

PROJECT TITLE

Improving volatile organic compound emission estimates for the Uintah Basin

APPLICANT INFORMATION

Bingham Research Center - Utah State University

Principal Investigator: Trang Tran

435-722-1770

[trang.tran@usu.edu](mailto:trang.tran@usu.edu)

Co-Principal Investigator: Huy Tran

435-722-1773

[huy.tran@usu.edu](mailto:huy.tran@usu.edu)

SPONSORED PROJECTS/RESEARCH OFFICE INFORMATION

Contact name: Rich McKinnon

Address: 1415 Old Main Hill, Logan, Utah 84322

Phone: 435-797-1661

Email address: rich.mckinnon@usu.edu

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PROJECT PERIOD

July 1, 2019, to March 31, 2021

## SCOPE OF WORK

### Abstract

Recent studies of winter ozone pollution in the Uintah Basin have indicated that underestimation of organic compound emissions and inadequate organic compound speciation profiles in existing oil and gas emission inventories are the main reasons leading to underestimation of ozone concentrations simulated by photochemical models. Improving the emission inventory both in the total emission amount of organic compounds and speciation profiles, therefore, are crucial tasks for the policymaking process to improve Uintah Basin air quality. We will carry out (1) distributed sampling and analysis of organic compounds, (2) receptor modeling, and (3) photochemical model simulations to (i) resolve the deficient organic compound emission estimates in existing emission inventories and (ii) develop basin-wide spatial and source-type emission factors of organic compounds for 3D-photochemical simulations. This study will result in an improved oil and gas emission inventory for photochemical simulations of winter ozone pollution events in the Uintah Basin.

### Basis and Rationale

The two comprehensive emission inventories (EI) developed for oil and gas exploration activities in the Uintah Basin, including the 2006 Western Regional Air Partnership (WRAP) Phase III and 2014 Air Agencies Oil and Gas EI, contain large uncertainties for organic compounds in both the total amount of emissions and the speciation profiles.

Being the first oil and gas EI available for the Uintah Basin until 2014 Air Agencies EI was released in 2016, WRAP-III has been the most widely used EI in many photochemical modeling studies for the region. Photochemical models that utilized the WRAP-III EI failed to reproduce winter ozone pollution events in the basin. Ahmadov et al. (2015), Emery et al. (2015) and Matichuk et al. (2017) suggested that underestimation of organic compound emissions in WRAP-III-based EIs were likely to be the main reason of underestimation of elevated ozone concentrations during pollution episodes. Recently, the Utah Department of Air Quality (UDAQ) developed the survey-based 2014 Air Agencies Oil and Gas EI to account for changes to the oil and gas industry over the last decade. The survey database used for this inventory, however, did not cover all oil and gas equipment/facility types. Assumptions were made to supplement the missing facility types with data collected by other inventories, such as the WRAP-III EI (projected), UDAQ mass balance calculations for evaporative pond emissions, and the EPA oil and gas tool for mud degassing. Emissions of organic compounds estimated upon those assumptions make up about one half of 2014 Air Agencies EI total organic compound emissions from oil and gas facilities over the entire Uintah Basin (UDAQ, 2018). Thus, it is likely that this improved inventory still contains some uncertainties regarding emissions of organic compounds. The final 2014 Air Agencies EI reported total organic compounds emitted from oil and gas activities in the Uintah Basin were about 90,383 tons/year, which is lower than the amount reported if the WRAP-III EI were projected from 2011 to 2014 using production data (e.g., 133,380 tons/year) (Oswald, 2017, UDAQ, 2018). The most recent photochemical simulations of winter ozone concentrations for the Uintah Basin (Lyman et al. (2018)), which applied the 2014 Air Agencies EI, still highly underestimated ozone concentrations during pollution events. Therefore, it is important to examine the accuracy of the 2014 Air Agencies EI regarding organic compound emissions for future use in photochemical models that will support the policymaking process.

Besides the aforementioned uncertainties in total emissions of organic compounds, organic compound speciation profiles are also important missing pieces in current emission inventories. Emery et al. (2015) and Lyman (2015) indicated that simulated ozone concentrations in the Uintah Basin were highly sensitive to carbonyls speciated in organic compound profiles. Yet, such information is inadequate in current organic compound speciation profiles (Lyman, 2015). WRAP III has so far provided the most representative organic compound speciation profiles for Uintah Basin oil and gas activities. Profiles in WRAP III were derived from averaging gas profiles obtained from GC/MS analysis of a few produced and flash gas samples collected at several wells and tanks (Hsu et al., 2016). Thus, they are not fully representative of actual emissions from more than 11,000 oil and gas wells in the Uintah Basin.

Moreover, these profiles did not include measurements of carbonyls, which are more photochemically reactive than hydrocarbons. The on-going Uintah Basin Composition Study conducted by UDAQ will provide measurement-based flash gas and raw gas speciation profiles that carry geologic formation resolution for a majority of the area of the Uintah Basin. However, these are still not direct measurements of emissions from actual emissions or leaks. Attributing these two types of organic compound speciation profiles (e.g., flash gas and raw gas profiles) to the more than 20 different emission source categories listed in the current EI is still quite a rough assumption and is therefore likely to carry with it uncertainties that need to be addressed. Lyman's (2015) direct emission measurements at few oil and gas facilities in Uintah Basin indicated that organic compound emission speciation profiles differ among different equipment types (e.g., oil tanks vs. condensate tanks, glycol dehydrators vs. pump jack engines, etc.). While USU will be collecting additional direct measurements of emissions in coming months, direct measurements for the more than 11,000 well facilities in the Uintah Basin is not feasible. Thus, it is important to find an alternative approach to developing an organic compound speciation profile database that carries geologic formation and equipment type dependences. Such database is extremely crucial for photochemical models to correctly simulate ozone concentration distribution within the Uintah Basin during pollution events.

Here we propose to conduct a synthesis analysis study combining measurements, receptor model analysis and photochemical simulations to resolve the deficient organic compound emission estimates in existing emission inventories and to develop spatial and source-type emission factors of organic compounds for 3D-photochemical simulations.

## Technical Approach

This study will include three main tasks: (1) distributed sampling and analysis of organic compounds, (2) receptor modeling, and (3) photochemical model simulations. Details about each task are given below. This study is a continuation of a pilot study we are currently carrying out with funding from the Utah Legislature and the Uintah Impact Mitigation Special Service District. The proposed work will leverage the following resources owned by Bingham Research Center resulting from their previous and on-going studies supported by other funding sources:

- i) The equipment built and tested and the analysis performed during the pilot study,
- ii) Simulation hours using computational resources provided by previous and on-going modeling-related projects and
- iii) Modifications made to meteorological model calculations for better simulation of inversion conditions contributing to winter ozone pollution events in the Uintah Basin (Lyman et al., 2018). Such modifications include data assimilation (e.g., nudging) with vertical

meteorological profiles collected by USU for winter 2018-2019 and subsequent winters using drone technology.

## Task 1: Sampling and Analysis of Organic Compounds

### Task 1.1: Portable Sampling Stations

This winter (winter 2018-19) we (i.e., Bingham Research Center (BRC)) have built and are deploying 14 portable organic compound sampling stations (six deployments planned). The sampling stations are solar-powered tripods with a small, heated housing for air sample collection, measurement, and control (via a raspberry pi microcomputer).

We collect formaldehyde and other carbonyl compounds with this system via a small pump and flow control device to pull air through a filtered inlet and then through a cartridge filled with 2,4-dinitrophenylhydrazine (DNPH)-coated silica beads. The first portion of each cartridge is packed with 1,2-bis(2-pyridyl) ethylene (BPE)-coated silica beads, which scrubs ozone and reduces sampling artifacts. Carbonyl compounds are retained in the cartridge, while other gas-phase compounds pass through. We collect light alcohols and C2-C10 hydrocarbons in evacuated silonite-coated stainless steel canisters. Some of the stations also include meteorological measurement systems. We deploy the stations for six-hour sample collection periods, which is the longest deployment period possible before significant breakthrough occurs on the DNPH cartridges. Sampling times can be programmed in advance or triggered remotely via cellular communication.

These 14 stations will be available for the proposed winter 2019-20 work, and we propose to build six additional stations.

### Task 1.2: Portable Sampling Station Deployment Configuration

This winter (2018-19), we are conducting deployments in different configurations and different areas of the Uinta Basin to determine sampling methods that will be most successful and to provide a first round of measurements for analysis and comparison against photochemical model output. Configurations we will test include:

- Stations in a cluster around particular sources or groups of sources, including oil wells, gas wells, gas wells with glycol dehydrators, compressor stations, gas processing plants, etc. We will compare measured emission plume speciation against available speciation profiles, including those developed for the ongoing Uinta Basin Composition Study, which is sponsored by Utah DAQ. This will also help us determine constraining factors for receptor model runs.
- An east-to-west transect from the area south of Myton where oil production is dominant, through the Pariette/Ouray area, and extending through central Uintah County where natural gas production is dominant. This will improve our understanding of the organic compound composition of the oil- versus gas-producing areas and how emissions from each area interact and impact photochemical ozone production in the low-elevation center of the basin (Pariette/Ouray area).
- A grid configuration for comparison against gridded photochemical model outputs (possibly)

Funding constraints limit the number of deployments possible during winter 2018-19, but these deployments will provide preliminary data on which we can build for the proposed winter 2019-20

measurements. We propose 20 deployments of 17 sampling stations for winter 2019-20. Deployment configurations for winter 2019-20 will depend on the results of the winter 2018-19 deployments.

### Task 1.3: Permanent Measurement Stations

Measurements at permanent sampling stations will provide a more complete time series of organic compound concentrations than will be possible with the portable stations, and a longer time series is necessary for developing emission signatures via Positive Matrix Factorization (PMF), as described below. Our research team operates several air quality monitoring stations around the Uinta Basin each winter. Among these, our Horsepool, Castle Peak, and Roosevelt stations are relevant to the proposed work. Horsepool sits at the north edge of an area of dense gas production in Uintah County, Castle Peak sits in an area of dense oil production in Duchesne County, and Roosevelt is within Roosevelt City. Meteorological parameters, ozone, and UV converter-based NO<sub>x</sub> are measured at all three stations (Utah DAQ measures meteorology, ozone, and molybdenum converter-based NO<sub>x</sub> at Roosevelt). PM<sub>2.5</sub>, NO<sub>y</sub>, methane, and total non-methane hydrocarbons are also measured at Roosevelt and Horsepool, and daily air samples are collected in evacuated canisters (which are analyzed in our laboratory for hydrocarbons and light alcohols) at these sites as well.

We collect canister samples at these sites via a custom eight-canister system that automatically pre-flushes the sample lines, switches among cans, and regulates sample flow. We have used these systems for the past three winters, and we have shown that they do not result in contamination or loss of target compounds. Organic compounds have not been measured at Castle Peak in the past, but with oil production in the basin increasing, particularly in the Castle Peak area, we feel that organic compound measurements at Castle Peak will be valuable in helping us understand emissions magnitude and speciation in that area. Thus, we propose to build and install a canister sampling system at Castle Peak.

We currently do not routinely measure concentrations of carbonyls at any of our monitoring sites. We propose to build DNPH cartridge sampling systems at the Horsepool and Castle Peak stations and to collect daily cartridge samples at both sites. The systems will include valves and a relay board to select one cartridge at a time (among eight cartridges), a pump to pull air through the cartridges, a mass flow controller to control and record sample flow, and a microcomputer to provide control and data logging.

Because sampling and analyzing canister and DNPH cartridge samples is expensive, collections at permanent monitoring stations for this work will be limited to a 4-6 week intensive campaign.

### Task 1.4: Low-cost Sensors for Methane and Total Organic Compounds

Also, to supplement the traditional monitoring taking place at the portable and permanent stations, we propose to equip each station with low-cost sensors for measuring methane and total organic compound (TOC) concentrations. Low-cost sensor measurements will be conducted by BRC staff and Eastern Research Group (ERG) personnel as a sub-contractor of BRC under this proposed project.

Comparisons between the collocated station and sensor data will be useful in informing UDAQ of the viability and feasibility of deploying low-cost technologies under the unique environmental conditions in the Uinta Basin. Further, measurements from the low-cost sensors will also allow us to understand changes in concentrations of organics over a finer temporal scale than is possible with the canister and DNPH cartridge-based measurements, both during each six-hour sampling period and in between sampling periods. Also, these measurements will also allow us to measure the methane/organic

compound ratio throughout the Basin. We will use with this ratio in receptor model analysis (see below), and we will apply this ratio to the top-down EI developed by Foster et al. (2018) to develop a top-down speciated organic compound emission inventory. We will compare this top-down inventory against existing inventories in our photochemical model.

Prior to the study, we will perform a comprehensive literature search, interview manufacturers, and review information from South Coast's Air Quality Sensor Performance Evaluation Center (AQ-SPEC) and EPA guidance documents to identify and rank methane and TOC sensors for consideration. After we have identified the top sensors, we will test the sensor operation using ERG's custom-built exposure chamber at their Morrisville, NC laboratory facility. The exposure chamber allows us to verify the performance of the methane and TOC sensors under different temperature and relative humidity conditions. After we have verified the performance of the top methane and TOC sensors, we will purchase and deploy the sensors to the field measurement stations for additional testing.

At the beginning of winter (October 2019), we will correlate all the sampling stations with the low-cost sensors at our Horsepool monitoring station, where we measure methane and speciated non-methane organics via conventional methods. After we have established confidence in the sensor data, we will, if needed, develop algorithms to correct the output from low-cost sensors against Horsepool station measurements. Throughout the winter, we will leave one low-cost sensor set (methane and TOC) at the Horsepool station to determine the performance of the sensors over time. At the end of the winter (March or April 2020), we will correlate all the stations to the Horsepool site again to assess sensor drift over the course of the study.

#### Task 1.5: Laboratory Analysis

After sample collection, we will analyze the DNPH cartridges and canisters in our laboratory for a suite of 13 carbonyl compounds, three alcohols, and 56 hydrocarbons.

We will use an Entech 7200 preconcentrator and 7016D autosampler to concentrate canister samples and introduce them to a gas chromatograph (GC) system for analysis. The GC system consists of two Shimadzu GC-2010 GCs with a flame ionization detector (FID) and a Shimadzu QP2010 Mass Spectrometer (MS). This method is a modification of EPA guidance for hydrocarbon analysis at Photochemical Assessment Monitoring Stations (EPA, 1998).

We will analyze DNPH sorbent cartridges following Uchiyama et al. (2009), which is similar to EPA Method TO-11A (EPA, 1999). To prepare samples for analysis, we will flush cartridges with a 5 mL solution of 75% acetonitrile and 25% dimethyl sulfoxide to release DNPH-carbonyls into solution. We will then analyze the solution via HighPerformance Liquid Chromatography (HPLC) with a diode array detector.

For both detection methods, we will calibrate the instrument on each analysis day with a five-point calibration curve and run an additional standard at the beginning and end of each analysis batch to check for signal drift or other errors. Each analytical batch will include a duplicate sample. We will analyze laboratory blanks during each laboratory analysis period and regularly collect and analyze field blanks. Field blanks will be taken to the field and installed just like normal samples, but sample air will not pass into them. For canister field blanks, we will pressurize the samples with ultrapure nitrogen prior to sampling.

## Task 2: Receptor Model Analysis

Knowledge of organic compound compositions of emissions is commonly used for studying the origins and characteristics of collected total organic compound samples (Gilman et al., 2013; Swarthout et al., 2013; Abeleira et al., 2017; Zheng et al., 2018). For example, based on wind direction and back trajectory HYSPLIT (<https://www.ready.noaa.gov/HYSPLIT.php>) model analyses for organic compounds collected from sets of evacuated canisters deployed at the Boulder Atmospheric Observatory (BAO) 300 m tower, Swarthout et al. (2013) reported that C2-C5 alkanes mostly came from the Wattenberg Field natural gas production region. In a similar study but using a gas chromatograph-mass spectrometer (GC-MS) technique for organic compound measurements, Gilman et al. (2013) attributed the majority of measured C2-C6 alkanes and approximately half of the calculated organic compound reactivity in the same area to oil and gas production.

Receptor models, such as the Positive Matrix Factorization (PMF) model (EPA, 2014), can add to and build upon trajectory and composition analyses and have been widely used as a source apportionment technique for aerosol (e.g., Song et al., 2006; Lanz et al., 2007; Ulbrich et al., 2009) and organic compounds (e.g., Guha et al., 2015; Abeleira et al., 2017; Zheng et al., 2018). These models use factor analysis and emissions composition information to identify sources that contributed to measured concentrations of atmospheric constituents. For example, Abeleira et al. (2017) reported that in spring and summer, organic compounds originating from oil and gas operations accounted for 40-60% of the calculated organic compound reactivity with hydroxyl radical in the morning, whereas organic compound reactivity from biogenic sources are dominant in the afternoon and evening in the Colorado Northern Front Range Metropolitan Area. PMF analyses also suggested that oil and gas production in northwest China contributes approximately 63% to annual average organic compound concentrations (Zheng et al., 2018).

In this study, we will perform the following analyses:

- We will carry out a wind analysis (wind speeds and directions) based on wind measurements from mobile meteorological stations that are collocated with the canisters, and in combination with wind measurements from other stationary meteorological stations where applicable. Based on this wind analysis, we will identify potential contributing sources within the immediate vicinity of canisters.
- We will conduct a HYSPLIT back trajectory analysis with meteorological quantities fed by our proposed meteorological simulations in Task 3. Based on HYSPLIT results, we will identify potential contributing sources in the far field of canister locations.
- The results from wind analysis and the HYSPLIT model will help identify potential contributing sources, both in the near field and far field, to measured organic compound concentrations. This information helps to develop an appropriate number of factors to be used as input for the PMF analysis.
- We will perform PMF model analysis with organic compound data collected from the canisters and DNPH cartridges. We will analyze the PFM outputs for a set of organic compounds and compare the organic compound compositions from PMF with those of known sources (based on previous emission composition measurements and samples collected in this study) to identify source activities (e.g., tanks, flash gas, fuel combustion, diesel truck) that contributed to measured concentrations.
- We will do a synthesis analysis combining the wind speed and direction, HYSPLIT and PMF results for definite identifications of source contributions to the canister samples. These

identifications include the type of sources (e.g., pump jack, well head etc) and location of sources. This information will help us to develop spatial and source-type emission factors of organic compounds for running the 3D-photochemical simulation presented in Task 3.

From this analyses, we will answer the following questions:

- Can organic compound compositions of known oil and gas sources reasonably explain the organic compound compositions in measurement data?
- Can any unidentified portion of organic compound compositions be explained with organic compound compositions from known sources outside the Uintah Basin?
- Do the majority of organic compounds come from oil and gas productions? Are there accountable contributions from non-oil and gas sources, including biomass burning, mobile sources, or biogenic sources?
- How does secondary (photochemical) transformation impact measured organic compound compositions?
- What differences in organic compound compositions exist between areas where gas vs. oil production is dominant?
- Do the organic compound speciation profiles for flashed and raw gas developed from the UDAQ composition study explain ambient organic compound compositions near well pads? This will help us to verify the accuracy of organic compound profiles developed from the UDAQ composition study.

### Task 3: Performing 3D Photochemical Simulations with Resultant Updates on Organic Compound Emissions

We will apply the most up-to-date Air Agencies emission inventory developed by UDAQ available by the time this study starts and the organic compound speciation profiles developed in the UDAQ composition study to run 3D-photochemical simulations. We will compare simulated organic compound concentrations against our measurements proposed in Task 1 to examine the accuracy of the oil and gas Air Agencies EI with respect to organic compounds. Another test run using the top-down emission inventory developed based on low-cost sensor measurements discussed in Task 1.4 will be performed to compare with the reference run using the Air Agencies EI. We will also utilize the process analysis tool available in photochemical model platform to track the influence of chemistry and advection processes happening within photochemical calculations. This will help to identify possible reasons for failures of the photochemical model in simulating elevated ozone concentrations in the Uintah Basin.

We will conduct sensitivity tests on organic compound emission speciation profiles. The reference run (REF) will be performed with the Air Agencies emission inventory and the organic compound speciation profiles developed in the UDAQ composition study; while the test runs (TEST; number of tests to be determined based on the results of Task 1 and 2) will be performed using the same EI but speciation profiles databased developed in Task 1 and 2. We will compare the results of those runs against measurements to examine how newly developed organic compound emission speciation profiles impact simulated ozone and organic compound concentrations.

Emission data will be processed by the Sparse Matrix Operator Kernel Emissions (SMOKE) model. Meteorological quantities will be produced with the Weather Research and Forecasting (WRF) model with all relevant modifications made to improve model performance in simulating inversion conditions in the Uintah Basin. These modifications include surface snow/albedo fix (Neeman et al., 2015) and nudging with surface and vertical meteorological profiles (Tran et al., 2018; Lyman et al., 2018), which

were proved to improve WRF performance in simulating various aspects of the inversion layer that affect ozone concentration distributions in the Uintah Basin. A BRC drone project will provide vertical profiles for conducting nudging in WRF simulations. WRF model domain setups will be kept identically with setups used by Tran et al. (2018): a one-way triple-nested domain at grid-spacing resolutions of 12, 4, and 1.3 km with 41 vertical layers extending from the surface to 14 km above ground. Only meteorological fields from the 1.3km domain will be used for photochemical simulations. The Comprehensive Air Quality Model with Extensions (CAMx) will be used as the photochemical model for this study. We will apply specific updates made to CAMx to better represent Uintah Basin winter conditions following Emery et al. (2015). The latest versions of all model platforms that are available by the time this study starts will be chosen to perform photochemical simulations.

WRF-CAMx simulations will be performed for two to three months of winter 2019-2020 to cover the periods when Task 1 measurements are conducted.

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## Expected Outputs and Outcomes

This study will test the accuracy of existing emission inventories (magnitude and speciation) and improve basin-wide spatial and source-type emission speciation profiles of organic compounds. It will also provide valuable measurement data for improving emission inventory and photochemical model development.

## Deliverables

This project will result in the deliverables shown in Table 1.

Table 1. Project deliverables and due dates.

DELIVERABLE	DUE DATE
Final speciated organic compound concentration dataset	May 2020
Low-cost sensor dataset	May 2020
Top-down emission inventory	July 2020
Spatial and source-type organic compound speciation profile dataset	60 days after organic compound composition data are available, data will be stored on this project archive storage space on University of Utah CHPC for UDAQ's use and available for public use (per request submitted on BRC webpage)
SMOKE-processed emission input/output files	30 days after Spatial and source-type organic compound speciation profile dataset is built, data will be stored on this project archive storage space on University of Utah CHPC for UDAQ's use and available for public use (per request submitted on BRC webpage)
WRF-CAMx configuration, input and output files	90 days after SMOKE-processed emission files are ready, data will be stored on this project archive storage space on University of Utah CHPC for UDAQ's use and available for public use (per request submitted on BRC webpage)
Quarterly reports	90, 180, 270, 360, 450 and 540 days after the project begins
Draft final report	60 days after WRF-CAMx simulations finished
Final Report	60 days after release of draft report

## Schedule

Table 2 shows planned milestones for the project. The project will last 21 months after field sample collection begins.

Table 1. Project schedule for milestones and date.

DATE	MILESTONE
7/1/2019 to 10/31/2019	Sampling station and low-cost sensor construction and testing
11/1/2019 to 3/31/2020	Deployments and laboratory analysis
4/1/2020 to 6/30/2020	Data analysis, emission inventory development, receptor modeling and photochemical modeling preparation
7/1/2020 to 3/31/2021	Receptor modeling and photochemical modeling: doing simulations, data analysis, writing reports
March 2021	Present results at the Science for Solutions Conference
3/31/2021	Completion of the project
4/1/2021 to 5/31/2021	Prepare draft final report.
7/31/2021	Final report due date.

## Budget

Budget costs will include:

- Personnel costs (\$48,717):
  - Two months for Trang Tran at \$10,862
  - Two months for Huy Tran at \$11,097
  - Two months for Trevor O'Neil at \$8,228
  - (Non-exempt salaried and/or hourly employees may occasionally accrue overtime during the field data collection portions of this project)
  - Two person-months of wages for a student employee at \$4,455
  - Fringe benefits calculated as 46.5% of salaries and 0.8% of student wages, for a total of \$14,075
- Travel costs (\$5,032):
  - Mileage costs for miles traveled to and from measurement sites, calculated at \$0.673 per mile. We anticipate traveling 6,800 miles (20 miles per station per sample deployment+collection × 20 deployments of 17 stations) for a total mileage cost of \$4,576
  - Travel for one person to the 2020 Science for Solutions air quality research conference, at a total cost of \$455, which includes:
    - \$10 for registration
    - \$150 for lodging
    - \$250 for travel/mileage

- \$45 for per diem
- Materials costs (\$45,374):
  - Materials costs for construction and maintenance of sampling equipment, including:
    - \$9,758 to construct sampling systems at the Horsepool and Castle Peak permanent monitoring stations
    - \$1,800 to construct three additional portable sampling stations
    - \$1,500 for maintenance and repair of sampling systems
  - Purchase of four terabytes of archive storage space at the Utah Center for High Performance Computing to retain model data, at \$120 per terabyte, for a total of \$480.
  - Materials costs for analysis of 468 DNPH cartridge samples at \$42 per sample, for a total of \$19,656.
  - Materials costs for analysis of 420 canister samples at \$29 per sample, for a total of \$12,180.
- Sub-award costs (\$28,151):
  - The sub-award will be to ERG, Inc. Subaward costs include:
    - 160 hours of labor at \$105.14 per hour, for a total of \$16,823. The hourly rate includes fringe benefits.
    - Materials costs for 29 sensors (305 each) + specialty gases, for a total of \$9,845
    - Travels for \$453
    - Markup for ODCs: 10% of ODC for \$1,030
- Indirect costs (\$12,726):
  - Facilities and administration costs are calculated as 10% of direct costs.

Table 3 provides a summary of the requested budget, and Table 4 breaks down the budget by specific tasks.

Table 3. Budget summary.

CATEGORY	COST
Salaries	\$30,187
Wages	\$4,455
Fringe benefits	\$14,075
Travel	\$5,032
Materials	\$45,374
Subaward to ERG, Inc.	\$28,151
Facilities and Administration Costs	\$12,726
TOTAL	\$140,000

Table 4. Budget broken down by project task.

TASK	COST
Sample collection and analysis, including construction and	\$103,190
Receptor modeling	\$17,827
Three-dimensional photochemical simulations	\$18,983
TOTAL	\$140,000

This project will cost more than the budget shown above. In addition to the requested \$150,000 budget, we will commit additional USU funding, without which the project could not be completed. This additional funding will include 148 hours of labor costs each for Trang Tran and Huy Tran, 230 hours of labor for Seth Lyman, 260 hours of labor for Trevor O'Neil, and 112 hours of labor for a student. The total direct cost of this additional labor is \$46,342.

USU will also commit existing materials and equipment to this project, including the following:

- The Horsepool and Castle Peak monitoring stations and analytical equipment at these sites (\$300,000)
- 14 existing portable sampling stations (\$8,400)
- Laboratory instrumentation to process and analyze canister samples, including a gas chromatography system, a sample preconcentrator, and equipment for cleaning canisters and preparing them for analysis (\$200,000)
- A liquid chromatography system for analyzing DNPH cartridge samples (\$50,000)
- Four computational nodes (96 cores) and 55TB Group Level Storages on University of Utah CHPC

## Personnel Roles and Responsibilities

### 1. Bingham Research Center – Utah State University personnel

Trang Tran, Senior Research Scientist, PI, will conduct project oversight, run WRF-CAMx sensitivity tests, conduct data analysis and writing report. Trang has 10 years of experiences with emission models, doing meteorological and photochemical simulations, and data analysis.

Huy Tran, Senior Research Scientist, co-PI, will run receptor model (e.g., PMF), conduct data analysis, prepare emission input files using SMOKE model and writing report. Huy has 13 years of experiences with receptor and dispersion models, emission models, doing meteorological and photochemical simulations and data analysis.

Seth Lyman, Associate Professor, will oversee and participate in collection and analysis of samples and contribute to data analysis and report writing. Seth has 14 years of experience with atmospheric measurements, including ambient air monitoring, emissions measurement, instrument development and construction, and data analysis.

Trevor O'Neil, Research Technician, will build sampling stations and participate in collection and analysis of samples. Trevor has worked on projects that involve field collection and laboratory analysis of canister and DNPH cartridge samples for four years and is our lead HPLC analyst.

Makenzie Holmes, Student Research Assistant and Anadarko Student Fellow, will build sampling stations and participate in collection and analysis of samples. Makenzie has been part of our team since April 2018. She has taken a lead role in building our existing sampling stations, and she is our GC-FID/MS analyst, under Seth Lyman's direction.

### 2. Eastern Research Group, Inc. personnel

Tracey Footer, Subcontract Manager and Deployment, is based near Salt Lake City, UT. Tracey is an environmental research scientist, with over 11 years of combined experience performing reference method sample analysis, supporting the development of performance-based measurement methods,

and researching and evaluating cutting-edge technology. Tracey's experience includes authoring technical reports and guidance documents, organizing and conducting field sampling, and performing industrial facility inspections using optical gas imaging. She is currently supporting the characterization of oil and natural gas stationary sources as the project manager and technical lead for EPA's Office of Research and Development (ORD) field measurement campaign project using next generation measurement approaches at multiple spatial scales concurrently.

Danny Greene, Technical Lead on Evaluation of Sensors. Danny Greene is a Senior Chemical Engineer in ERG's Morrisville, NC office. He has over 25 years of experience in methods development and regulatory support for EPA. He is an expert in characterizing various industries, including pulp and paper mills and animal feeding operations (AFOs). Danny is currently leading EPA's efforts to research and develop performance standards for low-cost sensors.

Regi Oommen, Data Analysis. Regi Oommen is a Senior Scientist in ERG's Morrisville, NC office. He has over 22 years experience in developing emissions inventories and characterizing ambient air monitoring concentrations for EPA, state, and local air agencies. Regi is the architect of EPA's Oil and Natural Gas Emissions Estimation Tool, developing the 2011, 2014, and 2016 national emissions inventories.

Christopher Kopp, Laboratory Testing Chamber. Christopher Kopp is a project manager and chemist with 12 years of experience in environmental sampling and analysis. He has managed multiple projects in the areas of method development and stationary emissions monitoring and has served as an analyst and technician on many laboratory projects. Christopher has experience with gas chromatography (GC), mass spectrometry (MS), flame ionization detectors (FIDs), high-pressure liquid chromatography, and ion chromatography (IC) instrumental operation; sample analysis; and the corresponding data review. He will conduct the sensor testing using ERG's exposure chamber.