
<tr><td>
</td><td>Dedicated direct connection to sampling probe and isokinetic sampling nozzles with no bends.

Certified pre-classifier for $PM_{2.5}$ and PM_{10} respectively (Cyclonic separator)

Integrated and automatic filter changer with double magazine slide-in module for up to 29 filters

Vacuum pump with automatic real-time flow control with a deviation of < 2% and sensor accuracy of ± 1.0 ºC

Radio Frequency Identification (RFID) functionality for automatic data integration and traceability of all filters

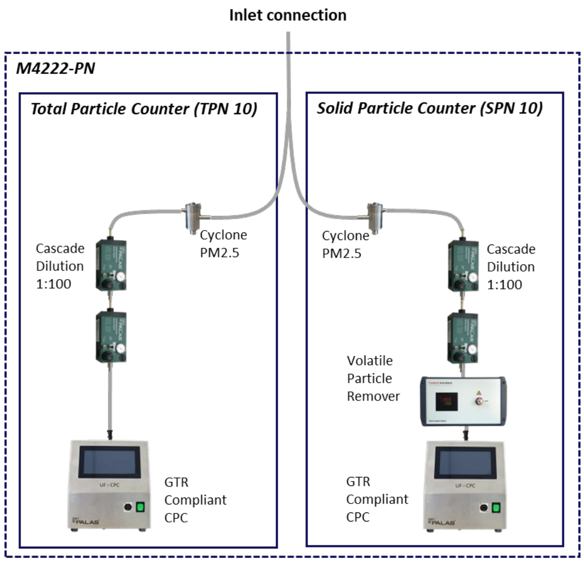
The sampling line is an antistatic PTFE tube with stainless steel braiding

Easy pump access for maintenance

Highly automated leak check

Power consumption of 150 W per unit

Full integration with LabLINK for dyno controls and data acquisition for the final report</td></tr>
<tr><td>LINK’s M4222-$PM_{2.5}$ and -PM_{10} measurements according to UNECE GTR 24</td><td>LINK’s M4222-PM specifications</td></tr>
</table>

<table>
<tr>
<td>
</td>
<td>Direct connection to sampling probe and isokinetic sampling nozzles

Certified pre-classifier (cyclonic separator)

Dilution system with real-time output

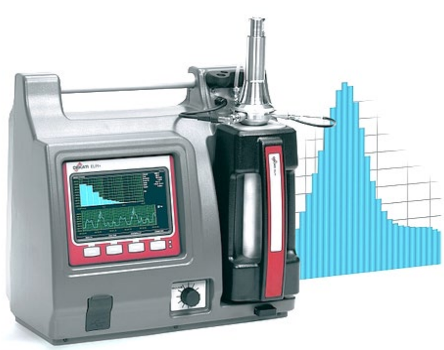
Particle number counting unit (PNC or CPC) capable of 1,000,000 #/cm³ in single count mode

vacuum pump (with automatic real-time flow control, sensors, and outlet air filter).

Automated output for normalized sampling flow, PCRF, and normalized-PCRF corrected concentration</td>
</tr>
<tr>
<td>LINK’s M4222-TPN/SPN measurements according to UNECE GTR 24</td>
<td>LINK’s M4222-TPM/SPN specifications</td>
</tr>
</table>

Figure 17 illustrates the LINK’s M4222-PM and M4222-PN systems fully compliant with the GTR 24 draft for the Euro 7 measurements of brake emissions.

Lastly, for brake emissions, the sampling tunnel has provisions to install other instruments for real-time particle sizing. Figure 18 illustrates the most common ones, already with the proper ProLINK software for controls, signal exchange, and data acquisition in sync with the brake data. The UCR team will bring proposals on the actual setups to use to measure metal pollutants integrated with legacy particle sizes commonly used for non-exhaust emissions from brakes.

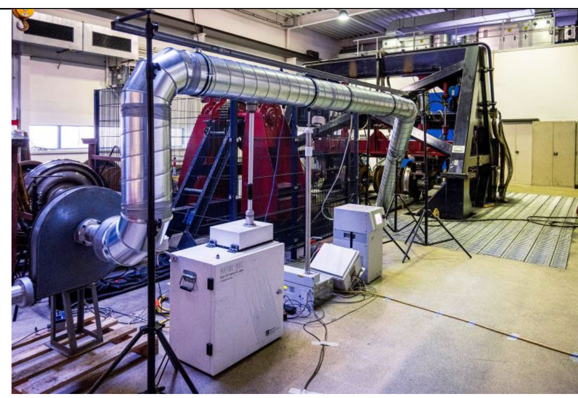
<table>
<tr>
<td></td>
<td>
</td>
</tr>
<tr>
<td>ELPI+</td>
<td>PALAS Fidas</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</table>

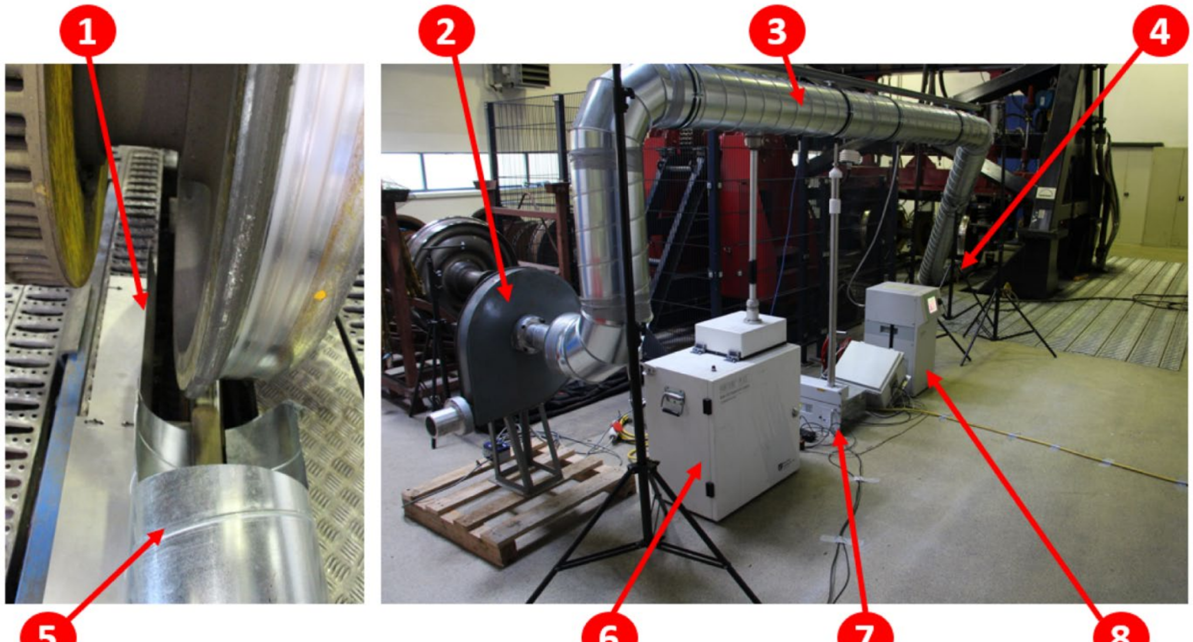
TSI APS	TSI EEPS

Figure 18 Examples of real-time particle sizers from 5.6 nm to 18 µm

For in-laboratory testing of wheels, LINK has access to a wheel-rail test rig located at the DB Rail Test Center outside Berlin. Figure 19 depicts the test rig in two configurations. The setup with non-exhaust emissions measurements is well documented (Fruhwirt et al. 2023). Non-exhaust emission measurement will be performed based on a similar approach to the constant volume sampling system (CVS) methodology. In particular, the sample system will be comprised of a sample inlet including baffle plates, sample ducts (0.25 m diameter), suitable fittings for probe sampling, and a radial fan. The sample flows of the analyzers will be taken from a horizontal sample duct at equal distances of roughly 80 cm as depicted in Fig 19 according to Fruhwirt et al. Some critical aspects of the setup will include the following:

- Sample aspiration near the ground and near the wheel and rail contact.
- Balance of airflows in the sampling tunnel and the sampling flow for the instruments to ensure isokinetic sampling.
- Sampling tunnel with inlet baffle plates, sampling duct (200 mm diameter), fittings, and portable fan with High-Efficiency Particulate Absorbing (HEPA) 13 filters.
- Measuring wheel emissions only on the outer wheel when simulating curves to ensure the measurements include flange contact.

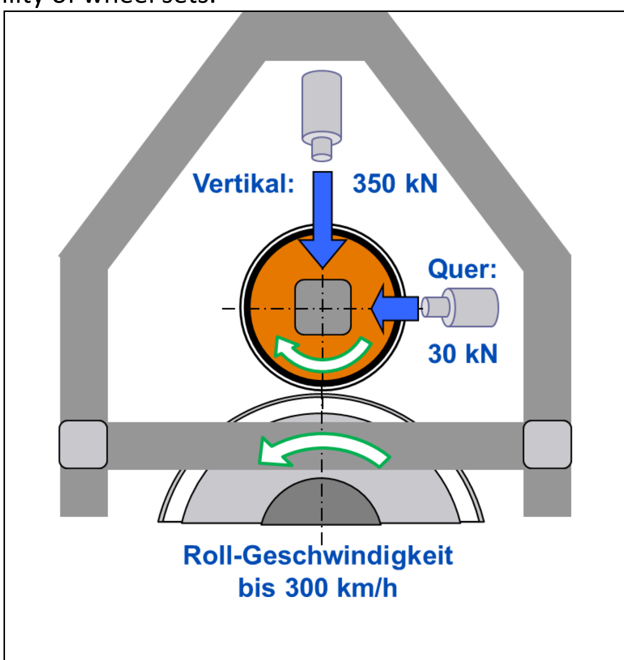
	
DB Test rig A during normal low-and high-speed wear and tribology testing using a full axle-set with two wheels under loading to reflect the test cycle	DB's Test rig A with setup for measuring wheel-rail emissions in one wheel only

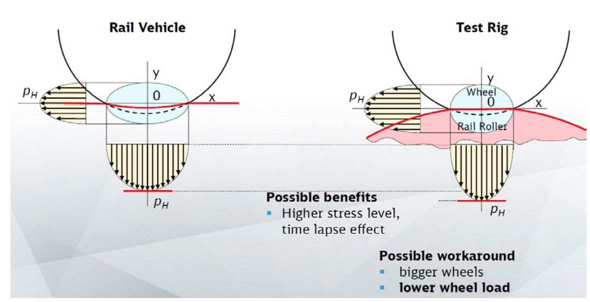


Example of rail wheel setup for emissions measurements. Left - sample inlet, right – sample system (1 – baffle plates, 2 - radial fan, 3 - horizontal air duct, 4 - sample inlet, 5 - sample duct, 6 - PartisolPlus 2025i, 7 - EDM180, 8 - EEPS)

Figure 19 Wheel-rail rig for in-laboratory testing

The configuration and main specifications of the wheel-rail rig are shown in Figure 20. The testing system uses a fixed rail roller (which can be resurfaced) and interchangeable wheel sets depending upon the rail application and availability of wheel sets.





Wheelset	– Diameter	– 400 – 1250 mm
	– Wheel Profile	– variable
Rail Roller	– Steel Grade	– R260
	– Diameter	– 2,1 m
	– Rail Profile	– 60E2, 1:40 inclination
	– Track Width	– 1435 mm
Parameters	– Axle Load	– up tp 340 kN (~34 t)
	– Sideload	– up to 30 kN
	– Simulated Curvature	– from 300 m up to ∞
	– Speeds	– up to 300 kph

Test rig parameters for vertical load, side load, and simulated train speed

Hertzian contact stress conditions of rail vehicle v. test rig and test parameters

Figure 20 Wheel-rail test rig parameters for testing and Hertzian contact stresses.

Deliverable:

Raw data collected, including detailed information on units of measurement and conditions at detailed resolution.

Task 6: Analyze Emission Data and Develop EFs

Under this task, ERG will take the lead on analyzing, reporting, and modeling the PM, PN, and gaseous emissions gathered in Task 5, with UCR providing a summary of emissions data under Task 6a and analytical equipment and services specific to Task 6b. Our team will draw on the direct experience of performing similar tasks for the CARB and Caltrans laboratory-based brake emission programs and multiple past on-road measurement programs. Our expertise in synthesizing raw field data into emissions factors and models will ensure the end product can be applied by CARB for informing BWWW modeling, emission inventory updates, and regulatory-level analysis.

Our approach for each subtask specified in the RFP is detailed in the following sections.

Deliverable:

Upon completion of Task 6, the Contractor will submit Interim Report #2 including all the QA/QC data collected, analysis results and information collected from Task 4-6.

Task 6a: Characterize BWWW Emissions by Train Type

Our team will characterize BW and WW PM2.5, PM10, and particle number emissions from the Task 5 tests according to the factors of the study design, including train type and route characteristics, and recorded information on brake type and material, wheel type and material, train and cargo weight, engine make, size, model and model year. Gravimetric filters and real-time PM, particle number, metals, and THC emissions will be summarized in line with these factors. Additional characterization of real-time data will provide sub-filter details on emissions such as speed and deceleration/cruise/acceleration event. PM collection efficiency and background contamination percentage will be estimated for each test. Once these data are compiled in a data platform determined in consultation with CARB, we will generate summary tables and charts of BW and WW emissions to allow comparison across different train types, brake and/or wheel materials, and route segments.

Deliverable:

A report including tables and graphs profiling BWWW PM emissions, including particle concentration, mass, and size distributions. The project team will submit this in a mutually agreed upon format.

Task 6b: Analyze PM Compositions

The project team, especially UCR, will conduct chemical analysis as planned for Task 4. The analysis will be comprehensive and will include a suite of chemical analyses, including metals and trace elements, OC/EC fractions, PAHs, oxidative potentials expressed by the ROS and DTT assays, and total Cr(VI) for collected gravimetric PM2.5 samples from Task 5. Analysis for metals and trace elements will also be performed for the collected gravimetric PM10 samples. UCR will use this information to estimate the mass percentage of major BW and WW PM2.5 and PM10 components. For the purpose of this project, UCR and the project team will collect separately BW, WW, and background samples from each train.

- Both PM2.5 and PM10 samples will be analyzed for metals and trace elements using the XRF (X-ray fluorescence) technique according to EPA Method IO-3.3. The XRF method analysis will include the quantification of sodium (Na), magnesium (Mg), aluminum (Al), silicon (Si), phosphorus (P), sulfur (S), chlorine (Cl), potassium (K), calcium (Ca), titanium (Ti), vanadium (V), chromium (Cr), manganese (Mn), iron (Fe), cobalt (Co), nickel (Ni), copper (Cu), zinc (Zn), gallium (Ga), germanium (Ge), arsenic (As), selenium (Se), bromine (Br), rubidium (Rb), strontium (Sr), yttrium (Y), zirconium (Zr), molybdenum

(Mo), palladium (Pd), silver (Ag), cadmium (Cd), indium (In), tin (Sn), antimony (Sb), barium (Ba), lanthanum (La), mercury (Hg), lead (Pb), and ruthenium (Ru).

- The QAT Tissuquartz quartz-fiber PM2.5 filters will be used for EC/OC analysis. Prior to testing, filters will be pre-cleaned by firing for 5 hours at 600 °C to remove carbonaceous contaminants. EC/OC analysis will be performed using a Thermal/Optical Carbon Aerosol Analyzer (Sunset Laboratory, Forest Grove, OR) according to NIOSH (National Institute of Occupational Safety and Health) Method 5040.
- A separate 47-mm Teflon filter will be used to measure PM2.5-bound polycyclic aromatic hydrocarbons (PAHs) with gas chromatography-mass spectrometry (GC-MS). Samples will be extracted in dichloromethane and methanol and will be combined and reduced in volume to approximately 1 mL by rotary evaporation, followed by pure nitrogen evaporation. The underivatized samples will be analyzed by auto-injection into a GC-MSD system (GC model 5890, MSD model 5973, Agilent). A 30 m x 0.25 mm DB-5MS capillary column (Agilent) will be used with a split-less injection. Along with the samples, a set of authentic quantification standard solutions will be injected and used to determine response factors for the compounds of interest. The target PAH compounds that will be quantified are Naphthalene, phenanthrene, anthracene, fluoranthene, acephenanthrylene, pyrene, benzo(ghi)fluoranthene, chrysene, 1-methylchrysene, retene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(j)fluoranthene, benzo(a)pyrene, benzo(e)pyrene, perylene, benzo[g,h, i]perylene, indeno [1,2,3-c,d]p yrene, and coronene.
- A chemical reactivity and cellular assay will be performed on a separate PM2.5 filter to assess the oxidative stress of BW and WW PM2.5 emissions. The PM2.5 filters will be extracted in ultra-pure MQ water. After a short mix on a vortexer and a 15-minute sonication period, the filter/PM suspensions will be agitated overnight on a platform table shaker isolated from light. The filter suspensions will be sonicated again post-leaching, and the unfiltered PM suspensions will then be sub-sampled for targeted analyses. The reactive oxygen species (ROS) generated by these extracts will be quantified with both a chemical method that measures the consumption rate of dithiothreitol, or DTT, and an in vitro method that measures PM-induced production of ROS via a fluorescent probe in a rat alveolar macrophage (NR8383) cell line. The DTT assay measures the prooxidant content of the sample based on its ability to transfer electrons from DTT to oxygen. The quantity of prooxidant is proportional to the rate of DTT consumption. The electron transfer reactions involved in the DTT oxidation are similar in many respects to the oxidative burst initiated by superoxide formation in the mitochondria of cells. The technique is responsive to redox-active organic compounds (e.g., quinones) and many redox-active metals; however, metals are significantly less efficient at oxidizing DTT than reactive quinones. The methodological details of the DTT assay and its applications have been described in previous studies (Cho et al., 2005; Eiguren-Fernandez et al., 2010).
- The ROS activity of the PM2.5 extracts will be measured by in vivo exposure to rat alveolar macrophage (NR8383, ATCC# CRL-2192) cells using 2',7'-dichlorofluorescin diacetate (DCFH-DA) as the fluorescent probe. DCFH-DA, a membrane-permeable compound, is de-acetylated by cellular esterases generating 2',7'-dichlorofluorescein (DCH), which is highly fluorescent. The fluorescent will be monitored using a plate reader method. Sub-samples of the primary water extracts will be further processed by chelation with the immobilized ligand iminodiacetate (Chelex chromatography) to remove the metal ions. For the Chelex treatment, mini-columns (1 mL polypropylene with Teflon frits) of Chelex will be prepared with 0.2 g of high-purity water-slurried Na-Chelex. Columns will be rinsed with high-purity water and buffered with 0.1 M sodium acetate. PM extracts will be processed through the columns, under gravity flow, in a solid phase extraction manifold at a flow rate of ~1.0 mL/min. The Chelex-processed extract will be collected and immediately assayed for ROS activity. Control samples will be processed through the Chelex columns to ensure that the treatment will not produce ROS active species or inhibit the activity of Zymosan (a β-1,3 polysaccharide of D-glycose). Zymosan will be used as a positive control as it is recognized by TLR-2 (Toll-like receptors) on macrophage cells, activating a strong immune-chemical and ROS response. ROS activity will be, therefore, reported in terms of Zymosan units to facilitate the comparison of various data sets (Landreman et al., 2008).
- For a subset of in-use tests, CE-CERT will collect PM2.5 samples on 47 mm sodium bicarbonate-impregnated cellulose filters for Cr(VI) analysis. Although we assume that almost all Cr will be CrVI due to high-temperature conditions during braking events, this hypothesis will be tested with additional sampling at the source. The filters will be transported and stored in the locomotive below freezing temperatures to prevent any decomposition of the solution. After one hour, the filters will be extracted

by sonicating the solution with 20 mM sodium bicarbonate. Ion chromatography (IC) will filter and analyze the extract to obtain hexavalent chromium concentrations. The analysis method is based on modifying the California Air Resources Board method (Hexavalent Chromium in Ambient Air Method CARB MLD-039).

- For the measurement of the near-real-time metal, the optical signal emitted by the plasma in TARTA is captured in real-time by a spectrometer. However, a calibration model is required during the post-analysis phase to quantify elemental concentrations. A machine learning-based multivariate calibration model has been developed to quantify trace metals measured by TARTA and to mitigate matrix effects. Additionally, the model eliminates the need for manually selecting representative wavelengths for the analytes, instead assigning importance to multiple wavelengths based on the coefficients of independent variables derived by the model. The SDSU team will supervise the QA and QC of TARTA spectra and apply the machine learning model to derive elemental concentrations from the collected data.

As discussed above, the project team will fabricate two separate sampling systems to collect brake-wear and wheel/rail-wear PM samples. Testing will be divided into two phases. The first phase will include dedicated testing for brake-wear PM emissions using one sampling system and in parallel background PM using the second sampling system. The second phase will consist of dedicated testing for wheel/rail-wear PM emissions using one sampling system and in parallel background PM using the second sampling system. Samples collected during both phases of the test campaign (measurement and background samples) will be analyzed for chemical constituents and toxicological properties, as outlined earlier. The measurement setup for this task is shown in Figure 13. Two identical sampling systems will be fabricated and installed on each train.

Suppose separation of brake, wheel/rail, and background is not possible in this phase of the analysis. In that case, source apportionment will be used to estimate the quantity of each source in the sample using EPA's Chemical Mass Balance (CMB) model.

Deliverable:

A chemical analysis report. The Contractor will submit this in a mutually agreed upon format.

Task 6c: Develop BWWW PM Emission Factors

Under this task, the ERG will characterize brake and wheel/rail PM and PN emissions in terms of grams and particles per distance and engine work using the results from Tasks 6a and 6b. This characterization will focus on adjusting and aggregating filter-level data to emission factors suitable for modeling in Task 6d at the appropriate level of detail supported by the data. This will entail correcting for PM sample collection efficiencies and total train emissions based on the number of brake assemblies and wheels per train (locomotives and rail cars). Factors of the study design, such as train type/weight, friction material type, rail condition, and speed will characterize emissions. In consultation with CARB and the Project Work Group, the project team will determine the best approach to characterize speed or engine work dependent emission factors.

Deliverable:

Corrected and adjusted BWWW PM emission factors. The Contractor will submit this data in a mutually agreed-upon format.

Task 6d: Develop BWWW EF Simulation Tool

Under this task, a computer model will be developed to estimate BWWW emissions factors applicable to California's rail travel range. The model will be created based on the traditional approach of [(Emission Factor) x (Activity)]. "Base" emission factors will be developed from Task 6c results, analyzed to determine significant effects from factors included in the test plan as well as factors determined from the literature review, and interpolated/extrapolated to cover the range of train types, engine class, emission standards, weights, speeds, rail materials, and grades in California. Operational parameters such as brake/wheel/rail material, rail miles traveled, route frequencies, number of stops, number of rail cars, and weight will be drawn from the market survey and mass balance analysis performed under Task 2 and activity data collection in Task 3. The modeling platform will be determined in consultation with CARB (e.g., MS Excel, database application, script, etc.), and documentation will be provided for model use and update.

Deliverable:

A computer simulation tool, either in a spreadsheet or database, to estimate BWWW PM EFs applicable to different train types. The Contractor will submit this data in a mutually agreed-upon format.

Task 7: Evaluate Potential Health Risks to Near-Railroad Communities

For this task, the UCI team will evaluate the potential health risks of BWWW PM emissions introduced to near-railroad communities based on the chemical analysis performed under Task 6b. The UCI team will estimate the relative exposure level of the near-railroad communities considering the acquired BWWW EFs, the distance between the communities and the railroads, train types, and the corresponding EFs. The UCI team will use tools like exposure models to show the estimated exposure levels and potential health risks for the impacted communities.

Task 7a: Dispersion Modeling

We will use a modified version of California LINE Source Dispersion Model Version 4 (CALINE4) (Benson et al., 1989; Wu et al., 2009a; Wu et al., 2009b) to predict ambient concentrations from railroad-related emissions based on EFs estimated in Task 6 for the centroid of each Census blocks up to 3 km from the railroads. This model has been used in multiple studies for exposure assessment of local traffic-related air pollution (Wu et al., 2009c) and several epidemiological studies that examined local traffic pollution and various health outcomes, including pregnancy outcomes (Wu et al., 2009d; Wu et al., 2016), child (Ritz et al., 2016) and maternal (Yan et al., 2019) serum metabolome, metabolic syndrome (Yu et al., 2020a), childhood cancer (Heck et al., 2013), adult cancer (Cheng et al., 2020), dementia and cognitive impairment (Pual et al., 2020; Yu et al., 2020b), and Parkinson's disease (Kwon et al., 2024).

Since the original CALINE4 could not simulate UFP number concentration, we have developed distance-dependent scaling functions within the CALINE4 model to predict particle number concentrations near roadways (Yuan et al., 2011). The scaling functions were developed by comparing measured UFP (6-220 nm) concentrations near freeways in California and Texas and corresponding UFP concentration estimates from the original CALINE4 model with no adjustment. The model was used to predict UFP concentrations for additional near-freeway locations, and the modeled concentrations agreed well with measurements (Pearson's > 0.92) (Yuan et al., 2011). Further, we evaluated the predicted and measured concentrations at four retirement community sites in the Los Angeles Air Basin with extended sampling time; results showed a moderately strong correlation between measured and predicted concentrations with Pearson's r = 0.75 for 357 daily particle number measurements (Wu et al., 2016).

Input data for the prediction process included roadway geometry, traffic counts, emission factors, and meteorological parameters (wind speed, wind direction, temperature, stability class, and mixing heights). Meteorological data will be obtained from the National Weather Service. We will use railroad configuration and traffic counts developed from Tasks 2 and 3. Day of the week and diurnal variability of train counts will be used to scale train activity profiles by weekday/weekend and diurnal traffic profile (24 hours). CALINE4 predictions in this study will not incorporate background pollution levels, thus solely representing the contribution from railroad activities.

Task 7b: Risk Assessment

To characterize the risk associated with railroad emissions, we will employ a methodology recommended by the U.S. Environmental Protection Agency, which allows for the calculation of cumulative risk or chronic daily intake (CDI) across multiple pollutants according to three potential exposure pathways (inhalation, ingestion, and dermal contact). This same approach was used in our previous study to assess the risk of exposure to metal mixtures in soil (lead, arsenic, manganese, chromium, nickel, copper, cadmium, and zinc) in an environmental justice community in Southern California (Masri et al., 2021a).

In calculating health risks for a given pollutant, it is worth noting that non-carcinogenic toxicity is understood to arise only above a discrete exposure level or threshold. In contrast, carcinogenicity is considered non-threshold and exhibits carcinogenic effects linearly, even at the lowest doses. These distinctions underly the uses of either a reference dose (for non-carcinogenic effects) or cancer slope factor (for carcinogenic effects). To derive the non-carcinogenic risk, the hazard quotient for a given pollutant will be calculated by dividing the CDI values for each particular pollutant, each exposure route, and separately for children and adults by the reference dose (RfD) (mg/kg/day). Similarly, to derive the lifetime carcinogenic risk, the cancer risk for a given pollutant will be calculated by multiplying the CDI values for each exposure route by the cancer slope factor $(mg/kg/day)^{-1}$ for that particular pollutant, exposure route, and separately for children and adults. The non-carcinogenic risk and cancer risk for individual pollutants and exposure routes will be summed up to obtain risks associated with multiple pollutants and exposure routes among children and adults. The reference doses and cancer slope factors will be obtained from the US EPA's Integrated Risk Information System (IRIS) (USEPA, 2024) and California OEHHA (OEHHA, 2005), where the values differ from the US from those applied by the California OEHHA, we will include the California-reported values when considering the full range of these parameters. For pollutants with a range of reported values, we will use the lower and upper end of the ranges to calculate separate lower and upper-risk estimates. For the cancer risk, we will consider a subset of pollutants that are considered carcinogenic, according to the California Office of Environmental Health Hazard Assessment (OEHHA). These risks will be mapped at the Census tract level to give a spatial representation of non-carcinogenic risk throughout the study region.

Task 7c. Exposure and Risk by Population Characteristics

Population-weighted pollutant concentrations from Census blocks will be aggregated to Census tracts. Since this project focuses on the impacts of primary emissions from railroads to nearby communities, pollutant concentrations (7a) and health risks (7b) will be assigned zero for Census tracts located 3 km away from any railroad. The exposure and risk data from Tasks 7a and 7b will be coupled with geospatial demographic and socioeconomic (SES) data to evaluate which communities have the highest probable exposures. We will obtain multiple sociodemographic measures at the Census tract level, including population count, age, and rural-urban classification from the US Census in 2020, the five-year average American Community Survey data about household income, poverty, race/ethnicity, education, insurance coverage, spoken languages, nativity, rent, and house values, land-use type data from Southern California Association of Government (Southern California Association of Governments, 2024), redlining classification based on digitized Home Owners' Loan Corporation maps (Nelson et al., 2024), Area Deprivation Index (ADI) reflecting neighborhood deprivation (Kind et al, 2018; University of Wisconsin School of Medicine and Public Health, 2024), and the CalEnviroScreen composite score indicating environmental disadvantaged community status defined by California EPA based on population characteristics and pollution burdens (Office of Environmental Health Hazard Assessment and California Environmental Protection Agency, 2024). The redlining data includes four categories (A: Best, B: Still Desirable, C: Declining, and D: Hazardous/redlining). The ADI is a validated composite index based on 17 measures of income, education, employment, and housing quality; higher ADI values indicate more significant neighborhood deprivation. Further, sensitive land uses, including daycares, schools, senior centers, and hospitals, will be obtained from the California State Geoportal database (California State Geoportal, 2024). The locations of these sensitive land-use facilities will be geocoded using ArcGIS (ESRI, Redlands, CA) and linked to specific Census tracts and pollution levels.

Summary statistics and statistical significance in differences for pollutant concentrations and risks will be calculated by proximity to the railroad, major sociodemographic factors, the status of disadvantaged communities, urban/rural areas, and land use type, including sensitive land use facilities. Census demographic factors will first be converted to percentages of the population in each Census tract, such as the percent of residents who identified as Latina/o/x or Hispanic, immigrant non-native residents, residents who reported speaking no or limited English, residents who did not have health insurance coverage, residents under five years of age, renter-occupied housing units, and residents with a college education or higher. Further, geospatial analysis will be conducted to map and visualize sub-areas or sub-populations with high exposure levels using the sociodemographic and land use variables in ArcGIS. Communities and sub-population groups disproportionately burdened by pollutant exposures will be identified. This type of analysis has been conducted extensively in Wu's group for air pollution (Sun et al., 2022; Masri et al., 2023), soil lead contamination (Masri et al., 2020), wildfire smoke (Masri et al., 2021b), built environment (Sun et al., 2021), as well as health risks (Masri et al., 2021a) or compound risks (Masri et al., 2022).

Deliverable (based on all subtasks):

A report discussing the exposure level and any potential health risks to near-railroad communities from train BWWW PM emissions will be submitted by the project team in a mutually agreed-upon format.

Task 8: Evaluate Study Limitations, Assess Current Programs, and Suggest Future Steps

The UCR team will identify uncertainties and limitations of sampling system design, testing cycle development, emission measurements, data collection procedures, PM and PN characterization, and discuss their potential impacts on the profiled PM emissions at Tasks 3, 4, 5, 6, and 7. The project team will also discuss further enhancements to measure and characterize non-exhaust PM emissions from trains. The project team will assess opportunities to reduce PM emissions using regenerative braking technology and other advanced train technologies.

The UCR team will consult with environmental justice expert(s) and community groups to identify and understand potential community concerns of train BWWW PM emissions and exposure. The project team will examine existing programs and policies and identify potentials and limitations to address the community concerns that can be considered for CARB's future policy considerations.

Three strategies to address this task include:

a. Ensure the Literature Review from Task 1 includes early research questions on this topic to guide the assessments on this task

b. Consult with and interview regional, federal, and international environmental agencies or research centers

c. A limited-scope set of selected interviews with rail operators, locomotive manufacturers, and braking system suppliers (rolling stock, bogies, wheels, discs, and friction materials)

Deliverable (based on all subtasks):

A report discusses this research's limitations, the following steps, and potential BWWW reduction technologies—a summary of community concerns, an assessment of current programs and policies, and future suggestions. The project team will submit this in a mutually agreed-upon format.

Task 9: Reports and Public Research Seminar

The project team will provide Interim Reports, a Final Report, a Public Research Seminar, and a Public Outreach Document. The first interim report, including results from Tasks 1-3, shall be delivered to and discussed with CARB staff prior to starting train BWWW PM emission measurements. A second interim report will be delivered to CARB at the end of Tasks 4-6, including QA/QC data and analysis results. The final report will encompass the entire project.

As part of the final report, the project team will draw on communications and outreach experience to produce a Public Outreach Document that summarizes key research findings from the study. Our team will also prepare and deliver a research seminar to display the significant conclusions of this study to the public, as well as journal articles and presentations at national and international conferences.

Task 9a: Draft Final Report

Six months before the end of the study, the project team will submit a draft final report (DFR), which will contain information from the interim reports, research findings, methodologies, implications, and recommendations. The DFR will also include a Public Outreach Document that will be used to communicate, in clear and direct terms, the key research findings from the study to the public. The guidelines for submitting the Public Outreach Document and the Equity Implications are outlined in Exhibit F. The DFR will go through a copy-editing process, for example, by leveraging the project team's institutional resources, to provide a document that is clearly written and absent of grammatical errors and formatting inconsistencies. Along with the draft final report, the project team shall deliver all raw data, analytical methods, analysis results, and modeling tools developed through the course of this project. The DFR will be submitted per the Final Report format, Exhibit F, and reviewed by CARB staff. CARB's comments will be sent to the Contractor, and after receiving the reviewer's comments, the Contractor shall modify and resubmit the modified DFR to the CARB Project Manager.

Task 9b: Draft Final Report - Revised

The modified DFR will be subject to formal review by the Research Screening Committee (RSC). Once the RSC accepts, the project team will revise the modified draft final report addressing the RSC comments and any remaining concerns from CARB staff and submit the revised final report to CARB. If CARB has additional comments on the report, the project team will be notified so appropriate changes can be made; otherwise, CARB will accept the revised final report as the final. The project team will submit the final report in an Americans with Disabilities (ADA) compliant format. All reports shall be delivered using CARB standard templates.

Task 9c: Public Research Seminar

UCR will prepare and deliver a research seminar to display the significant findings from this study to the public. The research seminar slides will be in an ADA-compliant format.

UCR will also lead the preparation of journal articles and conference presentations summarizing the project's results. UCR will submit those journal articles and conference technical papers to CARB for review before submission for publication.

Deliverable (based on all subtasks):

ADA-compliant, t research seminar presentation slides

Meetings

A. **<u>Initial meeting.</u>** Before work on the contract begins, the Principal Investigator and key personnel will meet with the CARB Contract Project Manager and other staff to discuss the overall plan, details of performing the tasks, the project schedule, items related to personnel or changes in personnel, and any issues that may need to be resolved before work can begin.

B. **Progress review meetings.** The Principal Investigator and appropriate members of his or her staff will meet with CARB's Contract Project Manager at quarterly intervals to discuss the progress of the project. This meeting may be conducted by phone.

C. **Technical Seminar.** The Contractor will present the results of the project to CARB staff and a possible webcast at a seminar at CARB facilities in Sacramento or Riverside.

Project Schedule

The Work Plan and Work Schedule provide a guideline for successful completion within the overall project timeline of 36 months. The estimated completion dates in the Project timeline (Table 8) assume that the contract will be finalized by June 15, 2024. Contract finalization delays may potentially impact the proposed schedule and necessitate minor schedule adjustments.

Project Management Plan

Table 8 Project timeline

Task	Responsible Party	Date of Completion
Task 0: Kickoff Meeting	UCR	June 15, 2024
Task 1: Literature Review		
Task 1a: Review of Train Duty Cycles and Non-Exhaust Emission Test Methods	UCR, ERG, LINK	July 15, 2024
Task 1b: Review of Train-Related Exposure Studies, Research on Potential Health Impacts on the Near-Railroad Communities	UCI, ERG, LINK, SDSU	
Task 2: Identify Test Train Types and Associated Materials and Routes		
Task 2a: Assemble a Project Workgroup	UCR, ERG, LINK	December 15, 2024
Task 2b: Market Survey of Brake, Wheel, and Rail Materials and Identify Representative Trains by Operation Types in California	ERG, LINK, UCR	
Task 2c: Characterize California Train Operations	ERG, LINK, UCR	
Task 3: Collect Train Activity Data and Develop California BWWW Testing Cycles by Train Type		
Task 3a: Collect Train Activity Data	UCR, ERG, LINK	September 15, 2025
Task 3b: Characterize Train Activity Patterns	UCR, ERG, LINK	
Task 3c: Decide BWWW Testing Approach and Develop California BWWW Test Cycles for Each Train Type	UCR, ERG, LINK, UCI	
Task 4: Develop a BWWW PM Emission Sampling System and a Test Plan		
Task 4a: Develop a BWWW PM Emission Sampling System	UCR, ERG, LINK, SDSU	February 15, 2026

Task 4b: Conduct Pilot Tests	UCR, ERG, LINK, SDSU	
Task 4c: Develop a Chemical Analysis Plan for PM Samples	UCR, SDSU	
Task 4d: Develop a Full Test Plan	UCR, ERG, LINK, UCI, SDSU	
Task 5: Conduct Train BWWW Emission Measurements	UCR, LINK, SDSU	August 15, 2026
Task 6: Analyze Emission Data and Develop EFs		
Task 6a: Characterize BWWW Emissions by Train Type	UCR, ERG, LINK, UCI	October 15, 2026
Task 6b: Analyze PM Compositions	UCR, SDSU	
Task 6c: Develop BWWW PM Emission Factors	ERG, LINK, UCR	
Task 6d: Develop BWWW EF Simulation Tool	ERG, LINK	
Task 7: Evaluate Potential Health Risks to Near-Railroad Communities	UCI, ERG, UCR	October 15, 2026
Task 8: Evaluate Study Limitations, Assess Current Programs, and Suggest Future Steps	UCR, ERG, LINK, UCI, SDSU	October 15, 2026
Task 9: Reports and Public Research Seminar		
Task 9a: Draft Final Report	UCR, ERG, LINK, UCI, SDSU	June 15, 2027
Task 9b: Final Report	UCR, ERG, LINK, UCI, SDSU	
Task 9c: Public Research Seminar	UCR	
Other: Project Workgroup Meetings	UCR	Four in total or as needed
Other: Progress reports	UCR	Quarterly
End of contract		June 15, 2027

HEALTH AND SAFETY

Contractors are required to, at their own expense, comply with all applicable health and safety laws and regulations. Upon notice, Contractors are also required to comply with the state agency's specific health and safety requirements and policies. Contractors agree to include in any subcontract related to the performance of this Agreement a requirement that the subcontractor comply with all applicable health and safety laws and regulations and, upon notice, the state agency's specific health and safety requirements and policies.

References

Abu-Allaban, M., Gillies, J.A., Gertler, A.W., Clayton, R., Proffitt, D. “Tailpipe, re-suspended road dust, and brake wear emission factors from on-road vehicles,” Atmospheric Environment, 37(1),5283-5293, https://doi.org/10.1016/j.atmosenv.2003.05.005

Amato, F., Pandolfi, M., Moreno, T., Furger, M., Pey, J., Alastuey, A., Bukowiecki, N., Prevot, A.S.H., Baltensperger, H., Querol, X. “Sources and variability of inhalable road dust particles in three European cities,” Atmospheric Environment, 45(37), 2011, 6777-6787, https://doi.org/10.1016/j.atmosenv.2011.06.003

Benson P, CALINE4: A Dispersion Model for Predicting Air Pollutant Concentrations Near Roadways. 1989, California Department of Transportation: Sacramento, CA.

California State Geoportal. Unlocking the Power of Government Data. 2024 [cited 2024 March 3rd]; Available from: https://gis.data.ca.gov/

Cheng I, Tseng C, Wu J, Yang J, Conroy SM, Shariff-Marco S, Li LF, Hertz A, Gomez SL, Le Marchand L, Whittemore AS, Stram DO, Ritz B, and Wu AH, Association between ambient air pollution and breast cancer risk: The multiethnic cohort study. International Journal of Cancer, 2020. 146(3): p. 699-711.

Cho, A.K., Sioutas, C., Miguel, A.H., Kumagai, Y., Schmitz, D.A., Singh, M., Eiguren-Fernandez, A., Froines, J.R. “Redox activity of airborne particulate matter at different sites in the Los Angeles Basin,” Environmental Research 2005, 99, 40-47, https://doi.org/10.1016/j.envres.2005.01.003

Councell T.B., Duckenfield K.U., Landa, E.R., Callender, E. “Tire-wear particles as a source of 476 zinc to the environment,” Environ. Sci. Technol 38:4206-4214, https://doi.org/10.1021/es034631f

Dahl, A., Gharibi, A., Swietlicki, E., Gudmundsson, A., Bohgard, M., Ljungman, A., Blomqvist, G., Gustafsson, M., “Traffic-generated emissions of ultrafine particles from pavement–tire interface,” Atmospheric Environment, 40(7), 2006, 1314-1323, https://doi.org/10.1016/j.atmosenv.2005.10.029

Fruhwirt et al. PM emissions from railways – Results of tests on a wheel-rail test bench. Transportation Research Part D: Transport and Environment 2023, 122, 103858.

Garg, B.D., Cadle, S.H., Mulawa, P.A., Groblicki, P.J., Laroo, C., Parr, G.A., “Brake Wear Particulate Matter Emissions,” Environ. Sci. Technol 35: 4463-4469, https://doi.org/10.1021/es001108h

Gysel N., Dixit P., Schmitz D.A., Engling G., Cho A.K., Cocker D.R., Karavalakis, G. “Chemical speciation, including polycyclic aromatic hydrocarbon (PAHs), and toxicity of particles emitted from meat cooking operations,” Science of the Total Environment 2018, 633, 1429-1436, https://doi.org/10.1016/j.scitotenv.2018.03.318

Han L., Zhuang G., Cheng S., Wang Y., Li, J. “Characteristics of re-suspended road dust and its impact on the atmospheric environment in Beijing,” Atmospheric Environment, 41(35), 7485-7499, https://doi.org/10.1016/j.atmosenv.2007.05.044

Health Effects Institute (HEI). (2010). Traffic-related air pollution: a critical review of the Literature on Emissions, Exposure, and Health Effects. HEI Special Report 17. Health Effects Institute, Boston, MA.

Heck JE, Wu J, Lombardi C, Qiu JH, Meyers TJ, Wilhelm M, Cockburn M, and Ritz B, Childhood Cancer and Traffic-Related Air Pollution Exposure in Pregnancy and Early Life. Environmental Health Perspectives, 2013. 121(11-12): p. 1385-1391.

Hesse, D., Augsburg, K., Feißel, T. “Real Driving Emissions Measurement of Brake Dust Particles.” Eurobrake Conference 2019

Huber, M.P., Mamakos, A., Hofbauer, M., et al. “Real Driving Emissions Sampling System for Brake Wear Particle Measurement.” EuroBrake 2022

Kampa, M. and Castanas, E. “Human health effects of air pollution,” Environmental Pollution, 151(2), 362–367. https://doi.org/10.1016/j.envpol.2007.06.012

Kind AJH and Buckingham WR, Making Neighborhood-Disadvantage Metrics Accessible - The Neighborhood Atlas. N Engl J Med, 2018. 378(26): p. 2456-2458.

Klöckner, P., Seiwert, B., Weyrauch, S., Escher, B. I., Reemtsma, T., Wagner, S. “Comprehensive characterization of tire and road wear particles in highway tunnel road dust by use of size and density fractionation,” Chemosphere, 2021, 279, 130530. https://doi.org/10.1016/j.chemosphere.2021.130530

Kupiainen, K.J. and Pirjola, L. “Vehicle non-exhaust emissions from the tyre–road interface – effect of stud properties, traction sanding and resuspension,” Atmospheric Environment, 45(25), 4141-4146, https://doi.org/10.1016/j.atmosenv.2011.05.027

Kwon D, Paul KC, Yu Y, Zhang KR, Folle AD, Wu J, Bronstein JM, and Ritz B, Traffic-related air pollution and Parkinson's disease in central California. Environmental Research, 2024. 240.

Lee, E., Sahay, K., O’Neil, E., Na, K., Biswas, S., Dzhema, I., Lin, P., Chang, O., Huai, T. “Evaluation of Heavy-Duty Vehicle Brake-Wear Emissions using a Chassis Dynamometer.” Presentation at the 30th CRC Real World Emissions Workshop (March 8-11, 2021)

Masri S, LeBrón A, Logue M, Valencia E, Ruiz A, Reyes A, Lawrence JM, and Wu J, Social and spatial distribution of soil lead concentrations in the City of Santa Ana, California: Implications for health inequities. Science of the Total Environment, 2020. 743.

Masri S, LeBrón AMW, Logue MD, Valencia E, Ruiz A, Reyes A, and Wu J, Risk assessment of soil heavy metal contamination at the census tract level in the city of Santa Ana, CA: implications for health and environmental justice. Environmental Science-Processes & Impacts, 2021a. 23(6): p. 812-830.

Masri S, Scaduto E, Jin YF, and Wu J, Disproportionate Impacts of Wildfires among Elderly and Low-Income Communities in California from 2000-2020. International Journal of Environmental Research and Public Health, 2021b. 18(8).

Masri S, Jin YF, and Wu J, Compound Risk of Air Pollution and Heat Days and the Influence of Wildfire by SES across California, 2018-2020: Implications for Environmental Justice in the Context of Climate Change. Climate, 2022. 10(10).

Masri S, Flores L, Rea J, and Wu J, Race and Street-Level Firework Legalization as Primary Determinants of July 4th Air Pollution across Southern California. Atmosphere, 2023. 14(2).

McCaffery C., Durbin T.D., Johnson K.C., Karavalakis G. "The effect of ethanol and iso-butanol on polycyclic aromatic hydrocarbon (PAH) emissions from PFI and GDI vehicles,” Atmospheric Pollution Research 2020, 11, 2056-2067. https://doi.org/10.1016/j.apr.2020.08.024

McCaffery C., Zhu H., Ahmed C.M.S., Canchola A., Chen J.Y., Li C., Johnson K.C., Durbin T.D. Lin Y.H., Karavalakis, G. “Effects of hydrogenated vegetable oil (HVO) and HVO/biodiesel blends on the physicochemical and toxicological properties of emissions from an off-road heavy-duty diesel engine,” Fuel 2022, 323, 124283. https://doi.org/10.1016/j.fuel.2022.124283

McCaffery C., Zhu H., Tang, T., Li C., Karavalakis, G., Cao S., Oshinuga A., Burnette A., Johnson K.C., Durbin T.D. "Real-world NOx emissions from heavy-duty diesel, natural gas, and diesel hybrid electric vehicles of different vocations on California roadways," Science of the Total Environment 2021, 784, 147224. https://doi.org/10.1016/j.scitotenv.2021.147224

McCaffery, C.; Zhu H., Li C., Durbin T.D., Johnson K.C., Jung H., Brezny R., Geller M., Karavalakis, G. "On-road gaseous and particulate emissions from GDI vehicles with and without gasoline particulate filters (GPFs) using portable emissions measurement systems (PEMS)," Science of the Total Environment 2020, 710, 136366. https://doi.org/10.1016/j.scitotenv.2019.136366

Miller, M. R., Raftis, J. B., Langrish, J. P., McLean, S. G., Samutrtai, P., Connell, S. P., Wilson, S., Vesey, A. T., Fokkens, P. H. B., Boere, A. J. F., Krystek, P., Campbell, C. J., Hadoke, P. W. F., Donaldson, K., Cassee, F. R., Newby, D. E., Duffin, R., Mills, N. L. "Inhaled Nanoparticles Accumulate at Sites of Vascular Disease," ACS Nano 11(5), 4542–4552. https://doi.org/10.1021/acsnano.6b08551

Nelson RK, Winling, L,. Mapping Inequality: Redlining in New Deal America. 2024 [cited 2024 March 3rd]; Available from: https://dsl.richmond.edu/panorama/redlining

OEHHA, CalEPA Human-Exposure-Based Screening Numbers Developed to Aid Estimation of Cleanup Costs for Contaminated Soil. 2005, California Office of Environmental Health Hazard Assessment: Sacramento, CA.

Office of Environmental Health Hazard Assessment and California Environmental Protection Agency, CalEnviroScreen 4.0., Agency O.o.E.H.H.A.a.C.E.P., Editor. 2024.

Ortiz, A. G., Guerreiro, C., de Leeuw, F. Air quality in Europe — 2019 report (Issue 5). https://doi.org/10.2800/822355

Paul KC, Haan M, Yu Y, Inoue K, Mayeda ER, Dang K, Wu J, Jerrett M, and Ritz B, Traffic-Related Air Pollution and Incident Dementia: Direct and Indirect Pathways Through Metabolic Dysfunction. Journal of Alzheimers Disease, 2020. 76(4): p. 1477-1491.

Perrenoud, A., Gasser, M., Rothen-Rutishauser, B., Gehr, P., and Riediker, M. "Characterisation of Nanoparticles Resulting from Different Braking Behaviours," Int. J. Biomed. Nanosci. Nanotechnol., 1:17–33. https://doi.org/10.1504/IJBNN.2010.034123

Pirjola, L.; Kupiainen, K.J.; Perhoniemi, P.; Tervahattu, H.; Vesala, H., "Non-exhaust emission measurement system of the mobile laboratory SNIFFER," Atmospheric Environment, 43(31), 4703-4713, https://doi.org/10.1016/j.atmosenv.2008.08.024

Ritz B, Yan Q, He D, Wu J, Walker DI, Uppal K, Jones DP, and Heck JE, Child serum metabolome and traffic-related air pollution exposure in pregnancy. Environmental Research, 2022. 203.

Rizza, V., Stabile, L., Vistocco, D., Russi, A., Pardi, S., Buonanno, G. "Effects of the exposure to ultrafine particles on heart rate in a healthy population," Science of the Total Environment, 650, 2403-2410. https://doi.org/10.1016/j.scitotenv.2018.09.385

Sadiktsis, I., Bergvall, C., Johansson, C., Westerholm, R. "Automobile Tires—A Potential Source of Highly Carcinogenic Dibenzopyrenes to the Environment," Environ. Sci. Technol 46:3326-3334 https://doi.org/10.1021/es204257d

Sanders, P.G., Xu, N., Dalka, T.M., Maricq, M.M., "Airborne Brake Wear Debris: Size Distributions, Composition, and a Comparison of Dynamometer and Vehicle Tests," Environ. Sci. Technol 37:4060-4069, https://doi.org/10.1021/es034145s

Shafer, M.M., Hemming, J.D.C., Antkiewicz, D.S., Schauer, J.J., “Oxidative potential of size-fractionated atmospheric aerosol in urban and rural sites across Europe.” Faraday Discuss. 2016, 189, 381.

Southern California Association of Governments, 2019 Annual Land Use, Governments S.C.A.o., Editor. 2024.

Sun Y, Mousavi A, Masri S, and Wu J, Socioeconomic Disparities of Low-Cost Air Quality Sensors in California, 2017-2020. American Journal of Public Health, 2022. 112(3): p. 434-442.

Sun Y, Wang XZ, Zhu JY, Chen LJ, Jia YH, Lawrence JM, Jiang LH, Xie XH, and Wu J, Using machine learning to examine street green space types at a high spatial resolution: Application in Los Angeles County on socioeconomic disparities in exposure. Science of the Total Environment, 2021. 787.

University of Wisconsin School of Medicine and Public Health, Area Deprivation Index. 2024.

USEPA. Integrated Risk Information System (IRIS): IRIS Chemicals. 2024 [cited 2024 March 5]; Available from: https://comptox.epa.gov/dashboard/chemical_lists/IRIS.

Wu J, Ren C, Delfino RJ, Chung J, Wilhelm M, and Ritz B, Association between local traffic-generated air pollution and preeclampsia and preterm delivery in the south coast air basin of California. Environ Health Perspect, 2009a. 117(11): p. 1773-9.

Wu J, Houston D, Lurmann F, Ong P, and Winer A, Exposure of PM2.5 and EC from diesel and gasoline vehicles in communities near the Ports of Los Angeles and Long Beach, California. Atmospheric Environment, 2009b. 43(12): p. 1962-1971.

Wu J, Houston D, Lurmann F, Ong P, and Winer A, Exposure of PM2.5 and EC from diesel and gasoline vehicles in communities near the Ports of Los Angeles and Long Beach, California. Atmospheric Environment, 2009c. 43(12): p. 1962-1971.

Wu J, Ren CZ, Delfino RJ, Chung J, Wilhelm M, and Ritz B, Association between Local Traffic-Generated Air Pollution and Preeclampsia and Preterm Delivery in the South Coast Air Basin of California. Environmental Health Perspectives, 2009d. 117(11): p. 1773-1779.

Wu J, Laurent O, Li L, Hu J, and Kleeman M, Adverse Reproductive Health Outcomes and Exposure to Gaseous and Particulate-Matter Air Pollution in Pregnant Women. Res Rep Health Eff Inst, 2016. 2016(188): p. 1-58.

Yang J., Roth P., Durbin T.D., Johnson K.C. Cocker D.R., Asa-Awuku A., Brezny R., Geller M., Karavalakis, G. “Gasoline particulate filters as an effective tool to reduce particulate and polycyclic aromatic hydrocarbon emissions from gasoline direct injection (GDI) vehicles: a case study with two GDI vehicles,” Environ. Sci. Technol 52:3275-3284, https://doi.org/10.1021/acs.est.7b05641

Yan Q, Liew Z, Uppal K, Cui X, Ling CX, Heck JE, von Ehrenstein OS, Wu J, Walker DI, Jones DP, and Ritz B, Maternal serum metabolome and traffic-related air pollution exposure in pregnancy. Environment International, 2019. 130.

Yuan Y, Zhu Y, and Wu J, Vehicular emitted ultrafine particle concentration and exposure spatial profile in Corpus Christi, Texas. Environmental Modeling and Assessment, 2011. 6: p. Article 8.

Yu Y, Paul K, Arah OA, Mayeda ER, Wu J, Lee E, Shih IF, Su J, Jerrett M, Haan M, and Ritz B, Air pollution, noise exposure, and metabolic syndrome - A cohort study in elderly Mexican-Americans in Sacramento area. Environment International, 2020a. 134.

Yu Y, Haan M, Paul KC, Mayeda ER, Jerrett M, Wu J, Lee E, Su J, Shih IF, Inoue K, and Ritz BR, Metabolic dysfunction modifies the influence of traffic-related air pollution and noise exposure on late-life dementia and cognitive impairment: A cohort study of older Mexican-Americans. Environmental Epidemiology, 2020b. 4(6).

Zhang, Y., Xu, C., Zhang, W., Qi, Z., Song, Y., Zhu, L., Dong, C., Chen, J., Cai, Z. “p-Phenylenediamine Antioxidants in PM2.5: The Underestimated Urban Air Pollutants,” Environ. Sci. Technol 56:6914-6921, https://doi.org/10.1021/acs.est.1c04500

Zum Hagen, F.H.F., Mathissen, M., Grabiec, T., Hennicke, T., Rettig, M., Grochowicz, J., Vogt, R., Benter, T., “On-road vehicle measurements of brake wear particle emissions,” Atmospheric Environment, Volume 217, 2019, 116943, https://doi.org/10.1016/j.atmosenv.2019.116943

EXHIBIT A1

SCHEDULE OF DELIVERABLES

List all items that will be delivered to the State under the proposed Scope of Work. Include all reports, including draft reports for State review, and any other deliverables, if requested by the State and agreed to by the Parties.

If use of any Deliverable is restricted or is anticipated to contain preexisting Intellectual Property with any restricted use, it will be clearly identified in Exhibit A4, Use of Preexisting Intellectual Property & Data.

Unless otherwise directed by the State, the University Principal Investigator shall submit all deliverables to State Contract Project Manager, identified in Exhibit A3, Authorized Representatives.

Deliverable	Description	Due Date
Initial Meeting	Principal Investigator and key personnel will meet with CARB Contract Project Manager and other staff to discuss the overall plan, details of performing the tasks, project schedule, items related to personnel or changes in personnel, and any issues that may need to be resolved before work can begin.	Month 1
Task 1 Literature review	Report reviewing train emissions research and studies, existing operation duty cycles, conventional and advanced engines, and brake and wheel technologies.	Month 2
Task 2 Identify Test Train Types and Associated Materials and Routes	Complete assembly of project workgroup. Report describing brake, wheel, rail, and associated technologies used for different types of trains in California. Report describing operations for representative types of trains in California.	Month 7
Task 3 Report describing operations for representative types of trains in California.	Interim Report #1 (including all results and information collected from Tasks. Interim Report #1 (including all results and information collected from Tasks. Activity patterns for each California representative train type. Report describing operations for representative types of trains in California.	Month 16
Task 4 Develop a BWWW PM Emission Sampling System and a Test Plan	A sampling system for measuring train BWWW PM emissions separately. Pilot test results. Sample analysis plan including testing protocols and procedures. Full test plan.	Month 21
Task 5 Conduct Train BWWW Emission Measurements	Raw data collection.	Month 27
Task 6 Analyze Emission Data and Develop EFs	Interim Report #2 (including all QA/QC data collected, analysis results, and information collected from Tasks 4-6). Report (including table and graphs profiling BWWW PM emissions, including particle concentration, mass, and size distributions.). Chemical analysis report. Corrected and adjusted BWWW PM emission factors. Computer simulation tool to estimate BWWW PM EFs that is applicable for different train types.	Month 29

Task 7 Evaluate Potential Health Risks to Near-Railroad Communities	Report discussing exposure level and any potential health risks to near-railroad communities from train BWWW PM emissions.	Month 29
Task 8 Evaluate Study Limitations, Assess Current Programs, and Suggest Future Steps	Report discussing limitations of this research, the next steps, and potential BWWW reduction technologies. Summary of community concerns, assessment of current programs and policies, and future suggestions.	Month 29
The following Deliverables are subject to paragraph 19. Copyrights, paragraph B of Exhibit C		
Task 9 Final Report	Written record of the project and its results. The Final Report shall be submitted in an Americans with Disabilities Act compliant format. The Public Outreach Document, as described in Exhibit A1, Section 2, shall be incorporated into the Final Report.	Month 36 to 37

EXHIBIT A2

KEY PERSONNEL

Last Name, First Name	Institutional Affiliation	Role on Project
Principal Investigator (PI):		
Karavalakis, Georgios	UCR	Project management, supervision, technical communications with CARB and project partners, sampling system design, data analysis, and final reporting
Co-PI(s) – if applicable:		
Toumasatos, Zisimos	UCR	Co-PI, Supervision and project administration, sampling system design, experimental setup, data analysis, and final reporting
Agudelo, Carlos	Link	Co-PI, providing technical support across all project tasks, perform laboratory testing and data analysis
Koupal, John	ERG	Co-PI, Development of emission factors, data analysis, technical support across all project tasks
Wu, Jun	UCI	Co-PI, emissions exposure analysis, evaluation of potential health risks
Li, Hanyang	San Diego State University	Co-PI, near-real-time metals measurements and data analysis

EXHIBIT A3

AUTHORIZED REPRESENTATIVES & NOTICES

The following individuals are the authorized representatives for the State and the University under this Agreement. Any official Notices issued under the terms of this Agreement shall be addressed to the Authorized Official identified below, unless otherwise identified in the Agreement.

State Agency Contacts Agency Name: **CARB**	**University Contacts** University Name:
Contract Project Manager (Technical) Name: Address: Research Division 1001 I Street, 7th Floor Sacramento, CA 95814 Telephone: (916) Email: @arb.ca.gov	***Principal Investigator (PI)*** Name: Georgios Karavalakis Address: CE-CERT 1084 Columbia Avenue Riverside, CA 92507 Telephone: Email: georgios.karavalakis@ucr.edu Designees to certify invoices under Section 14 of Exhibit C on behalf of PI: 1. Sara Connor, Financial Manager, CE-CERT, sara.connor@ucr.edu
Authorized Official (contract officer) Name: Alice Kindarara, Chief Address: Acquisitions Branch 1001 I Street, 19th Floor Sacramento, CA 95814 ***Send notices to (if different):*** Name: Address: Research Division 1001 I Street, 7th Floor Sacramento, CA 95814 Telephone: (916) Email: @arb.ca.gov	***Authorized Official*** Name: Ursula Prins PreAward Manager Address: Office of Research and Economic Development 245 University Office Building Riverside, CA 92521 Telephone: 951-827-4968 Email: ursulau.prins@ucr.edu

Administrative Contact Name: Address: Research Division 1001 I Street, 7th Floor Sacramento, CA 95814 Telephone: (916) Email: @arb.ca.gov	***Administrative Contact*** Name: Sara Connor Financial Manager Address: CE-CERT 1084 Columbia Avenue Riverside, CA 92507 Telephone: 951-781-5745 Email: sara.connor@ucr.edu
Financial Contact/Accounting Name: Accounts Payable Address: P.O. Box 1436 Sacramento, CA 95814 Email: AccountsPayable@arb.ca.gov **Send courtesy copy to:** rd.invoices@arb.ca.gov	***Authorized Financial Contact/Invoicing*** Name: Frances Marin Post Award Accounting Manager Address: 900 University Ave. Riverside, CA 92521-0001 Telephone: 951-827-1954 Email: Frances.Marin@ucr.edu 1. Designees for invoice certification in accordance with Section 14 of Exhibit C on behalf of the Financial Contact: Patrice Delgado, patrice.delgado@ucr.edu

EXHIBIT A4

USE OF PREEXISTING INTELLECTUAL PROPERTY & DATA

A. State: Preexisting Intellectual Property (IP)/Data to be provided to the University from the State or a third party for use in the performance in the Scope of Work.

☒ None

B. University: Restrictions in Preexisting IP/Data included in Deliverables identified in Exhibit A1, Deliverables.

☒ None

C. Anticipated restrictions on use of Project Data.
If the University PI anticipates that any of the Project Data generated during the performance of the Scope of Work will have a restriction on use (such as subject identifying information in a data set), then list all such anticipated restrictions below. If there are no restrictions anticipated in the Project Data, then check "none" in this section.

☒ None

EXHIBIT A5

RÉSUMÉ / BIOSKETCH

Georgios Karavalakis

Professor
Chemical & Environmental Engineering Department and CE-CERT
CE-CERT 022, University of California, Riverside, CA 92521-0434, georgios@ucr.edu

Professional Preparation

University of Portsmouth, UK, Bachelors (BEng Hons) in Engineering	2000
University of Portsmouth, UK, Master in Science (MSc), Environmental Engineering	2001
National Technical University of Athens, Greece, Ph.D. in Chemical Engineering	2009

Academic Appointments

2022-present: Professor, Bourns College of Engineering, Chemical and Environmental Engineering Department, University of California, Riverside
2021-2022: Adjunct Professor, Bourns College of Engineering, Chemical and Environmental Engineering Department, University of California, Riverside
2015-2021: Associate Adjunct Professor, Bourns College of Engineering, Chemical and Environmental Engineering Department, University of California, Riverside
2013-2015: Assistant Adjunct Professor, Bourns College of Engineering, Chemical and Environmental Engineering Department, University of California, Riverside
2021-present: Research Engineer (Research Faculty), Bourns College of Engineering, Center for Environmental Research and Technology (CE-CERT), University of California, Riverside, Riverside, California
2010-2014: Assistant Research Engineer II, University of California, Riverside, Bourns College of Engineering-Center for Environmental Research and Technology
2002-2009: Research Fellow, Laboratory of Fuels Technology and Lubricants, School of Chemical Engineering, National Technical University of Athens.

Non-Academic Appointments

2021-2023: Consultant, Yorke Engineering, LLC (Technical consulting and auditing services for commercial vehicle fleets not meeting the EPA emissions standards)
2007-2010: Elin Biofuels SA, Volos, Greece. Consulting Engineer.

Current Memberships in Professional Organizations

Society of Automotive Engineering (SAE)
American Association of Aerosol Research (AAAR)

Selected Publications (past 5 years)

(of more than 95 publications in refereed journals)

Ghadimi S., Zhu H., Durbin T.D., Cocker D.R., Karavalakis G. The impact of hydrogenated vegetable oil (HVO) on the formation of secondary organic aerosol (SOA) from in-use heavy-duty diesel vehicles. Science of the Total Environment 2022, 822, 153583.

Peng W., McCaffery C., Kuittinen N., Rönkkö T., R. Cocker D.R., Karavalakis G. Secondary organic and inorganic aerosol formation from a GDI vehicle under different driving conditions. Atmosphere 2022, 13, 433.

McCaffery C., Zhu H., Tang T., Li C., Karavalakis G., Cao S., Adewale Oshinnuga O., Burnette A., Johnson K.C., Durbin T.D. Real-World NOx Emissions from Heavy-Duty Diesel, Natural Gas, and Diesel Hybrid Electric Vehicles of Different Vocations in California Roadways. Science of the Total Environment 2021, 784, 147224.

Kuittinen N., McCaffery C., Zimmerman S., Bahreini R., Simonen P., Karjalainen P., Keskinen J., Rönkkö T., Karavalakis G. Using an oxidation flow reactor to understand the effects of gasoline aromatics and ethanol levels on secondary aerosol formation. Environmental Research 2021, 200, 111453.

McCaffery C., Zhu H., Karavalakis G., Durbin T.D., Miller J.W., Johnson K.C. Sources of air pollutants from a Tier 2 ocean-going container vessel: Main engine, auxiliary engine, and auxiliary boiler. Atmospheric Environment 2021, 245, 118023.

Kuittinen N., McCaffery C., Peng W., Zimmerman S., Roth P., Simonen P., Karjalainen P., Keskinen J., Cocker D.R., Durbin T., Rönkkö T., Bahreini R., Karavalakis G. Effects of driving conditions on secondary aerosol formation from a GDI vehicle using an oxidation flow reactor. Environmental Pollution 2021, 282, 117069.

Roth P., Yang J., Peng W., Cocker III D.R., Durbin T.D., Asa-Awuku A, Karavalakis G. Intermediate and high ethanol blends reduce secondary organic aerosol formation from gasoline direct injection vehicles. Atmospheric Environment 2020, 220, 117064.

Sabbir Ahmed C.M., Yang J., Chen J.Y., Jiang H., Cullen C., Karavalakis G., Lin Y-H. Toxicological responses in human airway epithelial cells (BEAS-2B) exposed to particulate matter emissions from gasoline fuels with varying aromatic and ethanol levels. Science of the Total Environment 2020, 706, 135732.

Yang J., Roth P., Durbin T., Karavalakis G. Impacts of Gasoline Aromatic and Ethanol Levels on the Emissions from GDI Vehicles: Part 2. Influence on Particulate Matter, Black Carbon, and Nanoparticle Emissions. Fuel 2019, 252, 812-820

Zisimos Toumasatos
Ph.D. Mechanical Engineer, Post-Doc Researcher, Center for Environmental Research & Technology
CE-CERT, University of California, Riverside, CA 92521-0434

Education

Aristotle University of Thessaloniki, Greece, Diploma in Mechanical Engineering 2014

International Hellenic University, Master, MSc, Greece, Oil and Gas Technology 2022

Aristotle University of Thessaloniki, Greece, Ph.D. in Mechanical Engineering 2022

Appointments

November 2023 - present

Assistant Researcher Engineer Step II

Bourns College of Engineering, Center for Environmental Research and Technology (CE-CERT), University of California, Riverside, Riverside, California

July 2022 – November 2023

Post-Doc Researcher

Bourns College of Engineering, Center for Environmental Research and Technology (CE-CERT), University of California, Riverside, Riverside, California

2017–2022

Freelancer Engineer and PhD research candidate in the Laboratory of Applied Thermodynamics (LAT) in Mechanical Engineering Department of Aristotle University of Thessaloniki (AUTH)

2016-2017

Staff of the armed forces, Hellenic Army (Greece) Military service as Second Lieutenant Reserve Officer in NATO Hellenic Army

2013–2015

Mechanical engineer, Research Assistant in the Laboratory of Applied Thermodynamics (LAT) worked on NEDC/WLTP correlation exercise project for efficient automotive fuel consumption measurements

Scholarships

‘IKY’ scholarship support program for PhD studies

Selected Publications

Zisimos Toumasatos, Anastasios Kontses, Stylianos Doulgeris, Zissis Samaras & Leonidas Ntziachristos (2021) Particle emissions measurements on CNG vehicles focusing on Sub-23nm, Aerosol Science and Technology, 55:2, 182-193, DOI: https://doi.org/10.1080/02786826.2020.1830942

Z. Toumasatos, A. Raptopoulos-Chatzistefanou, D. Kolokotronis, P. Pistikopoulos, Z. Samaras, L. Ntziachristos, The role of the driving dynamics beyond RDE limits and DPF regeneration events on pollutant emissions of a Euro 6d-temp passenger vehicle, Journal of Aerosol Science, Volume 161, 2022, 105947, ISSN 0021-8502, https://doi.org/10.1016/j.jaerosci.2021.105947

Toumasatos, Zisimos and Corsetti, Corrado and Kontses, Anastasios and Raptopoulos-Chatzistefanou, Anastasios and Beatrice, Carlo and Samaras, Zissis and Ntziachristos, Leonidas, Recommendations for Emission Testing and Control of Exhaust Particles from a Late Technology

Bi-Fuel Cng Vehicle. Available at SSRN: https://ssrn.com/abstract=4355488 or http://dx.doi.org/10.2139/ssrn.4355488 Journal of Aerosol Science (under review, pre-print version

Stylianos Doulgeris, **Zisimos Toumasatos**, Maria Vittoria Prati, Carlo Beatrice and **Zissis Samaras** * Assessment and design of real world driving cycles targeted to the calibration of vehicles with electrified powertrain. International Journal of Engine Research, 2021 1–16
https://doi.org/10.1177/14680874211038729

Samaras, Z., Andersson, J., Bergmann, A., Hausberger, S., **Toumasatos, Z**., et al., "Measuring Automotive Exhaust Particles Down to 10 nm," SAE Int. J. Adv. & Curr. Prac. in Mobility 3(1):539-550, 2021, https://doi.org/10.4271/2020-01-2209.

Doulgeris, A. Dimaratos, N. Zacharof, **Z. Toumasatos**, D. Kolokotronis, Z. Samaras, Real world fuel consumption prediction via a combined experimental and modeling technique, Science of The Total Environment, Volume 734, 2020, 139254, ISSN 0048-9697, https://doi.org/10.1016/j.scitotenv.2020.139254

Stefanos Tsiakmakis, Dimitrios Mertzis, Athanasios Dimaratos, **Zisimos Toumasatos**, Zissis Samaras, Experimental study of combustion in a spark ignition engine operating with producer gas from various biomass feedstocks, Fuel, Volume 122, 2014, Pages 126-139, ISSN 0016-2361, https://doi.org/10.1016/j.fuel.2014.01.013

Synergistic Activities

- • Member of the Society of Automotive Engineering (SAE)
- • Society of Petroleum Engineers (SPE)
- • Technical Chambers of Greece
- • Reviewer for the Journals: Atmosphere (MDPI, Impact Factor: 3.110), Catalyst (MDPI, Impact Factor: 4.501), Energies, Energy and Environment Section (MDPI, Impact Factor: 3.252) and Vehicles (MDPI)

Carlos Agudelo

Director Applications Engineering

Link Engineering Company

43855 Plymouth Oaks Blvd., Plymouth, MI 48170,

Professional Preparation

EAFIT University, Colombia, Bachelors, Production Engineering, 1988
Universidad de Antioquia, Colombia, Special Studies, Finance and Project Management, 1992
Smarter Solutions Inc., TX, Six Sigma Black Belt, 2007

Appointments

2023-present: ISO/TC 31/WG 13/ISO 18511 on Tyre Abrasion Rate Measurement Methods (outdoor and indoor)

- Technical input related to the in-vehicle convoy and indoor drum testing methods
- Adaptation of simulation tools and implementation of Euro 7 cycle for C1 tires
- Internal liaison with mechanical, controls, software, and test engineering for indoor drum method for C1 tires
- Liaison with customers regarding the development of C1 tires, including special systems for tire emissions measurement

ISO/TC 269/SC 2/WG 12/ISO 19341 Measurement methods of particle emission from braking on a railway test bench

- Technical input related to brake dynamometer technology applied to brake emissions
- Liaison to UNECE GTR 24 task forces
- Internal liaison to mechanical, controls, and non-exhaust engineering to upgrade rail brake dynamometers

2022-present: Liaison to UNECE Working Party on Noise and Tyres

- Technical lead to develop Euro 7 circuit for C1 tires in Europe
- Internal alignment with ISO/TC 31/WG 13/ISO 18511 Working Group

2017-present: Liaison to UNECE Working Parties Energy and Pollution – Non-Exhaust Brake Emissions

- TF1 on WLTP-Brake cycle
- TF2 on GRPE 83-40 and GTR 24 laboratory test method
- TF3 on interlaboratory studies ILS1, ILS2, and ILS 3, including application of statistical methods for repeatability, reproducibility, capability, and measurement uncertainty
- TF5 on commercial vehicle brake emissions

2017-present: Liaison to CARB and EPA for Non-Exhaust measurements and development of testing methods

- Light vehicle proving ground thermal assessment and lab brake emissions measurements
- Heavy vehicles proving ground thermal assessment and lab brake emissions measurements
- Light and heavy vehicle brake and tire on-road emissions measurements

2017-2024: Chair SAE Vehicle Dynamics Standards Committee, U.S.

2016-2024: Chair SAE Brake Dynamometer Standards Committee, U.S.

2012-present: Director Applications Engineering, Link Engineering Co. Plymouth, MI

2012-2014 Startup and ISO 17025 accreditation for copper, asbestiform fibers, and heavy metals per SAE J2975 (Better Brake rule from the States of California and Washington)

2008-2012: Chief Engineer Laboratory Testing, Link Testing Co., Detroit, MI

2001-2008: Engineering Manager Laboratory Testing, Link Testing Co., Detroit, MI

2001: Lead Test Engineer, Link Testing Co., Detroit, MI

1997-2000: General Manager, Mafriccion S.A., Medellin, Colombia

1993-1997: Corporate Strategy Division, Suramericana de Seguros, Medellin, Colombia

1990-1993: Process and Mechanical Engineering, Mafriccion S.A., Medellin, Colombia

Relevant Publications (SAE and EuroBrake Colloquium presentations and papers not included)

1. **Agudelo, Carlos**, Hartmut Niemann, Frederik Weis, and Alejandro Hortet. "Uncertainty of PM2. 5 and PM10 Sampling per EN12341 Applied to Brake Emissions Lab Measurements." In *International µ-Symposium Brake Conference*, pp. 147-172. Berlin, Heidelberg: Springer Berlin Heidelberg, 2023.
2. Mathissen, Marcel, Theodoros Grigoratos, Sebastian Gramstat, Athanasios Mamakos, RaviTeja Vedula**, Carlos Agudelo**, Jaroslaw Grochowicz, and Barouch Giechaskiel. "Interlaboratory Study on Brake Particle Emissions Part II: Particle Number Emissions." *Atmosphere* 14, no. 3 (2023): 424.
3. Grigoratos, Theodoros, Marcel Mathissen, RaviTeja Vedula, Athanasios Mamakos, **Carlos Agudelo**, Sebastian Gramstat, and Barouch Giechaskiel. "Interlaboratory Study on Brake Particle Emissions—Part I: Particulate Matter Mass Emissions." *Atmosphere* 14, no. 3 (2023): 498.
4. Grigoratos, T., Mamakos, A., Arndt, M., Lugovyy, D., Anderson, R., Hafenmayer, C., Moisio, M., Vanhanen, J., Frazee, R., **Agudelo, C**. and Giechaskiel, B., 2023. Characterization of particle number setups for measuring brake particle emissions and comparison with exhaust setups. *Atmosphere*, 14(1), p.103.
5. Koupal, John, Allison DenBleyker, Sandeep Kishan, Ravi Vedula, **Carlos Agudelo**, and Eastern Research Group. *Brake Wear Particulate Matter Emissions Modeling*. No. CA21-3232. California. Dept. of Transportation. Division of Research and Innovation, 2021.
6. **Agudelo, Carlos**, Ravi Teja Vedula, Sonya Collier, and Alan Stanard. "Brake Particulate Matter Emissions Measurements for Six Light-Duty Vehicles Using Inertia Dynamometer Testing." *SAE International Journal of Advances and Current Practices in Mobility* 3, no. 2020-01-1637 (2020): 994-1019.
7. Grigoratos, Theodoros, **Carlos Agudelo**, Jaroslaw Grochowicz, Sebastian Gramstat, Matt Robere, Guido Perricone, Agusti Sin et al. "Statistical assessment and temperature study from the interlaboratory application of the WLTP–brake cycle." *Atmosphere* 11, no. 12 (2020): 1309.
8. **Agudelo, Carlos**, Ravi Teja Vedula, Jesse Capecelatro, and Qingquan Wang. *Design of Experiments for Effects and Interactions during Brake Emissions Testing Using High-Fidelity Computational Fluid Dynamics*. No. 2019-01-2139. SAE Technical Paper, 2019.

Agudelo, Carlos, Ravi Teja Vedula, and Tyler Odom. *Estimation of transport efficiency for brake emissions using inertia dynamometer testing*. No. 2018-01-1886. SAE Technical Paper, 2018.

Dr.-Ing. Hartmut Niemann
Research Application Engineer

Link Engineering Company

Am Fleckenberg 10, 65549 Limburg, Germany,

Professional Preparation

Research Associate, Technical University Darmstadt, PhD Thesis: ‘Experimental Investigation of the influencing parameters on brake wear particle emissions of passenger car disc brakes’ 2022

Studies of Mechanical and Process Engineering at Technical University Darmstadt, Degree: M.Sc.2017

Appointments

2022 - today Research Application Engineer, Link Engineering Company GmbH, Germany.

- Development of driving cycles for brake emission purposes
- Development of brake emission measurement setups compliant with GTR24
- Liaison to UNECE Working Parties Energy and Pollution – Non-Exhaust Brake Emissions
- TF3: Interlaboratory studies for repeatability and reproducibility

2022 - today Horizon funded project ’AeroSolfd’ on city bus brake emissions. Performing brake emission dynamometer tests. Analyze measurement data

2016 External Masterthesis, Adam Opel AG, Rüsselsheim, ‘Analysis of the Applicability of Experiments on a Four Post Test Bench for Validation of Vehicle Vertical Dynamics’

2015 - 2016 Internship, Adam Opel AG, Vehicle Dynamic Simulation and Experimental Validation

2013 - 2017 Student Research Associate, Institute of Automotive Engineering, TU Darmstadt. Test execution and analysis e.g. for determination of tire characteristics. Responsibility for measuring rims and test carriers in the areas of tire characteristics and vehicle dynamics

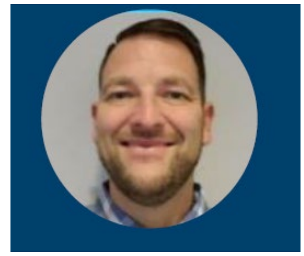
Relevant Publications

1. Agudelo, Carlos, **Hartmut Niemann**, Frederik Weis, and Alejandro Hortet. "Uncertainty of PM2. 5 and PM10 Sampling per EN12341 Applied to Brake Emissions Lab Measurements." In *International µ-Symposium Brake Conference*, pp. 147-172. Berlin, Heidelberg: Springer Berlin Heidelberg, 2023.

2. **Niemann, H.,** T. Speier, M. Hense, J. Guerrero, M. Zessinger, H. Steven, C. Casado Development of a driving cycle for dynamometer brake emission measurements of city buses in two European cities. *EuroBrake 2023*

3. **Niemann, Hartmut** (2021) Experimentelle Einflussgrößenanalyse der Partikelemission von Pkw-Scheibenbremsen. Technische Universität doi: 10.26083/tuprints-00019209, Dissertation, Erstveröffentlichung, Verlagsversion
4. **Niemann, Hartmut, et al.** "Influence of disc temperature on ultrafine, fine, and coarse particle emissions of passenger car disc brakes with organic and inorganic pad binder materials." *Atmosphere* 11.10 (2020): 1060.
5. **Niemann, Hartmut, et al.** "Map based simulation of brake wear particle emissions." *Proceedings of the EuroBrake*, Barcelona, Spain (2020): 2-4.
6. **Niemann, H.;** Winner, H.; Asbach, C.; Kaminski, H.; Zessinger, M. Untersuchung des Partikelemissionsverhaltens von Scheibenbremsen unter transienten Lasten. 17. *VDI-Fachtagung Reifen - Fahrwerk - Fahrbahn*, Hannover, 2019
7. **Niemann, Hartmut,** et al. System identification method for brake particle emission measurements of passenger Car disc brakes on a dynamometer. No. 2018-01-1884. *SAE Technical Paper*, 2018.

Greg Smith
Engineering Manager
Link Engineering Company



Summary of Experience

Mr. Smith has 21 years of testing and data acquisition experience. These rounded experiences include program management, test program design, test execution, data acquisition setup and operation, as well as data review and processing. He has extensive experience developing driving routes for numerous different driving patterns and objectives including emissions profiling, city and suburban traffic driving patterns, mountain descent, etc.

Mr. Smith has vast experience working with FMVSS and ECE test procedures including live testing with witness agents present (primarily ECE testing for European certification).

EDUCATION

B.S., Mechanical Engineering, University of Michigan, 2002

EMPLOYMENT

Engineering Manager-Advanced Vehicle Testing, Link Engineering Company (Dearborn, MI) 2022-Current

Product Manager-Data Acquisition Systems, Link Engineering Company (Dearborn, MI) 2019-2022

Engineering Supervisor-Brake Certification and Development, FCA (Chelsea, MI) 2016-2019

Engineering Manager-Vehicle Testing, Link Engineering Company (Dearborn, MI) 2013-2016

Supervising Engineer-Vehicle Testing, Link Engineering Company (Dearborn, MI) 2010-2013

Sr. Vehicle Test Engineer, Link Engineering Company (Dearborn, MI) 2005-2010

Vehicle Test Engineer, Link Engineering Company (Dearborn, MI) 2003-2005

RELEVANT PROJECTS

Detroit Suburban Traffic Testing Route Development. Developed new improved test route to more closely replicate customer driving patterns that generate brake judder due to DTV (Disc Thickness Variation). Studied traffic patterns, construction projects, sporting events, and existing test data to create a more refined mixture of City and Suburban Traffic driving patterns.

EPA SRC (Standard Road Cycle) driver's aid. Developed a driver's aid to accurately drive the SRC driving schedule at a Proving Grounds location due to lack mileage accumulation availability. Using the voice prompts and driver feedback system, accuracy was improved by 25-30% over previous best effort performance by the Proving Ground personnel.

Automated test reporting of FMVSS105/135 test procedures. Developed a streamlined, more efficient method of test reporting for many common FMVSS test procedures while at FCA, Chelsea Proving Grounds. Previous methodologies required several hours to process test data for common brake certification testing procedures. The new test reporting methods once implemented removed about 90% of the total Engineering labor from the test reporting process while improving the quality of the data, and proving additional information to the design and release engineering teams.

Jun Wu, Ph.D.

856 Health Sciences Rd (Quad), #3082, Irvine, CA 92697-1830

Education

B.E. Environmental Engineering, Tsinghua University, 1997
M.S. Environmental Engineering, Pennsylvania State University, 2000
Ph.D. Environmental Health, University of California, Los Angeles, 2004

Positions Held

2020 – present: Professor, University of California, Irvine, Department of Environmental and Occupational Health, Irvine, California
2019 – present: Graduate Director, University of California, Irvine, Environmental Health Sciences Graduate Program, Irvine, California
2021 – 2022: Inaugural Co-Director, University of California, Irvine, Center of Environmental Health Disparity Research, Irvine, California
2013 – 2020: Associate Professor, University of California, Irvine, Program in Public Health, Irvine, California
2006 – 2013: Assistant Professor, University of California, Irvine, Program in Public Health, Irvine, California
2004 - 2006 Assistant Researcher, University of California, Los Angeles, School of Public Health, Los Angeles, California

Select Awards

2023: The Research Associates, Athalie Clarke Achievement Award in Public Health
2023: Delta Omega 2023 Honoree for Public Health Faculty
2014: Internal Society of Exposure Science (ISES) Joan M. Daisey Outstanding Young Scientist Award
2010: Health Effects Institute Walter A. Rosenblith New Investigator Award
2005: Internal Society of Exposure Analysis (ISEA) Young Investigator Award
2003: Samuel J. Tibbitts Fellowship, School of Public Health, UCLA
2000, 2003: Chancellor's Fellowship, UCLA

Selected Extramural Grants

R01ES034445 Wu, LeBron, Flores (MPI) 05/09/23 – 02/29/28
National Institute of Environmental Health Sciences ; **Inequities in Childhood Life-Course Lead Exposure and Academic and Neurobehavioral Outcomes**

R01AG075739 Chen, Wu A, Wu J (MPI) 09/01/22 – 04/30/27
National Institute of Aging; **Impact of Climate Change on Life Expectancy in a Multiethnic Population**

#2148879 Allaire, Bredow, Wu (Co-PI) 08/15/22 – 12/31/24
National Science Foundation; **Drinking Water Governance, Equity, and Health**

#21RD003 Wu (PI) 02/15/22 – 02/14/26
California Air Resources Board; **Examining the Health Impacts of Short-Term Repeated Exposure to Wildfire Smoke**

#21RD006 Wu & Franklin (MPI) 03/01/22 – 02/28/26
California Air Resources Board; **High Spatiotemporal Resolution PM2.5 Speciation Exposure Modeling in California**

R01 ES030353 Wu and Darios (MPI) 08/01/19 – 04/30/25
National Institute of Environmental Health Sciences ; **Air Pollution and Pregnancy Complications in Complex Urban Environments: Risks, Heterogeneity, and Mechanisms**

Select Relevant Publications (from 127 peer-reviewed publications)

1. **Wu J**, Ren C, Delfino R, Chung J, Wilhelm M, Ritz B. 2009. Association between local traffic-generated air pollution and preeclampsia and preterm delivery in the South Coast Air Basin of California. *Environmental Health Perspectives* 117(11): 1773-1779.
2. **Wu J**, Laurent O, Li L, Hu J, Kleeman M. 2016. Adverse Reproductive Health Outcomes and Exposure to Gaseous and Particulate-Matter Air Pollution in Pregnant Women. Research Report 188. Boston, MA: Health Effects Institute.
3. Masri S, LeBrón AMW, Logue MD, Valencia E, Ruiz A, Reyes A, **Wu J**. 2021. Risk assessment of soil heavy metal contamination at the census tract level in the city of Santa Ana, CA: implications for health and environmental justice. Environmental Science: Processes & Impacts. doi: 10.1039/d1em00007a.

Synergistic Activities

1. Currently I am PI or MPI on more than five major federal and state grants focusing on environmental pollution, climate change, social vulnerability, and their individual or joint on various health outcomes, focusing on health equity. These active grants have good synergy with the proposed project.
2. Exposure assessment is a key but often the weakest component in environmental health studies. I focus on the use of geographical information system (GIS), dispersion modeling, spatial-temporal modeling, machine learning, as well as big data (e.g. satellite data) to improve the assessment of traffic-related air pollution, personal exposures, climate factors, built environment, and other exposures at high spatial and temporal scales. I published multiple papers that used dispersion modeling to estimate traffic-related air pollution and its impacts to various health endpoints. I also published one of the first studies that used satellite data to estimate daily particulate matter concentrations at a zip-code level before, during and after the 2003 southern California wildfires. Recently, sensor technologies were used in a community setting to better characterize pollution exposure at a high spatiotemporal resolution. Overall, I published 50 papers in the area of environmental exposure and risk assessment.
3. Environmental epidemiology is one of the major area of my research, particularly the impact of pollution, climate, and neighborhood built environment (e.g. green space, community resources) on reproductive heath, children's outcomes, and cancer. I have the expertise in combining enhanced exposure prediction methods with advanced biostatical tools. I published the first studies linking traffic-generated air pollution with the development of preeclampsia in pregnant women, studies showing certain pollution sources and components are possible risk factors for adverse pregnancy outcomes, and studies indicating beneficial effects of greenness on pregnancy outcomes. I published over 60 papers in the area of environmental epidemiology.

Studying environmental justice and health equity is my passion. I work extensively with local communities using a community participatory research method on community-identified environmental health problems. One example is the academic-community partnership that was established in 2017 to solve the problem of environmental justice concerns related to air pollution and soil lead contamination in Santa Ana, a city with high proportions of low income and Latino population. In addition to conducting research, I spend substantial effort to help build capacity of the community partners (e.g. knowledge sharing, consulting, and hands-on training), advocate for community needs, and help community organizations with their grant writing, aiming to enhance sustainability for long-term environmental justice work. I have co-published with community partners on 8 papers in the past five years. I am also leading two grants (National Institute of Health R01ES034445 and California Air Resources Board #21RD003) and co-leading a grant (National Science Foundation #2148879) focusing on environmental health equity issues.

SDSU
San Diego State University

Hanyang Li
Assistant Professor

Department of Civil, Construction, and Environmental Engineerin
San Diego State University
home 5500 Campanile Dr, San Diego, CA 92182

SUMMARY OF EXPERIENCE

Dr. Li's general research interest is the influence of air pollution on both climate and human health. Specifically, her research focuses on detecting and characterizing aerosols in various environmental conditions and understanding the processes that control their formation, evolution, and impacts. Her group at San Diego State University (SDSU) adopts a combination of laboratory experiments, field observations, computational analysis, and quantitative modeling to study aerosols. Dr. Li leads projects on the development of Toxic-metal Aerosol Real Time Analyzer (TARTA), trace metal monitoring, and air toxic field monitoring. Dr. Li developed TARTA as a postdoctoral research associate with Dr. Anthony Wexler at UC Davis. After joining SDSU, she has received funding from different agencies to build and deploy TARTAs to understand air quality, such as EPA - Enhanced Air Quality Monitoring for Communities and Breath California - Environmental Justice Community. Recently, California Air Resources Board awarded her a new contract concerning the improvement of TARTA for field deployment. As a researcher with a broad interest in public health, Dr. Li has experience in working with underserved populations on environmental justice issues and assessing air contaminants in their environment.

PROFESSIONAL APPOINTMENTS

- **Assistant Professor** August 2022 – Present

Department of Civil, Construction, and Environmental Engineering, San Diego State University

- **Postdoctoral Researcher** June 2020 – June 2022

Air Quality Research Center, University of California, Davis

EDUCATION

- **The Ohio State University, OH** (Ph.D. in Civil Engineering) May 2020

Dissertation: Identification, Quantification, and Constraint of Uncertainties Associated with Atmospheric Black Carbon Aerosols

- **University of Colorado Boulder, CO** (M.S. in Mechanical Engineering) May 2016
- **Northeast Forestry University, China** (B.E. in Civil Engineering) July 2014

CURRENT AND PENDING SUPPORT

Active

- PI, "Improvement of the Toxic-Metal Aerosol Real-Time Analysis (TARTA) Instrument for Field Deployment", 2023 – 2026, California Air Resources Board, $150,000.

- Co-PI, "TARTA vs XACT comparison at the ASCENT site in Pico Rivera", 2022 – 2024, California Air Resources Board, PI: Dr. Anthony Wexler from University of California Davis, $19,955 to Dr. Li.
- PI, "Air quality monitoring in Imperial Valley", 2023, SDSU Seed Grant Program, $7,500.
- PI, "Monitoring of toxic metal emissions from on-road vehicles", 2023, SDSU Weber Honors College Research Fellows Program, $1,000.
- Co-PI, "Toxic Metals Monitoring Regional Network: High time resolution community-based monitoring in California's Imperial Valley", 2023-2025, US EPA's Enhanced Air Quality Monitoring for Communities, $110,000 to Dr. Li.

Completed

- Sub-contractor, "Sacramento Environmental Justice Community Air Monitoring", September 2022 – December 2022, Breath California, PI: Dr. Wayne Linklater from California State University Sacramento, $9,010 to Dr. Li.

Pending

- PI, "Educating San Diegans on military emissions: Air Shows and Air Pollution (ASAP)", 2024 – 2026, US EPA's Environmental Education, $159,245. (submitted in October 2023)
- Co-I, "Engaging High School Students in Tobacco and Vape-Related Exposure Assessment and Communication", 2024-2026, University of California Tobacco-Related Disease Research Program (TRDRP), PI: Dr. Neil Klepeis from SDSU, $57,281 to Dr. Li. (submitted in October 2023)

PEER-REVIEWED PUBLICATIONS

- † ***Li, H.***, and May, A. A. (2022), Estimating absorption cross-section of ambient black carbon aerosols: theoretical, empirical, and machine learning models. *Aerosol Science & Technology.* https://doi.org/10.1080/02786826.2022.2114311

† Selected as a Research Infographic of Aerosol Science and Technology

- May, A. A., and ***Li, H.*** (2022), Application of machine learning approaches in the analysis of mass absorption cross-section of black carbon aerosols: sensitivity analyses and wavelength dependencies. *Aerosol Science & Technology.* https://doi.org/10.1080/02786826.2022.2114312
- ***Li, H.****, Mazzei, L., Wallis, C., & Wexler, A. S. (2022), Improving quantitative analysis of spark-induced breakdown spectroscopy: multivariate calibration of metal particles using machine learning. *Journal of Aerosol Science, 159.* https://doi.org/10.1016/j.jaerosci.2021.105874
- ***Li, H.****, Mazzei, L., Wallis, C., Davari, S. A., & Wexler, A. S. (2021), The performance of an inexpensive spark-induced breakdown spectroscopy instrument for near real-time analysis of heavy metal particles. *Atmospheric Environment, 264.* https://doi.org/10.1016/j.atmosenv.2021.118666
- † ***Li, H.***, and May, A. A. (2020), An exploratory approach using regression and machine learning in the analysis of mass absorption cross section of black carbon aerosols: model development and evaluation. *Atmosphere.* 11(11), 1185. https://doi.org/10.3390/atmos11111185

† Selected as the Editor's Choice Paper of Atmosphere

- ***Li, H.***, McMeeking, G. R., & May, A. A. (2020), Development of a new correction algorithm applicable to any filter-based absorption photometer. *Atmospheric Measurement Techniques, 13*(5), 2865-2886. https://doi.org/10.5194/amt-13-2865-2020

Li, H., Lamb, K. D., Schwarz, J. P., Selimovic, V., Yokelson, R. J., McMeeking, G. R., & May, A. A. (2019), Inter-comparison of black carbon measurement methods for simulated open biomass burning emissions. *Atmospheric Environment, 206,* 156-169. https://doi.org/10.1016/j.atmosenv.2019.03.010

John W. Koupal

Summary of Experience

Over 30 years' experience in air pollution research, analysis, compliance, and policy. Developed innovative methods to quantify air pollution and fuel consumption from cars and trucks, including updates to heavy-duty brake wear PM for EMFAC2021; assessed current and future impacts of clean vehicle and fuel policies at the local, state, federal and international levels; and shared expertise worldwide on air quality issues. Supported regulation development, technical feasibility and emission inventory assessments for a myriad of Clean Air Act vehicle rules including OBD, low sulfur gasoline, light-duty and heavy-duty tailpipe standards, tailpipe GHGs, and renewable fuels. Prior to joining ERG, John directed the group responsible for mobile source modeling and emission inventory development within the U.S. EPA; and worked for Nissan Motor Company on emissions certification and regulatory issues.

EDUCATION

B.S.E, Industrial & Operations Engineering, University of Michigan, 1989

EMPLOYMENT

Vice President/Principal Engineer, Eastern Research Group, Ann Arbor MI, 2012–present

Director, Air Quality & Modeling Center, U.S. EPA Office of Transportation & Air Quality, Ann Arbor, MI, 2006–2012

Environmental Engineer, U.S. EPA Office of Transportation & Air Quality, Ann Arbor, MI, 1997–2006; 1989–1995

Senior Staff Engineer, Nissan Research and Development, Ann Arbor, MI, 1995–1997

RELEVANT PROJECTS

Characterization of Tire-Wear and Brake-Wear PM Emissions Under On-Road Driving Conditions (CARB) Currently leading CARB 22RD002 project with similar elements and structure as 23RD010. Overseeing literature review of tire and brake emissions sampling systems, convening of a Project Advisory Committee, market survey, and design and development of on-board brake and tire wear emissions sample system. The project is in the first year of a three-year period of performance which will include a pilot study, test matrix development, on-road testing, emissions analysis, emission factor simulation model, and reporting (2023 – present).

Brake Wear Particulate Matter Emissions Research & Modeling (CalTrans) Led groundbreaking research study to measure brake PM data on heavy-duty (HD) trucks to update the California Air Resources Board's EMFAC2021 emissions model. Facilitated study design, brake temperature modeling, and adaptation of raw PM data into new emissions rates for EMFAC. The study measured brake PM on a variety of truck classes and brake configurations over several duty cycles and loadings. PM filter results were then used to update HD brake PM emissions based on statewide estimates of loaded/unloaded travel, axles per truck, speed distributions, and brake material replacement intervals. Coordinated efforts between Caltrans, California Air Resources Board, and U.S. EPA, as EPA is considering use of data for MOVES (2019 – 2021).

Support for EMFAC 2017 & 2021 (CARB, multiple projects) In addition to brake wear contribution listed above, led multiple projects to support CARB's improvement of EMFAC including: improving light heavy-duty truck GHG emission factors and speed correction factors; emission and activity modeling of PHEVs; update of evaportive emissions and activity module; and computational efficiency improvements (2013-2021)

Addressing Truck Emissions and Noise at Truck Freight Bottlenecks (FHWA) ERG assessed exhaust, brake and tire emissions at freight truck bottlenecks culminating in three case studies (Tacoma, Port of Houston, Chicago) which estimated baseline emissions and the impact of several mitigation scenarios including highway expansion, bans on old trucks, electrification, and traffic smoothing. Directed ERG efforts to set up MOVES project scale feature for each case study, incorporated traffic data from DANA supplied by prime, and developed approaches to model each mitigation measure within MOVES. Developed novel approaches to account for port truck activity within terminals, and reflect mitigations targeted at port and/or local fleets (2020-2022).

Analysis of Heavy Duty Diesel Truck Emissions Deterioration (CARB) Led evaluation of emissions deterioration of HD trucks based on several field studies, composed of emissions measurements on nearly 30,000 trucks. In addition to analysis, ERG developed recommendations for future research to continue to assess this question as the fleet continues to turn over to trucks equipped with exhaust aftertreatment devices. The initial objective of the study was to develop degradation profiles, or deterioration rates based on available data. This was to be assessed in two ways: first, look at common vehicle technologies and determine how the group emissions change over time. Second, look at a methodology similar to the currently employed "Radian" model, and attempt to establish emissions rates for vehicles with malfunctioning emissions control equipment like SCR systems and DPFs. In this methodology the frequency of occurrence on these malfunctioning systems would also be needed to develop the overall impact of fleet emissions. The focus for this was vehicles subject to the 2007 and later heavy-duty standards (2014-2015).

Northern Baja Emission Inventory Improvements (CARB) Led development of a detailed inventory for 6 U.S.-Mexico border crossings in California. Set up MOVES project scale scenarios (using U.S. MOVES and MOVES-Mexico model adapted by ERG) and applied detailed vehicle counts and vehicle wait times for passenger vehicles at each crossing for passenger vehicles and commercial trucks to estimate "hot spot" emissions at each site (2018-19). Follow-up work in progress to collect RSD in Baja California and analyze emissions for legal and illegal vehicles domiciled in Mexico, and visiting from California (2021-present).

Support for National Emissions Inventory (U.S. EPA and CRC, multiple projects) Supported input development and model for 2011,2014,2017 and 2020 NEIs. For 2020, helped EPA determine scope and role of telematics to improve vehicle activity inputs. Led work assignment to produced county-level vehicle age distribution data for the 2014 NEI, continuing ERG's ongoing support of the NEI to compile and QA state-supplied MOVES inputs and develop improved county-level default MOVES inputs. ERG worked with a data vendor (IHS) to purchase detailed vehicle population data for each U.S. county, and worked to synthesize into MOVES age distribution and vehicle population inputs used in the 2014 NEI. The other element of this work assignment was evaluation of MOVES predictions in a hot-spot environment, using MOVES project scale runs. (2013- present).

Evaluating Telematics Data to Improve Vehicle Emission Inventories (CRC, multiple projects) Led project CRC A-100 to provide state/local air agencies and U.S. EPA with more accurate vehicle activity data for MOVES2014a, based on the broadest application of telematics data for emissions modeling to date. ERG worked with StreetLight Data, Inc. to synthesize data from millions of personal and commercial vehicles operating on roads across the U.S. into MOVES2014 county databases inputs of average speed and VMT distribution, which were used in the 2014 NEI. ERG served as technical liaison to coordinate project objectives and deliverables between CRC and EPA. Led project CRC A-106 to continue evaluation of telematics to improve predictions of MOVES2014a with applicability to the NEI, regional, state, and local inventories. ERG analyzed location-based data culled from smartphone applications in Chicago, Atlanta, and Las Vegas) and synthesized these into MOVES2014a inputs for analysis and assessment, including an evaluation of emissions sensitivity. Finally, led CRC E-131 to evaluation multiple sources of telematics data to assess capabilities and limitations of telematics for improving vehicle emissions inventories (2016 – 2020).

Sandeep Kishan, PE

ERG

Summary of Experience

Mr. Kishan is the Vice President for ERG's Mobile Sources group. For more than 36 years he has worked on a wide range of projects related to automotive engineering, transportation, and vehicle emissions. He has extensive experience in developing real world vehicle emissions models to support the development of environmental and energy policy. He has worked with international, national, state, and local governmental organizations to develop the data and models to simulate vehicle and transportation systems, and their influence on ambient pollution and energy use. He has led the Mobile Sources group at ERG and Radian for the last 20 years.

He is one of the nation's leading experts in transportation emission modeling and development of control strategies to reduce pollution and improve fuel economy. His career has been focused on developing a better understanding of real-world vehicle emissions. He has supported the development of all major U.S. emissions models including U.S. EPA's MOBILE and MOVES models and California Air Resources Board's EMFAC model. Early in his career, Mr. Kishan supported the development of the Supplemental Federal Test Procedure Development for U.S. EPA. He was also the main author of the toxic emissions estimates in the U.S. EPA models.

EDUCATION

M.S., Mechanical Engineering, Texas A&M University, 1985

B.S., Mechanical Engineering, University of Bombay (India), 1983

EMPLOYMENT

Vice President, Eastern Research Group, Inc. (ERG), (Austin, TX), 2000–Present

Manager, ERG (Austin, TX), 1999–2000

Principal, Mobile Source Business, Radian International LLC (Austin, TX), 1993–1999

Senior Staff Project Manager, Radian International LLC (Austin, TX), 1996

Senior Mechanical Engineer, Radian Corporation (Austin, TX), 1991–1995

Staff Mechanical Engineer, Radian Corporation (Austin, TX), 1987–1990

Mechanical Engineer, Radian Corporation (Austin, TX), 1985–1986

Graduate Research Assistant, Department of Mechanical Engineering, Texas A&M University (College Station, TX), 1984–1985

Graduate Trainee Engineer, Tata Electric & Locomotive Co. (Poona, India), 1983

RELEVANT PROJECTS

Mr. Kishan has served on several mobile source review committees under the Federal Advisory Committee Act to support U.S. EPA in the development of MOVES. He is on the Industrial Advisory Council in Texas A&M University's Mechanical Engineering Department. In 2010, the Coordinating Research Council (CRC) recognized Mr. Kishan as an "outstanding contributor" for two decades of research and participation at CRC's On-road Vehicles Emissions Workshop. Examples of Mr. Kishan's relevant project experience are provided below.

Light-Duty Brake PM Emissions (CARB). Program manager for a project for CARB to update the light duty brake PM emission factors in EMFAC. Determined the temperature regimes of six light duty vehicle models and developed a temperature model to estimate brake temperatures based on a vehicle speed trace. Developed a novel brake dynamometer test cycle consisting of representative braking events based on matching in-use deceleration rates, brake event duration, vehicle speed, and brake temperature to real-world data. Managed a series of tests at Link's brake dynamometer laboratory of various brake pad materials for six vehicles. Analyzed data and generated emission factors that could be implemented in EMFAC, including base emission rates, deterioration rates, and speed correction factors.

Brake Wear Particulate Matter Emissions Research & Modeling (Caltrans). Program manager for groundbreaking research study to measure brake PM data on heavy-duty (HD) trucks to update the California Air Resources Board's EMFAC2021 emissions model. Facilitated study design, brake temperature modeling, and adaptation of raw PM data into new emissions rates for EMFAC. The study measured brake PM on a variety of truck classes and brake configurations over several duty cycles and loadings. PM filter results were then used to update HD brake PM emissions based on statewide estimates of loaded/unloaded travel, axles per truck, speed distributions, and brake material replacement intervals. Coordinated efforts between Caltrans, California Air Resources Board, and U.S. EPA, as EPA is considering use of data for MOVES (2019 – 2021).

Support for the development of CARB's Heavy Duty Vehicle Inspection Program. Mr. Kishan is the project Manager for providing support for the development of CARB's first-in-the-country inspection program. A key part of this support has been to develop options for conducting vehicle inspections via remote options such as telematic tools, roving inspectors, kiosks, and other decentralized options. ERG has also provided support for identifying tampering of diesel emissions control equipment and suggested processes for the inclusion of such inspection in the program.

Updates to Heavy Duty Vehicle Emissions Deterioration in the EMFAC model. Mr. Kishan is the project Manager for a study to collect and analyze heavy-duty truck OBD diagnostic data (SAE J1939 and SAE J1979) in order to determine rates of MIL illumination and failure rates for various emissions components in the fleet of trucks operating in California. A field study is being performed to gather in-field OBD data using various scan instruments, and ERG worked with vendors of telematics data to supplement the in-field OBD data. We then use the diagnostic data to develop the tampering and mal-maintenance matrices for use in the EMFAC model.

Software development and model design support for the California Air Resources Board's EMFAC mobile source emissions model. Mr. Kishan provided technical support to the California Air Resources Board to improve the scientific and computational methods used in the EMFAC2017 and EMFAC202x mobile source emissions models. Designed and implemented logging and profiling tools to trace program execution and identify computationally expensive operations. Suggested specific improvements to MySQL queries and Python code in order to improve computational efficiency. Designed and implemented a functional testing program to efficiently test for proper model execution across the full range of possible inputs. Performed beta testing, including quality assurance (QA) of emission rates. Currently developing recommendations for improving the structure of the next EMFAC release (EMFAC202x), including redesign of the evaporative emissions module and design of a heavy-duty inspection/maintenance module.

Smog Check Performance Analysis. Mr. Kishan led a major study for California BAR to evaluate the overall performance of the current California I/M program, analyzing thousands of emissions test results from roadside ASM testing. The random roadside pullovers collected data both before and after Smog Check testing. As part of this effort the overall effectiveness of Test-Only and Test-and-Repair stations were also compared. In addition, preliminary comparisons were developed among the different Test-and-Repair stations. Based on the determination of effectiveness by test type as well as by specific station, ERG and dKC made several recommendations for improving program performance.

PROFESSIONAL REGISTRATIONS

Mechanical Engineer, Texas, Registration # 77828, 1993

Heather Perez, GISP

Summary of Experience

Heather Perez is an Environmental Scientist and GIS Manager with over 22 years of emissions inventory and air quality experience. Ms. Perez has created comprehensive criteria, hazardous air pollutant, and greenhouse gas emission inventories for point, nonpoint, and mobile sources from local through national levels., emphasizing spatial and temporal accuracy in baseline and projected estimates. Ms. Perez has evaluated emission reduction techniques; compiled datasets of equipment and activity data, emission factors, and control devices; and created future year projections that account for sector growth, compliance with regulations, and implementation of control or fuel conservation programs. Her work has supported numerous federal, state, and local agency projects, including the rail component of U.S. EPA's National Emissions Inventory.

EDUCATION

M.E.M., Environmental Management, Resource Ecology, Duke University, 2002

B.S., Applied Biology, Xavier University, 2001

EMPLOYMENT

GIS Manager, Eastern Research Group, Research Triangle Park, NC, 2008–Present

Senior GIS Specialist and Environmental Scientist, Eastern Research Group, Research Triangle Park, NC, 2002-2008

Assistantship, Duke University's Nicholas School of the Environment, 2000-2002

LICENSES AND CERTIFICATIONS

2006-Present: Certified Geographic Information Systems Professional, GISCI

RELEVANT PROJECTS

National Emissions Inventory. Client: U.S. EPA. Supported point, nonpoint, and area Initiate and direct all geospatial innovations for the mobile source components of the U.S. EPA's triennial National Emission Inventory (NEI) since 2005. These inventories include criteria, hazardous air pollutant, and greenhouse gas emission estimates for all point, area, and mobile source categories for the entire nation including Puerto Rico and the U.S. Virgin Islands. Spearheaded the development of EPA's GIS shapefiles to more accurately represent the spatial location of mobile emissions in the NEI and related projects (including modeling), shifting from county-level emissions to segment, airport, or port-level emissions. Created polygons for underway and port commercial marine vessel (CMV) activity, points for airport and airport support activity, and line segments for rail activity, resulting in the creation of over 27,000 unique features which allow for previously unparalleled spatial accuracy. These shapefiles also included complete, consistent metadata updated with each inventory iteration. The 2014 effort further expanded the shapefile inventory with 5,500 additional refined hoteling and maneuvering port shapes customized to meet both inventory and modeling needs. Managed challenges associated with Big Data storage, processing, and analysis. Analytical results were summarized in a custom-developed database of emissions and activity to facilitate data and spatial data analysis. In addition to authoring, revising, and maintaining 5 different GIS layers for NEI use, manage emissions allocations and reallocations to these changing shapes, recommends improvements, and generates new files that meet the needs of both inventory and air quality modeling efforts, laying the foundation for the switch to using Automatic Identification System (AIS) data.

U.S. Rail Transportation Industry Update Updated the U.S railroad industry characterization originally performed in support of the 2008 Locomotive and Marine Rule. This update pertained to locomotive manufacturing, locomotive remanufacturing, and railroad owners and operators and included updated information about supply, demand, production and costs, operations and design, fleet profiles, traffic and hauling statistics, etc. While the 2008 characterization was limited to Class 1 railroads, this new characterization included Class II and III lines, which required identifying data sources that could be used to characterize the Class II and III rail industry and developing a data collection plan that can be used to gather the Class II and III line information from the sources previously identified. This will inform methods for a future study in which this Class II and III information is collected in order to allow a current and comprehensive rail characterization including the entire Class I, II, and III rail industry.

Analysis of Potential Application of "In-Use Useful Life" Rail Regulation in Canada; Client: Environment and Climate Change Canada (ECCC). Led a project to evaluate potential implications of California's "In-Use Useful Life" regulation on Canada's emissions given their interest in decarbonization. The project investigated the feasibility of implementing a similar regulation from technical, operational, practical, and economic perspectives accounting for challenges/considerations of the Canadian context. Data was compiled from Railway Association of Canada (RAC)'s Locomotive Emissions Monitoring (LEM) and Rail Trends reports and gap-filled with data from the US EPA's NEI as needed and with approval of the ECCC Project Authority. All compiled data was used to calculate projected fleet changes, potential modifications to activity types and patterns, and cost/benefits associated with these changes.

Identification of the origins of PM10 impacting the Yuma Ambient Monitoring Supersite. Client: Arizona Department of Environmental Quality. After conducting back trajectory modeling to identify the area of interest around the Yuma ambient monitoring supersite, curated a custom dataset of PM10 emission sources to support SIP development. Identified PM10 sources including the following: road dust; agricultural sources; mobile sources; area sources including construction, residential wood combustion, commercial cooking, and open burning; windblown dust; and permitted point sources. Data refinements include surface emissivity by land use and crop type, estimated activity by ownership/maintenance plans and spatial refinement of underlying data and proxies. Designed to address multiple different use scenarios, including during harvesting activities and "snowbird" season. Created a geodatabase to spatially represent all data and recommendations on application in emissions modeling. Provided bilingual support for collection, processing, and management of Mexico-based data and resulting analyses.

2014 Texas Statewide Commercial Marine Vessel Emissions Inventory and 2008 to 2040 Trend Inventories. Client: Texas Commission on Environmental Quality. Ms. Perez calculated actual and ozone season weekday criteria and GHG emission inventories for CMVs using updated emissions and activity-based projection factors all coastal counties in Texas. Created statewide air emissions inventories for submittal to the U.S. EPA's NEI included 2011, 2014 and 2017 as well as state implementation plan (SIP) inventories for 2012, 2014, 2017, 2020, 2023, 2026, and 2028 inventories for the HGB Area and the Dallas-Fort Worth areas. Managed all GIS activities including the development of a coastal inventory focused on activities in Texas State waters including criteria pollutants, GHGs, and HAPs. ERG developed trend emissions inventory data for both controlled and uncontrolled criteria emissions for years 2008 to 2040. The AIS dataset for this effort includes observations every 15 minutes for every vessel in the area of interest during 2013 (31,841,919 unique observations associated with 9,584 vessels) to provide a comprehensive picture of vessel movement and to reduce potential data gaps. Additional data were obtained from the Coast Guard, U.S. Army Corps of Engineers, National Transportation Safety Board, and National Marine Fisheries Service to supplement the AIS data and perform QA checks. Developed controlled emission factors from EPA data which accounted for fleet turnover and the implementation of regulatory programs and applied the emission factors to activity to calculate emissions for criteria, HAP, and GHG pollutants for the base year 2013. Adjustments were made to account for federal rules that were implemented relative to the year that the marine engine was originally manufactured and to account for compliance with emissions control area fuel sulfur standards and Texas Emissions Reduction Plan investments.

Roger Chang

Summary of Experience

- Over 22 years of experience with aircraft, marine vessel, and locomotive emissions development with database and model development.
- Developed the EPA's National Emissions Inventory (NEI) for 1978-2020 (three-year cycles)
- Managed the developed TCEQ's locomotive emissions inventories for SIP and CERR/AERR submittals 2008 2012, 2014, 2017, 2020, and 2023
- Developed port inventories that included marine vessels, locomotives, nonroad, and other mobile sources.
- Developed Rail Yard Emissions Inventories

EDUCATION

M.E.M. Water and Air Resources, Duke University, Durham, NC, 2001

B.A. Environmental Studies, University of Chicago, Chicago, IL, 1999

EMPLOYMENT

Environmental Scientist, Eastern Research Group, Inc., 2001 Present.

Water Resources Trainee, United States Geological Survey, Reston, VA, May 2000 2001.

Fortran 90 Programmer, Nicholas School of the Environment, Duke University, Durham, NC, February May 2000.

Regional Environmental Specialist, CIGNA Property & Casualty, Chicago, IL, 1998 1999.

RELEVANT PROJECTS

Development of Locomotive, Marine Vessel and Aircraft Component of the U.S. EPA's National Emission Inventory (NEI) (US EPA)Chang estimated criteria air pollutant emissions from locomotive sources for the 1978, 1987, 1990, 1996, 1999, 2000, 2001, 2002, 2005, 2008, and 2011 NEI. He calculated emissions using guidance provided by the EPA's Office of Transportation and Air Quality (OTAQ). He compiled emission factors and researched locomotive activity data from various sources (2001-2013).

TCEQ State Implementation Plan (SIP) Emission Inventories (TCEQ) Project manager for the aircraft/nonroad, commercial marine inventories, and rail inventories. These inventories included the 2012, 2014, 2017, 2020, 2023, 2026, and 2028 inventories. These inventories were for the Houston-Galveston-Brazoria Area and the Dallas-Fort Worth areas. He coordinated multiple teams concurrently. These inventories included obtaining both publicly available data from national sources as well as local data. The final inventories were also formatted into CERS xml format for TCEQ's TexAER system (2012-2018).

TCEQ Trend Inventories (TCEQ) project manager for multiple trend inventories. He managed the 2011 to 2045 trend inventory which used the 2017 as a base year and he managed the 2008 to 2040, trend inventories which used the 2014 as a base year. Both projections were for the entire state of Texas. These inventories included obtaining publicly available data from national sources and local data. The final inventories were also formatted into CERS xml format for the EPA's EIS as well as TCEQ's Texas Air Emissions Repository (TexAER) system (2020-2021).

TCEQ Consolidated Emissions Reporting Rule (CERR)/Hazardous Air Pollutant (HAP) Emission Inventories (TCEQ) **M**anaged TCEQ's CERR and HAP 2008 and 2011 inventories. He created the aircraft, commercial marine vessel, and locomotive inventories. For the aircraft inventories, he managed a small team that estimated emissions using the FAA's EDMS program and compiling generic emission factors for non-aircraft specific activity data. For the commercial marine vessel and locomotive inventories his team estimated emissions using local CMV and locomotive data in conjunction with GIS rail and shipping lane segments and port and yard shape files He created TexAER files for importation of all inventory data into the TCEQ's TexAER system. He populated the inventory into the EPA's new EIS using the EPA's new staging tables and xml. He submitted aircraft as a point inventory and the commercial marine vessel and locomotive inventories as area inventories (2009-2013)..

Development of Emission Inventory for the Port of Houston (Houston) Assisted in producing the 2013 inventory for Port of Houston area. This inventory comprised many sources of emissions including marine vessels, locomotives, and other mobile sources. He assisted in compiling emission factors and quality checking estimates. He also assisted compiling other emission source data in the Houston-Galveston-Brazoria Area to assess the air quality impact the Port of Houston has on the greater area (2014).

Development of Emission Inventory of BNSF Rail Yard for Mid-America Regional Council (MARC).) Developed an emission inventory of two intermodal facilities that are proposed for construction. The inventory comprised of all mobile and stationary sources including, line haul and switch locomotives, cargo handling equipment, highway trucks, fuel storage tanks, degreasing operations, boilers, generators, welding and painting operations. The inventory was used to develop an emissions model that could be applied to future inventory projects implemented by MARC staff to estimate emissions from similar sources (2010).

Development of Emission Inventory of Union Pacific (UP) Rail Yard (Dallas). worked on an emission inventory of the UP Dallas Intermodal Terminal for the City of Dallas. The inventory included all stationary and mobile emission sources including line haul, switch engines, cargo handling equipment and on-road vehicles for 2005 and 2010 (2011-2012).

Tyler Richman

Summary of Experience

Data Analyst with over three years of professional experience providing technical support to a variety of environmental consulting projects, including emission inventories and characterizations.

- Efficient at collecting, processing, analyzing, and visualizing geographic datasets using ESRI software applications.
- Capable of developing Python/R scripts, Jupyter Notebooks, and ArcGIS Toolboxes to automate workflows.
- Ability to apply analytical and software development knowledge to emission inventory and characterization projects.

EDUCATION

B.S., Atmospheric and Oceanic Science and Geographical Sciences, University of Maryland, 2019

EMPLOYMENT

2020–present
Data Analyst, Eastern Research Group, Inc. (ERG), Morrisville, NC

2019–2020
Field Operations Specialist, Vexcel Imaging, Frederick, MD

RELEVANT PROJECTS

National Emissions Inventory (NEI): Developing Emission Inventories for Commercial Marine Vessels. Client: EPA/OTAQ. Provided technical support to execute a computer program that models emissions from commercial marine vessels for EPA's National Emissions Inventory. Assisted environmental scientists in improving functionality of R code that standardizes, preprocesses, and calculates emissions from U.S. Coast Guard's Automatic Identification System (AIS) dataset. Resolved issues that occurred within code and gained insights into the reasons behind irregularities or unexpected results in model outputs. Provided detailed information regarding problems and irregularities for senior team members so that effective solutions could be incorporated into the model. Executed the program for AIS data from the years 2019, 2020, and 2021. Developed summary tables and visualizations from program outputs to showcase comparisons across years.

Toxics Release Inventory (TRI): Where You Live Analysis. Client: EPA/OCSPP. Conducted spatial analysis tasks to complete the Where You Live section of the EPA's annual Toxic Release Inventory (TRI) National Analysis. TRI is a resource provided by the EPA that informs users about toxic chemical releases and pollution prevention activities from industrial and federal facilities. The Where You Live section of TRI National Analysis summarizes the release of TRI chemicals at various geographic levels (state, county, metropolitan areas, and watersheds). Specific spatial analysis tasks include confirming the accuracy of TRI facility locations using geocoding tools, linking facilities to boundaries at various geographical levels, computing TRI statistics within geographic boundaries, spatial data management, and publication of web maps on EPA's GeoPlatform. Extended functionality of the Drupal application that showcases these web maps by adding sections to display summaries for 2-digit hydrological unit code (HUC) watershed boundaries and EPA regions as well as profiles for communities surrounding TRI facilities. Currently developing a ArcGIS Notebook with Python to automate this process.

ArcGIS Python Toolbox Development for Risk and Technology Review (RTR).
Client: United States Environmental Protection Agency, Sector Policies and Programs Division (SPPD). Mr. Richman developed an ArcGIS Toolbox using ArcPy and Pandas Python Libraries to automatically generate GIS layers for ArcGIS Online maps. This toolbox allows users to easily input source data for seamless creation of GIS point and polylines without the need for ArcGIS model builder or any other manual processing. The ArcGIS Online mapping process is an important step in the QA of Risk and Technology Review (RTR) modeling files. ERG provides QA support for RTR modeling file development under a task to support U.S. EPA's Sector Policies and Programs Division (SPPD). The ArcGIS Online map allows users to review and correct stack and fugitive release locations without the need for GIS software and expertise. The corrected release location information is extracted and processed using GIS software and used to update RTR modeling files.

TRI Facilities REST Service (EPA-OCSPP).Client: EPA/OCSPP. Developed an ArcGIS Python Toolbox that pulls the latest TRI facility release data from the EnvioFacts API, processes it into a feature class, and publishes the resulting layer onto REST Services. A standalone Python script that runs each tool within the ArcGIS Python Toolbox executes twice a year so that the REST Service is refreshed with the most up-to-date TRI facility release data. Manual quality assurance checks compare the data pulled from the EnviroFacts API to the REST Service layer. The REST Service layer containing data from the most recent reporting year is showcased within EPA's EJScreen web mapping tool. This system expands the capabilities of EPA's mission for providing both current and accurate information on the TRI program to the public.

Web Map Applications (EPA). Client: EPA. Utilized ESRI's Experience Builder to develop web map applications for the Landfill Methane Outreach Program (LMOP) National Map as well as the Chemical Data Reporting (CDR) Interactive Map. Thel LMOP National Map shows the locations of Landfill Gas (LFG) Energy Projects and Municipal Solid Waste (MSW) Landfills. Point features are color coded based on the type of project or landfill and pop-ups include information associated with the project or landfill. The CDR Interactive Map shows chemical reporting sites with associated details and characteristics of the surrounding area in the pop-up. Both web maps include REST Service layers of EJScreen Demographic Indies. Senior project managers periodically provide updated datasets for both maps which are efficiently processed and incorporated into the web maps.

PM10 Source Inventory for Yuma County, AZ. Client: Arizona Department of Environmental Quality (ADEQ). Provided technical support for a project that created an inventory of PM10 sources for the purpose of identifying potential causes of hazardous air quality levels detected by a monitoring station in Yuma County, AZ. Developed a Python program to batch execute the Hybrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT) model from user input parameters; this is much more efficient than manually pulling in back trajectories from the HYSPLIT desktop application. Two hour back trajectories in one hour increments (a back trajectory was obtained for each hour) was were created at the monitoring station location for days with hazardous levels of PM10 in the atmosphere. Created a convex hull from the back trajectories to obtain a surface area of interest in which to gather data. Produced a list of unpaved roads not maintained by local or federal government for the PM10 non-attainment area in Yuma County. Gathered additional geographic datasets of PM10 sources from a variety of resources. Created maps and visualizations for project documentation.

Yuma County Traffic Count (ADEQ). Client: Arizona Department of Environmental Quality (ADEQ). Developed a Python program to automate the selection of road segments for the Arizona Department of Environmental Quality's traffic count survey of Yuma County roads. The traffic count survey required a selection from several thousand road segments that meet specific criteria, such as a specific count of public and private roads, paved and unpaved roads, and geographic location. Classified the road segments into different categories in ArcGIS Pro based on the criteria. The program utilized an algorithm that tracked the fulfillment of the criteria requirements as roads were continuously selected. The program generated a list of road segments that met the survey's criteria by narrowing the selectable list of segments to only include roads pertaining to criteria that have not yet been met.

Henry Byoun

Summary of Experience

Mr. Byoun is an Environmental Scientist at ERG who specializes in mobile sources emissions analysis. His work at ERG primarily involves data analysis using Python, SQL, and SAS and working with U.S. EPA's MOVES model to analyze mobile source data and develop emissions models and inventories.

He has supported projects for local, state, and federal air agencies often involving QA of large datasets, data transformation, data visualization, and running emissions models. His recent work includes analysis of nationwide vehicle telematics data to prepare county level vehicle speeds and VMT profiles for use in emissions modeling and developing emissions inventories for Mexico.

EDUCATION

Certificate in Data Analysis and Visualization, University of Texas Austin, 2020

B.S., Chemistry, Minor Applied Mathematics, Pepperdine University, 2016

EMPLOYMENT

Environmental Scientist, Eastern Research Group, Inc. (ERG) (Austin, TX), 2021 - Present

Environmental Technician, TRC Companies, Inc. (Austin TX), 2018–2020

RELEVANT PROJECTS

National Emissions Inventory (2020, 2022). Mr. Byoun is a technical support on assisting U.S. EPA Office of Transportation and Air Quality (OTAQ) and Office of Air Quality Planning and Standards (OAQPS) to develop the on-road sectors of the National Emissions Inventory (NEI). For 2020, he analyzed over 100 million records of vehicle telematics data using Python to generate county level activity files including speed distributions and vehicle-miles traveled on the county level for use in the MOVES emissions model and SMOKE modeling process. He also analyzed national vehicle registration data using Python, SQL, and SAS to generate MOVES county database tables which include vehicle populations, vehicle age distributions, and fuels data. He reviewed county databases submitted by state agencies to identify errors or anomalies in the data. He runs the MOVES model to generate emissions factors and emissions inventories in a cloud computing environment to complete hundreds of runs in parallel significantly reducing run time. He is currently supporting similar efforts for the 2022 on-road NEI.

Mobile Source Hot-Spot Emissions Analysis. Mr. Byoun supported a project for EPA Office of Pollution Prevention and Toxics (OPPT) assessing emissions at mobile source "hot-spots". He assessed studies of high traffic areas to scope out and determine the on-road hot-spot site selection for the emissions analysis (Fort Lee, NJ I-95 traffic bottleneck). Developed MOVES formatted input data files using traffic count data from FHWA and average speed data from ATRI and ran the MOVES model to generate hourly emissions for the traffic hot-spot.

Updating Emissions Modeling Utility SEE. Spatial Emissions Estimator (SEE) is a modeling utility used by Houston-Galveston Area Council (H-GAC) which estimates regional on-road emissions inventories with highly detailed spatial resolution. This project involved updating SEE source code to transition its use of MOVES2014b to MOVES3 and MOVES3 to MOVES4 and implementation of new MOVES and utility input files. Mr. Byoun identified and implemented the necessary Python and MySQL source code changes and tested changes to ensure the utility operated correctly.

Developing Emissions Inventory for CAMe Mexico. Mr. Byoun supported a project for LT Consulting to develop a 2018 emissions inventory for the CAMe region of Mexico using the MOVES-Mexico model. Upon initial QA of Mexico mobile source input data, he identified various areas that required corrections. Using Python and SQL, he generated input county databases for over 500 Mexico counties or municipios. He ran the MOVES-Mexico for all counties in parallel in a cloud computing environment.

Updating Nonroad Emissions Modeling Utility Reasonable Further Progress Analysis Report TexN2. TexN2 is a python-based modeling utility used for estimating Texas-specific emissions from nonroad mobile sources that was developed by ERG for Texas Commission on Environmental Quality (TCEQ). Mr. Byoun updated the source code to generate a new reporting functionality for Reasonable Further Progress (RFP) analysis runs. Previously a full RFP run generated ten output files for each RFP scenario which would then be post-processed manually to calculate RFP emissions deltas. Mr. Byoun added the new reporting functionality which now compiles all ten scenario outputs, calculates, and summarizes the emissions deltas among the scenarios, and outputs the post-processed results in a single file.

Particulate Matter Hot Spot Analysis. Mr. Byoun supported a project which assessed “hot-spot” CO and PM using emissions and dispersion modeling using the MOVES and AERMOD model. He prepared input databases and ran MOVES to determine PM2.5, PM10, and CO emissions for year 2020 to future year 2045 for three different cities. He developed a post-processing spreadsheet using the results from MOVES and concentration estimates determined using AERMOD which calculates and displays results in pivot charts for PM and CO concentration for various roadway scenarios, (annual average daily traffic AADT) volume scenarios, and cities scaled to future years.

Mexico Motorcycle Emissions Analysis. Mr. Byoun supported a project analyzing and updating the MOVES-Mexico model. He conducted various analyses of motorcycle emissions testing data from Mexico motorcycle RSD data. He calculated emissions concentrations and emissions rates of various pollutants by vehicle make, model year, cylinder, etc. and conducted statistical analyses to determine significance of variables. He also calculated Mexico motorcycle emissions rates from MOVES-Mexico output data for comparison with RSD data.

Jie Yan

Summary of Experience

- Experienced in conducting independent environmental research and geovisualization by manipulating GIS layers into story map elements.
- Experienced in building databases for geospatial assessment projects and summarizing metadata into documentation.
- Developed interactive live maps on ArcGIS Online for clients' website using their watershed datasets.
- Performed large-scale computations via Pandas, SparkSQL in the U.S. Pollution Data to investigate the correlation, timing, and regional effects of major air pollutants.

EDUCATION

M.S., Environment & Sustainability in Geospatial Data Sciences, University of Michigan, Ann Arbor, MI, 2023

Certificate of Graduate Studies (Data Science), University of Michigan, Ann Arbor, MI, 2023

B.Eng., Urban and Rural Planning, Beijing Forestry University, Beijing, China, 2021

EMPLOYMENT

Data Analyst, Eastern Research Group, Inc. (ERG), Morrisville, NC, 2023-present

Research Assistant, Environmental Spatial Analysis Lab, University of Michigan, Ann Arbor, MI, 2022-2023

GIS Data Analyst, Huron River Watershed Council, Ann Arbor, MI, 2021-2023

Product Manager, Guizhou LiChuang Technology Development Co.Ltd, Guiyang, China, 2020

Assistant Engineer, China Academy of Urban Planning & Design, Beijing, China, 2020

Landscape Designer, China Academy of Urban Planning & Design, Beijing, China, 2019-2020

RELEVANT PROJECTS

2022 Airport Inventory for U.S. EPA Actively assisted in the creation of the 2022 airport inventory for the U.S. Environmental Protection Agency (EPA) by employing the Federal Aviation Administration's (FAA) Aviation Environmental Design Tool (AEDT) and extends to the integration of diverse publicly available activity datasets sourced from the FAA, encompassing detailed information on aircraft operations, emissions, and airport activities.

Forests for Water Quality in the Huron River Watershed GIS Analyst for developing web-based tools using ArcGIS to quantify ecosystem services and assess natural areas in the Huron River Watershed. Enhanced spatial datasets and built GIS models to analyze water quality and ecosystem benefits. Conducted town halls and field assessments to educate landowners on conservation options. Utilized Survey123 for assessments and distributed questionnaires on ecosystem services and water quality. Developed interactive maps on ArcGIS Online to illustrate correlations between geographical features and bioreserve sites. Delivered a formal report titled "Forests for Clean Water in the Huron River Watershed."(2021-2023)

Geospatial Assessments of Forest Carbon Storage and Sustainability within the New Obtawaing Biosphere Region (OBR) in Michigan Assist in deriving OBR-wide summaries stratified by stewardship types, ecoregions, forest types, and other strata of interest. Produced new GIS layers in ArcGIS and QGIS using basic exploratory raster GIS suitability/risk modeling methods. Contributed to establishing an organized framework of GIS databases, analysis products for researchers and partners to leverage. (2022-2023)

Independent Study on Geospatial Data Visualization GIS mapper for crafting seven polished GIS maps tailored for formal publication Assessing beech bark-diseased forest canopies over landscapes using high resolution open-source imagery in an ecological framework. Through extensive manipulation and formalization of GIS datasets, she meticulously reviewed and summarized metadata essential for enhancing GIS map layouts, subsequently documented for comprehensive understanding. (2022)

Correlations, Timing and Regional Effects of the Pollutants Used the U.S. Pollution Dataset (1990-2009) and the USA Airport Dataset (2000-2016) to summarize and visualize the correlations between cities and major pollutants via Matplotlib and Seaborn, as well as to find out the seasonal or daily patterns of pollutants and how these pollutants evolve over time. Performed tasks such as: Visualizing the impact of the numbers of flights on air pollution indicators, Calculating the correlation coefficient between air pollution index and the total number of flights, Exploring the periodicity of pollutants in year 2015, Exploring the top 20 polluted counties, etc. (2022)

“Fly me to the South”, an Ecological Research Project on Migratory Bird Species in North America Conducted comprehensive research on the impact of climate change on migratory bird populations, employing diverse methodologies to elucidate their dynamics. Utilizing APIs and web crawling techniques, she meticulously gathered bird and temperature data, ensuring a robust dataset for subsequent analyses. Leveraging the statistical capabilities of R, she constructed intricate linear regression models to discern the intricate relationships between temperature variations and the initial arrival dates of three distinct migratory bird species. Furthermore, employing ANOVA analysis, she explored the correlations and disparities among these species, unraveling nuanced insights into their response mechanisms to climatic shifts. (2022)

Waterfront Green Space Planning for ‘He River’ Project in Ji’an, Jiangxi, China Through extensive case study analysis, she utilized GIS techniques to dissect the intricate relationship between water bodies, terrain features, and residential areas, facilitating informed planning decisions. She delved into the statistical analysis of local rainfall patterns, essential for the design and implementation of an optimal sponge city system for Ji’an area. Leveraging the capabilities of ArcGIS, she developed sophisticated disaster models capable of forecasting waterlogging occurrences across various return periods. (2019)

EXHIBIT A6

CURRENT & PENDING SUPPORT

PI: George Karavalakis					
Status (active or pending)	**Award #** (if available)	**Source** (name of the sponsor)	**Project Title**	**Start Date**	**End Date**
PROPOSED PROJECT	23RD010	CARB	Characterization of Train Brake-Wear and Wheel/Rail-Wear PM Emissions	06/01/2024	05/31/2027
Active		CARB	CARB Emissions Compliance Testing	06/01/2020	05/31/2024
Active		SOUTH COAST AIR QUALITY MANAGEMENT DISTRICT	South Coast Air Quality Management District RFP #P2012-01: Technical Assistance for Advanced, Low- and Zero-Emissions Mobile and Stationary Source Tech	06/13/2014	05/31/2024
Active		Attorney General Funds - State of CA Department of Justice	Monitoring, Modeling, & Mitigating Emissions & Air Quality Impacts of Goods Movement in Inland Southern CA Environmental Justice Communities	1/01/2022	2/31/2024
Active		CARB (Air Resources Board)	Demonstration of Sensor Technologies for On-Road & Off-Road Heavy-Duty Diesel Vehicles	2/22/2022	2/22/2025
Active		CARB (Air Resources Board	Heavy-Duty Optional Low NOx Vehicle Testing	4/11/2022	3/31/2024
Active		SCAQMD	OMEGA: Objective Measurement/Monitoring/Mitigation of Emissions from Goods Movement and Impacts on Air Quality	12/27/2022	12/26/2025
PENDING	23RD009	California Air Resources Board	Characterizing Unfiltered Exhaust Leaks During Heavy-Duty Vehicle Operations and their Impacts on Disadvantaged Communities		

Co-PI: Zisimos Toumasatos					
Status (active or pending)	**Award #** (if available)	**Source** (name of the sponsor)	**Project Title**	**Start Date**	**End Date**
PROPOSED PROJECT	23RD010	CARB	Characterization of Train Brake-Wear and Wheel/Rail-Wear PM Emissions	06/01/2024	05/31/2027
Active		Attorney General Funds - State of CA Department of Justice	Monitoring, Modeling, & Mitigating Emissions & Air Quality Impacts of Goods Movement in Inland Southern CA Environmental Justice Communities	1/01/2022	2/31/2024
Active		CARB (Air Resources Board)	Demonstration of Sensor Technologies for On-Road & Off-Road Heavy-Duty Diesel Vehicles	2/22/2022	2/22/2025
Active		CARB (Air Resources Board	Heavy-Duty Optional Low NOx Vehicle Testing	4/11/2022	3/31/2024
Active		SCAQMD	OMEGA: Objective Measurement/Monitoring/Mitigation of Emissions from Goods Movement and Impacts on Air Quality	12/27/2022	12/26/2025
PENDING	23RD009	California Air Resources Board	Characterizing Unfiltered Exhaust Leaks During Heavy-Duty Vehicle Operations and their Impacts on Disadvantaged Communities		

Co-PI: Carlos Agudelo					
Status (active or pending)	**Award #** (if available)	**Source** (name of the sponsor)	**Project Title**	**Start Date**	**End Date**
PROPOSED PROJECT	23RD010	CARB	Characterization of Train Brake-Wear and Wheel/Rail-Wear PM Emissions	06/01/2024	05/31/2027
ACTIVE	22RD002		Characterization of Tire-Wear and Brake-Wear PM Emissions Under On-Road Driving Conditions	03/01/2023	03/01/2026
ACTIVE	n/a	UNECE / GRPE / PMP / TF3	Interlaboratory accuracy study for GTR 24	01/2024	06/2025

ACTIVE	n/a	PMP/TF5	Laboratory Measurement of Brake Emissions for Heavy-Duty Vehicles	01/2024	01/2030
ACTIVE	n/a	ISO TC 269 / SC 02 / WG 12 / AWI 19341	Railway applications — Measurement methods of particle emission from braking on a railway test bench	01/16/2023	01/16/2026
ACTIVE	n/a	UNECE / GRBP / TF TA	Procedure for determining the abrasion performance of tires of class C1, C2, and C3	04/2022	04/2032
ACTIVE	n/a	SAE & ISO Standard Development Organizations	Several Committees, task forces, and Standards	Ongoing	Ongoing
ACTIVE	n/a	Link Engineering	LabLINK (LIMS Software) Implementation	Ongoing	Ongoing
ACTIVE	n/a	Link Engineering	ADAS Vehicle Testing Development	Ongoing	Ongoing

Co-PI: Jun Wu					
Status (active or pending)	**Award #** (if available)	**Source** (name of the sponsor)	**Project Title**	**Start Date**	**End Date**
PROPOSED PROJECT	23RD010	CARB	Characterization of Train Brake-Wear and Wheel/Rail-Wear PM Emissions	06/01/2024	05/31/2027
CURRENTLY ACTIVE	21RD003	CARB	Examining the Health Impacts of Short-Term Repeated Exposure to Wildfire Smoke	2/15/2022	2/28/2026
CURRENTLY ACTIVE	21RD006	CARB	High Spatiotemporal Resolution $PM_{2.5}$ Speciation Exposure Modeling	3/1/2022	2/28/2026
CURRENTLY ACTIVE	R01ES034445	NIEHS	Research to Action: Inequities in Childhood Life-Course Lead Exposure and Academic and Neurobehavioral Outcomes (I-CLEAN)	5/9/2023	2/29/2028
CURRENTLY ACTIVE	R01AG075739	NIA	Impact of Climate Change on Life Expectancy in a Multiethnic Population	9/1/2022	5/31/2027

CURRENTLY ACTIVE	R01 ES030353	NIEHS	Air Pollution and Pregnancy Complications in Complex Urban Environments: Risks, Heterogeneity, and Mechanisms	8/01/2019	4/30/2025
CURRENTLY ACTIVE	R01ES0303 53-03S1	NIEHS	Environmental and Social Health Determinants of Pregnancy Outcomes Related to COVID-19 Pandemic	9/24/2021	4/30/2025
CURRENTLY ACTIVE	3P20CA253 254-03S2	NCI	CSUF and UCI-CFCCC Partnership for Cancer Health Disparities Research (1 of 2)	9/1/2023	8/31/2025
CURRENTLY ACTIVE	#2148879	NSF	Drinking Water Governance, Equity, and Health	8/15/2022	12/31/2024

Co-PI: Hanyang Li					
Status (active or pending)	**Award #** (if available)	**Source** (name of the sponsor)	**Project Title**	**Start Date**	**End Date**
PROPOSED PROJECT	23RD010	CARB	Characterization of Train Brake-Wear and Wheel/Rail-Wear PM Emissions	06/2024	05/2027
Active	21RD020	CARB	TARTA-XACT Comparison	09/2021	04/2024
Active		EPA	Toxic Metals Monitoring Regional Network (ToMMoRW): High time resolution community-based monitoring in California's Imperial Valley	1/1/2024	12/31/2026
Pending		EPA	Educating San Diegans on military emissions: Air Shows and Air Pollution	7/1/2024	6/30/2026
Pending		DOE	Real time Aerosol Trace Metals in the Mid-Atlantic Region: Sources and Influence on the Regional Environment	71/2024	6/30/2027
Pending		NSF	SBIR Phase I: Low-Cost Speciated Aerosol Real-Time Analyzer	9/1/2024	8/31/2025
Pending		NIH	Simulation for Environmental Exposure Education (S3E): A	6/1/2024	5/30/2026

			Serious Game Platform for Environmental Health Literacy		

Co-PI: John Koupal (ERG)

Status (active or pending)	**Award #** (if available)	**Source** (name of the sponsor)	**Project Title**	**Start Date**	**End Date**
PROPOSED PROJECT	23RD010	CARB	Characterization of Train Brake-Wear and Wheel/Rail-Wear PM Emissions	June 2024	May 2027
Active	22RD002	CARB	Characterization of Tire-Wear and Brake-Wear PM	April 2023	March 2026
Active	22AQP006	CARB	Hexavalent Chromium Emission Factors and Test Methods	June 2023	August 2024
Active	68HERC23F 0488	U.S. EPA	Mobile Source Emission Inventory Model & Emissions Activity Data Technical Support	September 2023	September 2024
Active		Hong Kong Environmental Protection Department	Mesoscale Model Development	March 2023	March 2025

EXHIBIT A7

THIRD PARTY CONFIDENTIAL INFORMATION REQUIREMENT

CONFIDENTIAL NONDISCLOSURE AGREEMENT

Exhibit A7 is not applicable for this Agreement

EXHIBIT D

ADDITIONAL REQUIREMENTS ASSOCIATED WITH FUNDING SOURCES

If the Agreement is subject to any additional requirements imposed on the funding State agency by applicable law (including, but not limited to, bond, proposition and federal funding), then these additional requirements will be set forth in Exhibit D. If the University is a subrecipient, as defined in 2 CFR 200 (Uniform Guidance on Administrative Requirements, Audit Requirements and Cost Principles for Federal Financial Assistance), and the external funding entity is the federal government, the below table must be completed by the State agency. (Please see sections 10.A and 10.B of the Exhibit C.)

State Agency to Complete (Required for Federal Funding Source):

Federal Agency	
Federal Award Identification Number	
Federal Award Date	
Catalog of Federal Domestic Assistance (CFDA) Number and Name	
Amount Awarded to State Agency	
Effective Dates for State Agency	
Federal Award to State Agency is Research & Development (Yes/No)	

University to Complete:

Research and Development (R&D) means all research activities, both basic and applied, and all development activities that are performed by non-Federal entities. The term research also includes activities involving the training of individuals in research techniques where such activities utilize the same facilities as other R&D activities and where such activities are not included in the instruction function.

This award ☐ does ☐ does not support Research & Development.

OR

Exhibit D is not applicable for this Agreement.

EXHIBIT E

SPECIAL CONDITIONS FOR SECURITY OF CONFIDENTIAL INFORMATION

Exhibit E is not applicable for this Agreement.