University Proposal to State

Improvement of the Toxic-Metal Aerosol Real-Time Analysis (TARTA) Instrument for Field Deployment

Principle Investigator:
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Official Authorized to Bind this Proposal:

Signature: Rick Gulizia

Submitted to:
State of California Air Resources Board
Research Division
PO Box 2815
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Prepared by:
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Projected Start/End Dates
August 1, 2023 - July 31, 2026

May 8, 2023

EXHIBIT A

SCOPE OF WORK

☒ Contract ☐ Grant

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

PI Name: Hanyang Li

Project Title: Improvement of the Toxic-Metal Aerosol Real -Time Analysis (TARTA) Instrument for Field Deployment

Project Summary/Abstract

This research project will facilitate the improvement of the Toxic-metal Aerosol Real-Time Analysis (TARTA) instrument developed by the University of California, Davis (UCD) under the California Air Resources Board (CARB) contract #17RD022. This project will leverage the prior work to develop an improved user-friendly version of the previous instrument (TARTA) for research, air monitoring, and citizen science applications. The project will produce five newly designed TARTA-2 for CARB's ownership and deployment for this project, as well as ongoing, and future CARB projects. This project will also leverage open-source software to develop a user interface that will run on a small computing device (SCD) integrated into the instrument. The project will also produce an EZ-swap nozzle/optics cartridge that removes the need for complex maintenance procedures. Such upgrades will improve the accuracy and precision of the toxic metal measurements while maintaining low detection limits of individual metals.

Statement of Significance

Decades ago, air pollution plagued many major cities in the United States (U.S.) and abroad. Many residents in these communities inhale unhealthy air. As federal and state regulations have reduced emission, air quality in metropolitan areas has improved dramatically so that now air quality is less uniform across urban areas with higher concentrations of air pollutants at near-source regions (e.g., roadways, industrial facilities, and power plants). This motivates a renewed look at instrumentation for measuring air pollution and the possibility of developing new instruments suited to investigating near-source air quality problems.

This project is concerned with the toxic metals in air pollution, which are known or suspected to cause cancer or other serious health effects. Metals or metal-containing compounds, such as Beryllium (Be), Cadmium (Cd), Chromium (Cr), Cobalt (Co), Lead (Pb), Manganese (Mn), Nickel (Ni), Mercury (Hg), and Selenium (Se) are included in the U.S. Environmental Protection Agency's (US EPA) list of Hazardous Air Pollutants (HAP). Other metals that are not on the U.S. EPA's HAP list have also been implicated in a range of adverse health effects so are of our concern. These include Aluminum (Al), Barium (Ba), Copper (Cu), Iron (Fe), Tin (Sn), Titanium (Ti), Zinc (Zn).

This research aligns with the monitoring need of toxic metals in communities. The legislation of Assembly Bill (AB) 617 created the foundation for CARB's Community Air Protection Program. This statewide effort has

resulted in the deployment of air quality monitors in communities most impacted by air pollution. The monitored air pollutants include particulate matter (PM), ozone, toxic air contaminants, nitrogen dioxide (NO_2), carbon monoxide (CO), sulfur dioxide (SO_2), volatile organic compounds, etc.

The Toxic Air Contaminant Identification and Control Act (AB 1807) is a California state law that requires CARB to identify and regulate toxic air contaminants. Specifically, AB 1807 mandates CARB to prioritize air toxics based on specific criteria. The criteria include the likelihood of harm to public health, amount of emissions, manner of usage and exposure in California, persistence of the substance in the atmosphere, and concentrations of the substance in communities. Accordingly, CARB has established the California Air Toxics Program to identify sources of air toxics pollutants within these communities and evaluate opportunities to reduce exposures to these pollutants.

The objectives of this research project are to improve TARTA's hardware design and develop software for monitoring purposes. At the end of the project, the Contractor will deliver five TARTA-2 instruments, which will be a ready-to-deploy monitoring device in the field, thereby making TARTA more appealing to researchers, educators, and the general public alike. The derived real-time data of elemental concentrations may be useful for identifying emission sources, localized hotspots, and spatial variation in airsheds. Overall, the goal of this project overlaps with the interests of CARB and other research entities, such as South Coast Air Quality Management District and the Environmental Defense Fund.

BACKGROUND

Fine $PM_{2.5}$ has been identified as a health concern, but temporally well-resolved measurements that describe the composition of $PM_{2.5}$ are lacking, particularly those of toxic metals. Additional opportunities to quantify ambient toxic metals are needed to verify toxic metal inventories and address concerns related to community-bound emissions from the industrial sector. However, existing methods used to measure ambient toxic metals are resource-intensive and semi-automated metal analyzers are often cost-prohibitive and require expertise in techniques such as X-ray fluorescence (XRF) analysis. As such, community-based organizations (CBO), air districts, and researchers have highlighted the need for low-cost alternatives to help understand toxic metal exposures at various locations throughout the state.

TARTA was developed under CARB contract #17RD022 as a proof-of-concept system that offers a low-cost, low-power alternative to existing ambient toxic metal analyzers in the market. The resulting instrument successfully detected and quantified multiple metals (e.g., Cr, Cu, Mn, Fe, Zn, Co) at a relatively comparable precision and accuracy to other existing technologies. Currently, two complex software packages and multiple operating systems are required in a precise engineering lab to collect and interpret the spectrum data generated by the spark-plasma system. Therefore, TARTA requires additional modifications to be field deployable.

EXPERIMENTAL TECHNIQUES

In this project, the Contractor will write open-source software that will run on a Small Computing Device (SCD), which will be integrated into the TARTA-2 instrument. The Contractor will also produce injection-molded pre-aligned particle trap/plasma cell units that will improve the usability of the instrument. The software integration will simplify the spectrum recognition and data collection system while the injection molded particle trap/plasma cell units will significantly reduce the maintenance requirements while reducing the size and weight of the instrument (i.e., removing the baseplate used for alignment and preset gaps on the injection molded plasma cell). These improvements will make the TARTA-2 a field-deployable instrument, which can be readily used by CARB staff and other end-users with minimal training.

PROJECT TASKS

Task 1: Software and Computer Control

The Contractor will write open-source software for calibration, spectrum recognition, data display, and storage of data. The Contractor will also integrate a Small Computing Device (SCD) (e.g., Intel NUC, Raspberry Pi) into TARTA-2 to control the operation and record data. The SCD will be compatible with the new open-source software. The Contractor will develop software that can display and record the concentration data along with appropriate time stamps. The software will allow users to easily download the concentration and spectrum data.

Considering that users of the TARTA-2 may have different experiences and understandings of aerosol devices, the Contractor will develop three modes of software interface: simple mode, basic mode, and advanced mode. Specifically, the simple mode will use different color legends to tell users how healthy the air is to breath (green → red) and which element is above the safe level. The basic mode will report each elemental concentrations in addition to the simple mode. The advanced mode will allow users to further analyze spectra results in a user-friendly graphical environment.

Deliverables:

- The Contractor will submit the open-source code set for the instrument and documentation for the code set.

- The Contractor will provide a demonstration to CARB staff of the new software and SCD working to control the instrument functions without interference from the high voltage spark.

Task 2: Hardware

2.1 The Contractor will also produce an EZ-swap plasma head (nozzle/optics cartridge) that removes the need for complex maintenance procedures. The Contractor will also design and build pre-gapped electrode/ground-concentrator heads using injection molding or similar low-cost and precise fabrication techniques. The Contractor will then incorporate the optics into an easily replaceable plasma head.

2.2 The Contractor will develop and implement a lighter/smaller holding frame and enclosure for the plasma head, spark hardware, optics, and SCD as single unit. The controls and a display for the instrument will also be housed in the same updated enclosure.

2.3 The Contractor will include a safety feature that disconnects the high-voltage system from the power source when the enclosure is accidentally opened (e.g., a door latch). The Contractor will also integrate an emergency shutdown system by using a remote relay coupled to the SCD via Bluetooth, Wireless Fidelity, and/or Personal Computer communication for remote diagnosis, restarting, and shutting down the TARTA-2.

Deliverable:

- The Contractor will provide a demonstration to CARB staff of the operational, revised instrument with the new enclosure, software control, integrated SCD, safety improvements, and remote connection/operation.

Task 3: Operation and Testing

3.1 The Contractor will develop a TARTA-2 user manual with step-by-step instructions for calibration and replacing consumables. The Contractor will include relevant specifications and a standard operating procedure (SOP) for testing flows and deployment of the instrument in the field. The Contractor will include a section on data download and formatting. The user manual will include a section describing the use of the instrument in plain language so the operation will be approachable by the lay person. The Contractor will submit a draft of the user manual for CARB review. The final user manual will be included in the DFR.

3.2 The Contractor will develop calibration standards. The first generation of TARTA was calibrated using aqueous samples, therefore a more accurate quantification method based on the XRF analysis of filter samples will be developed. The calibration models will be rebuilt based on the new quantification method. The Contractor will use National Institute of Standards and Technology (NIST) tracible metals standards to verify the current and new calibration paradigms. Based on the new method, the Contractor will establish a verification procedure that will be used periodically to validate, evaluate, and improve the accuracy of TARTA-2.

3.3 The Contractor will deploy TARTA-2 in the field to test readiness (prior to Task 4.3). The Contractor will conduct unattended testing of TARTA-2. The tests will be conducted in or near facilities with known toxic metal emissions and/or areas with concentrated emissions such as near-highway communities. The Contractor will investigate the possibility of using the instrument as a stack measurement tool for stack/source reporting. The field testing will enable the determination of maintenance requirements, such as when to replace electrodes. The field testing will be used to evaluate the minimum detection limit of TARTA-2.

Deliverables:

- The Contractor will prepare and deliver a TARTA-2 user manual with step-by-step instructions for calibration and replacing consumables, include relevant specifications, a SOP for testing flows and deployment of the instrument in the field, and include a section on data download and formatting. The user manual will also include a section describing the use of the instrument in plain language so the operation will be approachable by the lay person. The Contractor will submit a draft of the user manual for CARB review. The final user manual will also be included in the DFR.

- The Contractor will submit a summary of the instruments' performance from the readiness testing.

Task 4: Construct five TARTA-2 Instruments, Respond to End-User Feedback from CBO and CARB Staff, and Deliver Five TARTA-2 Instruments to CARB

4.1 The Contractor will construct five TARTA-2 instruments to provide meaningful data (e.g., be able to concentrate a sample to the point where the detection will be above Level of Detection (LOD) over a period of a minimum of 15 minutes to an hour depending on ambient concentrations. The Contractor will build and deliver five TARTA-2 instruments to CARB at the end of the contract.

4.2 To enable CARB staff to tune the instrument, the Contractor will train CARB staff, on how to adjust instrument algorithms (e.g., use a bigger pump and deploy two TARTA-2 to record data asynchronously) and how to test the instruments' capability.

4.3 The Contractor will conduct field testing to collect feedback regarding the user interface, operation, and maintenance on useability. The Contractor will work with CARB staff to identify at least one California CBO to test one instrument within California. The Contractor will also send two TARTA-2 instruments to CARB for field testing. The Contractor will utilize the remaining two TARTA-2 instruments to develop the specifications and user manual. The Contractor will provide CARB with a detailed list of all end-user feedback from the field testing Based on this feedback, the Contractor will work with CARB staff to identify top priorities to make additional modifications to improve the usability of the TARTA-2 instruments.

4.4 The Contractor will deliver the five TARTA-2 instruments to CARB for ownership.

4.5 The Contractor will work with CARB staff to formulate field deployment strategies for the future deployment.

Deliverables:

- The Contractor will provide CARB with a detailed list of all end-user feedback, including the top priorities to make additional modifications to the TARTA-2 in the DFR.

- The Contractor will train CARB staff on how to adjust instrument algorithms and how to test the instruments' capability.

- The Contractor will deliver five TARTA-2 instruments (at the end of the project) to CARB for ownership.

Task 5: Meetings and Reporting

At the beginning of the contract, the Contractor will participate in a kick-off meeting to give an overview of the project. The Contractor will meet with CARB staff quarterly and submit quarterly reports using the CARB-designated template, and an invoice for the same period will accompany each progress report. The progress reports will include plain-language summaries that can be posted publicly.

Six months prior to the end of the study, the Contractor will submit a DFR to include the final user manual with step-by-step instructions for calibration and replacing consumables, including relevant specifications, a SOP for testing flows, calibration, and deployment of the instrument in the field, and a section on data download and formatting. The Contractor will provide documentation and the source code for the operation of the instrument use in the SCD. The user manual will also include a section describing the use of the instrument in plain language so the operation will be approachable by the lay person. The DFR will also include a summary of the instruments' performance from the readiness testing (Task 3.3) and any suggestions from the initial software testing from Task 4.3. The DFR will be submitted in accordance with the Final Report format and will be 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 contract manager. The modified DFR will be subject to formal review by the Research Screening Committee (RSC). Once accepted by the RSC, the Contractor will revise the modified DFR addressing the RSC comments and any remaining concerns from CARB staff and will submit the revised final report to CARB. If CARB has additional comments on the report, the Contractor will be notified so appropriate changes can be made; otherwise, CARB will accept the revised final report as the final. The Contractor will submit the final report in an American with Disabilities compliant format. A notation in the DFR task should denote that the Contractor will incorporate a one-page Public Outreach Document into the Final Report, that will be widely used to communicate, in clear and direct terms, the key research findings from the study to the public. The format for the Public Outreach Document is outlined in Exhibit A1, Section 2. In addition, the Contractor will present study findings at a CARB research seminar, virtually or in-person.

DATA MANAGEMENT PLAN

Each spectrum collected by the spectrometer will be transferred to a computer system for storage, analysis and display of metals detected. The Contractor will generate three database directories (raw spectra, pre-processed data, and post-corrected elemental concentration). The work detailed in the data processing procedure will be carefully tracked and documented.

The field activities and the generated data will be logged through both handwritten research notebooks, as well as digitally generated documents. Copies of electronic data will be stored on backup expansion drives maintained by the Contractor and Google Drive provided by San Diego State University, (SDSU).
The results of the research will be disseminated through publication in research articles and professional conference presentations. All of the data products, computer software, and algorithm parameters will be available to interested parties upon request and will be transmitted electronically.

EXISTING FACILITIES

Dr. Hanyang Li's office and laboratory have ample space to perform this work. Colleagues on campus have expertise in software development and injection mold design that can help with TARTA improvement. Dr. Li will make use of the established relationship with environmental justice communities in Southern California to test the improved TARTA in the field. Dr. Anthony Wexler, the subcontractor (University of California, Davis [UCD]) of the project, has extensive experience designing and fielding new aerosol instrumentation. The Air Quality Research Center at UCD has the capability to analyze filter samples using the XRF technique and make laboratory aerosols composed of heavy metals.

PROJECT SCHEDULE

	Quarters											
	1	2	3	4	5	6	7	8	9	10	11	12
Task												
1												
2												
3												
4												
5												
	mp	mp	mp	mp	mp	mp	mp	mp	mp	mp	d	fr

m = meeting with CARB staff; p = quarterly progress report; d = deliver draft final report; f = deliver final report; r = research seminar

MEETINGS

- Initial meeting. 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.

- 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.

- Technical Seminar. The Contractor will present the results of the project to CARB staff and a possible webcast at a CARB research seminar (virtually or in-person at CARB facilities in Sacramento).

PROJECT MANAGEMENT PLAN

The project will be managed by Dr. Hanyang Li, Assistant Professor of environmental engineering at SDSU. Dr. Li was the lead developer of TARTA while a Post-Doctoral Fellow in Dr. Anthony Wexler's group at UCD. In this project, Dr, Li will oversee a Graduate Student Researcher (TBA) to work on device design, testing, characterization, and field deployment, as well as software development.

The subcontractor will be Dr. Anthony Wexler and Chris Wallis (an engineer in the Air Quality Research Center) at UCD. Dr. Wexler will provide guidance and technical support as needed. Chris Wallis will provide assistance for technical, software, and hardware problems. All investigators will work on report writing.

Dr. Fred Brechtel, the Chief Executive Officer and Owner of Brechtel, will advise the Contractor on instrument optimization and manufacturing based on expertise on the development of airborne PM measurement technologies.

POSSIBILITES FOR FUTURE DEVELOPMENT OF THE TARTA-2

If future funding becomes available, the following are three "explorable possibilities" that could be derived from this work:

- *Possibility 1: Explore the Direction of the Air Flow*

  The Contractor could investigate the modification of the flow direction to pull the air sample into the plasma chamber instead of "pushing" the air sample. Such modification would require an airtight redesign of the plasma chamber, resulting in higher cost and complexity. If the flow direction is changed, the Contractor could use NIST calibrated flow device to check and calibrate flow.

- *Possibility 2: Investigate the Range of Particle Sizes Vaporized by the Spark Plasma*

  If large particles (e.g., coarse particles or dust) cannot be ionized by the original TARTA system, the Contractor could evaluate the need for a controlled inlet or a higher voltage spark to ionize them. The investigation should include the reversing of the airflow direction to account for possible scavenging of particles by the pump to account for the particle size bias.

- *Possibility 3: Investigate the Use of TARTA-2 in a Mobile Setting*

  The Contractor could investigate enhancing the TARTA-2 unit to give meaningful data (e.g., be able to concentrate a sample to the point where the detection will be above LOD for on-road data collection in a mobile platform at a high temporal frequency (e.g., five minutes or shorter). This investigation could also include a dual or multi-instrument setup operating on alternate time base(s) to increase effective time resolution.

REFERENCES

1. Li, H., Mazzei, L., Wallis, C. D., Davari, S. A., & Wexler, A. S. (2021). The performance of an inexpensive spark-induced breakdown spectroscopy instrument for near real-time analysis of toxic metal particles. *Atmospheric Environment*, 118666. https://doi.org/10.1016/j.atmosenv.2021.118666

2. Li, H., Mazzei, L., Wallis, C. D., & 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*, 105874. https://doi.org/10.1016/j.jaerosci.2021.105874

3. Li, H., Mazzei, L., Wallis, C., & Wexler, A.S. (under review), Detection of atmospheric particulate metals in near real-time: tunnel, urban and rural environments. Aerosol Science and Technology

EXHIBIT A1

SCHEDULE OF DELIVERABLES

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 the 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
Progress Reports & Meetings	Quarterly progress reports and meetings throughout the agreement term, to coincide with work completed in quarterly invoices. The progress reports will include plain-language summaries that can be posted publicly.	Quarterly
Task 1 - Software and Computer Control	• Open-source code set for the instrument and documentation for the code set. • Demonstration to CARB staff of the new software and SCD working to control the instrument functions without interference from the high voltage spark.	Month 12 Month 18
Task 2 - Hardware	• Demonstration of the completed new enclosure to CARB staff of the operational, revised instrument with the new enclosure, software control, integrated SCD, safety improvements, and remote connection/operation.	Month 24
Task 3 - Operation and Testing	• The Contractor will prepare and deliver a TARTA-2 user manual with step-by-step instructions for calibration and replacing consumables, include relevant specifications, a SOP for testing flows and deployment of the instrument in the field, and include a section on data download and formatting. The user manual will also include a section describing the use of the instrument in plain language so the operation will be approachable by the lay person.	Month 30
Task 4 - Construct five TARTA-2 Instruments, Respond to End-User Feedback from CBO and CARB Staff, and Deliver Five TARTA-2 Instruments to CARB	• Detailed list of all end-user feedback, including the top priorities to make additional modifications to the TARTA-2 in the DFR. • Train CARB staff on how to adjust instrument algorithms and how to test the instruments' capability. • Deliver five TARTA-2 instruments, at the end of the project, to CARB for ownership.	Month 30 Month 34 Month 36

Draft Final Report	Draft version of the Final Report detailing the purpose and scope of the work undertaken, the work performed, and the results obtained and conclusions.	Six (6) months prior to agreement end date.
Data	Data compilations which were first produced in the performance of this Agreement by the Principal investigator or the University's project personnel.	Two (2) weeks prior to agreement end date.
Technical Seminar	Presentation of the results of the project to CARB staff and a possible webcast at a seminar at CARB facilities in Sacramento or El Monte.	On or before agreement end date.
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.	Two (2) weeks prior to agreement end date.

1. Reports and Data Compilations

A. With respect to each invoice period University shall submit, to the CARB Contract Project Manager, one (1) electronic copy of the progress report. When emailing the progress report, the "subject line" should state the contract number and the billing period. Each progress report will begin with the following disclaimer:

The statements and conclusions in this report are those of the University and not necessarily those of the California Air Resources Board. The mention of commercial products, their source, or their use in connection with material reported herein is not to be construed as actual or implied endorsement of such products.

B. Each progress report will also include:

1. A brief narrative account of project tasks completed or partially completed since the last progress report;

2. A brief discussion of problems encountered during the reporting period and how they were or are proposed to be resolved;

3. A brief discussion of work planned, by project task, before the next progress report; and

4. A graph or table showing allocation of the budget and amount used to date.

5. A graph or table showing percent of work completion for each task.

C. If the project is behind schedule, the progress report must contain an explanation of reasons and how the University plans to resume the schedule.

D. Six (6) months prior to Agreement expiration date, University will deliver to CARB five (5) bound copies of a draft final report. The reports may be stapled or spiral bound, depending on size. The draft final report will conform to Exhibit A1, Section 2 – Research Final Report Format.

E. Within forty-five (45) days of receipt of CARB's comments, University will deliver to CARB's Contract Project Manager two (2) copies of the final report incorporating all reasonable alterations and additions. Within two (2) weeks of receipt of the revised report, CARB will verify that all CARB comments have been addressed. Upon acceptance of the amended final report approved by CARB in accordance to Exhibit A1, Section 2 – Research Final Report Format, University will within two (2) weeks, deliver to CARB two (2) camera ready UNBOUND originals of a final report incorporating all final alterations and additions.

F. Together with the final report, University will deliver a copy of the report on CD, using any common word processing software (please specify the software used) and a set of all data compilations as specified in Exhibit A1 – Schedule of Deliverables.

G. University's obligation under this Agreement shall be deemed discharged only upon submittal to CARB of an acceptable final report in accordance to Exhibit A1, Section 2 – Research Final Report Format, report CD, all required data compilations, and any other project deliverables.

2. Research Final Report Format

The research contract Final Report (Report) is as important to the contract as the research itself. The Report is a record of the project and its results and is used in several ways. Therefore, the Report must be well organized and contain certain specific information. The CARB's Research Screening Committee (RSC) reviews all draft final reports, paying special attention to the Abstract and Executive Summary. If the RSC finds that the Report does not fulfill the requirements stated in this Exhibit, the document will not be approved for release, and final payment for the work completed may be withheld. This Exhibit outlines the requirements that must be met when producing the Report.

Note: In partial fulfillment of the Final Report requirements, the Contractor shall submit a copy of the Report on a CD in PDF format and in a word-processing format, preferably in Word – Version 6.0 or later. This is in addition to the submission of any paper copies required. The CD shall be clearly labeled with the contract title, CARB contract number, the words "Final Report", and the date the report was submitted.

Legibility. Each page of the approved Final Report must be legible and camera-ready.

Accessibility. In order to maintain compliance with California Government Code Sections 7405 and 11135, and Web Content Accessibility Guidelines, Assembly Bill No. 434, the final Report must be submitted in an Americans with Disabilities Act compliant format. The final Report will be posted on the CARB website and therefore must be in an accessible format so that all members of the public can access it.

Binding. The draft Report, including its appendices, must be either spiral bound or stapled, depending on size. The revised Report and its appendices should be spiral bound, except for two unbound, camera-ready originals.

Cover. Do not supply a cover for the Report. The CARB will provide its standard cover.

One-sided vs. two-sided. To conserve paper, the draft Report, the revised Report, and the unbound camera-ready copies should be printed on both sides of the page.

Watermark. Each page of the draft Report must include a watermark stating “DRAFT.” The revised report should not include any watermarks.

Title. The title of the Report should exactly duplicate the title of the contract unless a change is approved in writing by the contract manager.

Spacing. In order to conserve paper, copying costs, and postage, please use single or one-line (1) spacing.

Page size. All pages should be of standard size (8 ½" x 11") to allow for photo-reproduction.

Large tables or figures. Foldout or photo-reduced tables or figures are not acceptable because they cannot be readily reproduced. Large tables and figures should be presented on consecutive 8 ½" x 11" pages, each page containing one portion of the larger chart.

Color. Printing shall be black on white. However, color images are acceptable where necessary.

Corporate identification. Do not include corporate identification on any page of the Final Report, except the title page.

Unit notation. Measurements in the Reports should be expressed in metric units. However, for the convenience of engineers and other scientists accustomed to using the British system, values may be given in British units as well in parentheses after the value in metric units. The expression of measurements in both systems is especially encouraged for engineering reports.

Section order. The Report should contain the following sections, in the order listed below:

Title page
Disclaimer
Acknowledgment (1)
Acknowledgment (2)
Table of Contents
List of Figures
List of Tables
Abstract
Executive Summary
Body of Report
References
List of inventions reported and copyrighted materials produced
Glossary of Terms, Abbreviations, and Symbols
Appendices

Page numbering. Beginning with the body of the Report, pages shall be numbered consecutively beginning with “1”, including all appendices and attachments. Pages preceding the body of the Report shall be numbered consecutively, in ascending order, with small Roman numerals.

Title page. The title page should include, at a minimum, the contract number, contract title, name of the principal investigator, contractor organization, date, and this statement: "Prepared for the California Air Resources Board and the California Environmental Protection Agency"

Disclaimer. A page dedicated to this statement must follow the Title Page:

The statements and conclusions in this Report are those of the contractor and not necessarily those of the California Air Resources Board. The mention of commercial products, their source, or their use in connection with material reported herein is not to be construed as actual or implied endorsement of such products.

Acknowledgment (1). Only this section should contain acknowledgments of key personnel and organizations who were associated with the project. The last paragraph of the acknowledgments must read as follows:

This Report was submitted in fulfillment of [CARB contract number and project title] by [contractor organization] under the [partial] sponsorship of the California Air Resources Board. Work was completed as of [date].

Acknowledgment (2). Health reports should include an acknowledgment to the late Dr. Friedman. Reports should include the following paragraph:

This project is funded under the CARB's Dr. William F. Friedman Health Research Program. During Dr. Friedman's tenure on the Board, he played a major role in guiding CARB's health research program. His commitment to the citizens of California was evident through his personal and professional interest in the Board's health research, especially in studies related to children's health. The Board is sincerely grateful for all of Dr. Friedman's personal and professional contributions to the State of California.

Table of Contents. This should list all the sections, chapters, and appendices, together with their page numbers. Check for completeness and correct reference to pages in the Report.

List of Figures. This list is optional if there are fewer than five illustrations.

List of Tables. This list is optional if there are fewer than five tables.

Abstract. The abstract should tell the reader, in nontechnical terms, the purpose and scope of the work undertaken, describe the work performed, and present the results obtained and conclusions. The purpose of the abstract is to provide the reader with useful information and a means of determining whether the complete document should be obtained for study. The length of the abstract should be no more than about 200 words. Only those concepts that are addressed in the executive summary should be included in the abstract.

Example of an abstract:

A recently developed ground-based instrument, employing light detecting and ranging (lidar) technology, was evaluated and found to accurately measure ozone concentrations at altitudes of up to 3,000 meters. The novel approach used in this study provides true vertical distributions of ozone concentrations aloft and better temporal coverage of these distributions than other, more common methods, such as those using aircraft and ozonesonde (balloon) techniques. The ozone and aerosol measurements from this study, in conjunction with temperature and wind measurements, will provide a better characterization of atmospheric conditions aloft and the processes involved in the formation of unhealthful ozone concentrations than can be achieved with traditional ground-based monitors.

Executive Summary. The function of the executive summary is to inform the reader about the important aspects of the work that was done, permitting the reader to understand the research without reading the entire Report. It should state the objectives of the research and briefly describe the experimental methodology[ies] used, results, conclusions, and recommendations for further study. All of the concepts brought out in the abstract should be expanded upon in the Executive Summary. Conversely, the Executive Summary should not contain concepts that are not expanded upon in the body of the Report.

The Executive Summary will be used in several applications as written; therefore, please observe the style considerations discussed below.

Limit the Executive Summary to two pages, single spaced.

Use narrative form. Use a style and vocabulary level comparable to that in Scientific American or the New York Times.

Do not list contract tasks in lieu of discussing the methodology. Discuss the results rather than listing them.

Avoid jargon.

Define technical terms.

Use passive voice if active voice is awkward.

Avoid the temptation to lump separate topics together in one sentence to cut down on length.

The Executive Summary should contain four sections: Background, Objectives and Methods, Results, and Conclusions, described below.

THE BACKGROUND SECTION. For the Background, provide a one-paragraph discussion of the reasons the research was needed. Relate the research to the Board's regulatory functions, such as establishing ambient air quality standards for the protection of human health, crops, and ecosystems; the improvement and updating of emissions inventories; and the development of air pollution control strategies.

THE OBJECTIVES AND METHODS SECTION. At the beginning of the Objectives and Methods section, state the research objectives as described in the contract. Include a short, one or two sentence, overview of what was done in general for this research.

The methodology should be described in general, nontechnical terms, unless the purpose of the research was to develop a new methodology or demonstrate a new apparatus or technique. Even in those cases, technical aspects of the methodology should be kept to the minimum necessary for understanding the project. Use terminology with which the reader is likely to be familiar. If it is necessary to use technical terms, define them. Details, such as names of manufacturers and statistical analysis techniques, should be omitted.

Specify when and where the study was performed, if it is important in interpreting the results. The findings should not be mentioned in the Objectives and Methods section.

THE RESULTS SECTION. The Results section should be a single paragraph in which the main findings are cited and their significance briefly discussed. The results should be presented as a

narrative, not a list. This section must include a discussion of the implications of the work for the Board's relevant regulatory programs.

THE CONCLUSIONS SECTION. The Conclusions section should be a single short paragraph in which the results are related to the background, objectives, and methods. Again, this should be presented as a narrative rather than a list. Include a short discussion of recommendations for further study, adhering to the guidelines for the Recommendations section in the body of the Report.

Body of Report. The body of the Report should contain the details of the research, divided into the following sections:[1]

INTRODUCTION. Clearly identify the scope and purpose of the project. Provide a general background of the project. Explicitly state the assumptions of the study.

Clearly describe the hypothesis or problem the research was designed to address. Discuss previous related work and provide a brief review of the relevant literature on the topic.

MATERIALS AND METHODS. Describe the various phases of the project, the theoretical approach to the solution of the problem being addressed, and limitations to the work. Describe the design and construction phases of the project, materials, equipment, instrumentation, and methodology. Describe quality assurance and quality control procedures used. Describe the experimental or evaluation phase of the project.

RESULTS. Present the results in an orderly and coherent sequence. Describe statistical procedures used and their assumptions. Discuss information presented in tables, figures, and graphs. The titles and heading of tables, graphs, and figures, should be understandable without reference to the text. Include all necessary explanatory footnotes. Clearly indicate the measurement units used.

DISCUSSION. Interpret the data in the context of the original hypothesis or problem. Does the data support the hypothesis or provide solutions to the research problem? If appropriate, discuss how the results compare to data from similar or related studies. What are the implications of the findings? Identify innovations or development of new techniques or processes. If appropriate, discuss cost projections and economic analyses.

SUMMARY AND CONCLUSIONS. This is the most important part of the Report because it is the section that will probably be read most frequently. This section should begin with a clear, concise statement of what, why, and how the project was done. Major results and conclusions of the study should then be presented, using clear, concise statements. Make sure the conclusions reached are fully supported by the results of the study. Do not overstate or overinterpret the results. It may be useful to itemize primary results and conclusions. A simple table or graph may be used to illustrate.

RECOMMENDATIONS. Use clear, concise statements to recommend (if appropriate) future research that is a reasonable progression of the study and can be supported by the results and discussion.

References. Use a consistent style to fully cite work referenced throughout the Report and references to closely related work, background material, and publications that offer additional information on aspects of the work. Please list these together in a separate section, following the body of the Report. If the Report is lengthy, you may list the references at the end of each chapter.

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[1] Note that if the research employs multiple distinct methods, analyses, etc., the final report can include separate materials/methods, results, and discussion sections to allow for coherent discussion of each set of analyses and findings. However, the executive summary and conclusions sections should synthesize the collective findings of the entire study.

List of inventions reported and publications produced. If any inventions have been reported, or publications or pending publications have been produced as a result of the project, the titles, authors, journals or magazines, and identifying numbers that will assist in locating such information should be included in this section.

Glossary of terms, abbreviations, and symbols. When more than five of these items are used in the text of the Report, prepare a complete listing with explanations and definitions. It is expected that every abbreviation and symbol will be written out at its first appearance in the Report, with the abbreviation or symbol following in parentheses [i.e., carbon dioxide (CO2)]. Symbols listed in table and figure legends need not be listed in the Glossary.

Appendices. Related or additional material that is too bulky or detailed to include within the discussion portion of the Report shall be placed in appendices. If a Report has only one appendix, it should be entitled "APPENDIX". If a Report has more than one appendix, each should be designated with a capital letter (APPENDIX A, APPENDIX B). If the appendices are too large for inclusion in the Report, they should be collated, following the binding requirements for the Report, as a separate document. The contract manager will determine whether appendices are to be included in the Report or treated separately. Page numbers of appendices included in the Report should continue the page numbering of the Report body. Pages of separated appendices should be numbered consecutively, beginning at “1”.

3. Other Deliverables

A. Any other deliverables shall be provided in a mutually agreed upon format unless the deliverable format is already specified in Exhibit A.

EXHIBIT A2

KEY PERSONNEL

List Key Personnel as defined in the Agreement starting with the PI, by last name, first name followed by Co-PIs. Then list all other Key Personnel in alphabetical order by last name. For each individual listed include his/her name, institutional affiliation, and role on the proposed project. Use additional consecutively numbered pages as necessary.

Last Name, First Name	**Institutional Affiliation**	**Role on Project**
Principal Investigator (PI):		
Hanyang Li	San Diego State University	Principal Investigator (PI)
Other Key Personnel:		
Anthony S. Wexler	UC Davis	Subcontractor

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: San Diego State University Research Foundation
Contract Project Manager (Technical) Name: Steve Mara Address: Research Division 1001 I Street, 7th Floor Sacramento, CA 95814 Telephone: (279) 842-9574 Email: steve.mara@arb.ca.gov	***Principal Investigator (PI)*** Name: Hanyang Li Address: 5500 Campanile Drive San Diego State University San Diego, CA 92182 Telephone: 619-594-3802 Email: hli6@sdsu.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: Renee Carnes Address: Research Division 1001 I Street, 7th Floor Sacramento, CA 95814 Telephone: (279) 208-7754 Email: renee.carnes@arb.ca.gov	***Authorized Official*** Name: Sandra Nordahl Address: SRCC 5250 Campanile Drive San Diego, CA, 92182 ***Send notices to (if different):*** Email: sdsurfawards@sdsu.edu
Administrative Contact Name: Renee Carnes Address: Research Division 1001 I Street, 5th Floor Sacramento, CA 95814 Telephone: (279) 208-7754 Email: renee.carnes@arb.ca.gov	***Administrative Contact*** Name: Steve Torok Address: 5250 Campanile Drive San Diego, CA, 92182 Telephone: 619-594-6620 Email: sdsurfawards@sdsu.edu

Financial Contact/Accounting	***Authorized Financial Contact/Invoicing***
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**	Name: Kelly Ainsworth Address: 5250 Campanile Drive San Diego, CA, 92182 Telephone: 619-594-5772 Email: sdsurfcashier@sdsu.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 or ☐ List:

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

☒ None or ☐ List:

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 or ☐ List:

EXHIBIT A5

RÉSUMÉ / BIOSKETCH

Hanyang Li

Assistant Professor
Department of Civil, Construction, and Environmental Engineering
San Diego State University
5500 Campanile Dr, San Diego, CA 92182

Email: hli6@sdsu.edu
Phone: (619) 594-3802
Personal Webpage: PageURL

PROFESSIONAL APPOINTMENTS

- **Assistant Professor** July 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

RESEARCH INTERESTS

- Air quality monitoring
- Environmental justice
- Computational analysis of air pollution
- Development of portable instruments to monitor atmospheric pollutants

CURRENT AND PENDING SUPPORT

Active

- 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, $13,955 to Dr. Li.
- PI, “Air quality monitoring in Imperial Valley”, SDSU Seed Grant Program, $7,500 to Dr. Li
- PI, “Monitoring of toxic metal emissions from on-road vehicles”, SDSU Weber Honors College Research Fellows Program, $1,000 to Dr. Li

Awarded

- 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 (submitted in March 2022).

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.
-

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

MANUSCRIPTS UNDER REVIEW

1. ***Li, H.***, Mazzei, L., Wallis, C., & Wexler, A.S., Detection of atmospheric particulate metals in near real-time: tunnel, urban and rural environments. *Aerosol Science and Technology*

COURSE TAUGHT

2. ENVE320 (San Diego State University): Designing solutions for environmental problems (Fall 2022)

MENTORING EXPERIENCES

Cecilio Cazares, undergraduate student, San Diego State University	2022
Leonardo Mazzei, undergraduate student, UC Davis	2020 – 2021
Belinda Isabel Ortega, graduate student, UC Davis	2021
Di Xu, undergraduate student, the Ohio State University	2020
Olivia Ambuehl, undergraduate student, the Ohio State University	2017

INVITED PRESENTATIONS

- Characterization of primary aerosols and instrument development. Annual Conference of the Atmospheric Environment Branch of the Chinese Society of Environmental Sciences *(Virtual meeting, November 2022)*
- Air pollution characterization and instrument development. Department of Civil, Construction, and Environmental Engineering, San Diego State University *(San Diego CA, April 2022).*
- Primary aerosol identification and quantification. NOAA Chemical Sciences Laboratory *(Virtual, January 2022).*
- Design and development of an instrument for toxic-metal aerosol real time analysis. UC Davis MAE graduate seminar *(Davis CA, November 2021).*

CONFERENCE PRESENTATIONS

- Detecting toxic metals in ambient particulate matter using a low-cost and near real-time analyzer. *Air Sensors International Conference (Pasadena CA, May 2022)*
- Field Testing PurpleAir Sensors Alongside IMPROVE Air Quality Monitoring System (poster). *Air Sensors International Conference (Pasadena CA, May 2022)*
- Application of an inexpensive instrument for measurements of atmospheric metal particles (poster). *American Geophysical Union 2021 fall meeting (New Orleans LA, December 2021).*
- Improving quantitative analysis of spark-induced breakdown spectroscopy: multivariate calibration of toxic metal particles using machine learning. *American Association for Aerosol Research (Virtual meeting, October 2021).*
- Development of an inexpensive spark-induced breakdown spectroscopy instrument for measurements of atmospheric toxic metals. *American Association for Aerosol Research (Virtual meeting, October 2021).*
- Application of an inexpensive spark-induced breakdown spectroscopy instrument for measurements of atmospheric metal particles (poster). *UC Davis Environmental Health Sciences Center (Davis CA, October 2021).*
- Development of an instrument for toxic-metal aerosol real time analysis. *6th UCD Postdoctoral Research Symposium (Virtual meeting, March 2021).*
- Estimation of the mass absorption cross section of atmospheric black carbon using regression and machine learning approaches. *American Association for Aerosol Research (Virtual meeting, October 2020).*
- Development of a universal correction algorithm for filter-based absorption photometers. *American Association for Aerosol Research (Portland OR, October 2019).*
- Constraining uncertainties associated with black carbon emissions during biomass burning (poster). *Byrd Center Symposium (Columbus, OH, March 2019).*
- Inter-comparison of techniques for the measurement of black carbon from biomass burning: influence of optical and chemical properties. *International Aerosol Conference (St. Louis MO, September 2018).*
- Quantitative comparison of correction algorithms applied filter-based black carbon measurements during the FIREX campaign (poster). *International Aerosol Conference (St. Louis MO, September 2018).*
- Inter-comparison of black carbon measurement techniques using biomass burning smoke. *Chinese Environmental Scholars Forum (Raleigh NC, June 2018).*
- A systematic inter-comparison of black carbon measurement techniques using biomass burning smoke. *American Association for Aerosol Research* (*Raleigh NC, October 2017).*

NAME: **Anthony S. Wexler**

eRA COMMONS USER NAME (credential, e.g., agency login): aswexler

POSITION TITLE: Distinguished Professor and Director

EDUCATION/TRAINING *(Begin with baccalaureate or other initial professional education, such as nursing, include postdoctoral training and residency training if applicable. Add/delete rows as necessary.)*

INSTITUTION AND LOCATION	DEGREE *(if applicable)*	Completion Date MM/YYYY	FIELD OF STUDY
University of California, Berkeley	B.S.	06/1976	Engineering Physics
Massachusetts Institute of Technology	S.M.	03/1978	Mechanical Engineering
California Institute of Technology	Ph.D.	12/1990	Mechanical Engineering

A. Personal Statement: My research employs theoretical, mathematical modeling and measurement techniques to investigate gas and particle pollutants in the atmosphere and their health impacts. As director of the Air Quality Research Center at UC Davis and formerly of EPA's San Joaquin Valley Aerosol Health Effects Research Center (SAHERC), I have experience managing substantial funding and personnel. I have published over 250 peer-reviewed papers many of which are related to air quality and climate.

- **Mentoring:** Over the past 10 years, I have been the mentor for 5 post-doctoral fellows and 3 graduate students. I meet weekly with my laboratory team to discuss research progress and guide them. I also meet monthly with the research team that investigates the neurotoxicity of traffic-related air pollution, which involves graduate students, research staff and faculty colleagues to check in on progress and advise on next steps.
- **Qualification as a Mentor:** Over the course of my career, I have financially supported and mentored 25 post-doctoral fellows and 26 graduate students. I am especially proud of mentoring the three female post-doctoral fellows and graduate students in the physical sciences and engineering who have gone on to obtain faculty positions where they mentor the next generation of female scientists and engineers.

Ongoing and recently completed projects I would like to highlight include:

Funding Source: NIH
Title: Do atmospheric ultrafine particles lodge in the brain and cause cognitive decline leading to Alzheimer's Disease Related Dementias?
PI: Pam Lein
Dates: August 1, 2022 to July 31, 2027
The goal of this project is to relate our prior finds on how ultrafine air pollution particles lead to Alzheimer's disease in a rat pre-clinical model to a cohort of Alzheimer's patients.

Funding Source: USDA
Title: Specialty Crop Research Institute on Wine Taint from Wildfire Smoke
PI: Elizabeth Tomasino, Oregon State University
Dates: January 1, 2022 to December 31, 2024
This supports development of a new instrument to help wine grape growers and vintners assess which grapes are tainted by wildfire smoke so should not be harvested.

Funding Source: California Air Resource Board

Title: Design and Development of an Instrument for Toxic-metal Aerosol Real Time Analysis (TARTA)
PI: Anthony Wexler
Dates: 06/01/18 – 05/31/22
The goal of this project is developing a new instrument for online measurement of atmospheric toxic metals. The project is motivated by environmental justice concerns: Underrepresented communities living in close proximity to industries that emit toxic metals need methods for assessing their exposure to these metal emissions. The instrument will use incandescence breakdown spectroscopy for metals analysis.

B. Positions and Honors

Positions and Employment

Distinguished Professor, Mechanical and Aeronautical Engineering, Civil and Environmental Engineering, and Land, Air and Water Resources, University of California, Davis	2015-present
Director, Air Quality Research Center, University of California, Davis	2005-present
Director, Crocker Nuclear Laboratory, University of California, Davis	2009-2016
Professor, Mechanical and Aeronautical Engineering, Civil and Environmental Engineering, and Land, Air and Water Resources, University of California, Davis	2000-2015
Professor, Department of Mechanical Engineering, University of Delaware	1999-2000
Assoc. Professor, Department of Mechanical Engineering, University of Delaware	1994-1999
Assistant Professor, Department of Mechanical Engineering, University of Delaware	1991-1994
Research Associate, Department of Physiology and Biophysics, School of Medicine, University of Southern California	1984-1990

Selected Professional Experience and Professional Memberships

User Advocate, Helping the Public Understand Effects of Emissions on Local Air Quality, The Opportunity Project, US Census Bureau, July – September, 2020.

Distinguished Lecturer, Center for Aerosol Science and Technology, Washington University in St. Louis, November 2019

Member, Endowment Committee, American Association for Aerosol Research, 2019 - present

Member, External Advisor Board, EU project Transport derived Ultrafines and the Brain Effects (TUBE), coordinated by Associate Professor Pasi Jalava at the University of Eastern Finland (UEF). 2020 – present.

Juror, Smogathon Semi-Final Competition in Berkeley and Final Competition in Krakow, Poland, 2017.

Member, Scientific Advisory Committee, Center for Air, Climate, and Energy Solutions, Carnegie Mellon University and University of Minnesota, 2016-2021.

Member, American Association for Aerosol Research representative to the International Aerosol Research Assembly, 2014-2018.

Member, Management Company Selection Committee, American Association for Aerosol Research, 2014

Chair, Haagen-Smit Prize Committee, Atmospheric Environment, 2013-2017

Member, Nominating Committee, American Association for Aerosol Research, 2011

Chair, International Advisory Committee, Center for Excellence in Environmental Studies, King Abdulaziz University, Jeddah, Saudi Arabia, 2011-2015

Consultant, Novozymes, 2010-2011

Member, National Research Council Committee to evaluate the Army's Enhanced Particulate Matter Surveillance Project Report, 2009

Selected Honors and Awards

Chair, Haagen-Smit Prize Committee, Atmospheric Environment	2013-2016
Chair, International Advisory Committee, Center for Excellence in Environmental Studies, King Abdulaziz University, Jeddah, Saudi Arabia,	2011-2016
Elected to Fellow status, American Association for Aerosol Research	2011
Outstanding Mid-career Research Faculty Award, College of Engineering, UC Davis	2005
President of the American Association for Aerosol Research	2005-2006
Appointed to Editorial Board, Atmospheric Environment	2004

C. Contributions to Science (trainees are unlined)

1) Ambient Aerosol Measurement Technology: Ambient aerosols are associated with adverse pulmonary, cardiovascular and neurological health effects yet the responsible time courses, sizes, compositions and concentrations of these particles are not fully known. Improved instruments help to relate particle properties to adverse health effects. We are currently developing new instruments for measuring toxic metals in the atmosphere and volatile organic compounds, both in real time. Recent Publications: (1) Takahama, S., A.M. Dillner, A.T. Weakley, M. Reggente, C. Bürki, M. Lbadaoui-Darvas, B. Debus, A. Kuzmiakova, and A.S. Wexler. Atmospheric particulate matter characterization by Fourier Transform Infrared spectroscopy: a review of statistical calibration strategies for carbonaceous aerosol quantification in US measurement networks. Atmos. Meas. Tech. amt-2018-70, (2) Venecek, M.A., Y. Zhao, J. Mojica, C.E. McDade, P.G. Green, M.J. Kleeman and A.S. Wexler, Characterization of the 8-Stage Rotating Drum Impactor under Low Concentration Conditions. J. Aerosol Sci. 100:140-154, 2016. (3) Bein, K.J. and A.S. Wexler, A High-Efficiency, Low-Bias Method for Extracting Particulate Matter from Filter and Impactor Substrates. Atmos. Environ. 90:87-95, 2014. (4) Chua, B., A.S. Wexler, N.C. Tien, D.A. Niemeier, and B.A. Holmen, Collection of Liquid Phase Particles by Microfabricated Electrostatic Precipitator. J. Microelectromech. Sys., 22:1010-1019, 2013. (5) Engel, D., M. Hummel, F. Hoepel, K.J. Bein, A.S. Wexler, C.A. Garth, B. Hamann, and H. Hagen, Towards High-dimensional Data Analysis in Air Quality Research, Comp. Graphics Forum, 32:101-110, 2013.

2) Atmospheric Aerosol Modeling and Thermodynamics: Many chemical compounds in the atmosphere are hygroscopic and/or are semivolatile so partition between the gas and particle phases. We have established a web site (E-AIM) with tools for modeling these process. Recent Publications: (1) Wexler, A.S., Raoult was Right After All. ACS Omega 4:12848−12852, 2019, (2) Cappa, C.D., S. H. Jathar, M. J. Kleeman, K. S. Docherty, J. L. Jimenez, J. H. Seinfeld, and A. S. Wexler, Simulating Secondary Organic Aerosol in a Regional Air Quality Model Using the Statistical Oxidation Model -- Part 2: Assessing the Influence of Vapor Wall Losses. Atmos. Chem. Phys. 16:3041-3059, 2016. (3) Wang, J. and A.S. Wexler, Adsorption of organic molecules may explain growth of newly nucleated clusters and new particle formation. Geophys. Res. Lett. 40:2834-2838, 2013. (4) Dutcher, C.S., X. Ge, A.S. Wexler, and S.L. Clegg, An Isotherm-Based Thermodynamic Model of Multicomponent Aqueous Solutions, Applicable over the Entire Concentration Range. J. Phys. Chem. A 3198-3213, 2013. (5) Wexler, A.S. and C.S. Dutcher, Statistical Mechanics of Multilayer Sorption: Surface Tension. J. Phys. Chem. Lett. 1723-1726, 2013.

3) Airway Shape and Particle Deposition: The shape of human airways and flow in them governs the amount and location of particle deposition which in turn influences their resulting health effects. We have measured and modeled these processes. Recent Publications: (1) Asadi, S., A.S. Wexler, C.D. Cappa, S. Barreda, N. Bouvier, and W. Ristenpart, Aerosol emission and superemission during human speech increase with voice loudness. Sci. Reports 9.1 (2019): 2348. (2) Broche, L., G. Perchiazzi, L. Porra, A. Tannoia, M. Pellegrini, S. Derosa, A. Sindaco, J.B. Borges, L. Degrugilliers, A. Larsson, G. Hedenstierna, A.S. Wexler, A. Bravin, S. Verbanck, B.J. Smith, J.H.T. Bates, and S.Bayat, Dynamic Mechanical Interactions between Neighboring Airspaces Determine Cyclic Opening and Closure in Injured Lung. Acta Physiologica 217:141, 2016. (3) Srirama, P.K., C.D. Wallis, D.Y. Lee, and A.S. Wexler, Imaging Airways and Particles Deposited in Them: Extra-thoracic Airways of Laboratory Animals, J. Aerosol Sci.45:40-49, 2012. (4) Lee, D.Y. and A.S. Wexler, Simulated annealing implementation with shorter Markov chain length to reduce computational burden and its

application to the analysis of pulmonary airway architecture. Computers in Biology and Medicine 41:707-715, 2011. (5) Lee, D.Y., C.D. Wallis, L.S. Van Winkle, and A.S. Wexler, Disruption of tracheobronchial airway growth following postnatal exposure to ozone and ultrafine particles. Inhal. Toxicol. 23:520-531, 2011.

4) Ambient Particle Toxicology: Ambient aerosol particles are associated with a range of adverse health effects. We have worked with toxicologists to elucidate the mechanisms underlying these associations. Recent Publications: (1) Carosino, C.M., K.J. Bein, L.E. Plummer, A. Castaneda, Y.J. Zhou, A.S. Wexler, and K.E. Pinkerton, Allergic Airway Inflammation is Differentially Exacerbated by Temporal and Seasonal Ambient Particles: Heme Oxygenase-1 as an Acute Biomarker. J. Toxicol. Environ. Health A 78:254-266, 2015. (2) Van Winkle, L.S., K.J. Bein, D.S. Anderson, K.E. Pinkerton, F. Tablin, D.W. Wilson, A.S. Wexler, Biological dose response to PM2.5: Effect of particle extraction method on platelet and lung responses. Tox. Sci. doi: 10.1093/toxsci/kfu230, 2014. (3) Breysse, P.N., R.J. Delfino, F. Dominici, A.C P. Elder, M.W. Frampton, J.R. Froines, A.S. Geyh, J.J. Godleski, D.R. Gold, P.K. Hopke, P. Koutrakis, N. Li, G. Oberdörster, K.E. Pinkerton, J.M. Samet, M.J. Utell, and A.S. Wexler. U.S. EPA Particulate Matter Research Centers: Summary of Research Results for 2005–2011. Air Quality, Atmosphere and Health, DOI 10.1007/s11869-012-0181-8, 2012. (4) Plummer, L., W. Ham, M.J. Kleeman, A.S. Wexler and K.E. Pinkerton, Influence of season and location on pulmonary response to California's San Joaquin Valley airborne particulate matter. J. Toxicol. Environ. Health A Current Issues 75:253-271, 2012.

A more complete list of published work in

https://faculty.engineering.ucdavis.edu/wexler/

EXHIBIT A6

CURRENT & PENDING SUPPORT

PI: Hanyang Li					
Status (currently active or pending approval)	**Award #** (if available)	**Source** (name of the sponsor)	**Project Title**	**Start Date**	**End Date**
PROPOSED PROJECT	23RD001	CARB	Improvement of the Toxic-Metal Aerosol Real -Time Analysis (TARTA) Instrument for Field Deployment	TBD	TBD
CURRENTLY ACTIVE	21RD020	CARB	TARTA-XACT Comparison	9/23/2022	10/23/2023
CURRENTLY ACTIVE		SDSU	SEED Award	1/1/2023	12/31/2023

PI: Anthony Wexler					
Status (currently active or pending approval)	**Award #** (if available)	**Source** (name of the sponsor)	**Project Title**	**Start Date**	**End Date**
PROPOSED PROJECT	23RD001	CARB	Improvement of the Toxic-Metal Aerosol Real -Time Analysis (TARTA) Instrument for Field Deployment	TBD	TBD
CURRENTLY ACTIVE	21RD020	CARB	TARTA-XACT Comparison	9/23/2022	10/23/2023
CURRENTLY ACTIVE		UC Multicampus Research Programs and Initiatives	Toxic Air Pollutants in California Environmental Justice Communities	01/01/2023	12/31/2026
CURRENTLY ACTIVE		NIEHS	UC Davis Environmental Health Science Core Center	05/01/2020	03/31/2025
CURRENTLY ACTIVE		UC Tobacco-Related Disease Research Program (TRDRP)	What is the local lung dose of smoke from emerging tobacco products?	09/01/2019	03/31/2024

EXHIBIT A7

THIRD PARTY CONFIDENTIAL INFORMATION REQUIREMENT

CONFIDENTIAL NONDISCLOSURE AGREEMENT

Exhibit A7 is not applicable for this Agreement.

EXHIBIT E

SPECIAL CONDITIONS FOR SECURITY OF CONFIDENTIAL INFORMATION

Exhibit E is not applicable for this Agreement.