EXHIBIT A
SCOPE OF WORK

☒ Contract ☐ Grant

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

PI Name: Allen Goldstein

Project Title: Understanding and Characterizing Emission Factors from Burning Structures in California Due to Wildfires

Project Summary/Abstract

California wildfires have grown in size and intensity due to climate change and historical forest management practices, threatening California public health, forests, and homes. Over 25% of California's population lives in high-fire risk areas, where human-made structures and natural vegetation mix at the wildland-urban interface (WUI). It is critical to understand emissions from WUI fires, including emissions from burning structures that may contain toxic chemicals from burning metals, plastics, and other petroleum-based products. The mission of the California Air Resources Board (CARB) is to achieve air quality and climate mitigation goals that protect California's population from the harmful effects of air pollution. Through this contract, an improved characterization of WUI structure fire emissions will be provided to CARB for incorporation into California's Natural and Working Lands (NWL) model and First Order Fire Effects Model (FOFEM). The improvement of these models will allow CARB to better predict how wildfires spread in different ecosystems and conditions, and better predict air quality, health, and economic outcomes from future policy and climate scenarios.

The University of California, Berkeley (UCB or Contractor) will measure structure fire emissions and determine emission factors (EF) through collaboration with an ongoing study of structure combustion with the Insurance Institute for Building & Home Safety (IBHS) and the California Department of Forestry and Fire Protection (CAL FIRE). Under a series of Structure Separation Experiments (SSE), IBHS plans to individually burn a series of sheds and full-scale accessory dwelling units (ADU) built to the California Building Code. The Contractor will also conduct laboratory experiments with more fuels and compare these to large-scale measurements to provide a broad EF dataset applicable to more structure types. The Contractor will measure large-scale emissions using a custom drone-based collection and sampling system capable of retrieving filters of fine particulate matter (PM2.5) mass, organic carbon/elemental carbon (OC/EC), and metals, and gas sorbent tubes and filters collecting intermediate volatility organic compounds (I/VOCs) and semi-volatile organic compounds (SVOCs), respectively. Real-time carbon dioxide (CO2), carbon monoxide (CO), temperature and relative humidity (RH) will be measured as well. The filters and sorbent tubes will be analyzed at UCB for speciated organics, and filters will be analyzed for PM2.5 mass, OC/EC, and metals by an analytical services laboratory.

The Contractor will analyze the measured chemical composition and EFs from structure fires in a broader context by comparing EFs to IBHS's SSE fire physics measurements, as well as data from prior campaigns, including: the FireLab and wildfire field campaigns, controlled burns in California mixed conifer and other ecosystems, and the 2017 Napa/Sonoma fires that impacted the San Francisco Bay Area. This analysis will place structure fire EFs in the broader context of wildland fires and will be useful to develop a framework through which structure fire emissions can be estimated in the future. The publicly available results will provide improved estimates of EFs to CARB and allow researchers and the public to learn about emissions from structure fires.

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

☐ Performance of the Scope of Work is anticipated to involve 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.

Statement of Significance

California wildfires are becoming larger and more frequent: available observations since 1932 show that the eight (8) largest wildfires happened between 2017 and 2021.~~1~~ From an air quality health risk perspective, PM2.5 and ozone (O3) formed from fire emissions are two (2) of the most important components. A recent study shows that increasing wildfires are erasing decades of air pollution gains in the Northwest, including rural parts of Northern California. Climate change will exacerbate the problems involving wildfires in the western United States (US). A warmer and drier climate, in combination with fire-control practices over the last century, has produced a developing situation with more frequent fires that are of higher severity, thus increasing impacts on local and regional air quality.

Over 25% of California's population lives in high fire risk areas, where human-made structures and natural vegetation meet or mix at the WUI. As of 2018, ~49 million residential homes in the US are in the WUI, increasing by ~350,000 houses per year. The rapid expansion of the WUI leads to more human-ignited wildfires. It is critical to understand emissions from WUI fires, including emissions from burning structures that may contain toxic chemicals from burning metals, plastics and other petroleum-based products.

The mission of CARB is to achieve air quality and climate mitigation goals that protect California's population from the harmful effects of air pollution. Recognizing the importance of characterizing WUI structure fire emissions and behavior, CARB requested proposals for a Research Project entitled "Determine emission factors and chemical speciation from burning structures due to wildfires in California for use in air quality and health impact assessments" to participate in a series of SSEs in which structures constructed to the California Building Code will be burned. The SSEs will be conducted by IBHS. The collaboration between the Contractor and IBHS will supplement the fire physics and behavior observations recorded by IBHS, with the Contractor adding direct emissions measurements and developing EFs from structure fire emissions. The joint experiments through participation in the SSE efforts will provide critical information to better understand the atmospheric impacts of structure fires, including those in the WUI, in the state of California.

Quantifying the chemical composition and properties of structure fire emissions is needed to improve CARB's NWL model and FOFEM. The development of these models will allow CARB to better predict how wildfires spread in different ecosystems and conditions, and better predict air quality, health, and economic outcomes from future policy and climate scenarios facing California. Furthermore, policies that involve updated structure separation distances and building codes are highly important for reducing the severe health, safety, and economic costs generated from WUI structure fires, and are likely the most effective way of reducing future structure fire emissions in a hotter, drier, and more variable climate. Hence, there is an urgent need to reduce WUI structure fire risk and to better understand the impacts of wildfire and structure fire emissions on the atmosphere and climate system, and for policy-relevant science to aid in the process of designing the California WUI.

The scope of this project includes measurements via ground- and airborne-based (i.e., drone) sampling platforms during controlled structure burns. Ground sampling will be conducted by IBHS and will provide fire physics and behavior data, and airborne sampling will be conducted by the Contractor to provide fire emissions measurements. Additional experiments will be conducted by burning specific building materials in the UCB Fire Research Lab and similar emissions captured from these controlled environments. **These controlled environments will be modified to represent non-ideal but realistic burning conditions by varying both heating rates and ambient oxygen to understand the effect of under-ventilated conditions on emissions.** Emission profiles from two (2) distinct types of structure fires in the field and a range of other materials will be compared: namely ADUs. These building types capture an important segment of structures in the California WUI. **Laboratory materials tested will include a broader array of common building materials, many overlapping with large-scale tests, as well as older samples to represent different states of construction across the state. This study provides a unique opportunity where an array of laboratory samples burned under different states can be compared directly to large-scale burns to better isolate the effect of materials and conditions on overall emissions of large-scale fires and improve our understanding of the complex processes contributing to these emissions.**

The measurements of detailed speciation of VOCs and particulate matter (PM) emitted from structure burns will be used to improve CARB's fire emissions inventory development. Specifically, the results of this project will be used by CARB to improve the NWL model and FOFEM. Finally, quantifying the chemical composition and properties of structure fire emissions will improve the modeling of smoke chemistry and air quality impacts that help safeguard both forest and human health, addressing important environmental justice concerns for vulnerable communities.

Scope of Work

Project Objectives and Summary

Objectives of this research project are to: 1) analyze gaseous and particulate OC emission samples from structure fires collected during laboratory experiments and by the Contractor using their airborne sampling platform in coordination with the SSEs conducted by IBHS; 2) evaluate wildfire and structure fire EFs in the literature; and 3) quantify EFs for PM2.5, metals, OC, EC, VOCs, IVOCs, and SVOCs from structure burns of ADU, and laboratory experiments of specific WUI structure components **under varying burning conditions**. Calculated EFs will be compared with those from wildfires and available SSE data to better understand how reducing fire risk through increased structure separation distance or increased building resiliency also alters emissions.

This project will provide emission profiles from a set of structure burns representative of structures in the California WUI. Measured EFs will be provided to CARB to evaluate and improve the model estimates of short-lived climate pollutants and other air pollutants in FOFEM and NWL. Outcomes will include improved EFs from WUI structure fires and comparison to EFs from wildfires, including recently measured and published values.

Background

California wildfires are becoming larger and more frequent: available observations (since 1932) show that the eight (8) largest wildfires happened between 2017 and 2021.[1] Climate change, in combination with fire-control practices over the last century, has produced a developing situation with more frequent fires of higher severity, thus increasing impacts on local and regional air quality. Many of these recent large fires took place in the WUI. As of 2018, ~49 million residential homes in the US are in the WUI, increasing by ~350,000 houses per year (**Figure 1**).[2] The rapid expansion of the WUI leads to more human-ignited wildfires and causes more human exposure to wildfire smoke.

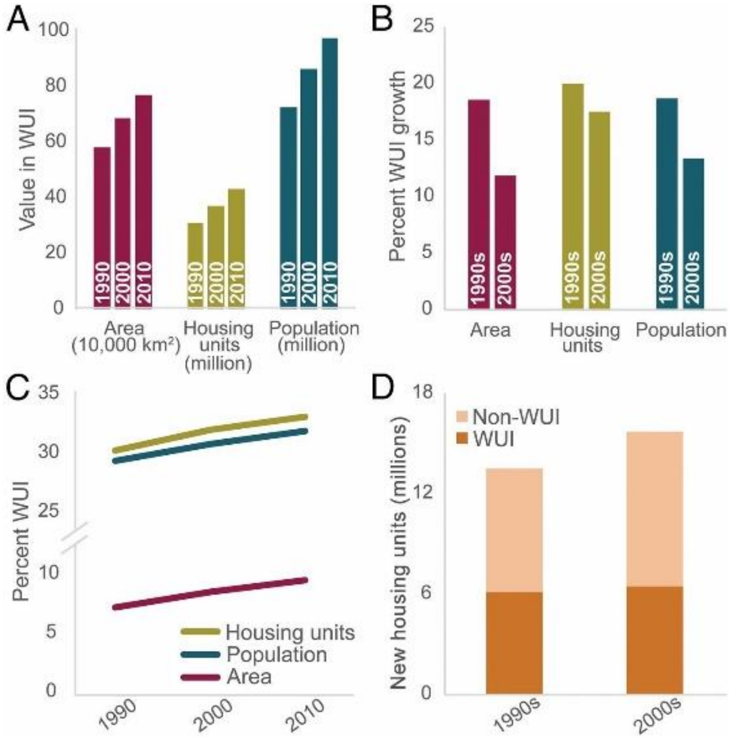

Figure 1. The rapid growth of area, housing units, and population in the WUI from 1990 to 2015. Figure from Radeloff et al. (2018).[2]

CARB is enhancing the NWL component of CARB's Scoping Plan update. This modeling will result in carbon, water, fire, air quality, health, and economic outcomes associated with various future climate and management scenarios. A portion of this model focuses on settlements, which includes incorporating structural carbon emissions into the WUI modeling effort. Structural fire emission factors are needed to accurately estimate the emission mitigation associated with avoiding structure fires as a result of wildfire. This sector would be combined with the forest and shrubland "Regional Hydro-Ecological Simulation System (RHESSys)" modeling. RHESSys will produce estimate of annual large catastrophic fires. CARB can combine the RHESSys fire outputs with the WUI defensible space model to estimate annual structure fire emissions, in addition to the vegetative biomass fire emission.

WUI fires are fueled by both biomass and manufactured materials. Fuel treatments, such as prescribed fire and the mechanical removal of vegetation, are often implemented to reduce the spread and intensity of large wildland fires.[3] Building and community policies are the concomitant strategy to reduce the risk of structure fires. Defensible space (or structure separation distance) and building code policies harden structures and communities against destruction, but their effect is limited by homeowner adoption[4] and raises equity concerns about affordability.

In WUI fires, numerous structures containing household materials, in addition to biomass fuels, are burned or heated. Fires can emit high levels of trace gases, including nitrogen oxides (NO_x), CO and CO_2; intermediate-, semi-, and volatile organic compounds (I/S/VOC); and primary (directly emitted) PM. During plume evolution, I/S/VOCs react to form O_3 and secondary PM (i.e., secondary organic aerosol, SOA), thereby degrading air quality downwind and potentially endangering human health. The quantities and properties of the emitted compounds are highly variable and largely dependent on fuel type and burn conditions, thus differences in emissions are expected between natural land fires and WUI fires.

Laboratory studies consistently show that the EFs (mass of emission per mass of fuel burned) of many hazardous air pollutants such as benzene, polycyclic aromatic hydrocarbons (PAH), and chlorine-containing compounds from non-biomass fuels are higher than from natural fuels,[5] which presents a hazard to local and downwind communities. Within WUI fires, emissions can vary significantly depending on material or structure burned. A cone calorimetry study showed that PAH and PM EF yield were highest for polyester and polystyrene, while manufactured wood products had the lowest yield (**Figure 2**).[6] However, the use of binders and adhesives in manufactured wood products produced substantial variability in yields.[6]

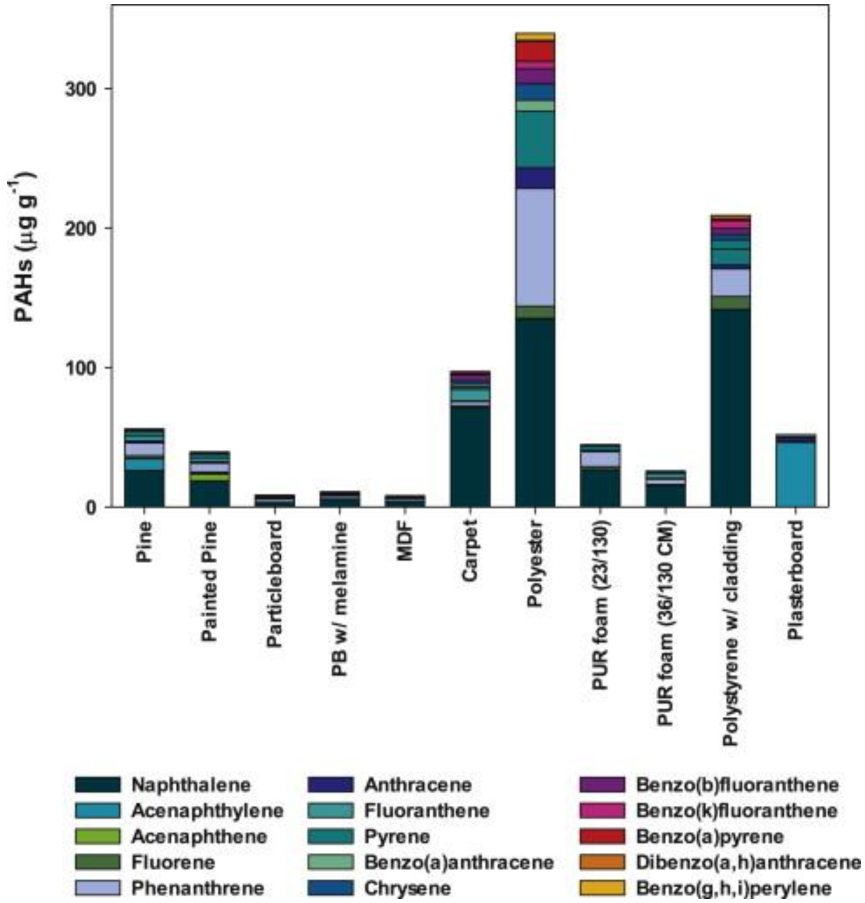

Figure 2. PAH emission factors in several manufactured materials common in WUI structures. Figure from Reisen et al. (2014).[6]

However, emissions characterization has largely been constrained to laboratory studies, and the existing emission inventories of WUI structure fires (e.g., CARB 1999 and US Environmental Protection Agency [EPA]-WUI 2020) lack the needed chemical speciation of emissions in both gas and particle phases to assess atmospheric impacts and human exposure.[7] The CARB 1999 inventory only includes total organic gases, CO, NO_x, SO_x, and PM, based on burning a model wood building in 1972. Since then, the materials in new buildings have changed substantially. The EPA-WUI 2020 method expanded the 1999 inventory by including around 20 compounds derived from 17 laboratory combustion studies. The representativeness of such measurements and the level of speciation of WUI fire emission remains insufficient.

In real wildland or WUI fires spread occurs rapidly and can result in non-ideal burning conditions at the flame front, such as reduced oxygen availability compared to the ambient. The increasing prevalence of extreme, large-scale fires such as mass fires occurring after extensive tree mortality in the southern Sierra Nevada[8] or during numerous community-scale conflagrations in WUI[9] push the limits where these conditions may be exacerbated and dominate burning conditions. Unfortunately, these extreme conditions are projected to become more prevalent under a changing climate[10]. Due to the increasing prevalence of these conditions, it is important to further understand the effects of non-ideal burning conditions on emissions factors.

In the WUI, fires do not occur in the open, but rather spread between structures and other flammable items distributed across an urban area. The majority of burnable material, other than vegetation, is located in structures or vehicles. As previously noted, these structures burn with a different pattern then vegetation, igniting from radiation, flame contact or embers, igniting materials within and progressing to a fully involved structure fire[11,12]. At this stage the fire becomes ventilation limited as indoor areas within compartments (e.g., closed rooms) are limited in terms of oxygen availability through limited openings while large fuel loads increase fuel availability within the space[13]. Their enclosed nature also allows for trapped heat and significantly higher temperatures and heating rates than occur in the open. As fuel becomes depleted, the compartment fire starts to decay and burning rates decrease. A large portion of the fuel burning inside structures, therefore, burns under high heat, oxygen limited conditions. While the fire dynamics occurring under these conditions are well understood, emissions occurring under these burning conditions are not.

Because of these under ventilated conditions the fire community has recognized the effects of under-ventilation (reduced oxygen) on combustion products, in particular how the emissions of CO and a select group of toxic products changes inside compartment fires[14]. This information is critical for understanding toxic exposure during building fires and has been paired with a range of testing in the laboratory as well as mouse exposures, etc. Early studies by Tewarson [15] first documented CO yields from different burning materials, with later studies[16,17] demonstrating the importance of ventilation and heating conditions during compartment fires on CO production. A whole field has developed around this problem with the specific focus of toxic product production affecting human health in interior fires, with authors such as Purser[14] and Stec [18,19] leading many studies. Most experiments focus on key effluents known to affect human health in enclosed situations, such as CO, HF, HCl, HBr, HCN, Acrolein, and Formaldehyde under specific conditions. These experiments, interestingly, have shown that some yields increase with under-ventilated conditions, while others decrease, depending on the fuel type. These effects are increasingly important as many fuels will burn under these conditions in compartments during WUI fires, however well-ventilated exterior fires will also occur. Still, an incredibly limited number of compounds are of focus for these toxicity studies in comparison to the expansive set of compounds of interest for air quality that are proposed in this study.

While the under-ventilated conditions occurring in structures have been recognized for many years, until recently it was often assumed that fires through vegetation occurred under well ventilated conditions due to their access to ambient air. Some authors, however, have hypothesized that oxygen availability may be limited at the flame front during combustion due to flames blocking the entrainment of ambient oxygen to the flame, especially as the size of flames increases[20]. This was hypothesized and demonstrated in recent modeling studies[21] of spreading fires. Larger experiments were recently run at the Missoula Fire Sciences Laboratory 3 m x 3 m wind tunnel where in situ measurements of oxygen were taken[22]. Interestingly, measurements showed that oxygen can be significantly decreased at the flame front depending on properties of the fuel stand, with values as low as 2-5% mol% O_2 in dense fuel stands and 8 mol% O_2 in sparsely packed beds. Therefore, the assumption that open burning conditions exclusively occur in either compartments or even vegetation fires may no longer be fully appropriate. With large mass fires occurring more often due to fuel buildup and large-scale tree mortality, larger flame fronts with reduced oxygen conditions may be even more prevalent. This has great importance when considering emissions as, for some species, these might vary extensively based on burning conditions but have yet to be characterized.

Therefore, there is a critical need to conduct new measurements of gaseous and particulate emissions to improve predictions of structure fire emissions and their effects on air quality and climate. The Contractor has assembled a uniquely qualified team to advance scientific understanding of the linkages between fire and structure separation distances and fire emissions and impacts. Characterization and quantification of structure fire emissions are needed to improve modeling of their impact on human health and climate. Furthermore, fire exposure and material resilience policies are vital tools for reducing WUI fire severity, and likely the most effective way of reducing future WUI structure fire emissions in a hotter, drier, and more variable climate. Hence, there is an urgent need to harden WUI structures and communities and to better understand the impacts of wildfire and structure separation distance on the atmosphere and climate, and for policy-relevant science to aid in the process of reducing the destructive capacity of wildfires.

Research Methods

The quantities and chemical composition of gases and PM emitted from structure fires are affected by fire intensity, combustion phase, and fuel type. New field-based measurements of these emissions are needed to support evaluation of the air quality impacts of emissions from structure fires. The Contractor will conduct airborne sampling of structure burn emissions in collaboration with ~~I~~IBHS's upcoming SSEs to determine emission factors and chemical speciation, and assess how emissions relate to fire or structure characteristics. The IBHS project was developed to investigate the fire physics and propagation between structures under realistic conditions, and the Contractor will add emission measurements to the SSEs. The Contractor has communicated with ~~NIST~~ IBHS and was granted permission to participate in SSEs.

The research plan as outlined below includes six (6) tasks:

(1) Prepare for Structure Separation Experiments
(2) Collect Emissions Measurements
(3) Laboratory-Scale Emissions Measurements
(4) Laboratory-Scale study on the effect of burning conditions on emissions
(5) Analyze collected SSE Samples & Data
(6) Draft Final Report
(7) Amend Final Report

Task 1: Prepare for Structure Separation Experiments

Structure Separation Experiments: The SSEs were designed to assess the structure-to-structure fire spread from a source structure to a target structure, with the purpose of identifying safe structure separation distance (SSD) and assess its relationship with building type, material burned, and fire characteristics. In a single SSE, a source structure is burned and the heat flux that the fire provides to the target structure is measured. The Contractor will participate in SSE, currently scheduled to start in 2023. IBHS will burn ADUs ("in-law" dwellings built close to primary residential structures) as source structures. All burned ADUs will be newly constructed with materials conforming to the California Building Code (24 CCR Part 2),[23] using relevant building material and code-compliant assemblies.

The SSE project is a collaboration between state and federal agencies and private institutions, and planned to be hosted by IBHS. The project is led by IBHS. With the exception of specific roles, the broader efforts of the entire consortium will be referred to as led by ~~NIST~~ IBHS in this Agreement. ~~NIST~~ IBHS will lead and perform all burns and pre-fire fuel characterization inventories associated with the proposed SSE, thus any changes to the experimental plan or changes in the fuels investigated, will be at their discretion. The Contractor will conduct emissions measurements from the IBHS led burns regardless of changes to fulfill the stated objectives in this agreement.

During SSEs, IBHS will generate distinct measurements of fire behavior as part of each burn.

Unmanned Aerial Vehicle (UAV) Sensor Package and Sampling: The Contractor will use airborne (i.e., UAV)-based measurements to sample near-fire emissions during the structure burns at IBHS. An UAV-based sampling system was identified as the most viable option for reliable emission measurements due to the extreme intensity of the fires presenting both safety and logistical constraints. The UAV was chosen to enable actively following the smoke plume migration during sampling and for the ability to retrieve the UAV and exchange sampling cartridges multiple times over one **(1)** burn. UAV measurements are better suited for capturing emissions after the smoke's initial cooling to provide more representative atmospheric conditions for sampling both gases and particles that evolve rapidly near combustion sources. By sampling close to local atmospheric conditions, the Contractor will provide representative near-field EFs.

The Contractor will design a custom-built package specifically for the demands of this project. This package will be largely based on the previously developed package (called the Firehawk), which was developed for a CARB-funded contract to determine forest fire EFs at the Blodgett Forest Research Station during prescribed burns in the spring of 2021. The current Firehawk package weighs ~3 kg and can be carried by a heavy lift drone (e.g., DJI Matrice 600 Pro hexcopter) for approximately 20 minutes, providing continuous gas sampling and timed separate collection of I/VOCs and SVOCs on sorbent tubes and quartz filters, respectively. Real-time monitoring of CO_2 is transmitted to the ground team by radio telemetry to gauge when the drone is in the smoke plume and to determine when sufficient sample has been collected. Three (3) sets of batteries with ground re-charging stations and shore power nearby allow for near continuous flying.

For Task 1, the Contractor will adapt the Firehawk UAV sampling package to expand the allowed filter analyses to include mass and metals along with gas and particle phase organic species. This change necessitates adding an additional particle sampling channel using Teflon filter media compatible with the analyses for measuring $PM_{2.5}$ mass and metals. Three (3) parallel channels will be included each consisting of a quartz filter (organics), a Teflon filter (mass, metals) and a sorbent tube (VOCs). The particle sampling will use pre-loaded and light-weight filter samplers with incorporated impactors to provide 2.5 µm sized particulate fraction. By using pre-loaded samplers that are easily swapped out between flights, the UAV sampling can be accomplished by a team of two (2) individuals and the amount of sample handling can be minimized for increased sample integrity. Additionally, each sample will start with a clean inlet that avoids sample carryover from the extreme concentrations anticipated with plume sampling. In total, nine (9) sampling channels (each under miniature valve control) will share pumps to provide three (3) timed sets of gas/particle samples per flight (approximately four [4] minutes each) while still targeting a 15-minute flight time. Each of the three (3) active channels will possess dedicated mass flow sensors for sample volume determination. All channels will be under independent radio control for maximum flexibility.

Task 2: Collect Large Scale Emissions Measurements

Structure Separation Experiments: SSE will occur at the IBHS Research Center, located in Richburg, South Carolina. Burns will occur outdoors on concrete (approximately 45 ft x 150 ft) at the IBHS Research Center, directly adjacent to the wind tunnel outflow. Source structures to be burned will be placed in-line with the door to the IBHS wind tunnel at 0° (i.e., with one [1] wall perpendicular to potential induced wind flow). Target structures will be placed at varying distances from the source structure, also in-line with the wind tunnel outflow. A map showing the area at IBHS and general structure locations is provided in **Error! Reference source not found.**.[4]

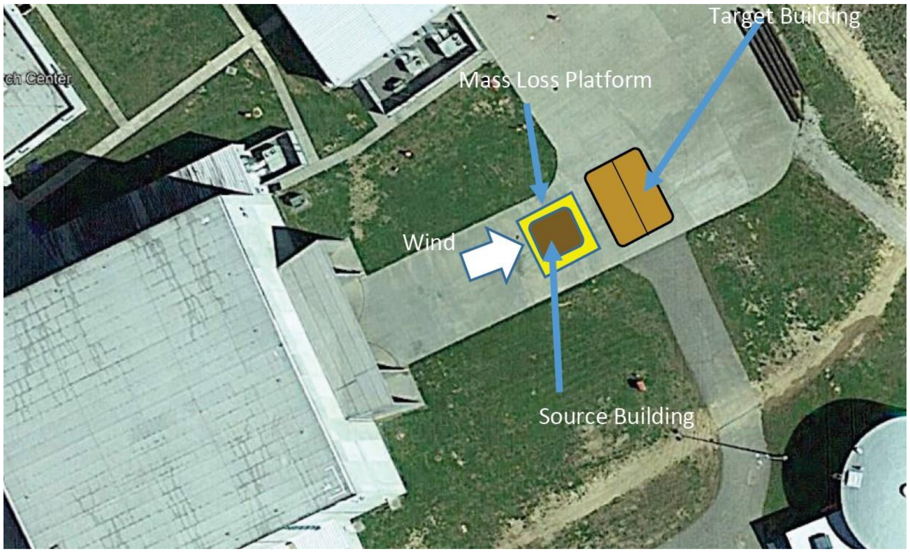

Figure 3. Aerial view of test facility and locations of target and source buildings. Positions and orientations are approximate. Imagery: Google, Landsat/Copernicus. Overlays: NIST. Figure from Maranghides et al. (2021).[4]

Eight (8) ADUs will be burned as source structures during SSE, currently scheduled to begin in 2023. Three (3) ADUs will be burned under calm conditions (i.e., without induced wind) to measure heat and mass loss rates. Three (3) ADUs will be burned under wind-driven conditions generated by the IBHS wind tunnel to assess the impact of convection on flame slant and safe SSD. Two (2) more ADUs will be burned under conditions to be determined after the first six (6) are completed. The selected wind speed will depend on the estimated heat loss rate from the calm condition results but is estimated to be 20–40 mph. For the wind speed experiments, target structures will be rotated at either 0° or 45° relative to the source structure. Each burn will be separated by approximately 1–2 weeks. As each ADU and SFH will be burned using different materials and orientations, no exact configuration is expected to be repeated in these experiments but instead will provide a more realistic range of controlling parameters.

Structures burned under calm conditions will be placed on a matrix of load cells to calculate mass loss. Structures in wind-driven will not use the mass loss platform due to the expected interference from advection. In every burn, the source structure will be ignited by exposing wood cribs to a known amount of n-heptane or by igniting the cribs with a drip torch. The necessary crib fuel loading will be determined from the source structure size.

Sampling Approach: The Contractor will use a drone-based UAV sampling and sensor package built for this contract (Task 1) to deploy directly into the atmospherically-advected SSE smoke plumes. Continuous real-time (~1 Hz) gas sensor data will be transmitted to the ground station, and remote-controlled valving will be used to collect sequential sets of gas and particle samples. Monitoring CO_2 levels ensures sufficient sample is collected on each set of sample channels before switching to the next. While excess sample collection does not present a problem for analysis, it does affect the turnaround time between sample sets that would limit the total number collected. Real-time monitoring of accumulated sample through real time sensing is critical to managing this trade-off between quality and quantity of sampling.

The structure burn experiments are expected to last approximately 60 minutes. Three (3) or four (4) UAV flights per burn are anticipated based on these estimated burn timescales. The Contractor will launch the Firehawk UAV from a safe distance crosswind with visual lines of sight with the fires to allow flights into the plume well above the flame (limited by regulated ceiling of 120 m). A Federal Aviation Administration (FAA) certified drone pilot (Nathan Kreisberg or other) will pilot or direct all flights. A PhD student in the UCB

Goldstein group will be trained as a drone pilot to support Co-Investigator Kreisberg or other pilot during sampling.

Burns will typically start in the afternoon or at dusk. At that time, the expected wind direction is from the southwest. IBHS test requirements specify that burns under calm conditions will not be conducted when wind speeds exceed 3–4 mph. UAV pilots will be placed at a safe stand-off distance to the northwest side of the experiments to minimize smoke exposure and avoid the induced winds in experiments generated by wind. By positioning launches below the advected plume position, a more direct path to intercept the smoke plume is possible that avoids flying over personnel. Should transport direction differ from expectation, the pilots will be able to easily re-locate the UAV to a new location to intercept the fire plume. UAV pilots will maintain a clear line of site with the UAV at all times. Minimal UAV maneuvering should be necessary given the fixed fire position. Flight plans will seek highly restricted, nearly vertical flight trajectories to both minimize UAV aviation power consumption and operation risks.

The ADU burns will generally last approximately one (1) hour, providing an estimated nine (9) samples minimum while some ADU burns without wind will last ~90 minutes, enough time to allow an estimated 12 samples to be collected per burn. The Contractor will collect samples in sets of three (3) samples per flight clustered around different stages of each burn (ignition, burn, smolder). Each of these phases will capture different fire emission characteristics typically found in any fire. Through the eight (8) ADU burns (three [3] with and three [3] without induced wind and two [2] slower without induced wind), an estimated total number of 86 samples will be collected including 16 blanks + 8 background samples taken before each burn. The intended sample matrix is shown in Table 1.

Table 1. Preliminary structure fire emissions sampling matrix

			# Samples					
SSE Phase	Fire Source	# Structures	Pre-burn bkgnd	Ignition Phase	Flaming Phase	Smolder Phase	Dyn/Stat Blanks	**Totals**
2A	ADU	3	3	6	9	6	6	**30**
2B (wind)	ADU	3	3	6	9	6	6	**30**
3	SFH	2	2	4	12	4	4	**26**
	Totals =	**8**	**8**	**16**	**30**	**16**	**16**	**86**

Gaseous Organic Compounds: The Contractor will use adsorption/thermal desorption cartridges will be used to collect gaseous I/VOCs from the drone-based platform. The Contractor will used dual-sorbent bed cartridges (Tenax TA and Carbograph 1 in series) that can collect I/VOCs over a broad range (C_3 oxygenates to C_{15} sesquiterpenes), including hydrocarbons, aromatics, alcohols, ketones, aldehydes, and other species.[25]

Particulates: The Contractor will collect particulates on pre-fired quartz filters for organic analysis (speciated SVOCs and OC/EC) and Teflon filters for $PM_{2.5}$ and metals analysis using Personal Environmental Monitor Samplers (MSP Corp.) or equivalent Personal Environmental Monitor Samplers with 2.5 µm particle size cut-off.

Background and Dynamic Blanks: For both filters and cartridges, the Contractor will collect airborne background samples daily for background subtraction of the smoke samples. Static blanks (handling integrity) will be collected on each burn day while several dynamic blanks (flown without sampling) will be collected on the last flight during the smoldering phase.

Real-Time Sensor Measurements: During each flight, the Contractor will acquire continuous gas measurements using a non-dispersive infrared (NDIR) gas sensor for CO_2 and an electrochemical cell sensor for CO in addition to temperature and relative humidity sensors. The gas sensors will allow quantification of fuel burned ($\Delta CO + \Delta CO_2$ over background) and modified combustion efficiency (MCE: ratio of ΔCO_2 /(ΔCO +

ΔCO_2)) to allow emission factor calculation and fire state characterization, respectively. These sensors will be protected from semi-volatile condensation artifacts by high adsorption capacity glass fiber inlet filters as successfully demonstrated during a prior prescribed forest fire study.[26] The Contractor will calibrate the gas sensors before and after each burn using zero and span gases.

Task 3: Laboratory-Scale Emissions Measurements

The Contractor will perform laboratory experiments to augment large scale structure burns with independent data on emissions from individual WUI components. For the bulk of these experiments a steady-state combustion apparatus operating under controlled atmospheres and radiant heating, uniquely designed in Professor Gollner's UCB Fire Research Laboratory[17], will be used to generate emissions of a variety of representative WUI fuels under conditions representative of large-scale WUI fires at laboratory scale. Sampling of both gaseous and particulate effluents will be conducted across a range of desired materials to build a database of emissions factors for fuels common in WUI construction including exterior paneling, framing, composite wood, interior furnishings, carpet, and asphalt shingles. The Contractor will select specific components and samples/brands following a thorough literature review and consultation with CARB staff based on their availability, commonality, and use in SSE burns. Incorporating some overlap between materials used in laboratory-scale EFs and large scale tests will help determine the source of some individual components from bulk values under less controlled conditions. The final list of materials will be selected after IBHS finalizes their material selection. Following discussions and draft material lists the Contractor estimated on the order of a dozen materials to characterize. This includes on the order of half a dozen materials to test that typify the ADU burns, with another half a dozen not included in these burns that typify other buildings. A firm number will be communicated to CARB staff after the list is final and approved by IBHS.

Laboratory conditions can be varied on the apparatus using changes in airflow or external heating to mimic different large-scale behaviors, such as smoldering, flaming, or high heating rates experienced under flashover inside a compartment.

For all experiments real-time emissions will be sampled using solid-state sensors (O_2, CO, CO_2, NO_x, SO_x) with either an ENERAC 700 or California Analytical Instruments ZPA NDIR Gas analyzer rack. Particulate mass ($PM_{2.5}$) will be measured in real time using a TSI DustTrack alongside gravimetric $PM_{2.5}$ filter calibration. Real-time sampling of additional gaseous species will be accomplished with a custom-designed Thermo Nicolet IS-50 Fourier Transfer Infrared Radiometer (FTIR) sampling ~20 calibrated gaseous effluents. Professors Goldstein and Gollner will augment additional sampling with adsorption/thermal desorption cartridges, pre-fired quartz filters for organic analysis, and Teflon filters for $PM_{2.5}$ and metals analysis for at least two (2) each of exterior paneling, framing, composite wood, interior furnishing, carpet, and asphalt shingle samples.

Task 4: Laboratory-Scale study on the effect of burning conditions on emissions

The laboratory apparatus proposed in Task 3 affords the research team a unique ability to systematically adjust heating, oxygen, and flow rate conditions while maintaining steady combustion to directly isolate the influence of burning conditions on emissions. This is important to isolate and understand the impacts of this effect and whether EFs of some fuels or effluents should be adjusted for extreme burning conditions as mentioned previously. The small fuel sample size and ability to easily collect gaseous and particulate samples for speciation allows for a detailed study of conditions to be undertaken. A recent fundamental study by the Co-PI on cellulose demonstrates the ability of the apparatus to carefully study limiting conditions[27,28], however this past work focused on limits without detailed emissions characterization.

In this task the contractor will perform laboratory experiments to augment both laboratory testing of WUI fuels proposed above, additional WUI fuels found in older building types, as well as on vegetative fuels that would be present either in wildland fires or ornamental vegetation in the WUI. One sample of each WUI fuel type selected for Task 3 (exterior paneling, framing, composite wood,

interior furnishings, carpet, and asphalt shingles) will be tested under varying oxygen and heating conditions to see how a wide variety of effluents changes under these conditions. An extension to work in Task 3 will involve the study of fuels from older construction, including six selected samples of furnishing, wall samples with paint, etc. that may have very different emissions profiles including lead, PAHs, benzene, etc. that aren't present in other new materials. To represent the possible oxygen-limited conditions in either large wildland fires or intermix WUI zones, representative vegetative fuels from 5 different biomes, including ponderosa pine, eucalyptus, scrub oak, grasses, and chaparral will be taken and studied under similar heating and oxygen-limited conditions. In total 17 materials will be sampled over a range of conditions, forming an incredibly extensive database.

Experiments in the steady-state combustion apparatus will be used to test fuel combustion under a variety of ventilation, oxygen, and heating conditions. Oxygen will first be systematically reduced in tests, ranging from ambient to as low as 8 mol % O_2, depending on limiting conditions determined for each fuel type. A similar approach at specific concentrations will then be used from high to low heat fluxes representing flashover to smaller fires, although a focus will be on the higher heat fluxes often present inside structure fires or those occurring at a wildland fire front. As ambient conditions are varied fuels may transition between flaming and smoldering conditions, depending on their limits. Including smoldering is important as char oxidation was noted in Howell et al.[22] to be significantly impacted by reduced oxygen conditions and is known to produce a wide range of effluents.

For all experiments real-time emissions will be sampled using the same instrumentation as in Task 3, including real-time sensing using solid-state sensors, particulate mass, and an FTIR. Professors Goldstein and Gollner will augment additional sampling for a selected set of the 17 materials above based on initial results from real-time sampling with adsorption/thermal desorption cartridges, pre-fired quartz filters for organic analysis, and Teflon filters for $PM_{2.5}$ and metals analysis. It is estimated about two dozen test points will use full speciation.

The result of Tasks 1-4 will be a unique dataset of emissions measurements including large-scale burns of ADUs, a full sampling of emissions from individual materials, and changes depending on burning conditions. Comparing these results across the range of conditions proposed may allow not only for a useful dataset, but also for some explanation of different effluents and their source, tracing species due to both materials and potential burning conditions.

Task 4 5: Analyze Samples and SSE Data

Gaseous Organic Speciation: The Contractor will analyze cartridge samples offline using two-dimensional gas chromatography coupled with high-resolution time-of-flight mass spectrometry (GC×GC-HToFMS). Speciated I/VOC analysis will be performed using a Markes select-eV GC×GC-HToFMS equipped with a Zoex GC×GC modulator, and a Gerstel automated thermal desorption system at UCB. Selection of column sets will be optimized for enhanced separation of targeted compounds. The ~~c~~**C**ontractor expects to use a column set with a DB-VRX primary column (30 m, 0.25 mm I.D., 1.4 µm film, Agilent, Santa Clara, CA) and a Stabilwax secondary column (1.5 m, 0.25 mm I.D., 0.5 µm film, Restek, Bellefonte, PA), but will also use other column sets if needed.

The Contractor will process the GC×GC-HToFMS data using a combination of proprietary software from GC Image (GC Image, LLC) and in-house developed data analysis algorithms. Detected compounds will be grouped by carbon number and functionality, which simplifies classification of emissions as a function of fuel/burn characteristics, as well as CARB's model development. Measurements will include approximately 50 target species for I/VOC quantification.

Particulate Compound Speciation: The Contractor will analyze a portion of the SVOC quartz filter samples for chemical speciation by gas chromatography-mass spectrometry at UC Berkeley using a GC×GC-HToFMS system consisting of an Agilent 7890A GC, a TOFWERK HToFMS, a Zoex GC×GC modulator, and a Gerstel thermal desorption system with an autosampler.

To analyze the sample, a small punch of each quartz filter is thermally desorbed at 320°C in a helium flow using the Gerstel thermal desorption system. The helium gas stream is saturated in n-methyl-n-(trimethylsilyl) trifluoroacetamide, for online derivatization during thermal desorption. The compounds are trapped at 30°C prior to injection onto the first column. Compounds are first separated by volatility with a Rxi-5Sil MS column, then by polarity with a Rtx-200 MS column. The HToFMS is then used to ionize and measure the mass fragments of the separated compounds. Quantification is based on the ratio of HToFMS response to internal standards and authentic or surrogate external standards matching the paired retention times. Calibration standards will include a wide range of relevant compounds– including aromatic/aliphatic hydrocarbons (e.g. PAHs), phenol derivatives, furan derivatives, and terpenes–to positively identify and quantify such compounds. Measurements will include approximately 100 target species for $PM_{2.5}$ quantification.

Though a vast number of compounds remain unidentified, the Contractor has built a mass spectral (MS) library in the NIST format. This MS library, named University of California, Berkeley, Goldstein Library of Organic Biogenic and Environmental Spectra (UCB-GLOBES), includes mass spectra from FIREX biomass burning samples and additional relevant field samples. UCB-GLOBES can be used to match and keep track of compounds observed in the SSEs.

Through a combination of structure and laboratory material burns, this project aims to establish some specific tracers for structure burns, which will aid wildfire emission analysis.

Other Particulate Compound Analyses: The Contractor will analyze another portion of each quartz filter for OC/EC by thermal-optical analysis. All Teflon filters will be pre- and post-weighed by microbalance to provide a gravimetric mass equivalent to the US EPA Federal Reference Method determination of $PM_{2.5}$. The Contractor will analyze a subset of the Teflon filters by ion coupled plasma-mass spectrometry for a suite of heavy metals including chromium, arsenic, lead and cadmium with demonstrated health risks for inhalation. These bulk and inorganic measurements will be conducted by the UC Davis Atmospheric Science Research Center Analytical Laboratory that routinely performs such analyses on a fee-for-service basis. The Contractor has budgeted for 100 filter samples to be analyzed by these methods.

Emission Factor Analysis: The measurements described above will generate data for combustion diagnostics including MCE. Measurements of CO_2 and CO will enable calculation of EFs (in units of g species per kg fuel burned) by the carbon mass balance method for all of the other co-sampled gaseous and particulate species (including individual compounds like PAHs and metals as well as “bulk” EFs, such as PM, OC, and EC).

Analysis of Structure Materials and Fire Behavior: A key element of this project is the effort to relate building type, material properties, and fire behavior with emission profiles. IBHS will provide data on structure features and fire properties to aid the contractors in contextualizing observed EFs. Testing of specific SSE materials in a laboratory apparatus will aid in distinguishing contributions from specific components. Data available to the Contractor will depend on final SSE experimental design by IBHS, instrument performance, data quality, and timing of analysis by the IBHS team.

Structure variables IBHS plans to collect include size, construction materials, and separation distance between the source and target structures. Source structures will be burned on a load cell matrix under calm conditions, providing measurements for mass loss rate and heat loss rate over the duration of the fire. IBHS will also record key fire behavior metrics, including temperature, heat flux, flame lean (under wind-driven scenarios), wind speed, and visible and IR video. The Contractor will work with IBHS to gain access to all available final data products to aid in EF contextualization.

The Contractor will conduct a critical review of the existing literature to provide background on current understanding of the physicochemical properties of gaseous and particulate species emitted from structure fires and the fuel loading and makeup of common materials used in residential and commercial structures found in the WUI. Findings from the literature review will help provide context to SSE EF results and help inform future efforts to model WUI emissions. In addition, the Contractor will consider data from prior experiments, field campaigns and WUI emissions estimates to compare SSE emission profiles with those observed in wildland fires. These sources may include current methodologies adopted by CARB and the EPA, while campaigns may include the FIREX-AQ FireLab and wildfire field campaigns, controlled burns in California mixed conifer and other ecosystems, and the 2017 Napa/Sonoma fires that impacted the San Francisco Bay Area for which the Contractor has already collected and analyzed samples.[25,29–32] The Contractor will also compare SSE EFs with and without wind results to evaluate EFs from ADUs under different wind conditions.

The Contractor will evaluate speciated SSE EFs with respect to available structure material and fire behavior data from IBHS. The Contractor will use the measured SSE EFs from ADUs and SFHs, available SSE data, and findings from the literature review and comparison analyses to recommend structure fire EFs to use in CARB's emission modeling. The Contractor will also propose a performance-based design framework linking emission factors with key fire metrics or building characteristics (e.g. construction inventory, rates of mass loss and heat loss, and MCE) to contextualize EFs.

The California WUI is heterogeneous and varies in structure age, material, size, and location; these properties will dictate specific fire regimes and produce different emission factors. This Agreement is limited to studying the emissions from structures chosen for the SSEs by IBHS, USFS, CBIA, and CAL FIRE. Therefore, the EF results from this Agreement will most closely relate to newer structures compliant with recent versions of the California Building Code. While the Contractor will attempt to relate EFs to structure material, size, and fire behavior using results from additional laboratory experiments, these results will truly provide a starting point for CARB modelers to quantify structure fire emissions in the diverse California WUI.

The SSE experiments will improve understanding of how fires ignite and spread within the WUI; the physics and dynamics of wildland fire spread; the processes by which structures ignite from embers, radiation, or flame contact; and emissions from wildfire smoke. Researchers from IBHS, USFS, CBIA, and CAL FIRE will be involved in the SSE data generation and analysis. This collaboration allows the Contractor to interact with these experts throughout the project. Their expertise will be leveraged as needed and especially during the EF interpretation analysis.

CARB maintains inventories of criteria pollutant, toxics and greenhouse gas emissions associated with biomass burning (wildfires, prescribed fires and agricultural residue burning) and structure fires. Many structures, as well as entire communities, have been damaged or destroyed by large-scale California wildfires in recent years. The extent and unique chemical composition of emissions generated as wildfires consume communities means that in order for CARB to better understand and assess associated air quality impacts and health risks, the CARB Air Quality Planning & Science Division (AQPSD) is embarked in efforts to develop new tools for generating geospatially and temporally explicit emission inventories of structure fires.

Additional opportunities to collaborate with fire science researchers exists at UCB. A separate ongoing AQPSD-funded research project will build upon both existing CARB sources and methods and will incorporate new information and work products generated over the course of this Agreement. In this way, new information and data emerging from the Contractor will be available for a scaling-up from the laboratory scale to the scale of regional emission inventories. The AQPSD project Contract Manager for the project will be Klaus Scott. The structure fires inventory tools development work will be led by Dr. Maggi Kelly of the Geospatial Innovation Facility, housed in the UCB Department of Environmental Science, Policy and Management. As needed, there will be direct interaction between these two (2) UCB research contracts to make sure data provided will be in appropriate format to facilitate CARB's development of structure fires inventory tools. Mr. Scott will assist Dr. Kelly with coordination in between Drs. Goldstein and Gollner.

Data Management: The Contractor will develop datasets for use by the air quality management and scientific communities by characterizing smoke emissions and relating them to building type (e.g., ADU vs. SFH), building material, and fire characteristics. These results will allow CARB to inform their operational models, such as NWL and FOFEM, by validating estimates of fuel consumption, characterizing emissions, and providing a performance-based design framework to contextualize emission factors.

Data to be collected by the Contractor will consist of emissions measurements of CO, CO_2, I/VOCs, SVOCs, $PM_{2.5}$ mass and metals. Other data to be provided to the Contractor by IBHS and collaborators include building construction inventory, structure size, mass loss rate, heat loss rate, and wind speed. Laboratory, IBHS data, and CO/CO_2 data will be acquired at time resolutions ≥1-Hz while speciated S/I/VOCs and $PM_{2.5}$ will be measured as a bulk sample encompassing approximately 15 minutes of SSE burn emissions.

Emissions measurements will undergo quality assurance and quality control (QA/QC) through calibration standards, blanks, and detection limits as described in Task 2. The Contractor- and IBHS-supplied data will include their QA/QC processes which will be cited.

All data is expected to be stored in hierarchical data format (for GC×GC-HToFMS) or comma-separated variable files (all other sources). Chemical speciation data will be saved as comma-separated variable files. Other data products may include burn summary statistics or sub-sampling to decrease time resolution. Continuous flight records for each burn will be used to generate time series of UAV position (latitude, longitude, altitude) referenced to Coordinated Universal Time (UTC) to allow synchronizing with sensor measurements and bulk sampling times.

Throughout the eight (8) ADU burns, it is not expected that any structures composition or size will be repeated exactly. Due to the limited sample size of structures, statistical validity will be constrained to the available emissions and fire behavior data. High time resolution measurements will provide sufficient sample sizes of observations over the duration of experiments and a structure burn. Gaseous and particulate chemical speciation will include ~3–4 time resolved samples per burn. After calibrated analysis on high resolution instruments (including GC×GC-HToFMS), these data will be sufficient to provide a robust estimate of the average and variance of emissions for hundreds of speciated compounds. Additional comparisons will be possible with the laboratory-scale measurements.

Task ~~5~~6: Draft Final Report

The primary deliverable will be a final report which will describe the background, experimental and analytical methods, and results. The Contractor will submit the final report in a format that is compliant with the Americans with Disabilities Act. In the final report, The Contractor will include a one-page Public Outreach Document that will use clear and accessible language for communicating this work to the public.

Final data products created under this contract will include: 1) a database of chemical species collected on filters and sorbent tubes and detected by GC×GC-HToFMS; compounds will be quantified by peak area and identified by name or compound class, using standards as available; 2) particulate bulk measurements, including $PM_{2.5}$ mass, OC/EC mass and relative abundance, and metals speciation; 3) calculated EFs for bulk gaseous and particulate compounds (e.g., total PM), for individual species and for classes of compounds (e.g., ‘PAHs’) in gas and particle phases; the EF database will include metadata to link EFs with fuel characteristics and burn conditions; 4) temporal profiles of online gaseous chemical species (e.g., CO, CO_2); 5) pre-fire fuel characterizations, including component inventory along with burn conditions and actual or estimated fuel consumption for the structure fires at IBHS. Final data produced pursuant to this proposal is planned to be provided to CARB and made available for public access by the end of the proposed contract period.

Task ~~6~~ 7: Amend Final Report
The Contractor will address CARB reviewer input on the draft report and submit an amended Final Report.

Project Schedule
Task 1: Prepare for Structure Separation Experiments
Task 2: Collect Emissions Measurements
Task 3: Laboratory-Scale Emissions Measurements
Task 4: Laboratory-Scale study on the effect of burning conditions on emissions
Task ~~**4**~~ **5**: Analyze Samples and SSE Data
Task ~~**5**~~ **6**: Draft Final Report
Task ~~**6**~~ **7**: Amend Final Report

Table 2. Project Schedule

	Year 1				**Year 2**				**Year 3**				Year 4			
Task 1: Prepare for Structure Separation Experiments (SSE)	▨	▨	▨	▨												
Task 2: Collect Emissions Measurements from SSE					▨	▨	▨	▨	▨							
Task 3: Laboratory-Scale Emissions Measurements		▨	▨	▨	▨	▨	▨	▨								
Task 4: Burning conditions laboratory measurements		▨	▨	▨	■	■	■	■								
Task 5: Analyze Samples and SSE Data							▨	▨	▨	▨	▨					
Task 6: Draft Final Report											▨	▨				
Task 7: Amend Final Report													▨	▨		
	m,p	p	m,p	p	m,p	p	m,p	p	m,p	p	m,p	p	m,p	d	m,p	f

p = Quarterly Progress Reports
d = Deliver draft final report
f = Deliver final report
m = meeting with ARB staff

Regular phone meetings with CARB staff (m) will occur at 6-month intervals, and quarterly written progress reports (p) will be provided as required by CARB. The expected timing for these communications is shown in Table 2, along with the timing for delivering the draft final report (d) and the final report (f).

Project Management Plan
This section identifies the key members of the research team involved in this project. It delineates their role in the project and describes their relationships to each other. There will be regular teleconferences of the research team. In the period leading up to the field campaign, these meetings will be more frequent.

This project builds on current and past collaborations between Goldstein and Kreisberg, using advanced analytical techniques to improve chemical characterization of the gas and particles emitted from biomass burning, as well as to improve model predictions of smoke chemistry and impacts. With the addition of Kreisberg, the team gains a research engineer experienced in developing field sampling equipment, sampling with an airborne drone, and licensed by the FAA to fly the drone.

UCB
Allen Goldstein, Environmental Science, Policy, & Management, and Civil & Environmental Engineering: PI Goldstein will oversee the collection and analysis of gaseous and particle-phase organic chemicals, the drone-based sampling, and participate actively in the management and coordination of the overall project. Goldstein will be the main contact for coordination between CARB staff and the Contractor.

Aerosol Dynamics Inc.
Nathan Kreisberg, Research Engineer: Co-I Kreisberg will work with the Goldstein group in preparing field sampling equipment, preparing the drone measurement package, and will actively participate as a drone pilot during the SSE sampling campaign.

Existing Facilities

IBHS

The IBHS Research Center is located in Richburg, South Carolina on a 90-acre plot and is designed to test structure resiliency against a variety of environmental and engineering challenges. Among other capabilities, IBHS offers a wind tunnel over 21,000 ft^2 in size capable of up to Category 3 hurricane-force winds (12–120 mph), a hail-firing cannon, and a weight scale that can support a SFH. With the structure separation experiments, IBHS and collaborators also bring heat flux sensors, thermocouples, and anemometers.

UCB

Professor Goldstein has University of California laboratory facilities equivalent to 1,350 ft^2, equipped for chemical analysis of organic atmospheric trace gasses and aerosols, field measurement of VOCs, aerosols, and micrometeorological conditions, and development of analytical instrumentation. He also has office space for researchers and staff equivalent to 1,200 ft^2 with appropriate computer and internet facilities including workstations dedicated to analysis of 2-D GC and high-resolution time-of-flight mass spectrometry data. In addition, he has access to all of UCB's shared facilities including machine shops, electronic shops, glass shops. Major equipment relevant to this Agreement includes two high-resolution thermal desorption GC×GC-HToFMS systems consisting of Agilent 7890A GCs, time-of-flight mass spectrometers, Zoex GC×GC modulator, and Gerstel thermal desorption systems with autosampler. Major equipment also includes a drone (DJI Matrice 600 pro) for airborne sampling.

Professor Gollner has University of California laboratory facilities in one (1) primary hall equivalent to 1,880 ft^2, equipped to perform combustion experiments and subsequent measurements. An estimated 3000 CFM of ventilation is available on two (2) lines supporting two (2) laminar flow hoods, six (6) ducts, three (3) wind tunnels and a pressure chamber for custom experiments. A separate room (~300 ft^2) is used for larger fire experiments needing higher ventilation, supporting 3000 CFM on one (1) hood. Refrigerators and ovens are available to store live vegetation samples. Equipment relevant to this proposal include a linear tube heater apparatus designed for material smoke generation at controlled conditions, a cone heater, an FTIR custom designed for smoke speciation, a TSI DustTrack, gravimetric sampling equipment, a CAI gas analysis rack, and assorted thermal analysis equipment and data acquisition systems.

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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 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.

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 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.	Quarterly
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 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.
The following Deliverables are subject to paragraph 19. Copyrights, paragraph B of Exhibit C		
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 must accompany a related invoice covering the same 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 summary of the status of the project, including whether the project is on schedule. If the project is behind schedule, the progress report must contain an explanation of reasons and how the University plans to resume the schedule.

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

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

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

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

C. Six (6) months prior to Agreement expiration date, University will deliver to CARB an electronic copy of the draft final report in both PDF and Microsoft Word formats. The draft final report will conform to Exhibit A1, Section 2 – Research Final Report Format.

D. Within forty-five (45) days of receipt of CARB's comments, University will deliver to CARB's Contract Project Manager an electronic copy 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 an electronic copy of the final report in both PDF and Microsoft Word formats.

E. As specified in Exhibit A1, Section 2, Final Report will be submitted in an Americans with Disabilities Act compliant Format.

F. Together with the final report, University will deliver 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, 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 in PDF format and in a word-processing format, preferably in Word – Version 6.0 or later. The electronic copy file name shall contain the CARB contract number, the words "Final Report", and the date the report was submitted.

Accessibility. 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 but be in an accessible format so that all members of the public can access it.

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. However, minor changes to the title may be approved provided the new title does not deviate from the old title. These minor changes must be approved in writing by the contract manager. Significant changes to the title would require a formal amendment.

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

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
Public Outreach Document
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.

Public Outreach Document. The public outreach document is a one-page document that will be widely used to communicate, in clear and direct terms, the key research findings from the study to the public. CARB will be translating the document into other languages. This document must adhere to the following guidelines:

- Single space, limited to one-page or about 500 words.
- Use narrative form and active voice.
- Incorporate a graphic that it is easy to interpret and captures the results' central message.
- Avoid jargon and technical terms. Use a style and vocabulary level comparable to that of sixth grade reading level.
- The document should contain a title and the following five sections: Issue/s, Main Question, Key Research Findings, Conclusion/s, and More Information. Guidance on how to write these sections is described below.

  TITLE: Adopt a short, non-technical title to make the topic clear and concise. The title will likely differ from the original title of the contract.

  ISSUE/S: In one to two paragraphs, describe why the project was needed. In this section, identify the problem leading to this study and what the study was set to accomplish to help address the problem. Reference any history that is relevant such as a regulation, legislation, program, law, or other. Without going into detail and disclosing the research findings, mention the methods used in the study and how it informed the results.

  MAIN QUESTION: Present a concise central research question driving this project.

  KEY RESEARCH FINDING/S: This section covers the key research findings. List key points and or findings.

  CONCLUSION/S: In one to two paragraphs, discuss how the results could be used. Mention its relevance to policies, rules, regulations, legislations, or CARB programs. Include suggestions for next steps, additional research, or other actions.

  MORE INFORMATION: In two to three short sentences provide specifics about the study. This section should include the full title of the study, sponsor, authors, and where the full report can be found (the final report will be posted on the CARB website). In addition to a direct contact to gain more information (author and CARB contract manager).

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 accessible to the general audience. Assume the audience is being exposed the subject for the first time.

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 sentences, 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.

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.

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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.

EXHIBIT A2

KEY PERSONNEL

Last Name, First Name	Institutional Affiliation	Role on Project
Principal Investigator (PI):		
Goldstein, Allen	UCB	PI
Co-PI		
Gollner, Michael	UCB	Co-PI
Other Key Personnel:		
Kreisberg, Nathan	Aerosol Dynamics, Inc.	Co-Investigator

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: **UCB**
Contract Project Manager (Technical) Name: Nehzat Motallebi Address: Research Division 1001 I Street, 5th Floor Sacramento, CA 95814 Telephone: (916) 277-0553 Email: Nehzat.Motallebi@arb.ca.gov	***Principal Investigator (PI)*** Name: Allen Goldstein Address: Environmental Science, Policy & Management Mulford Hall University of California Berkeley, CA 94720-3114 Telephone: (510) 643-2451 Email: ahg@berkeley.edu
Authorized Official (contract officer) Name: Alice Kindarara, Branch Chief Address: Acquisitions Branch 1001 I Street, 19th Floor Sacramento, CA 95814 ***Send notices to (if different):*** Name: Sarah Szepesi Address: Research Division 1001 I Street, 5th Floor Sacramento, CA 95814 Email: Sarah.Szepesi@arb.ca.gov	***Authorized Official*** Name: Angela R. Ford, Associate Director Address: Sponsored Projects Office University of California, Berkeley 1608 Fourth Street, Suite 220 Berkeley, CA 94710-1749 Telephone: (510) 642-0120 Email: SPOawards@berkeley.edu

Administrative Contact Name: Sarah Szepesi Address: Research Division 1001 I Street, 5th Floor Sacramento, CA 95814 Email: Sarah.Szepesi@arb.ca.gov	***Administrative Contact*** Name: Angela Martinez, Contract & Grant Officer Address: Sponsored Projects Office University of California, Berkeley 1608 Fourth Street, Suite 220 Berkeley, CA 94710-1749 Telephone: (510) 642-8113 Email: angela.m@berkeley.edu
Financial Contact/Accounting Name: Accounts Payable Address: P.O. Box 1436 Sacramento, CA 95814 Email: AccountsPayable@arb.ca.gov **Send courtesy copy to Sarah Szepesi:** Email: sarah.szepesi@arb.ca.gov	***Authorized Financial Contact/Invoicing*** Name: Elizabeth Chavez, Director Address: Contracts and Grants Accounting University of California, Berkeley 1608 Fourth Street, Suite 201 Berkeley, CA 94710-1103 Telephone: (510) 643-4246 Email: CGAawards@berkeley.edu Designees for invoice certification in accordance with Exhibit C – University Terms and Conditions, Section 14 on behalf of the Financial Contact: 1. Julio Rodriguez, CGA Supervisor, jrrodriguez@berkeley.edu 2. Lynne Coulson, CGA Manager, lcoulson@berkeley.edu 3. Esther Chang, CGA Supervisor, estherc@berkeley.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

ALLEN H. GOLDSTEIN
Professor and MacArthur Foundation Chair. University of California, Berkeley (UCB)
Department of Environmental Science, Policy and Management (ESPM),
330 Hilgard Hall, Berkeley, California 94720-3114; ahg@berkeley.edu; phone (510) 643-3788

EDUCATION AND TRAINING

BS & BA	University of California at Santa Cruz, Chemistry & Politics	1989
MA	Harvard University, Chemistry	1991
PhD	Harvard University, Chemistry	1994
Postdoc	Harvard University, Earth and Applied Sciences	1994-1995

PROFESSIONAL APPOINTMENTS

Associate Dean Academic Affairs, Rausser College of Natural Resources, UCB	2020-present
Professor, Department of Civil and Environmental Engineering (CEE), UCB	2008-present
Professor, Department of ESPM, UCB	2005-present
Visiting Professor, Max Planck Institute for Chemistry, Mainz, Germany	2019
Visiting Professor, Hong Kong Polytechnic Institute, Department of CEE	2018-2019
Visiting Professor, Institute of Atmos. Sciences and Climate (CNR-ISAC), Italy	2018
Chair, Department of ESPM, UCB	2007-2010
Visiting Professor, Royal Melbourne Institute of Technology, Australia	2005-2006
Visiting Professor, CSIRO Marine and Atmospheric Research, Australia	2005-2006
Associate Professor, Department of ESPM, UCB	2001-2005
Assistant Professor, Department of ESPM, UCB	1996-2001
Faculty Chemist, Lawrence Berkeley National Laboratory	1996-present
Visiting Scientist, National Oceanographic and Atmospheric Admin.	1994

5 SYNERGISTIC ACTIVITES

Nat. Acad. of Sci. Committee “Emerging Science on Indoor Chemistry”	2021-2022
Editorial Advisory Board, Environmental Science & Technology (ACS pub)	2017-2023
Board of Directors, American Association of Aerosol Research	2016-2019
Co-Chair, IGAC Scientific Steering Committee	2013-2016
Nat. Acad. of Sci. Committee “Future of Atmospheric Chemistry Research”	2014-2016

RECENT HONORS AND AWARDS

Award for Creative Advances in Environmental Science and Technology, American Chemical Society (ACS)	2021
Elected Fellow, American Association for Aerosol Research (AAAR)	2020
John D. and Catherine T. MacArthur Foundation Chair (Endowed Chair, UCB)	2019-2024
Yoram J. Kaufman Outstanding Research and Unselfish Cooperation Award, American Geophsical Union (AGU)	2019
Elected Fellow, American Association for the Advancement of Science (AAAS)	2018
David Sinclair Award, American Association for Aerosol Research (AAAR)	2018
Fulbright Senior Scholar (Italy & Australia)	2018 & 2005
Humboldt Research Award	2017
Highly Cited Researcher, Clarivate Analytics	2017-2021

Elected Fellow, American Geophysical Union (AGU) 2011

SELECTED PUBLICATIONS FROM PAST 3 YEARS (# indicates author from Goldstein group)
(Total peer review publications > 390; Google Scholar citations > 47,000; h-index = 107)

#Liang, Y., #D. Sengupta, M.J. Campmier, #D.M. Lunderberg, J.S. Apte, A.H. Goldstein, Wildfire smoke impacts on indoor air quality assessed using crowdsourced data in California, *Proceedings of the National Academy of Sciences*, 118 (36) e2106478118, 2021.

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#Katz E.F., #D.M. Lunderberg, W.L. Brown, D.A. Day, J.L. Jimenez, W.W Nazaroff, A.H. Goldstein, and P.F. DeCarlo, Large Emissions of Low-Volatility Siloxanes During Residential Oven Use, *Environ. Sci. Technol. Lett.,* doi.org/10.1021/acs.estlett.1c00433, 2021.

#Wernis, R. A., N.M. Kreisberg, #R.J. Weber, #Y. Liang, J. Jayne, S. Hering, and A.H. Goldstein, Development of an In Situ Dual-Channel Thermal Desorption Gas Chromatography Instrument for Consistent Quantification of Volatile, Intermediate Volatility and Semivolatile Organic Compounds, *Atmos. Meas. Tech*., https://doi.org/10.5194/amt-2021-156, 2021.

Kim, J., A.H. Goldstein, R. Chakraborty, K. Jardine, #R. Weber, P.O. Sorensen, S. Wang, B. Faybishenko, #P.K. Misztal and E.L. Brodie, Measurement of Volatile Compounds for Real-Time Analysis of Soil Microbial Metabolic Response to Simulated Snowmelt. *Front. Microbiol*.,12:679671. doi: 10.3389/fmicb.2021.679671, 2021.

#Katz, E.F., H. Guo, P. Campuzano-Jost, D.A. Day, W.L. Brown, E. Boedicker, M. Pothier, D.M. Lunderberg, S.Patel, K. Patel, P.L. Hayes, A. Avery, L. Hildebrandt Ruiz, A.H. Goldstein, M.E. Vance, D.K. Farmer, J.L. Jimenez and P.F. DeCarlo, Quantification of Cooking Organic Aerosol in the Indoor Environment Using Aerodyne Aerosol Mass Spectrometers, *Aerosol Science and Technology*, DOI: 10.1080/02786826.2021.1931013, 2021.

#Lunderberg, D.M., #P.K. Misztal, #Y. Liu, #C. Arata, #Y. Tian, #K. Kristensen, #R.J. Weber, W.W Nazaroff, and A.H. Goldstein, High-Resolution Exposure Assessment for Volatile Organic Compounds in Two California Residences, *Environ. Sci. Technol.*, doi.org/10.1021/acs.est.0c08304, 2021.

#Lunderberg, D.M., #Y. Liu, #P.K. Misztal, #C. Arata, #Y. Tian, #K. Kristensen, W.W Nazaroff, and A.H. Goldstein, Intake fractions for volatile organic compounds in two occupied California residences, *Environ. Sci. Technol. Lett.*, doi.org/10.1021/acs.estlett.1c00265, 2021.

#Drozd, G.T., #R.J. Weber, and A.H. Goldstein, Highly resolved composition during diesel evaporation with modeled ozone and secondary aerosol formation: Insights for pollutant formation from evaporative IVOC sources, *Environ. Sci. Technol.*, doi.org/10.1021/acs.est.0c08832, 55, 9, 5742–5751, 2021.

#Liang, Y., #C.N. Jen, #R.J. Weber, #P.K. Misztal, and A.H. Goldstein, Chemical Composition of PM2.5 in October 2017 Northern California Wildfire Plumes, *Atmos. Chem. Phys*., doi.org/10.5194/acp-21-5719-2021, 21, 5719–5737, 2021.

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Goldstein, A.H., W.W Nazaroff, C.J. Weschler, J. Williams, How Do Indoor Environments Affect Air Pollution Exposure?, *Environ. Sci. Technol.*, 10.1021/acs.est.0c05727, 55, 100–108, 2021.

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#Yee, L., #G. Isaacman-VanWertz, #R. Wernis, N. Kreisberg, M. Glasius, M. Riva, J. Surratt,S. de Sa, S. Martin, M.L. Alexander, B. Palm, W. Hu, P. Campuzano-Jost, D. Day, J. Jimenez, Y. Liu, P. Misztal, P. Artaxo, J. Viegas, A. Manzi, R. Souza, E. Edgerton, K. Baumann, A.H. Goldstein, Natural and anthropogenically-influenced isoprene oxidation in the Southeastern U.S.A. and central Amazon, *Environ. Sci. Technol.*, 54, 10, 5980–5991, 2020.

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#Lunderberg, D., #K. Kristensen, #Y. Liu, #P. Misztal, #Y. Tian, #C. Arata, #R. Wernis, N. Kreisberg, W.W. Nazaroff, and A.H. Goldstein, Characterizing Airborne Phthalate Concentrations and Dynamics in a Normally Occupied Residence, *Environ. Sci. Technol*., 53, 137,337-7346, DOI: 10.1021/acs.est.9b02123, 2019.

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#Gray, E., S. Gilardoni, D. Baldocchi, B.C. McDonald, M.C. Facchini, and A.H. Goldstein, Impact of Air Pollution Controls on Radiation Fog Frequency in the Central Valley of California, *Journal of Geophysical Research: Atmospheres*, 124, doi: 10.1029/2018JD029419, 2019.

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Five other relevant publications

#Gentner, D., #G. Isaacman, #D.R. Worton, #A.W.H. Chan, T.R. Dallmann, L. Davis, S. Liu, D.A. Day, L.M. Russell, K.R. Wilson, #R. Weber, #A. Guha, R.A. Harley, A.H. Goldstein, Elucidating secondary organic aerosol from diesel and gasoline vehicles through detailed characterization of organic carbon emissions, *Proceedings of the National Academy of Sciences*, 10.1073/pnas.1212272109, V109, N45, 18318-18323, 2012.

Glasius, M., and A.H. Goldstein, Recent Discoveries and Future Challenges in Atmospheric Organic Chemistry, *Environ. Sci. Technol*., 50, 2754−2764, DOI: 10.1021/acs.est.5b05105, 2016.

#Park., J-H., A.H. Goldstein, J. Timkovsky, #S. Fares, #R. Weber, J. Karlik, #R. Holzinger, Active Atmosphere-Ecosystem Exchange of the Vast Majority of Detected Volatile Organic Compounds, *Science*, Vol. 341 no. 6146 pp. 643-647, doi: 10.1126/science.1235053, 2013.

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Goldstein, A.H., and I.E. Galbally, Known and Unexplored Organic Constituents in the Earth's Atmosphere, *Environmental Science and Technology*, 41, 5, 1514 - 1521, 2007.

MICHAEL J. GOLLNER
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Department of Mechanical Engineering
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EDUCATION AND TRAINING

BS	University of California at San Diego, Mechanical Engineering	2008
MS	University of California at San Diego, Mechanical Engineering	2010
PhD	University of California at San Diego, Mechanical Engineering	2012

PROFESSIONAL APPOINTMENTS

Associate Professor, Department of Mechanical Engineering, UCB	2021 – Present
Assistant Professor, Department of Mechanical Engineering, UCB	2020 – 2021
Associate Professor, Department of Fire Protection Engineering, U. Maryland	2017 – 2019
Affiliate Professor, Department of Aerospace Engineering, U. Maryland	2015 – 2019
Affiliate Professor, Department of Mechanical Engineering, U. Maryland	2013 – 2019
Assistant Professor, Department of Fire Protection Engineering, U Maryland	2012 – 2019

5 SYNERGISTIC ACTIVITES

Treasurer and Board of Directors, International Association of Wildland Fire	2018 – 2021
Chair, Research Advisory Comm., NFPA Fire Protection Research Foundation	2020 – 2021
Congressional Testimony, House Committee on Oversight and Reform	2022
Member, CAL FIRE Hazard Severity Zones Technical Review Committee	2020 – Present
Associate Editor, Fire Technology	2014 – Present

RECENT HONORS AND AWARDS

Hiroshi Tsuji Early Career Researcher Award, The Combustion Institute	2020
Proulx Early Career Award International Association of Fire Safety Science	2017
Fire Protection Research Foundation Medal	2016
NSF CAREER Award	2016

PUBLICATIONS FROM PAST 3 YEARS (21 of 63 total publications)

McNamee, M., Meacham, B., van Hees, P., Bisby, L., Chow, W.K., Coppalle, A., Dobashi, R., Dlugogorski, B., Fahy, R., Fleischmann, C. Floyd, J., Galea, E., Gollner, M., Hakkarainen, T., Hamins, A., Hu, L., Johnson, P., Karlsson, B., Merci, B., Ohmiya, Y., Rein, G., Trouve, A., Wang, Y., Weckman, E., IAFSS Agenda 2030 for a Fire Safe World, *Fire Safety Journal*, 110, 102889, December 2019. (DOI)

Manzello, S.S., Suzuki, S., Gollner, M.J., Fernandez-Pello, C., Role of Firebrand Combustion in Large Outdoor Fire Spread, *Progress in Energy and Combustion Science*, 76, 100801, January 2020. (DOI)

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Hariharan, S. B., Hu, Y., Gollner, M.J., Oran, E.S., Effects of circulation and buoyancy on the transition from a fire whirl to a blue whirl, *Physical Review Fluids* 5, 103201, October 2020. (DOI)

Ren, X., Zeng, D., Wang, Y., Xiong, G., Agarwal, G., Gollner, M.J., Temperature measurement of a turbulent buoyant ethylene diffusion flame using a dual-thermocouple technique, *Fire Safety Journal, Fire Safety Journal,* 120, March 2021, 103061. (DOI)

Tao, Z., Bathras, B., Kwon, B., Biallas, B., Gollner, M.J., Yang, R., Effect of Firebrand Size and Geometry on Heating from a Smoldering Pile under Wind, *Fire Safety Journal*, 120, March 2021, 103031. (DOI)

Hakes, R.S.P., Coenen, W., Sanchez, A.L., Gollner, M.J., Williams, F.A., Stability of laminar flames on upper and lower inclined fuel surfaces, *Proceedings of the Combustion Institute*, 38(3): 4515–4523, April 2021. (DOI)

Salehizadeh, H., Hakes, R.S.P., Gollner, M.J., Critical Ignition Conditions of Wood by Cylindrical Firebrands, *Frontiers in Mechanical Engineering*, 7:630324., March 2021. (DOI)

Hajilou, M., Hu, S., Roche, T., Garg, P., Gollner, M.J., A Methodology for Experimental Quantification of Firebrand Generation from WUI Fuels, *Fire Technology*, April 2021. (DOI)

Hariharan, S.B., Farahani, H.F., Rangwala, A.S., Dowling, J.L., Oran, E.S., Gollner, M.J., Comparison of particulate-matter emissions from liquid-fueled pool fires and fire whirls, *Combustion and Flame*, 227:483–496, May 2021. (DOI

Garg, P., Roche, T.,Eden, M.,Matz,J. ,Oakes, J.M., Bellini, C., Gollner, M.J., Effect of moisture content and fuel type on emissions from vegetation using a steady state combustion apparatus, *International Journal of Wildland Fire*, 31(1) 14–23, October 2021. (DOI)

Cobian-Iniguez, J, Richter, F, Camignani, L, Liveretou, C., Xiong, H. Stephens, S., Finney, M. Gollner, M.J., Fernandez-Pello, C., Wind effects on smoldering behavior of simulated wildland fuels, *Combustion Science and Technology*, 240, January 2022. (DOI)

Ren, X., Ju, X., Sluder, E., Yang, L., Gollner, M.J., Effect of freestream turbulence on the structure of boundary- layer flames, *Combustion and Flame*, 236, February 2022, 111750. (DOI)\

Hariharan, S.B., Farahani, H.F., Rangwala, A.S., Oran, E.S., Gollner, M.J., Effects of Natural and Forced Entrainment on PM Emissions from Fire Whirls, *Environmental Science and Technology*, 56(6):3480–3491, February 2022. (DOI)

Richter, F, Bathras, B, Barbetta Duarte, J., Gollner, M.J., “The Propensity of Wooden Crevices to Smoldering Ignition by Firebrands, *Fire Technology*, 1-22 April 2022

Thomsen, M., Carmignani, L., Rodriguez, A., Scudiere, C., Liveretou, C., Fernandez-Pello, A.C., Gollner, M.J., Olson, S., Ferkul, P., “Downward Flame Spread Rate Over PMMA Rods Under External Radiant Heating”, *Fire Technology*, April 2022. (DOI)

Wang, S., Lin, S., Liu, Y., Huang, X., Gollner, M.J., Smoldering ignition using a concentrated solar irradiation spot, *Fire Safety Journal*, 129, May 2022, 103549. (DOI)

Ji, W., Richter, F., Gollner, M.J., Deng, S. Autonomous kinetic modeling of biomass pyrolysis using chemical reaction neural networks, *Combustion and Flame*, 240, 111992, June 2022. (DOI)

Ju, X., Ren, X., Sluder, E.., Yang, L., Gollner, M.J., Flame attachment and downstream heating effect of inclined line fires, *Combustion and Flame*, 240, June 2022, 112004. (DOI)

Ren, X., Sluder, E.T., Heck, M.V., Grumstrup, T.P., Finney, M.A., Makiharju, S.A., Gollner, M.J., Scaling analysis of downstream heating and flow dynamics of fires over an inclined surface, *Combustion and Flame*, 242, 112203, August 2022. (DOI)

Miller, R.K., Richter, F., Theodori, M., Gollner, M.J., Professional wildfire mitigation competency: a potential policy gap, *International Journal of Wildland Fire*, In Press (DOI)

NATHAN M. KREISBERG
Senior Research Scientist, Aerosol Dynamics Inc.

Education

B.A., Physics, 1983, University of California, Berkeley, CA
Ph.D., Physics, 1991, University of Texas, Austin, TX

Professional Experience

1994 to present	Research Scientist, Aerosol Dynamics Inc., Berkeley, CA
1991 to 1994	Collaborator/consultant, Los Alamos National Laboratory, Los Alamos, NM
1985 to 1991	Welch Fellow, Research and Teaching Assistantships, Department of Physics, University of Texas, Austin, TX

Patents
US Patent 6,284,025, Particle microtrap screen (with S.V. Hering)
US Patent WO2014055652 A3, Wick wetting for water condensation systems (with S.V. Hering, S.R. Spielman and G.S. Lewis)

Peer-Reviewed Publications (15 out of 54 total)

Wernis, R.A., Kreisberg, N.M., Weber, R.J., Liang, Y., Jayne, J., Hering, S.V., and Goldstein, A.H.: Development of an In Situ Dual-Channel Thermal Desorption Gas Chromatography Instrument for Consistent Quantification of Volatile, Intermediate Volatility and Semivolatile Organic Compounds, *Atmos. Meas. Tech.*, 2021, 14, 6533–6550.

Hurley, J., N. Kreisberg, B. Stump, C. Bi, P. Kumar, S. Hering, P. Keady, and G. Isaacman-VanWertz: A new approach for measuring the carbon and oxygen content of atmospherically relevant compounds and mixtures. Atmospheric Measurement Techniques, 2020, 13, 4911-4925.

Jen, C. N., Hatch, L. E., Selimovic, V., Yokelson, R. J., Weber, R., Fernandez, A. E., Kreisberg, N. M., Barsanti, K. C., and Goldstein, A. H.: Speciated and total emission factors of particulate organics from burning western U.S. wildland fuels and their dependence on combustion efficiency, *Atmos. Chem. Phys.*, 2019, 1-22, DOI: 10.5194/acp-19-1013-2019.

Jen, C. N., Liang, Y., Hatch, L., Kreisberg, N. M., Stamatis, C., Kristensen, K., Battles, J. J., Stephens, S., York, R. A., Barsanti, K. C., and Goldstein, A. H.: High Hydroquinone Emissions from Burning Manzanita, *Environmental Science & Technology Letters*, 2018, Article ASAP, DOI: 10.1021/acs.estlett.8b00222.

Yee, L. D., Isaacman-VanWertz, G., Wernis, R. A., Meng, M., Rivera, V., Kreisberg, N. M., Hering, S. V., Bering, M. S., Glasius, M., Upshur, M. A., Gray Bé, A., Thomson, R. J., Geiger, F. M., Offenberg, J. H., Lewandowski, M., Kourtchev, I., Kalberer, M., de Sá, S., Martin, S. T., Alexander, M. L., Palm, B. B., Hu, W., Campuzano-Jost, P., Day, D. A., Jimenez, J. L., Liu, Y., McKinney, K. A., Artaxo, P., Viegas, J., Manzi, A., Oliveira, M. B., de Souza, R., Machado, L. A. T., Longo, K., and Goldstein, A. H.: Observations of sesquiterpenes and their oxidation products in central Amazonia during the wet and dry seasons, *Atmos. Chem. Phys.* 2018, 18, 10433-10457, DOI: 10.5194/acp-18-10433-2018.

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Walls, H. J., Kim, J. H., Yaga, R. W., Harvey, L. A., Haines, L. G., Ensor, D. S., Hering, S. V., Spielman, S. R., and Kreisberg, N.: Long-term viable bioaerosol sampling using a temperature- and humidity-controlled filtration apparatus, a laboratory investigation using culturable E. coli, *Aerosol Science and Technology* 2017, 51, 576-586.

Isaacman-VanWertz, G., Yee, L. D., Kreisberg, N.M., Wernis, R., Moss, J.A., Hering, S.V., de Sá, S.S., Martin, S.T., Alexander, M.L., Palm, B.B., Hu, W., Campuzano-Jost, P., Day, D.A., Jimenez, J.L., Riva, M., Surratt, J.D., Viegas, J., Manzi, A., Edgerton, E., Baumann, K., Souza, R., Artaxo, P., and Goldstein, A.H.: Ambient Gas-Particle Partitioning of Tracers for Biogenic Oxidation, *Environmental Science & Technology* 2016, 50, 9952-9962, 10.1021/acs.est.6b01674.

Chan, A., Kreisberg, N.M., Hohaus, T., Campuzano-Jost, P., Zhao, Y., Day, D., Kaser, L., Karl, T., Hansel, A., Teng, A., Ruehl, C., Sueper, D., Jayne, J., Worsnop, D., Jimenez, J., Hering, S., and Goldstein, A.: Speciated measurements of semivolatile and intermediate volatility organic compounds (S/IVOCs) in a pine forest during BEACHON-RoMBAS 2011, *Atmospheric Chemistry and Physics* 2016, 16, 1187-1205.

Preble, C. V., T. R. Dallmann, N. M. Kreisberg, S. V. Hering, R. A. Harley and T. W. Kirchstetter. "Effects of particle filters and selective catalytic reduction on heavy-duty diesel drayage truck emissions at the port of Oakland." *Environmental science & technology* 2015, 49(14): 8864-8871.

Isaacman, G., N. Kreisberg, L. Yee, D. Worton, A. Chan, J. Moss, S. Hering and A. Goldstein. "Online derivatization for hourly measurements of gas-and particle-phase semi-volatile oxygenated organic compounds by thermal desorption aerosol gas chromatography (SV-TAG)." *Atmospheric Measurement Techniques* 2014, 7(12): 4417-4429.

Kreisberg, N., D. Worton, Y. Zhao, G. Isaacman, A. Goldstein and S. Hering. "Development of an automated high-temperature valveless injection system for online gas chromatography." *Atmospheric Measurement Techniques* 2014, 7(12): 4431-4444.

Zhao, Y., N. M. Kreisberg, D. R. Worton, G. Isaacman, D. R. Gentner, A. W. Chan, R. J. Weber, S. Liu, D. A. Day and L. M. Russell. "Sources of organic aerosol investigated using organic compounds as tracers measured during CalNex in Bakersfield." *Journal of Geophysical Research: Atmospheres* 2013, 118(19): 11,388-311,398.

Zhao, Y., N. M. Kreisberg, D. R. Worton, G. Isaacman, R. J. Weber, S. Liu, D. A. Day, L. M. Russell, M. Z. Markovic and T. C. VandenBoer (2013). "Insights into secondary organic aerosol formation mechanisms from measured gas/particle partitioning of specific organic tracer compounds." *Environmental science & technology* 2013, 47(8): 3781-3787.

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EXHIBIT A6

CURRENT & PENDING SUPPORT

PI: Allen Goldstein

Status	**Award #**	**Source**	**Project Title**	**Start Date**	**End Date**
Active	22RD004	CARB	Understanding and Characterizing Emission Factors from Burning Structures in California Due to Wildfires	11/01/2022	~~10/31/2025~~ **10/30/2026**
Active	G-2018-11240	Sloan Foundation	Chemistry of Homes: Environmental Microbes and Moisture	01/01/2019	12/31/2022
Active	G-2019-11412	Sloan Foundation	Renewal: To expand understanding of the processes controlling indoor chemistry	07/01/2019	12/31/2023
Active	DE-SC0020051	Department of Energy ASR	Advancing Molecular Level Understanding of Aerosol Processes in the Amazon and Integration with Modeling	08/15/2019	08/14/2022
Active	1801971-UCB2	National Science Foundation	Laboratory Investigation of Oceanic Organic Emissions	04/01/2019	09/30/2023
Active	19RD008	CARB	Understanding and Mitigating Wildfire Risk in California	01/01/2020	6/29/2023
Active	20RD003	CARB	Airborne Flux Measurements of Volatile Organic Compounds and Oxides of Nitrogen in California	10/01/2020	03/01/2023
Active		National Oceanic & Atmospheric Administration	A multispecies approach to investigate the changing cocktail of atmospheric urban carbon	09/01/2020	08/31/2023
Pending		National Oceanic & Atmospheric Administration	Analyzing Emitted Organic Trace Gas and Aerosol Speciation at the Wildland-Urban Interface and their Atmospheric Chemical Transformations	09/01/2022	08/31/2025

Co-Investigator: Michael J. Gollner

Status	Award #	Source	Project Title	Start Date	End Date
Active	22RD004	CARB	Understanding and Characterizing Emission Factors from Burning Structures in California Due to Wildfires	11/01/2022	10/30/2026
Active	8GG21815	CAL FIRE	Approaches to Quantifying Structural Ignition Risk in the Wildland-Urban Interface	05/2022	03/2026
Active	500821-78051	NIH	Cardiopulmonary Risk-Assessment from Smoke Exposure at the Wildland Urban Interface	02/2022	11/2026
Active	106575-Q1367301	UL	Fireband Ignition of Building Materials	01/2022	10/2023
Active	22-CR-11221637-190	USDA Forest Service	Identifying Influencing Factors on Radiant and Convective Energy Transport Associated with Firefighter Safety Zones Size and Safe Separation Distance.	10/2022	9/2023
Active	70NANB22H059	NIST	Collaborative Research: Wildland Urban Interface and the Built Environment: Design, Evacuation and Retreat Under No-Notice Fire Hazards	05/2022	04/2024
Active	1854952	NSF	PREEVENTS Track 2: Fire Spread at the Wildland-Urban Interface (WUI) Modeling and Data Assimilation for Prediction and Risk Assessment (WUI MAPR)	01/2020	06/2023
Active	70NANB19H053	NIST	Development of a Fundamental Model for Ignition for Structural Wildland-Urban Interface (WUI) Fuels Subjected to Firebrand Attack	01/2020	07/2023
Active	80NSSC22K0582	NASA	Material Ignition and Suppression Test (MIST) in Space Exploration Atmosphere	05/2022	04/2025
Active	80NSSC17M0065	NASA	Material Testing and Selection in Support of the Spacecraft Fire Safety Demonstration Experiments	10/2020	09/2025
Active	140E0121C0004	BSEE/DOI	Efficient Remediation of Oil Spills using Fire Whirls – Phase II	01/2021	01/2023
Active	60NANB21D122	NIST	Quantification of Firebrand Production from WUI Fuels for Model Development	08/2021	07/2023

Active	2230636	NSF	SCC-IRG Track 1 Designing Smart, Sustainable Risk Reduction in Hazard-Prone Communities: Modeling Risk Across Scale of Time and Space	10/2022	9/2026
Active	2114740	NSF	AccelNet-Design: FIRENET: An international network of networks for prediction and management of wildland fires	10/2021	09/2023
Active	10821	Gordon and Betty Moore Foundation	Development and Implementation of a Model for WUI Fire Spread	12/2021	11/2023
Pending		Joint Fire Science Program	Fueling resilience: A risk-based comparison of post-fire programs and recovery outcomes in Northern California	09/2022	8/2025

Co-Investigator: Nathan Kreisberg

Status	**Award #**	**Source**	**Project Title**	**Start Date**	**End Date**
Active	22RD004	CARB	Understanding and Characterizing Emission Factors from Burning Structures in California Due to Wildfires	11/01/2022	~~10/31/2025~~ **10/30/2026**
Active		Department of Energy	Aerosol Chemistry Field Calibration System	05/03/2021	05/02/2023
Active		Department of Energy	Time-resolved Chemical Characterization of Atmospheric Aerosols	04/2020	04/2022
Active		National Institutes of Health	A simple instrument for in-situ, time-resolved speciated measurement of the 16-EPA priority Polycyclic Aromatic Hydrocarbons	04/01/2020	3/31/2022
Active	19RD008	CARB	Understanding and Mitigating Wildfire Risk in California	4/01/2020	3/31/2023
Pending		National Oceanic & Atmospheric Administration	Analyzing Emitted Organic Trace Gas and Aerosol Speciation at the Wildland-Urban Interface and their Atmospheric Chemical Transformations	09/01/2022	08/31/2025

EXHIBIT A7

THIRD PARTY CONFIDENTIAL INFORMATION REQUIREMENT

CONFIDENTIAL NONDISCLOSURE AGREEMENT

Exhibit A7 is not applicable for this Agreement