UtahStateUniversity
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A Proposal Submitted to the Utah Division of Air Quality Science for Solutions Research Grant Program

1. Summary Information Page

Project Title: Emissions of Reactive Organics from Natural Gas-Fueled Engines

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Funding Requested:
We request $117,300 from the Utah Division of Air Quality to carry out this project. We will provide $23,125 in matching funds.

Project Period:
The project will begin on 1 July 2020 and end on 31 December 2021.

2. Scope of Work

2.1. Abstract

We propose a project to improve estimates of the magnitude and composition of emissions from natural gas-fueled artificial lift engines in the Uinta Basin. Recent ambient air measurements have implicated natural gas-fueled engines as a large source of reactive organics, including formaldehyde, ethylene, propylene, and other compounds. These compounds are under-represented in the Utah Air Agencies Oil and Gas Emissions Inventory (UEI), and measurement-based updates to the inventory are needed to account for their sources. The current UEI uses emission factors for engines that are out of date and were not collected in our region. These emission factors need to be updated with more detailed, current, local data.

We will fill this gap by measuring emissions of NO_x, organics, and other compounds from about 50 natural gas-fueled engines in the Uinta Basin. These data will allow the Utah Division of Air Quality (Utah DAQ) to understand more accurately and model this source of ozone-forming pollution in the Uinta Basin and develop science-based, effective emissions reduction strategies for wintertime ozone.

2.2. Basis and Rationale

2.2.1. Background and Previous Work

Areas of the Uinta Basin below an elevation of 6,250 feet have been classified by the U.S. Environmental Protection Agency (EPA) as a marginal nonattainment area for ozone. Because of ozone exceedance days that occurred during February and March 2019, the area is certain to become a moderate non-attainment area when EPA re-assesses its attainment status in 2021. The designation as a moderate nonattainment area will trigger a requirement for Utah DAQ (and EPA and the Ute Tribe for areas of the Basin that are Indian Country) to develop an Implementation Plan that brings the Basin into attainment of the EPA ozone standard. As part of this plan, Utah DAQ will be required to develop regulations to reduce emissions and show with three-dimensional photochemical modeling that those regulations will reduce ozone enough to achieve attainment of the standard.

Our team's current meteorological model for winter 2013 successfully reproduces actual temperature-elevation relationships, solar radiation, inversion layer height, and day-on-day buildup of ozone (see Section 8 of Lyman et al. (2019)). When we use this meteorological model with the 2014 Utah Air Agencies Oil and Gas Emissions Inventory (UDAQ, 2018) and non-oil and gas emissions from the EPA National Emissions Inventory in the CAMx chemical transport model, however, simulated ozone concentrations are much too low. In our recent annual report (Lyman et al., 2019), we showed that, while simulated total organic compound concentrations are within the same range as reality (Figure 2-1), the simulated concentrations of many reactive organics are much too low (Figure 2-2).

We measured speciated organics at a number of sites around the Uinta Basin during winter 2019, and our measurements confirmed that concentrations of reactive organics, including (1) formaldehyde and other carbonyls, (2) ethylene, propylene, and other reactive alkenes, and (3) aromatics are important components of total organics in the Basin atmosphere. Figure 2-3 shows data from one of the sample days from this study. Of particular interest are the high concentrations of alkenes, which were observed primarily in the western Basin and were dominated by ethylene and propylene. We concluded in our 2019 annual report (Lyman et al., 2019) that the most likely source of the observed ethylene and propylene was natural gas-fueled artificial lift engines and that these compounds were responsible for the majority of the ozone reactivity of total organics at the western measurement stations.

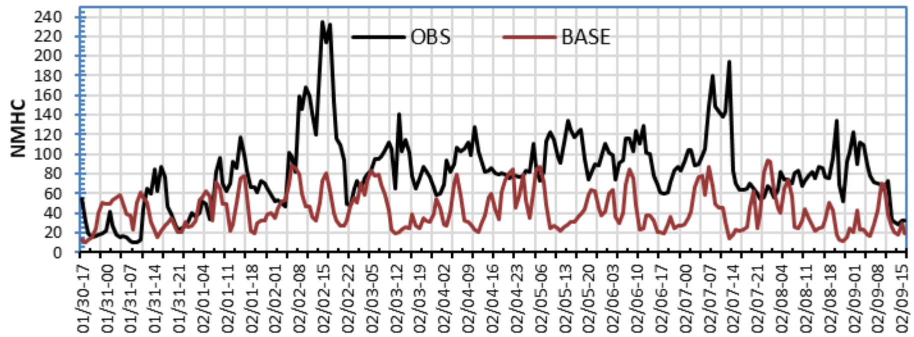

Figure 2-1. Observed (OBS) and modeled (BASE) total non-methane hydrocarbons at the Horsepool monitoring station during January and February 2013. Units are ppb. Taken from Section 10 of Lyman et al. (2019).

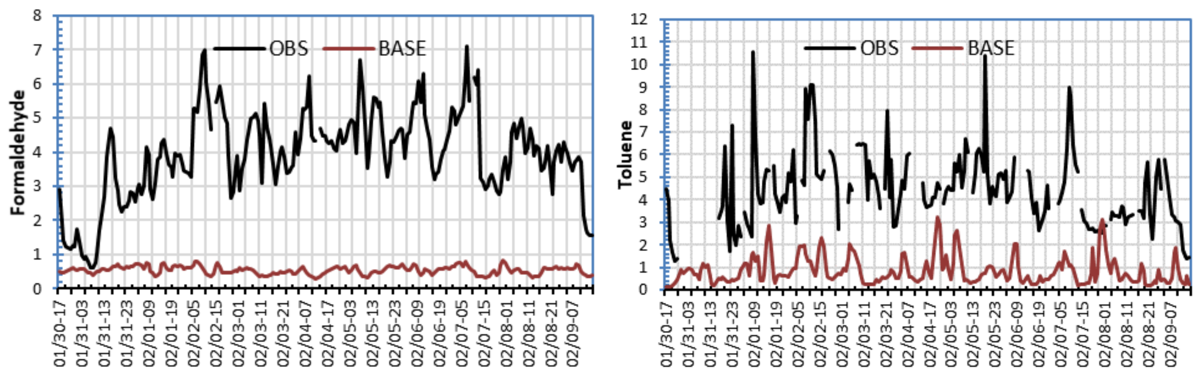

Figure 2-2. Observed (OBS) and modeled (BASE) formaldehyde (left) and toluene (right) at the Horsepool monitoring station during January and February 2013. Units are ppb. Taken from Section 10 of Lyman et al. (2019).

Section 7 of our 2019 annual report describes measurements we collected of fluxes of carbonyls at the air-snow interface (Lyman et al., 2019). We conclude in the report that, while measurable emissions of carbonyls from snow do occur, carbonyl emissions from snow are small relative to inventoried emissions from oil and gas sources. Also, we recently completed a study with Utah DAQ to measure organic compound concentrations from raw gas and liquid storage tanks in the Uinta Basin. Utah DAQ is currently preparing an integrated final report of this work, but a summary appears in our annual report (Lyman et al., 2019). This study, as well as a Utah DAQ-funded emissions measurement project we completed in 2015 (Lyman and Tran, 2015), showed that emissions of alkenes and aldehydes from raw gas and tanks are very low. Our previous work showed the same to be true for produced water ponds (Lyman et al., 2018), subsurface leaks at well pads (Lyman et al., 2017), and methanol use at well pads (Lyman et al., 2014).

Our 2015 emissions measurement study did show high carbonyl emissions from artificial lift engines (Lyman and Tran, 2015), and available composition data show that these engines are sources of alkenes, including ethylene and propylene (see Oliver and Peoples (1985), EPA (2018), and the discussion in Section 5 of Lyman et al. (2019)). Furthermore, carbonyl and alkene concentrations in our 2019 ambient air measurement study were concentrated in the part of the Uinta Basin with a high concentration of oil wells with natural gas-fueled artificial lift engines, and not in an area with electric motors to provide lift or in the area dominated by gas production.

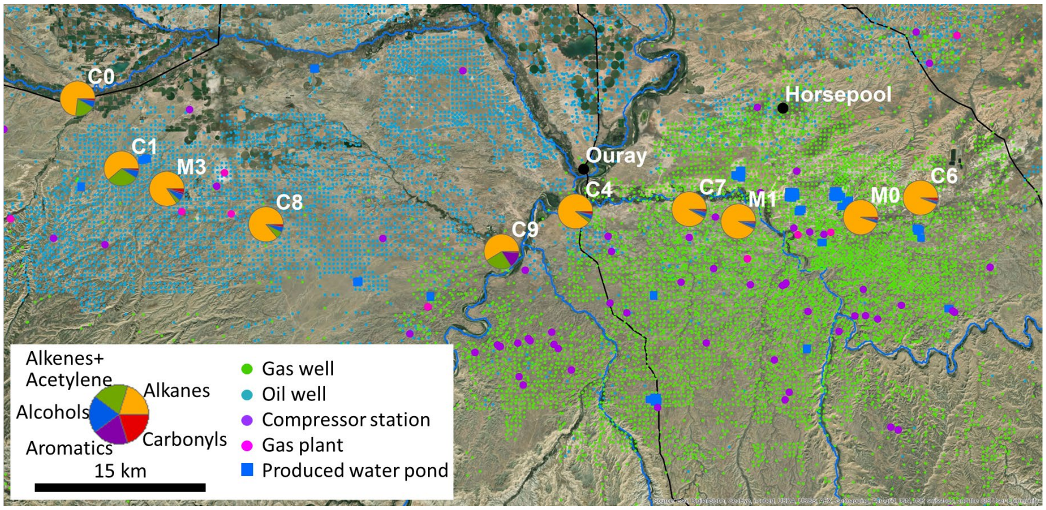

Figure 2-3. Composition (percent by volume) of organic compounds measured at stations in a transect across the Uinta Basin on 27 February 2019. Taken from Section 5 of Lyman et al. (2019).

2.2.2. Rationale

As explained above, the most likely reason for under-prediction of ozone in current photochemical models is that the composition of inventoried emissions is not reactive enough. Utah DAQ's and our recent work to measure the composition of organic compound emissions from raw gas and tank sources will lead to more accurate emissions composition estimates, but these are not significant sources of carbonyls or alkenes. Work is still needed to identify and characterize the sources of carbonyls and alkenes to the Uinta Basin atmosphere. Many lines of evidence point to combustion sources as the probable source, and our ambient air measurements from winter 2019 provide circumstantial evidence that artificial lift engines are particularly important.

Estimates of the magnitude and composition of emissions from artificial lift engines rely on data that are extremely outdated (the EPA Speciate database uses data from a study conducted in 1985 (Oliver and Peoples, 1985)), and that were conducted far from the Uinta Basin. New measurements of emissions from natural gas-fueled artificial lift engines are needed to improve emissions estimates and photochemical model outputs. These measurements need to be carried out (1) in the Uinta Basin (2) during realistic winter conditions (since cold temperatures can reduce combustion temperatures and impact engine performance), and (3) with detailed speciation information. Our plan for carrying out this work appears in Section 2.3.

2.2.3. Alignment with 2021 Science for Solutions Research Grant Goals and Priorities

This project aligns with the following Science for Solutions Research Grant Goals and Priorities, as listed on the grant website:

- Emissions Inventory Improvements
    - Source-specific organic compounds emission rate estimates
    - Source-specific organic compounds speciation profiles
    - NO_x emissions
    - Methane emissions and ozone formation impacts

2.2.4. Regulatory Applications

The collected measurement data will allow Utah DAQ to:

- Create a more accurate emissions inventory for NO_x and organic compounds,
- More accurately model wintertime ozone, and
- Make emissions control decisions that are more likely to be effective and economical.

2.2.5. Measurable Benefits Utah DAQ Can Report to the Legislature

This project will provide information that Utah DAQ can use to improve emissions inventories and make better decisions about how to control ozone-forming emissions. Our final report will contain information about differences between engine emissions data that were previously in the emissions inventory and new, updated emissions data derived from this work. Utah DAQ can report these improvements to the legislature as benefits of the Science for Solutions Research Grant program.

2.2.6. Leveraging of Other Resources

This project builds on a wealth of previous work provided or funded by Utah DAQ and the Utah legislature, including:

- A project to measure organic compound concentrations in the ambient atmosphere at a number of portable monitoring stations positioned around the Uinta Basin. The first phase of this project is described in Section 5 of our annual report (Lyman et al., 2019). The second phase is currently underway, and the majority of the project is funded by Utah DAQ. The first phase of this work allowed us to discover high concentrations of ethylene and propylene that appear to originate from natural gas-fueled artificial lift engines.
- A project funded by Utah DAQ to measure organic compound composition of emissions from raw gas and flash gas sources at oil and gas wells. Utah DAQ is currently preparing a final report from this project. A project summary appears in Section 6 of our annual report (Lyman et al., 2019).
- Many years of work, carried out by USU and many others, to improve simulations of meteorology, chemistry, and ozone-forming emissions in the Uinta Basin. Previous modeling work carried out by USU has been funded by the Uintah Impact Mitigation Special Service District, the Utah legislature, Utah DAQ, the Bureau of Land Management, and Deseret Power.

Existing resources that will be available for this project include:

- Field emissions measurement equipment, including analyzers, measurement hardware, electronics, a trailer, and generators. The purchase and construction of this equipment were funded mostly by the U.S. Department of Energy (GSI, 2018; Lyman et al., 2018), and partly by Utah DAQ (Lyman and Tran, 2015). The replacement value of this equipment is $150,000.
- High-performance liquid chromatograph (HPLC) and accessories for carbonyls analysis, with a replacement value of $80,000.
- 90 6-L silonite-coated canisters for non-methane organics and alcohols, along with laboratory equipment for cleaning, diluting, sampling, preconcentrating, and analyzing whole air samples collected in the canisters. The canisters and equipment have a replacement value of $250,000.

Partnerships and additional funding sources that will be provided for this project include:

- R&R Oilfield Services has agreed to provide their labor, travel, and equipment at no charge. We will pay for compressed gases and any measurement equipment maintenance and repair costs incurred by R&R. R&R usually charges $1,500 per engine maintained and tested. The total value of their contribution to this project is $7,500-$15,000.
- USU will provide $23,125 in matching funds for this project (the Uintah Basin Air Quality Research Project, which is funded by the Utah legislature).

2.3. Technical Approach

2.3.1. Emissions Measurements

We will measure emissions of oxides of nitrogen (NO and NO_2), carbon dioxide, oxygen, carbon monoxide, methane, a suite of 52 non-methane hydrocarbons, three light alcohols, and thirteen carbonyls from about 50 natural gas-fueled artificial lift engines in the Uinta Basin. While our primary concern is emissions of organic compounds, information about emissions of other compounds will provide a complete characterization of this source type and provide Utah DAQ with additional data that will be useful for regulatory efforts. We will collect emissions measurements in two ways:

1. We will measure as-found emissions from about 50 engines throughout the Uinta Basin.
2. We will collaborate with R&R Oilfield Services to measure emissions from between 5 and 10 additional engines. R&R Oilfield Services, based in Vernal, specializes in maintaining and repairing artificial lift engines. For these engines, we will measure as-found emissions, R&R staff will modify engine operating conditions (see 2.3.2.5), and we will measure emissions again. This will allow us to determine how engine operating parameters impact emissions magnitude and composition.

2.3.1.1. Types of Engines to be Measured

Many different types of engines are used to draw oil from underground reservoirs, but two types of engines dominate in the Uinta Basin: 51% are made by Arrow, 44% are made by Ajax, and only 5% are made by other manufacturers (UDAQ, 2018). 61% of all lift engines at oil wells are either the Ajax E-42 or the Arrow L-795, both of which are listed in the inventory as being two-stroke lean-burn engines. 99% of all Ajax engines are two-stroke lean-burn. 60% of Arrow engines are two-stroke lean-burn, and the other 40% are four-stroke rich-burn engines. (Lean-burning engines have an excess of air relative to the amount required for complete fuel combustion, while rich-burning engines operate with a just enough air for complete combustion.)

We will measure emissions from Ajax engines and from two-stroke and four-stroke Arrow engines. We will attempt to measure emissions from engines operated by several different companies. We have spoken with several companies about this project and begun the process of securing access to their well pads for these measurements.

2.3.1.2. Field Measurement Methods

We will measure emissions from the exhaust stack of each engine. We will also use a Bascom Turner Gas Rover (i.e., a handheld natural gas detector) to detect combustible gas emissions from oil vents and other possible non-exhaust sources on each engine. We will measure emissions from all detected emission sources.

For non-exhaust sources, we will measure emissions with our high-flow measurement system (we have used this system on previous Utah DAQ-funded projects). To measure a leaking component with our high flow sampler, we will wrap an antistatic polymer bag around the component to contain the emission plume and connect the bag to a sample duct. A blower will pull gas from the bag, through the ducting, and into a flow measurement tube. We will use a Fox Thermal Instruments Model FT3 mass flow meter to measure the flow rate through the measurement tube. We will correct the flow for temperature, pressure, and gas composition. We will sample from this stream to determine the concentration of the compounds of interest in the sampled gas. We will calculate the emission rate as the concentration of a given organic compound in the sampled gas (in mg m^{-3}; corrected for the concentration of the compound in ambient air) multiplied by the total flow rate (m^3 min^{-1}).

Our method for measurement of emissions from exhaust stacks will be identical to measurements made with the high flow sampling system, except that we will sample gas directly from the exhaust stream, without additional flow provided by the high-flow blower. We will measure the flow rate from the exhaust stack with an Abaco mass air flow meter. We will measure the exhaust gas composition by inserting a 1 cm stainless steel tube into the stack at a depth of 0.5 m. Natural gas engine exhaust stacks in the Uinta Basin have many different designs, including vertical and horizontal orientations, various diameters, and stack ends that may have NPT threads, a flange connection, or other configurations. We will visit each engine prior to our measurements to verify the exhaust stack design and prepare the needed materials to attach the flow meter to the stack.

We will measure emissions of NO, NO_2, carbon monoxide, oxygen, and the exhaust gas temperature with an Ecom J2KN emissions analyzer. For the measurements carried out in cooperation with R&R Oilfield Services, we will use their Ecom J2KN. For other measurements, we will rent an Ecom J2KN from the manufacturer. We will use a Los Gatos Research Greenhouse Gas Analyzer to measure methane, carbon dioxide, and water vapor concentrations in sample gas and background air.

We will collect 6-L silonite-coated stainless steel canister samples and analyze them in the laboratory for non-methane hydrocarbons and alcohols, and we will collect BPE-DNPH cartridge samples and analyze them in the laboratory for carbonyls.

We will measure the flow rate of each engine for at least five minutes, and we will collect chemical measurements from engines (and high flow measurements) over 15-minute intervals.

2.3.1.3. Canister Analysis

After sampling, we will analyze canisters for a suite of 52 hydrocarbons and three alcohols. We will use an Entech 7200 preconcentrator and 7016D autosampler to concentrate samples and introduce them to a gas chromatograph (GC) system for analysis. We will use the cold trap dehydration method with an Entech 7200 to preconcentrate sample air and introduce it to the GC system. The GC system will consist of two Shimadzu GC-2010 GCs with a flame ionization detector (FID) and a Shimadzu QP2010 Mass Spectrometer (MS), respectively. The FID will detect C2 and C3 compounds, and the MS will detect all other compounds.

2.3.1.4. BPE-DNPH Cartridge Analysis

We will analyze BPE-DNPH cartridges following Uchiyama et al. (2009) for a suite of 13 carbonyls. We will keep used and unused cartridges refrigerated or on ice, except when installed for sampling. We will analyze cartridges within 14 days of sampling. Prior to analysis, we will flush cartridges with a solution of 75% acetonitrile and 25% dimethyl sulfoxide to release DNPH-carbonyls into solution. We will analyze an aliquot of the solution with a Hewlett Packard series 1050 High-Performance Liquid Chromatograph (HPLC) with a Restek Ultra AQ C18 column and a diode array detector.

2.3.1.5. Engine Modification Tests

For the engine modification tests conducted with R&R Oilfield Services, after measuring as-found emissions, R&R staff will optimize engine speed, fuel intake, oil use, combustion temperature, and possibly other parameters, and we will then measure exhaust emissions again to determine whether these changes reduce emissions of NO_x and/or organic compounds. R&R staff will help us determine and record engine characteristics before and after these modifications.

2.3.1.6. Meteorological Measurements

At each location where we measure engine emissions, we will measure ambient temperature, and relative humidity (New Mountain NM150WX), wind speed and direction (Gill WindSonic), and barometric pressure (Campbell CS100) on a tower extended from the measurement trailer to a height of 6 m. We will check the meteorological measurements against a NIST-traceable standard annually.

2.3.1.7. Quality Assurance

Quality assurance activities for field measurements will include:

1. We will send the Fox FT3 flow meter for factory calibration at the beginning of the project, and we will verify its calibration at the beginning and end of winter 2020-21 with a Pacer anemometer.
2. We will calibrate all other flow meters and flow controllers against a BIOS Drycal flow meter, which is calibrated annually with a NIST-traceable standard.
3. We will calibrate the Ecom J2KN daily at two points along its measurement range with a compressed gas cylinder containing NO, carbon monoxide, carbon dioxide, and methane, and we will calibrate it for oxygen using ambient air. At the beginning and end of the measurement campaign, we will use a gas-phase titration method to calibrate for NO_2 and calibrate the instrument at 5 points.
4. We will perform a leak check of the measurement system's flow path on each measurement day.
5. We will calibrate the LGR analyzer for methane and carbon dioxide at at least two points along its measurement range, including one zero point, on each field measurement day. We will calibrate the instrument for water vapor with a dewpoint generator monthly. We will calibrate this instrument at 5 points at the beginning and end of the measurement campaign.
6. We will inject high-purity methane into the high flow measurement system at a known flow rate on each measurement day, and we will determine the percent recovery of the injected methane.
7. We will flood the tubing that leads to canisters and DNPH cartridges with air scrubbed of organic compounds and collect at least three of each type of sample. These samples will constitute field blanks for the system.
8. We will prepare a compressed gas cylinder that contains a known concentration of each of the hydrocarbons and alcohols measured in the canister samples. We will fill three canisters in the laboratory with gas from this cylinder, and we will also connect the cylinder to the upstream end of the sample collection system and fill three canisters with the system. We will compare results from the laboratory and field systems to determine whether the field system results in loss of measured compounds. We will perform these field spikes in actual wintertime field conditions.
9. We will use the gas cylinder described in (7) to add gas containing known concentrations of hydrocarbons and alcohols to the inlet of the high flow measurement system and the engine sampling system. We will collect one canister sample before the gas addition and one sample during the gas addition and determine the percent recovery of the added gas. We will perform this matrix spike test at least twice.
10. We will add the output from formaldehyde and propionaldehyde permeation tubes in a Dynacal permeation oven to the upstream end of the sample collection system and collect five DNPH cartridges with the system. We will determine the percent recovery of the permeated

compounds by the DNPH cartridges. We will calibrate the permeation tube output gravimetrically. We will perform these field spikes in actual wintertime field conditions.

11. We will use the permeation tube system described in (9) to add gas containing known concentrations of carbonyls to the inlet of the high flow measurement system and the engine sampling system. We will collect one DNPH cartridge sample before the gas addition and one sample during the gas addition and determine the percent recovery of the added gas. We will perform this matrix spike test at least twice.
12. For three sample canisters collected in normal field conditions, we will analyze the canisters in our laboratory and then send them to AAC, Inc., a commercial analytical laboratory, to verify that our results for the samples are similar to those of the outside lab.
13. We will attempt to analyze for acetone in the canister samples. We already measure acetone in the DNPH cartridges, and the purpose of this work will be to determine the similarity between acetone measured by the two methods.

2.3.1.8. Recording Operating Conditions

For each artificial lift engine we encounter, we will record the following operating conditions:

- Engine make and model
- Stack diameter
- Stack orientation (horizontal or vertical)
- Stack height (or length, if horizontal)
- Stack temperature
- Stack flow rate
- Fuel valve position (and fuel intake rate, if known)
- Oil intake
- Modifications or upgrades relative to the standard engine design (e.g., pre-combustion chamber (Chapman and Nuss-Warren, 2006; Hohn and Nuss-Warren, 2011), gas injection system, etc.)

2.3.2. Analysis and Reporting

We will synthesize results from the project into overall conclusions and outcomes. We will also prepare reports and a final dataset, prepare for and attend the 2021 Air Quality: Science for Solutions conference and the 2021 American Geophysical Union Fall Meeting, and prepare a peer-reviewed publication.

Our analysis will include:

- Quality assurance results
- Summary data, including separation by engine type, engine characteristics, and meteorological conditions
- Statistical relationships between emissions and engine characteristics.
- A comparison of measured emissions versus the magnitude and composition of emissions predicted by AP-42 emission factors and contained in the 2017 UEI (including UEI data for the specific engines measured and for the average of all similar engines).

2.4. Expected Outputs and Outcomes

The overall outcome of this project will be improved emissions information for natural gas-fueled artificial lift engines in the Uinta Basin. This information will be in the form of a measurement dataset and a final project report.

2.5. Deliverables

Deliverables for this project will include:

- Quarterly progress reports
- A final technical report
- A final emissions measurement dataset
- Presentations at the 2022 Air Quality: Science for Solutions conference and the 2021 American Geophysical Union Fall Meeting
- A peer-reviewed publication

2.6. Schedule

This project will begin in July 2020 and end in December 2021 (18 months). We will carry out this project according to the schedule shown in Table 2-1.

Table 2-1. Gantt chart showing the project schedule.

	Jul-Sep 2020	Oct-Dec 2020	Jan-Mar 2021	Apr-Jun 2021	Jul-Sep 2021	Oct-Dec 2021
Measurement system prep.						
Initial test measurements						
Field measurements						
Analysis and final report prep.						
Quarterly reports						
Final Report and Final Datasets						
Attendance at conferences						
Peer-reviewed publication						

3. Budget

The total project budget is $140,425. 16% ($23,125) of the budget will be provided from internal USU funds (i.e., from the Uintah Basin Air Quality Research Project, which is funded by the Utah legislature). The portion of the project budget we request from Utah DAQ is $117,300.

This project will be completed as a collaboration between USU and R&R Oilfield Services. R&R Oilfield Services has generously agreed to provide their services without cost. USU will provide some materials that will be used by R&R Oilfield Services, and these are included in USU's budget.

3.1. Budget Details

Table 3-1 shows the project budget. Notes about the budget include the following:

- We calculated benefits at 45.5% of salaries and 0.8% of student wages.
- Field maintenance and repair costs are for calibration, maintenance, and repair of our emissions measurement equipment. We calculated repair costs as 5% of replacement costs annually. Calibration and maintenance costs include calibration and carrier gases and other consumables.
- Econ J2KN rental costs and flow meter calibration costs were provided to us by the manufacturers of these instruments.
- Laboratory analysis costs include compressed gases, calibration standards, and maintenance and repair costs for laboratory equipment.
- Supplies for R&R Oilfield Services include equipment maintenance and repair costs, calibration gases, and other consumables.
- The mileage rate is the actual cost to USU per mile for a four-wheel-drive vehicle capable of pulling our emissions measurement trailer.
- Costs for travel for one person to the Science for Solutions Conference include:
    - Hotel costs (one night, one room) at $140 per night,
    - Per diem for one person at $50 per day for each full travel day and $37.50 for the first and last days,
    - Registration for one person at $10 each, and
    - 400 miles of travel at $0.60 per mile.
- Costs for travel for one person to the American Geophysical Union Fall Meeting include:
    - Hotel costs (4 nights) at $160 per night,
    - $650 for airfare,
    - 5 days of per diem at $50 per full day and $37.50 for the first and last days, and
    - $600 for conference registration.
- We have included indirect costs at 10% of total costs.

Table 3-1. Total project budget.

	Emissions Measure-ments	Analysis and Reporting	Total Funded by Utah DAQ	Matching Funds	Grand Total
PERSONNEL					
Seth Lyman 378h@$62/h	$10,165	$8,209	$18,374	$5,000	$23,374
Huy Tran 263h@$41/h	$3,701	$7,127	$10,828		$10,828
Technician 618h@$29/h	$6,482	$2,408	$8,890	$9,304	$18,194
Student 198h@$15/h	$2,975	$0	$2,975		$2,975
BENEFITS @ 45.5%	$9,282	$8,073	$17,356	$6,508	$23,864
SUPPLIES					
Field maint. and repair	$2,628		$2,628		$2,628
Econ J2KN rental	$8,400		$8,400		$8,400
Calibrate flow meters	$1,500		$1,500		$1,500
Lab analysis	$18,027		$18,027		$18,027
Supplies for R&R	$10,000		$10,000		$10,000
TRAVEL					
3750 miles@$1.07/mile	$4,013		$4,013		$4,013
Travel for 1, Sci. for Solns.		$465	$465		$465
Travel for 1, AGU Mtg.		$2,115	$2,115		$2,115
TOTAL DIRECT COSTS	$77,173	$28,397	$105,570	$20,812	$126,383
TOTAL INDIRECT @10%	$8,575	$3,155	$11,730	$2,312	$14,043
TOTAL PROJECT COST	$85,748	$31,552	**$117,300**	$23,125	$140,425

4. Personnel Roles and Responsibilities

Seth Lyman (USU) will be the project PI. He has successfully completed a wide array of air quality research projects during his career, and he has extensive experience with emissions measurements from oil and gas sources. Seth will manage the project, take the lead in field measurements, and lead analysis and reporting efforts.

Huy Tran (USU) will be a project co-PI. He has 13 years of experience with receptor and dispersion models, emissions models, meteorological and photochemical simulations, field emissions measurements, and air quality data analysis. Huy will participate in field measurements, data analysis, and writing reports.

Rafael Vargas (R&R Oilfield Services) is an expert in natural gas-fired engine maintenance, repair, and emissions testing. Rafael will provide technical expertise for emissions measurements, and he or his staff will modify the operating conditions of some engines so we can determine how these conditions affect emissions.

5. References

Chapman, K.S., Nuss-Warren, S.R., 2006. Cost-Effective Reciprocating Engine Emissions Control and Monitoring for E&P Field and Gathering Engines. Kansas State University, https://www.osti.gov/servlets/purl/889641-sJKpYl/.

EPA, U.S., 2018. SPECIATE Version 4.5 through 4.0, https://www.epa.gov/air-emissions-modeling/speciate-version-45-through-40.

GSI, 2018. Integrated Component-specific Measurements to Develop Emission Factors for Compressors and Gas Gathering Lines. GSI Environmental, Inc., Austin, Texas, https://www.netl.doe.gov/sites/default/files/2019-01/FE0029084_FInal.pdf.

Hohn, K., Nuss-Warren, S.R., 2011. Cost-Effective Reciprocating Engine Emissions Control and Monitoring for E&P Field and Gathering Engines. Kansas State University, https://www.osti.gov/servlets/purl/1032856.

Lyman, S., Mansfield, M.L., Tran, H., Tran, T., Holmes, M., 2019. 2019 Annual Report: Uinta Basin Air Quality Research. Utah State University, Vernal, Utah, https://usu.box.com/s/co626elackqkw9ead14wkma14jjv9eng.

Lyman, S., Shorthill, H., Mansfield, M.L., Tran, H., Tran, T., 2014. Final Report: 2013-14 Uintah Basin Winter Ozone Study, Vernal, Utah, http://rd.usu.edu/htm/reports.

Lyman, S., Tran, T., 2015. Measurement of Carbonyl Emissions from Oil and Gas Sources in the Uintah Basin. Utah State University, Vernal, Utah, http://binghamresearch.usu.edu/files/CarbonylEmiss_FnlRprt_31jul2015.pdf.

Lyman, S.N., Mansfield, M.L., Tran, H.N., Evans, J.D., Jones, C., O'Neil, T., Bowers, R., Smith, A., Keslar, C., 2018. Emissions of organic compounds from produced water ponds I: Characteristics and speciation. Sci. Total Environ. 619, 896-905.

Lyman, S.N., Watkins, C., Jones, C.P., Mansfield, M.L., McKinley, M., Kenney, D., Evans, J., 2017. Hydrocarbon and Carbon Dioxide Fluxes from Natural Gas Well Pad Soils and Surrounding Soils in Eastern Utah. Environ. Sci. Technol. 51, 11625-11633.

Oliver, W.R., Peoples, S.H., 1985. Improvement of the emission inventory for reactive organic gases and oxides of nitrogen in the South Coast Air Basin. Volume 1. Main report. Final report. Systems Applications, Inc., San Rafael, CA (USA), https://ww3.arb.ca.gov/ei/speciate/r21t40/rf25doc/refnum25.htm.

Uchiyama, S., Naito, S., Matsumoto, M., Inaba, Y., Kunugita, N., 2009. Improved measurement of ozone and carbonyls using a dual-bed sampling cartridge containing trans-1, 2-bis (2-pyridyl) ethylene and 2, 4-dinitrophenylhydrazine-impregnated silica. Anal. Chem. 81, 6552-6557.

UDAQ, 2018. Uinta Basin: 2014 Air Agencies Oil and Gas Emissions Inventory, https://deq.utah.gov/legacy/destinations/u/uintah-basin/air-agencies-emissions-inventory/index.htm.