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Utah Department of Environmental Quality
Science for Solutions Research Grant – FY 2020

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Investigating Sources of Ammonia Uncertainty in Modeling the Salt Lake City $PM_{2.5}$ Nonattainment Area

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1.0 Summary Information Page

1.1 Project Title

Investigating Sources of Ammonia Uncertainty in Modeling the Salt Lake City $PM_{2.5}$ Nonattainment Area

1.2 Applicant Information

Organization:	Ramboll Environment and Health
Address:	50 West Broadway, Suite 300 Salt Lake City, UT 84101
Principal Investigator:	Chris Emery, Senior Managing Consultant
Phone number:	(415) 899-0740
Email address:	cemery@ramboll.com

1.3 Sponsored Projects/Research Office Information:

Not applicable.

1.4 Funding Requested

Total Project Budget:	$111,396
UDAQ Funding:	$86,396
Sponsored co-funding:	$25,000

1.5 Project Period

July 1, 2019 – March 31, 2020

2.0 Scope of Work

2.1 Abstract

Ramboll and our teaming partner, Dr. Randy Martin at Utah State University (USU), are pleased to present this proposal in response to the "Science for Solutions Research Grant - FY 2020." Our proposed scope of work will comprehensively investigate causes for an apparent ammonia (NH_3) emissions shortfall in the photochemical modeling system employed by the Utah Division of Air Quality (UDAQ) to support the Salt Lake City (SLC) fine particulate ($PM_{2.5}$) State Implementation Plan (SIP) update. The need to supply the model with additional NH_3 emissions from unknown sources presents a major model uncertainty that may affect the accuracy of the $PM_{2.5}$ attainment demonstration. Currently there is little information that points to whether the NH_3 shortfall is caused by inventory inaccuracies and/or model deficiencies. Our project will review current SLC NH_3 inventories and measured concentration patterns; quantify NH_3 emission uncertainties for key sources; thoroughly investigate modeling uncertainties and deficiencies, update the modeling system and refine modeled NH_3 emissions; and re-evaluate modeling results and $PM_{2.5}$ sensitivity to NH_3 and NOx emissions to improve the estimated projection of future PM trends. Our proposed project will address two goals and priorities defined in the RFP: $PM_{2.5}$ Chemistry and Precursor Gases, and Air Quality Modeling and Emissions Inventory Improvements. Ramboll is the developer of the Comprehensive Air quality Model with extensions (CAMx), upon which the UDAQ's SIP modeling platform is based. Our proposed project will benefit greatly from insights and experience gained from Ramboll's review and use of UDAQ's modeling platform during 2018, and from Dr. Martin's involvement in winter 2017 and 2019 field studies. With contributions from USU and Ramboll's staff in our SLC office, we collectively have a direct vested interest in improving air quality in the region.

2.2 Basis and Rationale

Salt Lake City is designated as a serious nonattainment area (NAA) for the 24-hour $PM_{2.5}$ National Ambient Air Quality Standard (NAAQS). In its SIP update for the area, the UDAQ demonstrates attainment of the $PM_{2.5}$ standard by 2019 based on photochemical modeling and weight-of-evidence analyses. According to the SIP (UDAQ, 2018) and the 2017 Utah Winter Fine Particulate Study (UWFPS; Baasandorj et al., 2018), $PM_{2.5}$ concentrations often exceed the standard during wintertime persistent cold air pool (PCAP) events. Over 70% of exceedance-level $PM_{2.5}$ mass is comprised of "secondary" pollutants; i.e., compounds that are chemically formed in the atmosphere from direct emissions of gas precursors. This secondary component is dominated by ammonium nitrate, formed from emissions of NH_3 and nitrogen oxides (NOx). The UDAQ's photochemical modeling of a historical PCAP event in January 2011 can replicate measured $PM_{2.5}$ concentrations and composition rather well, but only after artificially increasing NH_3 emissions by over 50% to make up for an apparently lack of inventoried NH_3. The SIP makes clear that the artificial NH_3 injection is a major model uncertainty that may affect the accuracy of the modeled attainment demonstration because it impacts the ability to predict how $PM_{2.5}$ differentially responds to NH_3 and NOx emissions. Currently there is little information that points to how much of the NH_3 shortfall is caused by inventory inaccuracies or model deficiencies. For example, peer-reviewed literature indicates an underprediction of NH_3 emissions by the MOVES motor vehicle emission factor model (Sun et al., 2014); additionally, the photochemical model employed by UDAQ lacks a "bidirectional" surface NH_3 flux (NH_3 deposited to the surface can subsequently re-volatilize back to the air).

Ramboll has developed this proposal to comprehensively investigate the modeled NH_3 shortfall. Our scope of work includes several tasks addressing the following topics: (1)

review current SLC NH_3 inventories and estimation procedures, and spatial and temporal concentration patterns measured during recent (2017) and planned (2019) winter PCAP field studies; (2) quantify NH_3 emission uncertainties for key sources, with particular attention to on-road vehicle emissions during cold conditions; (3) thoroughly investigate modeling uncertainties in the UDAQ modeling platform, including the NH_3 injection methodology, and apply an updated model version that includes bidirectional NH_3 flux as a means to refine the estimated NH_3 shortfall; (4) refine modeled NH_3 emissions from information developed above and re-evaluate modeled results against measurements; and (5) investigate $PM_{2.5}$ sensitivity to NH_3 and NOx emissions to improve the estimated projection of future PM trends. Our proposed project will address the following two goals and priorities defined in the RFP: (1) $PM_{2.5}$ Chemistry and Precursor Gases; (2) Air Quality Modeling and Emissions Inventory Improvements.

2.3 Technical Approach

The UDAQ's SIP modeling platform comprises CAMx version 6.30. The model was applied for a 10-day PCAP event in early January 2011, on a nested grid system with 1.33 km resolution over the SLC NAA and 4 km resolution over the State of Utah. Meteorological inputs for the episode were developed by the University of Utah using the Weather Research and Forecasting Model (WRF). Emission inputs were based on 2011 and 2014 inventories, the latter of which was projected to years 2016, 2017, 2019, and 2020 by accounting for growth in population and sector-specific activity, on-road vehicle fleet turnover, and current and anticipated emission controls on stationary sources. Raw emissions data were processed to model-ready data using the Sparse Matrix Operator Kernel Emissions (SMOKE) system.

The UDAQ implemented several changes to the modeling system to improve model performance in replicating the temporal and spatial patterns of measured $PM_{2.5}$ concentrations and composition over the January 2011 episode. One of the most significant of these modifications was the need to increase NH_3 emissions by county within the SLC NAA (by roughly 70% in Salt Lake County alone) in order to alleviate a large under prediction of ammonium nitrate. Another modification involved artificially enhancing the strength and depth of vertical mixing throughout the modeled episode to compensate for certain over predictions. Enhanced vertical mixing may have contributed to the amount of NH_3 injection needed to reach observed levels. Despite ultimately achieving very good agreement with measurements, the injection of additional NH_3 above the reported inventory is a major source of model uncertainty that likely impacts the modeled $PM_{2.5}$ response to NH_3 and NOx emissions reductions. As far as we currently understand, the additional NH_3 injection was maintained and unaltered for the future year emission scenarios.

The intensive UWFPS conducted in early 2017 yielded a large set of measurement data that will be critically useful to this study; details are provided by Bassandorj et al. (2018). Our teaming partner Dr. Martin and collaborators are planning to conduct a saturation monitoring study in January-February 2019 to characterize the spatial distribution of NH_3 and chloride throughout the SLC NAA (Martin et al., 2018). The study will include weekly-integrated sampling at 40 passive monitors throughout the basin, as well as 10 mini-vol filter sites for ionic analysis in targeted areas, with 3-4 co-located sites for elemental and carbon analysis. One site will be located on the ridgeline between the SLC and Utah valleys to assess inter-basin exchange. The study will locate meteorological sites and lidar at that location as well. Additionally, the study will include mobile sampling platforms. A key element in the program plan is to use mobile sampling to estimate on-road vehicle NH_3 emissions. Investigators expect to make the field study data publicly available in summer 2019.

Our proposed technical approach is designed to quantify and improve upon several specific hypothesized causes for the current NH_3 shortfall in the UDAQ's photochemical modeling system:

1. Lack of bidirectional surface NH_3 flux in the CAMx model and any mitigating influence of snow cover;
2. Potential influence of enhanced vertical mixing on the amount of NH_3 injection UDAQ needed to reach measured concentrations;
3. Under estimates of on-road NH_3 emissions reported by the MOVES model, especially in the cold environment of SLC PCAP episodes;

Our approach consists of five tasks as detailed below.

Task 1: Characterize Model Uncertainty

Ramboll will request the complete, final SIP modeling platform from the UDAQ to support our analyses. Output from an initial test run will be quantitatively compared to UDAQ's output files to ensure reproducibility.

By reviewing SIP technical support documents and discussions with UDAQ, we will examine the episodic NH_3 emission inventories and estimation procedures to identify key sources of uncertainty for the largest emitting sectors. We will review and characterize simulated NH_3 patterns throughout the SLC NAA modeling grid for the UDAQ 2019 emissions scenario. Model results with and without the artificial NH_3 injection will be compared to measurements from the winter 2019 monitoring study to assess spatial and temporal agreement and to characterize key differences, to the degree that meteorological conditions during the 2019 monitoring period(s) align with the January 2011 modeling episode.

Task 2: Implement and Test Model Improvements

The CAMx photochemical model includes the process of "dry deposition", which refers to diffusive transfer of gases and particulates from the model's lowest atmospheric layer to the surface, analogous to the flow of electric current through resistors along a circuit, and the irreversible uptake of those compounds by surface elements (vegetation, soil, water, snow) according to chemical-specific attributes. Until recently, the dry deposition process has been strictly a removal process for all chemical species, based on the approach of Zhang et al. (2003). Ramboll has recently added the bidirectional NH_3 algorithm of Zhang et al. (2010) and Whaley et al. (2018) to CAMx. Implemented within the dry deposition function, the new approach assigns NH_3 "emission potentials" by land cover type that determine temperature-dependent compensation points along the circuit (Figure 1) and thus the direction and magnitude of the net NH_3 flux between the lowest atmospheric model layer and surface elements. Under conditions of high compensation points relative to atmospheric concentrations, the net flux is from the surface to the atmosphere, i.e. emission; when atmospheric concentrations are high relative to the compensation points, the net flux is to the surface, i.e., deposition. In all cases with non-zero emission potential, NH_3 deposition rates to the surface are reduced (or reversed) relative to the original deposition function, which implicitly assumes zero emission potential. Use of the bidirectional NH_3 process will increase the buildup of atmospheric NH_3 during multi-day stagnation events and reduce the emissions shortfall. We propose to evaluate bidirectional NH_3 deposition in CAMx and refine the standard emission potentials for SLC under winter episode conditions.

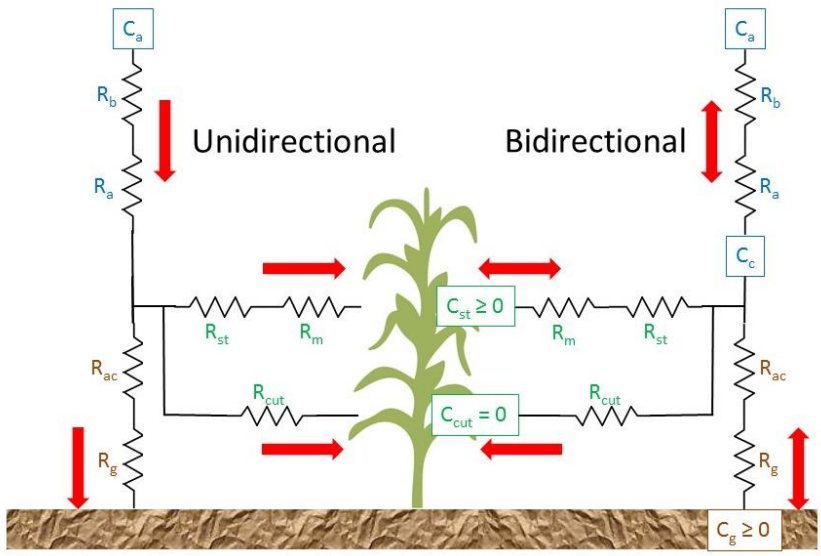

Figure 1. Right side shows a schematic of the bdirectional NH_3 deposition/re-emission scheme of Zhang et al. (2010) and Whaley et al. (2018); left side shows the original unidirectional deposition scheme of Zhang et al. (2003). Respective pathway resistances (R) and bidirectional compensation points (C) are shown.

The new bidirectional capability has been implemented in a new version of CAMx (v7.0), expected for public release in early 2019. Since this release is three versions beyond the UDAQ's modeling platform, v7.0 includes several other updates and improvements. Therefore, an initial test run with v7.0, without invoking the bidirectional NH_3 function, will be necessary to isolate the impacts from these other changes. We expect any output differences to be minor. Then we will invoke the bidirectional scheme using default surface parameters as set in the public release, document spatial and temporal impacts to total reduced nitrogen (NH_3 + particulate ammonium or NH_4), particulate nitrate and sulfate concentrations, and qualitatively compare resulting NH_3 patterns with 2019 observational data as in Task 1.

Ramboll will then conduct sensitivity tests addressing alternative emission potential assignments by land cover type and the effects of snow cover (e.g., fully insulating the surface from the atmosphere vs. fully transparent). Selection of alternative emission potentials and the role of snow cover will be assessed from a literature review (to the extent possible) and through discussions with the original authors of the bidirectional function. This task will include a review of the UDAQ's spatial land cover classification inputs and consider any updates deemed necessary. Based on results of sensitivity testing, a final configuration or plausible range of parameters will be set for subsequent modeling analyses. The original NH_3 emission shortfall estimate will be updated according to these results.

As mentioned above, the UDAQ increased vertical mixing rates and depths during the development of their modeling platform to alleviate over predictions in certain gas and $PM_{2.5}$ concentrations that were especially apparent early in the January 2011 modeling episode. This change was applied around the same time the NH_3 injection was implemented. If the diffusion adjustment was applied too deep, then it is possible that the NH_3 emissions shortfall, and thus the amount injected, were over estimated. In other words, the same chemical improvement from an NH_3 injection may be achieved with a lower quantity of additional emissions into a shallower mixed layer.

Model tests will be conducted to isolate the effects of the diffusion adjustment on the amount of additional NH_3 emissions needed to agree with 2019 measured concentrations. Tests with and without the bidirection NH_3 process will be compared, and effects on precursor gas and $PM_{2.5}$ chemical components will be assessed relative to 2011 measurements similarly to the approach described in the SIP. We will attempt to identify an optimum diffusion adjustment that minimizes the remaining NH_3 shortfall without negatively impacting model-measurement agreement for other precursor gas and $PM_{2.5}$ concentrations. Based on our findings, the NH_3 emission shortfall estimate will be further updated.

Once all model adjustments are finalized, a final analysis will address the UDAQ's method for the NH_3 injection itself. According to the SIP, UDAQ estimated county-level NH_3 emission shortfalls from model-measurement concentration differences throughout the SLC NAA and then added those additional emissions uniformly over all hours and across all grid cells within each county. As we understand it, the rationale for this methodology is based on the assumption that the NH_3 shortfall is from unknown, potentially un-inventoried sources and thus no *a priori* knowledge exists about its spatial or temporal distribution. We believe that underestimates for one or several known NH_3 sources are likely contributing to the modeled NH_3 under prediction. Therefore, we propose to scale up the known gridded emission inputs for 1-3 major source categories (e.g., on-road mobile, area, agricultural) to investigate which adjustments best remedy the deficit. This approach would preserve the inhomogeneous emissions distribution. Based on the final NH_3 shortfall calculated from the model improvements described above, we will test the effects of a scaling approach vs. homogeneous injection on NH_3 concentration patterns, compare to 2019 measured NH_3 distributions, and quantify impacts to model-measurement comparisons for $PM_{2.5}$ and component species concentrations.

Task 3: Ammonia Emission Uncertainties

Given the large number of source types that emit NH_3, and the widely dispersed nature of many of those sources, pinpointing the causes for the NH_3 emissions shortfall is challenging. Agricultural activity is often identified as the largest source, and this remains true in rural areas well removed from SLC. Agricultural lands in the NAA have given way to urban sprawl and commercial/industrial uses. Outside of area sources, on-road vehicles comprise the largest remaining NH_3 source in the basin. Large uncertainties also remain for wastewater. Under this task, our team will investigate vehicular source uncertainty in detail.

We propose to perform a literature review of recent studies to characterize current knowledge of NH_3 emissions from motor vehicles. Tailpipe NH_3 emission estimates in EPA's MOVES2014 model were developed with data from well before 2014. The data available to EPA at that time may not have been able to fully address all conditions, including cold weather, aging or unmaintained vehicles, unique driving activities, and the latest diesel heavy-duty vehicles using selective catalytic reduction (SCR) to reduce NOx emissions. There are published studies (Sun et al., 2014, 2016) indicating that light-duty vehicle NH_3 emissions may be under estimated by a factor of 2 under "normal" conditions. While this discrepancy may be related to the age of data upon which MOVES is based, it is also possible that even more NH_3 may be emitted under conditions specific to Utah.

Light-duty gasoline vehicles represent the overwhelming fraction of vehicles, and their NH_3 emission rates have been investigated over many years. Several conditions have been suggested to affect NH_3 emission rates that are present in Utah, including high load demands such as climbing grades and acceleration events, cold conditions, and aged vehicles (Durbina et al., 2004). For example, Suarez-Bertoa et al. (2014) show that NH_3 emission rates increase by about 25% when cold (-7°C) compared to warm (22°C). A larger

impact occurs for engine load, where just a small percentage of grades or high acceleration modes can cause emission increases by orders of magnitude (Huai et al., 2003). For example, high power test cycles produce 5.5 times the NH_3 as a standard (lower power) test cycle. We will also detail how aged catalysts affect NH_3 emission rates from older vehicle age distributions in Utah[1].

Heavy-duty vehicles with SCR inject urea into the exhaust system that thermally decomposes to NH_3 to reduce NOx emissions. SCR technology has been evolving since the 2010 model year when the diesel NOx emission standard first required SCR. SCR catalysts are inefficient below 200°C and cannot destroy NH_3 and NOx when cold. The NH_3 that "slips" through the catalyst under any, but especially cold conditions, has not been well characterized to date. There are a variety of heavy-duty engine aftertreatment control designs and operating programs that affect average NH_3 emission rates. Because NH_3 is introduced in the exhaust, there is a potential for significant NH_3 tailpipe emissions, and we will investigate studies that have characterized these emissions.

We will review the latest relevant literature that characterizes tailpipe NH_3 emissions and compare with EPA MOVES2014 emissions rates during both winter and summer conditions in Utah. We will use the result of the literature review, reconciled against 2019 field study measurements of on-road NH_3 emissions to the extent possible, to suggest alternative NH_3 emissions rates from on-road vehicles and then adjust the modeling inventories accordingly. We will quantify NH_3 uncertainty during SLC PCAP conditions by scaling MOVES output by process/source category and estimating the impact to the overall NH_3 emissions inventory. In a sensitivity study, we will supply the revised emissions to the updated CAMx model from Task 2 (without the artificial NH_3 increase) and re-assess whether an NH_3 emission shortfall remains.

Task 4: Final Modeling Platform

A final emissions inventory reflecting the updates applied under Task 3 will be developed and processed to model-ready inputs for both 2016 base and 2019 future years. Any remaining NH_3 shortfall will be added to the modeled emission input files using the scaling technique applied under Task 2. The final model configuration adopting all updates and inputs from Tasks 2 and 3 will be run for the modeling period and output re-evaluated against measurements. CAMx results from 2016 and 2019 scenarios will be used to project 2019 attainment year design values following the approach described in the SIP. Additional sensitivity tests using the updated 2019 emission inputs will be undertaken to investigate $PM_{2.5}$ sensitivity to NH_3 and NOx emission reductions. Sensitivity testing will employ a "brute force" technique, where emissions are reduced and the model re-run to report impacts on $PM_{2.5}$ concentrations. We may additionally utilize the Decoupled Direct Method (DDM) of sensitivity analysis, which is an instrumented "Probing Tool" available in CAMx that reports first-order (linear) response to emission perturbations in a single run (i.e., without a multitude of sensitivity runs). Since DDM calculates sensitivity relationships among all species, it could provide more in-depth information on the effectiveness of various emission reductions on $PM_{2.5}$ patterns beyond just NH_3 and NOx.

Task 5: Project Management and Reporting

This task will comprise project management activities during the execution of the contract. Activities include: (1) day-to-day staff and resource management; (2) internal team

[1] https://autoalliance.org/in-your-state/UT/pdf/?export

meetings and external conference calls with UDAQ including a project kickoff meeting; (3) monthly invoicing and progress reporting to UDAQ; (4) preparation of quarterly progress reports; (5) assembly of the draft and final project report; (6) preparation for, and attendance at a Science for Solutions technical conference in Utah; and (7) sharing of data and modeling system with UDAQ.

2.4 Expected Outputs and Outcomes

Based on the modeling and evaluation methodology described above, the Ramboll team expects to provide UDAQ with the following products from our proposed study:

1. An updated and improved CAMx modeling platform, with a tailored configuration of the bidirectional ammonia flux capability specific to the conditions present during UDAQ's modeling episode;
2. An updated set of vertical diffusion inputs to the CAMx model specific to the UDAQ's modeling episode that minimizes the modeled NH_3 shortfall while maintaining an appropriate replication of $PM_{2.5}$ and its component species concentrations throughout the modeling episode;
3. An improved estimate of on-road vehicle NH_3 emissions for the attainment demonstration episode, both as model-ready inputs and as tabular summaries;
4. An updated estimate (if any) of the remaining modeled NH_3 shortfall, using an improved approach based on scaling final NH_3 emission inputs, along with associated model emission input files;
5. An updated model sensitivity analysis of $PM_{2.5}$ response to NH_3 and NOx emission reductions in the SLC NAA, including model scripts, input and output files from all tests.

2.5 Deliverables

<u>Monthly Progress Reports</u>

We are proposing to conduct this study on a time and materials basis. As such, Ramboll will submit monthly invoices for labor and other direct costs around the 15th of the following month. Each invoice will be accompanied by a brief monthly progress report that summarizes activities performed during the month, anticipated activities for the following month, and a budget summary.

<u>Quarterly Progress Reports</u>

As required by the RFP, the Ramboll team will prepare 2-page quarterly progress reports over the course of the contract. We assume that reports will be due at the end of each calendar quarter (March, June, September, December). Each report will first briefly restate the project's purpose, goals and objectives, followed by completed activities and progress by task, any technical problems encountered, and any planned or implemented solutions developed to solve or mitigate them. The report will also include any changes in approach, objectives and schedule. The final project report will suffice for the last quarterly report.

<u>Final Report</u>

A final project report is required within 90 days of project completion. The Ramboll team will develop a draft report and submit it to UDAQ for review at the close of all technical work. The team will then address comments and suggestions received on the draft, compile the final report and submit it to UDAQ by the specified deadline. The final report will contain all of the components required by UDAQ and listed in the RFP.

Conference Presentation

As required by the RFP, the Ramboll team will prepare and deliver an oral or poster presentation at a Science for Solutions conference. The presentation will include study objectives, approach, results, and recommendations for any additional investigation. The specific conference that we attend will be decided in coordination with UDAQ; based on information in the RFP and our proposed schedule, we expect to attend the conference in Spring 2020 after our study is fully completed.

2.6 Data Sharing

The Ramboll team will share with UDAQ all datasets and models developed or updated during the course of the proposed project. We will arrange with UDAQ the most appropriate way to provide the data publicly; as suggested in the RFP, this may be either via the UDAQ website or one of the team members sites. Following the specifications of the RFP, all data to be shared will be made available within 8 months of project completion. We anticipate the following data will be generated and shared from this project:

- All CAMx model updates specific to this work and unique to the UDAQ's SIP modeling platform (all other general CAMx updates are periodically made available to the public at Ramboll's website www.camx.com);
- All emissions inventory and model-ready emission files that the Ramboll team adjusted or altered;
- All other model inputs that may be adjusted or altered;
- All CAMx output files, or a subset of key files selected in coordination with UDAQ;
- Any new measurement or modeling datasets or derivative products that may be important to UDAQ's work, selected in coordination with UDAQ.

2.7 Schedule

Our proposed project schedule with key deliverable dates is shown in Figure 2. We anticipate a start date of July 1, 2019 and expect to complete the project by March 31, 2020 to include the 2020 Science for Solutions conference. We expect to complete all data sharing by the project end date.

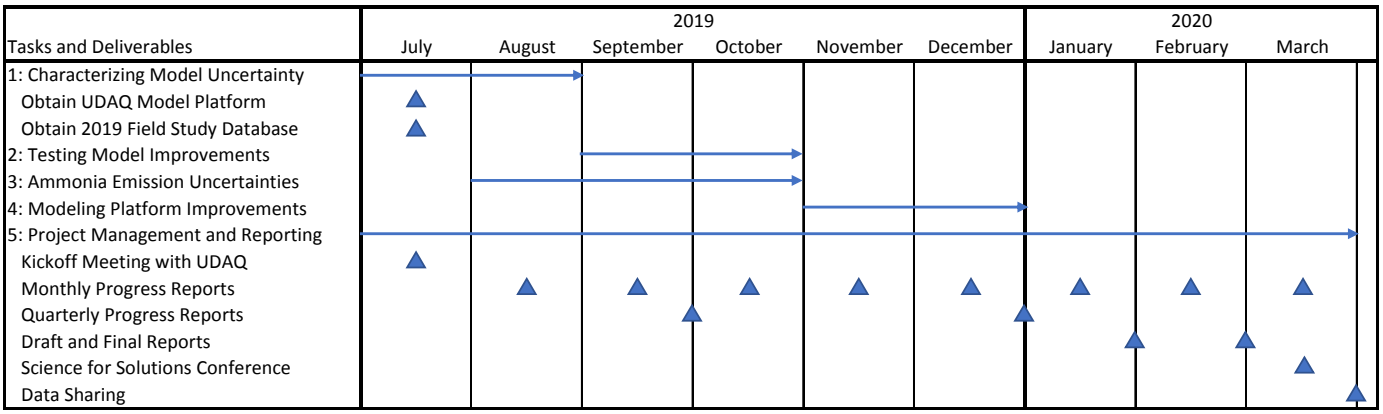

Figure 2. Proposed project schedule by task, including deliverable dates.

2.8 References

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3.0 Budget

The total estimated cost for the scope of work described in Section 2 is $111,396. We have a co-funding commitment from Marathon Petroleum of $25,000 (see Appendix B for commitment letter). Therefore, the total requested funding from UDAQ is $86,396. We may also be able to secure co-funding from Hexcel Corporation in the near future, which would reduce UDAQ funding equivalently.

Table 1 presents a detailed budget workup for our proposed project, which includes costs by task, personnel (fully loaded labor rates, hours and cost), and other direct costs. Ramboll's loaded labor rates are developed by applying our indirect rates (Fringe, Overhead, G&A and Fee) to bare salaries. We base our indirect costs on the preceding fiscal year's actual expenditures for benefits and fringes, overhead, and G&A expenses. At the end of each fiscal year, actual expenses are compared to the previous year's and any significant variances in indirect rates are applied back through rate adjustments.

Table 1. Proposed project budget, including breakdown by task, personnel (rates, hours and cost), and other direct costs.

	Hourly Labor Rate	Task 1 Characterize Model Uncertainty		Task 2 Model Improvements		Task 3 Emission Uncertainties		Task 4 Final Model Platform		Task 5 Management & Reporting		Total All Tasks	
Lbr Category/Name		**Hrs**	**Dollars**	**Hrs**	**Dollars**	**Hrs**	**Dollars**	**Hrs**	**Dollars**	**Hrs**	**Dollars**	**Hrs**	**Dollars**
Principal													
Greg Yarwood	242.05	2	484	12	2,905	2	484	2	484	4	968	22	5,325
Sr. Managing Consultant													
Chris Lindhjem	197.97	2	396		0	40	7,919		0	24	4,751	66	13,066
Chris Emery	201.26	16	3,220	32	6,440	16	3,220	24	4,830	70	14,088	158	31,799
Managing Consultant													
Tejas Shah	164.96	4	660		0	8	1,320	4	660	6	990	22	3,629
Sr. Consultant 2													
Chao-Chung Chien	156.71		0		0		0		0		0	0	0
Michele Jimenez	145.17	8	1,161		0	12	1,742	12	1,742	12	1,742	44	6,387
Marco Rodriguez	156.71		0		0		0		0		0	0	0
Yesica Alvarez	136.93		0		0	24	3,286		0		0	24	3,286
Ross Beardsley	128.68	8	1,029	32	4,118	8	1,029	16	2,059	18	2,316	82	10,552
Marcus Trail	120.97	8	968	20	2,419	8	968	16	1,936	16	1,936	68	8,226
Consultant 3													
Kaitlyn Lieschke	107.23	2	214	8	858	4	429	4	429		0	18	1,930
Pradeepa Vennan	121.35	2	243	8	971	4	485	4	485		0	18	2,184
Jean Guo	115.47	2	231	8	924	4	462	4	462		0	18	2,079
Sr. Support	108.15		0		0		0		0	4	433	4	433
Support	103.43		0		0		0		0	12	1,241	12	1,241
Ramboll Labor Subtotal		54	8,607	120	18,635	130	21,344	86	13,087	166	28,465	556	90,138
Subcontractor													
Randy Martin, USU			1,600		1,200		8,000		0		4,000	0	14,800
ODCs - travel											200		200
10% G&A on Subcontractors	0.00%		0		0		0		0		0		0
Labor Subtotal		54	10,207	120	19,835	130	29,344	86	13,087	166	32,665	556	105,138
Other Direct Costs													
Communications (1)	3%		258		559		640		393		854		2,704
Computing (2)	3%		258		559		640		393		854		2,704
Travel			0		0		0				750		750
Misc.			100										100
ODCs Subtotal			616		1,118		1,281		785		2,458		6,258
GRAND TOTAL		54	10,823	120	20,953	130	30,625	86	13,872	166	35,123	556	111,396

Ramboll adds 3% to our personnel direct labor costs for telephones, copier services, and facsimile charges, and 3% of our personnel direct labor costs for computers and printers (6% total). These indirect rates are not applied to sub-contractor costs.

Our teaming arrangement with Dr. Randy Martin at Utah State University involves an individual sub-contracting arrangement directly with Dr. Martin, and not through the Division of Sponsored Programs of Utah State University. Ramboll is waiving our customary 10% G&A fee on sub-contractor costs for this proposal. Dr. Martin's fixed-fee cost is $15,000.

Other direct costs include high-volume data disk drive to transfer modeling platform datasets from UDAQ at the start of the project and to send project-generated datasets back to UDAQ at the close of the project. Other direct costs also include travel for a single-person 2-day trip by air with meals and hotel accommodations (Ramboll), and a 1-day single-person trip by auto (Dr. Martin), to attend the 2020 Science for Solutions conference. No other costs related to equipment, materials/supplies, or travel is anticipated during the project.

We are proposing to conduct this study on a time and materials basis. As such, Ramboll will submit monthly invoices for labor and other direct costs around the 15th of the following month. We request payment terms on a net 30-day basis.

4.0 Personnel Roles and Responsibilities

Ramboll has direct, relevant experience that is essential to successfully conduct the proposed project. Ramboll is the developer of the CAMx photochemical model, upon which the UDAQ's SIP modeling platform is based. Under sponsorship from the Utah Petroleum Association during 2018, we reviewed and applied UDAQ's photochemical modeling platform to address several issues: (1) calculate $PM_{2.5}$ source apportionment for multiple emission sectors throughout the SLC NAA; (2) perform major stationary source precursor demonstrations; (3) assess contributions from residential wood smoke; (4) investigate sources of particulate chloride; and (5) develop technical comments and suggestions on UDAQ's photochemical modeling to support the $PM_{2.5}$ SIP attainment demonstration. During 2014-2015, Ramboll (and previously ENVIRON) contracted with UDAQ to develop new chemical capabilities in CAMx relevant to winter, snow-covered conditions and applied these updates to investigate modeled ozone underpredictions in the Uinta basin. More regionally, for over a decade Ramboll (and previously ENVIRON) has played a central role in developing and analyzing CAMx-based modeling datasets for the Western Regional Air Partnership (WRAP) and more recently the Western States Air Resources Council (WESTAR). These have included projects such as the WRAP/Westjump Study, Three-States Air Quality Study (3SAQS), and Western Air Quality Study (WAQS), all of which investigated ozone, $PM_{2.5}$ and regional visibility, including impacts from oil and gas development. Details for recent projects that we have conducted in the region are listed in Appendix B.

Below we list the key personnel that will conduct the proposed scope of work, noting their titles and describing their main roles and responsibilities. We also provide a summary paragraph for each describing relevant qualifications and experience. Full resumes for each are presented in Appendix A. The project will be managed and conducted by Ramboll, utilizing staff from our offices in Salt Lake City and the San Francisco Bay Area. Our team includes Dr. Randy Martin at the Utah State University in Logan as an individual sub-contractor. Additional Ramboll staff, not listed here for page restrictions, will be utilized in this project to support our key personnel. Figure 2 presents our proposed organizational structure for the study.

Chris Emery, Senior Managing Consultant, will serve as Ramboll's Principal Investigator and Project Manager of the proposed project. In this capacity, Mr. Emery will serve as technical lead and oversee the contract with UDAQ. He will also manage day-to-day project activities including ensuring the project remains on schedule and budget, managing personnel assignments, and communicating progress, technical issues, and results to UDAQ. Mr. Emery will lead all meetings with UDAQ, serve as primary author of all progress reports

and final project reports, and present project results at the annual Science for Solutions Conference.

Mr. Emery has 28 years of experience in numerical modeling and analysis of urban and regional air pollution and meteorology. His expertise includes design, development and application of air quality modeling systems. Mr. Emery co-authors the Comprehensive Air Quality Model with extensions (CAMx), which is used by UDAQ to support their $PM_{2.5}$ SIP. Recently he has extensively reviewed UDAQ's SIP modeling application, contributing to public comments and interacting directly with UDAQ staff on modeling issues. Over the years, he has applied CAMx and a variety of other models for private and public clients, in both local and regional regulatory arenas, throughout the US and abroad. His projects have included ozone, PM and carbon monoxide modeling to support regulatory planning; determining effects of alternative and innovative air quality management strategies; analyzing source contributions and emission sensitivity; among others. Mr. Emery has applied and evaluated meteorological models and global chemical transport models to develop inputs needed by regional photochemical modeling applications. He has served as a member of the American Meteorological Society's Board of the Urban Environment.

Dr. Greg Yarwood, Principal, will serve as Ramboll's Principal in Charge for the project, and will contribute expert assistance and insights into chemical processes in the CAMx model during all modeling tasks.

Dr. Yarwood is an internationally recognized expert with over 25 years of experience in atmospheric chemistry, air quality modeling, photochemical model development, interpreting ambient air quality data, and emissions inventory development. He directs air quality, meteorological and emissions modeling studies for clients in government and industry, with emphasis on photochemical air pollution issues such as ozone, secondary particulate matter (PM), visibility and air toxics. He has developed emission inventories for industrial sources, mobile sources and natural biogenic sources. Dr. Yarwood directs the development of Ramboll's Comprehensive Air quality Model with extensions (CAMx). He developed the Carbon Bond 2005 (CB05) and Carbon Bond version 6 (CB6) chemical mechanisms and has implemented specific chemical updates under projects for UDAQ. He has performed international air quality studies in Europe, the Middle East, China and Africa. Greg was a member of the USEPA's Board of Scientific Counselors for the Clean Air Research Program.

Dr. Randy Martin, Research Associate Professor at Utah State University, will serve as a valuable resource as an individual sub-contractor to Ramboll. Dr. Martin will assist with accessing and analyzing local measurement data from both past and planned field study campaigns. Specific activities will include data analysis support, assistance with measurement-model-inventory comparisons, and lending local insights and experience into the relationships between emission sources and ambient concentrations in the region.

Dr. Martin is a Research Associate Professor of Environmental Engineering at Utah State University with a joint appointment at the Utah Water Research Laboratory (UWRL). He has been at USU since the summer of 2000, combining research, teaching, and outreach duties associated with all things Air Quality. He also serves as an Associate Director of the Utah Climate Center where his duties are associated with maintaining Cache Valley's National Atmospheric Deposition Program National Trends Network (NTN) and Ammonia Monitoring Network (AMoN) sites. Dr. Martin has also been a member of the State of Utah's Air Quality Board since 2017. Dr. Martin's research interests center around the measurement and analysis of atmospheric trace species, most notably the characterization and behavior of

ambient fine particulate matter ($PM_{2.5}$ and PM_{10}), reactive hydrocarbons and related oxidation products (e.g. ozone). His expertise includes air pollution photochemistry, air quality monitoring, biogenic emissions measurements, air pollution modeling, advanced oxidation processes for gaseous pollutant control, and source particulate fractionation and measurement. Dr. Martin has been heavily involved with Utah air quality issues including studies of the Uinta Basin's wintertime ozone issues, $PM_{2.5}$ behavior and characteristics in the Cache Valley and along the Wasatch Front, and mobile source emissions inherent to Utah's vehicle fleet and regional conditions.

Dr. Chris Lindhjem, Senior Managing Consultant, will contribute expert analysis of mobile-source ammonia emission factors, and in particular will assist in developing an approach to adjust ammonia emissions estimated by the MOVES emission factor model specific to PCAP conditions in SLC. He will work closely with Dr. Martin to leverage field study measurement results for this purpose.

Dr. Lindhjem is an expert on emissions from highway and non-road vehicles, engines and fuels. Prior to joining Ramboll, Dr. Lindhjem's work at US EPA's Office of Transportation and Air Quality included on- and off-road mobile source regulation development, emission measurements and analysis, emission control strategies and emission inventory modeling, such as regulated pollutants and chemical compositional analysis to estimate toxic and other emissions. He has evaluated a broad range of local and national mobile source emission issues, including emission estimates and potential emission reductions from a variety of planned or demonstrated control strategies for on-road gasoline and heavy-duty diesel vehicles, as well as off-road equipment. He works with local, regional and national officials and private clients to improve on- and off-road emission inventories for regional evaluation in addition to individual facilities, such as ports, rail yards and metropolitan areas.

Dr. Ross Beardsley, Senior Consultant, will manage all photochemical modeling activities during the project. This will include implementing all adjustments to CAMx configuration and inputs obtained from UDAQ, running the modeling system (model and all pre-/post-processors), conducting post-modeling analyses, and developing all graphics and tabular summaries. Dr. Beardsley will be assisted by other photochemical modeling experts at Ramboll.

Dr. Beardsley is experienced in both the development and use of air quality models. He has advanced knowledge of atmospheric processes, as well as environmental monitoring and data analysis. Ross has developed new atmospheric modeling tools and utilized such regional and global models as CAMx, CMAQ, and GEOS-Chem, including direct experience with UDAQ's CAMx system for Salt Lake City modeling. Ross was the primary developer of a comprehensive secondary organic aerosol (SOA) model that predicts the chemical and physical transformation of volatile organic compounds (VOCs) in the atmosphere. He also co-developed the fully automated Florida Air Quality Modeling System (http://data.as.essie.ufl.edu/faqms/) that generates three-day forecasts of Florida's air quality using WRF for meteorology and CMAQ for air quality.

Tejas Shah, Managing Consultant, will manage all emissions modeling activities during the project. This will include implementing emission adjustments by source sector and processing raw inventory and emission factor data to model-ready inputs using the SMOKE processor, according to the configuration obtained from UDAQ. Mr. Shah will be assisted by other emission experts at Ramboll.

Mr. Shah has over 15 years of experience with air pollution analyses. His expertise includes emission modeling, emission inventory development, spatial analysis with GIS, database tool development, control-measure evaluation and economic impact analysis. He has extensive experience using US and Canadian national emissions inventories. Mr. Shah's projects at Ramboll include Sparse Matrix Operator Kernel Emissions (SMOKE) processing of regional and project-level emission inventories for various projects in the Intermountain West, including direct experience with UDAQ's SMOKE system for Salt Lake City modeling. He has also prepared gridding surrogates and speciation profiles for the SMOKE model input; augmented SPECIATE—a repository of speciation profiles; and prepared landuse/landcover inputs for CAMx and the MEGAN biogenic model.

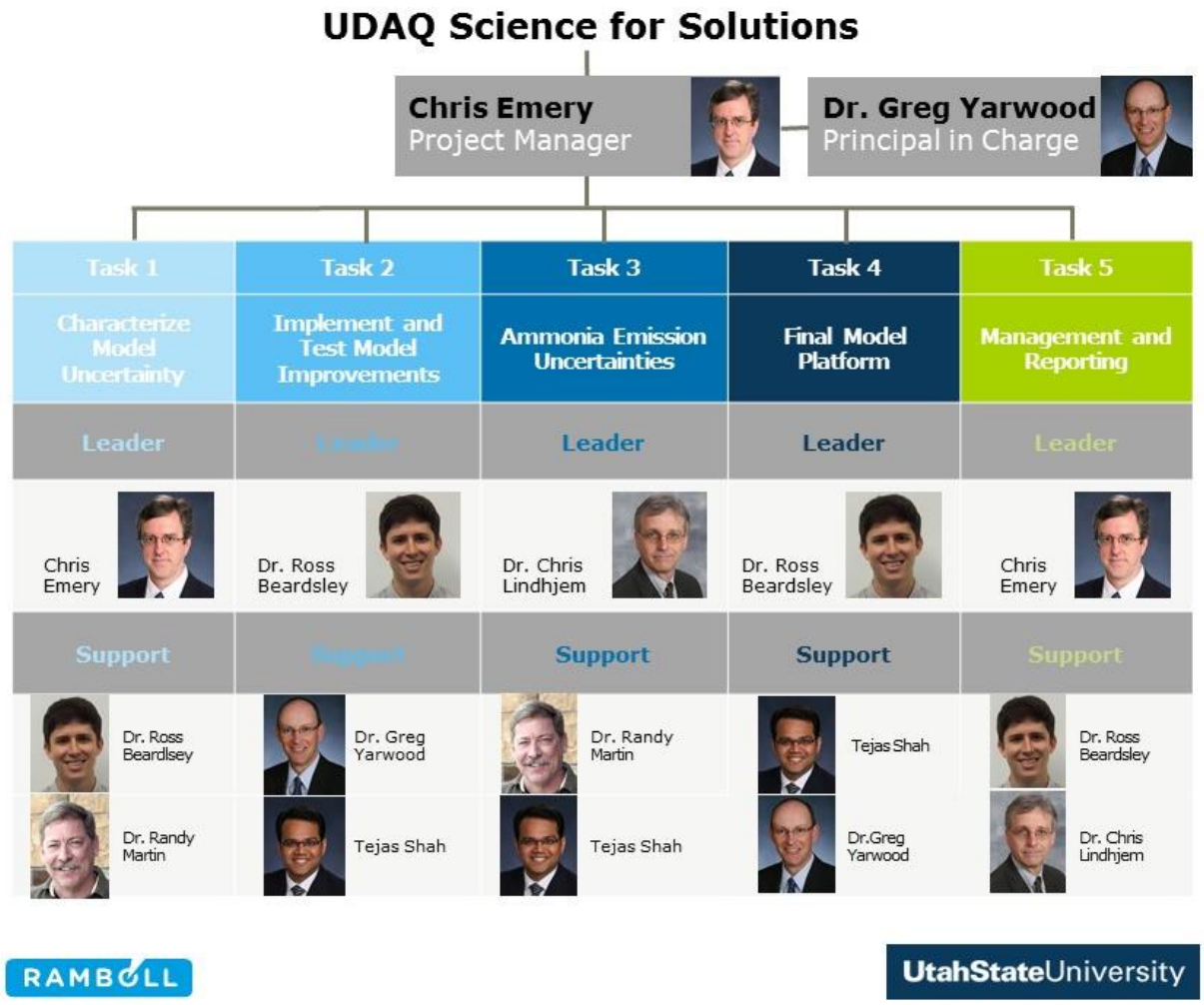

Figure 3. Proposal organizational structure for the proposed project.

APPENDIX A

Resumes of Key Personnel

CHRISTOPHER A. EMERY

Senior Managing Consultant

Chris Emery has 27 years of experience in numerical modeling and analysis of urban and regional air pollution and meteorology. His expertise includes design, development and application of air quality modeling systems. Chris co-authors the Comprehensive Air Quality Model with extensions (CAMx)—a regional nested grid photochemical model with Plume-in-Grid and Probing Tool extensions. He also prepares the CAMx User's Guide, and manages public distributions of CAMx and support programs. He has delivered CAMx training for numerous US and international clients including private, governmental, and academic institutions for over fifteen years. He has applied a variety of models for private and public clients, in both local and regional regulatory arenas, throughout the US and abroad. His projects have included ozone, particulate matter (PM_{10} and $PM_{2.5}$) and carbon monoxide modeling to support regulatory planning; determining effects of alternative and innovative air quality management strategies; analyzing source contributions and emission sensitivity; modeling fate of toxic air pollutants; studying prospective and retrospective air quality trends; estimating North American background ozone; and simulating source impacts on national parks and wilderness areas. Chris has applied and evaluated meteorological models and global chemical transport models to develop inputs needed by regional photochemical modeling applications. He has served as a member of the American Meteorological Society's Board of the Urban Environment.

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EDUCATION

1990 MS, Meteorology, San Jose State University, San Jose, USA
1988 BS, Meteorology, San Jose State University, San Jose, USA

CAREER

1995-Present, Senior Managing Consultant, Ramboll (formerly ENVIRON)
1990-1995, Staff and Senior Scientist, ICF Systems Applications International

EXPERIENCE

Air Quality Model Development

- Co-developer of Ramboll's Comprehensive Air Quality Model with extensions (CAMx); manages updates and distribution and associated pre- and postprocessors, model documentation and training.
- For UDAQ, implemented physical and chemical updates into CAMx to better characterize snow-covered winter conditions in the Uintah Basin of Utah.
- Leading a program to provide technical support for CAMx applications throughout China.
- Co-developer of emission estimating models for sea salt, wind-blown dust, and lightning NOx.

- Assisting the development and testing of a real-time CAMx air quality forecasting system for Texas.
- Co-developer of the Mesoscale Model InterFace (MMIF) program that directly translates MM5 and WRF meteorological output to CALPUFF and AERMOD input format.

Air Quality Model Applications

- Reviewed attainment demonstration modeling developed by the State of Utah for the Salt Lake City $PM_{2.5}$ SIP and conducted specialized analyses including source apportionment and major point source precursor demonstration modeling.
- Developed modeling guidance for assessing single-source impacts on ozone and PM2.5 in the Lower Fraser Valley of British Columbia.
- Managed assistance to the San Francisco Bay Area Air Quality Management District of California with developing CMAQ modeling of toxic contaminants in support of analyses related to AB617 actions.
- Managed assistance to the San Joaquin Valley Air Pollution Control District of California with CMAQ/SMOKE air quality modeling in support of the PM2.5 State Implementation Plan.
- Managed the development of CAMx ozone and $PM_{2.5}$ modeling systems and databases to support regulatory modeling for Baton Rouge, LA, Phoenix, AZ, Birmingham, AL, San Francisco Bay Area, CA, Boise, ID, San Antonio/Austin, TX, among others.
- Managed an analysis of and comments on EPA's draft guidance on Modeled Emissions Rates for Precursors (MERP) addressing single-source impacts on ozone and PM2.5.
- Evaluated global chemical transport models (GEOS-Chem, MOZART, AM3) to characterize US background sources of ozone and to supply boundary conditions for regional models (CAMx and CMAQ).
- Assisted in the development of a CAMx ozone and PM modeling program for the Po Valley (Milan) area of Italy, the Marseille area of France, and the Medellin area of Colombia.
- Managed a unique modeling project of North America to estimate ozone sensitivity to US anthropogenic precursor reductions to help inform the EPA ozone NAAQS review process.
- Managed a North American modeling analysis to estimate spatial and temporal patterns in background ozone over the US, and related source attribution, for input to the EPA ozone NAAQS review process.

Meteorological Model Applications and Analysis

- Managed a high-resolution application of WRF to the Upper Green River Basin in southwest Wyoming to support winter photochemical modeling of the area.
- Managed an application of WRF to provide boundary conditions for highly refined computational fluid dynamics (CFD) windflow modeling of a neighborhood in the South Coast air basin in California.
- Managed testing of WRF meteorological model improvements that allow for more detailed treatment of clouds and vertical diffusion in the CAMx photochemical model.

Specialized Analyses

- Managed an analysis of impacts on mobile-source NOx, VOC, and CO emissions from gasoline RVP changes in Baton Rouge, LA.
- Reviewed and developed new recommendations on photochemical model performance evaluation and benchmarks for statistical performance metrics.
- Assisted in an EPA evaluation of various modeling platforms for the purpose of simulating single-source impacts on ozone, PM, visibility, and AQRVs for NEPA, PSD, and NSR assessments.
- Applied and evaluated modeling methodologies that simulate the impacts of Urban Heat Island (Cool Communities) measures involving intensive tree planting and use of light-colored building materials to lower urban temperatures and ambient pollutant concentrations in Los Angeles and Houston.
- Assisted in the development of guidance for performance evaluation of air quality modeling systems for PM2.5 and visibility.

PROFESSIONAL AFFILIATIONS AND ACTIVITIES

- Air and Waste Management Association (AWMA)
- American Meteorological Society (AMS)

RECENT PUBLICATIONS

Emery, C., Z. Liu, A.G. Russell, M.T. Odman, G. Yarwood, N. Kumar. 2017. "Recommendations on statistics and benchmarks to assess photochemical model performance." Journal of the Air and Waste Management Association, DOI: 10.1080/10962247.2016.1265027.

Downey, N., C. Emery, J. Jung, T. Sakulyanontvittaya, L. Hebert, D. Blewitt, G. Yarwood. 2015. "Emission Reductions and Urban Ozone Responses Under more Stringent US Standards". Atmos. Environ., 101, 209-216, http://dx.doi.org/10.1016/j.atmosenv.2014.11.018.

Baker, K.R., C. Emery, P. Dolwick, G. Yarwood. 2015. "Photochemical Grid Model Estimates of Lateral Boundary Contributions to Ozone and Particulate Matter across the Continental United States." Atmos. Environ., 123, 49-62.

Karamchandani, P., C. Emery, G. Yarwood, B. Lefer, J. Stutz, E. Couzo & W. Vizuete. 2015. "Implementation and Refinement of a Surface Model for Heterogeneous HONO Formation in a 3-D Chemical Transport Model". Published online in Atmospheric Environment; 2015 January; doi: 1016/j.atmosenv.2015.01.046.

Yarwood, G., C. Emery, K. Baker, and P. Dolwick. 2014. "Resolving and Quantifying Ozone Contributions from Boundary Conditions Within Regional Models." Air Pollution Modeling and its Application XXIII. Springer Proceedings in Complexity, DOI: 10.1007/978-3-319-04379-1_17. Springer International Publishing Switzerland.

Lefohn, A., C. Emery, D. Shadwick, H. Wernli, J Jung, S. Oltmans. 2014. "Estimates of Background Surface Ozone Concentrations in the United States Based on Model-Derived Source Apportionment." Atmos. Environ., 84., 275-288, http://dx.doi.org/10.1016/j.atmosenv.2013.11.033.

Yarwood, G., C. Emery, J. Jung, U. Nopmongcol, T. Sakulyanontvittaya. 2013. "A Method to Represent Ozone Response To Large Changes In Precursor Emissions Using High-Order Sensitivity Analysis In Photochemical Models." Geosci. Model Dev., 6, 1601–1608, doi:10.5194/gmd-6-1601-2013. September.

Emery, C.A., J. Jung, N. Downey, J. Johnson, M. Jimenez, G. Yarwood, R. Morris. 2012. "Regional and Global Modeling Estimates Of Policy Relevant Background Ozone Over the United States." Atmos. Environ., Volume 47, pp 206-217. February.

Nopmongcol, U., B. Koo, E. Tai, J. Jung, P. Piyachaturawat, C. Emery, G. Yarwood, G. Pirovano, C. Mitsakou, G. Kallos. 2011. "Modeling Europe with CAMx for the Air Quality Model Evaluation International Initiative (AQMEII)." Atmos. Environ., doi:10.1016/j.atmosenv.2011.11.023

Emery, C.A., E. Tai, R.E. Morris and G. Yarwood. 2011. "Investigation into Approaches to Reduce Excessive Vertical Transport Over Complex Terrain in a Regional Photochemical Grid Model." Atmos. Environ., Volume 45, Issue 39, pp 7341-7351. December.

Emery, C.A. and G. Yarwood. 2010. "Modeling Chemically Reactive Air Toxics with CAMx. Air Pollution Modeling and its Application XX." Douw Steyn, S. Triviktrama Rao, eds., Springer.

Martien, P., S. Tanrikulu, Y. Jia, D. Fairley, C. Tran, J. Matsuoka, H. Hildin, C. Emery, and G. Yarwood. 2010. "Evaluation of Toxic Air Contaminants in the San Francisco Bay Area. Air Pollution Modeling and its Application XX." Douw Steyn, S. Triviktrama Rao, eds., Springer.

GREGORY YARWOOD

Principal

Dr. Greg Yarwood is an internationally recognized expert with over 25 years of experience in atmospheric chemistry, air quality modeling, photochemical model development, interpreting ambient air quality data, and emissions inventory development. He holds a PhD in chemistry from the University of Cambridge and his publications in peer-reviewed scientific journals are highly cited with an h-index of 30 (30 publications cited more than 30 times). Greg directs air quality, meteorological and emissions modeling studies for clients in government and industry, with emphasis on photochemical air pollution issues such as secondary particulate matter (PM), visibility, ozone and air toxics. He has developed emission inventories for industrial sources, mobile sources and natural biogenic sources. Greg directs the development of Ramboll's Comprehensive Air quality Model with extensions (CAMx: http://www.camx.com) for modeling ozone, PM2.5 and toxic air contaminants at urban to regional scale. CAMx is unique in providing advanced modeling techniques for source attribution and sensitivity analysis which Dr. Yarwood designed and implemented. He assists the state of Texas in developing ozone State Implementation Plans (SIPs) for the Houston and Dallas non-attainment areas and assists "near-nonattainment areas" with planning activities to further improve their air quality. Greg is an experienced communicator of technical information at public meetings, workshops, trainings and scientific conferences. He has performed international air quality studies in Europe, the Middle East, China and Africa. Greg was a member of the USEPA's Board of Scientific Counselors for the Clean Air Research Program.

CONTACT INFORMATION
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EDUCATION

PhD, Chemistry, University of Cambridge, UK
BSc, Chemistry, University of Bath, UK

CAREER

1995-Present, Principal, Ramboll (formerly Environ)
1991-1995, Senior Scientist, ICF Systems Application International
1988-1991, Post-Doctoral Researcher, Centre for Atmospheric Chemistry, York University, Canada
1987-1988, Post-Doctoral Researcher, Brookhaven National Laboratory, New York

EXPERIENCE

Regional Air Quality Planning

- Near-real-time (NRT) photochemical modeling for Texas since 2013. The WRF/CAMx-based system models US-wide air quality with fine-scale resolution for Dallas and Houston.
- Global modelling using GEOS-Chem to determine contributions of US and foreign emissions to background ozone in Texas' ozone non-attainment areas.

- Developed ozone control strategies for the Northeast Texas region through a multi-stakeholder process. These measures are included in the Texas State Implementation Plan (SIP) and the region is attaining the National Ambient Air Quality Standards (NAAQS).
- Regional air quality planning studies for the Arabian Gulf (confidential client), China (Pearl River Delta) and Southern Africa (Cross-border Air Pollution Impact Assessment).
- Modeling weekday/weekend emissions changes and air quality for the Los Angeles area to demonstrate that lower weekend NOx emissions are the cause of higher weekend ozone.

Emission Inventories

- Directed emission inventories to assess electrification of vehicles and mobile equipment and associated changes in electric power generation.
- Directed optical remote sensing studies to measure VOC, NOx and SOx emissions from chemical industry facilities in Texas and the Middle East.
- Developed the GloBEIS biogenic emission inventory system as an ACCESS database application. Directed software development, GIS analysis of landcover and satellite data, and tree surveys.
- Developed procedures for analyzing point-specific data to develop VOC speciation profiles for photochemical modeling of the Houston and Dallas areas.
- Analyzed the effects of reformulated/alternative fuels and advanced vehicles on mobile source emissions for the joint Auto/Oil Air Quality Improvement Research Program (AQIRP).

Photochemical Model Development

- Ramboll's Comprehensive Air quality Model with extensions (CAMx). Greg has primary responsibility for the gas-phase chemistry for ozone and secondary PM, and the advanced "probing tools" for source apportionment (OSAT and PSAT), sensitivity analysis (DDM) and chemical process analysis (CPA).
- Designed a full-chemistry plume-in-grid model for CAMx called IRON-PiG (Incremental Reactions for Organics and NOx) to better represent the evolution of plumes from major point-sources within a grid model simulation.

Air Quality Data

- Developed conceptual models describing the reasons for high 1-hour and 8-hour ozone in the Dallas area and Northeast Texas to guide the development of the State Implementation Plan.
- Designed aircraft-based and surface monitoring studies for ozone and precursors in Texas.
- Analyzed ozone air quality benefits for reformulated fuels and advanced vehicle programs across all of Canada for the Canadian Council of the Ministers of the Environment.
- Reviewed VOC receptor modeling and ambient ratio (VOC/NOx and CO/NOx) studies for evidence of systematic biases between emission inventories and ambient data.

Atmospheric Chemistry

- Member of the CRC Research Panel on the Atmospheric Chemistry of Hydrocarbons (RPACH) that published reviews of the chemistry of alkenes and aromatic hydrocarbons.
- Developed the 2005 version of the Carbon Bond mechanism (CB05) used for EPA regulatory modeling studies of ozone, particulate matter and air toxics.
- Made laboratory measurements of reaction rates for NOx species under high temperature (combustion) and low temperature (stratospheric) conditions.

PROFESSIONAL AFFILIATIONS AND ACTIVITIES

- Air and Waste Management Association (AWMA)
- American Association for Aerosol Research (AAAR)
- American Chemical Society (ACS)
- American Geophysical Union (AGU)

RECENT PUBLICATIONS

2019
Simulation of fresh and chemically-aged biomass burning organic aerosol.
Atmospheric Environment, 196, pp.27-37.
Authors: Posner, L.N., Theodoritsi, G., Robinson, A., Yarwood, G., Koo, B., Morris, R., Mavko, M., Moore, T. and Pandis, S.N.

2018
Multipollutant modeling of ozone, reactive nitrogen and HAPs across the continental US with CMAQ-CB6.
Atmospheric Environment. doi.org/10.1016/j.atmosenv.2018.11.060
Authors: Luecken, D.J., Yarwood, G. and Hutzell, W.T.

2017
Strong influence of deposition and vertical mixing on secondary organic aerosol concentrations in CMAQ and CAMx.
Atmospheric Environment. doi.org/10.1016/j.atmosenv.2017.10.035.
Authors: Shu, Q., Koo, B., Yarwood, G. and Henderson, B.H.

2017
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Authors: Nopmongcol, U., Grant, J., Knipping, E., Alexander, M., Schurhoff, R., Young, D., Jung, J., Shah, T. and Yarwood, G.

2016
Source Apportionment of Emissions from Light-Duty Gasoline Vehicles and Other Sources in the United States for Ozone and Particulate Matter.
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Authors: Vijayaraghavan, K., C. Lindhjem, B. Koo, A. DenBleyker, E. Tai, T. Shah, Y. Alvarez, G. Yarwood.

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2014
Emission Measurements of Alkenes, Alkanes, SO2 and NO2 from Stationary Sources in Southeast Texas over a 5-Year-Period Using SOF and Mobile DOAS.
Journal of Geophysical Research: Atmospheres. January.
Authors: Johansson, J., J. Mellqvist, J. Samuelsson, B. Offerle, B. Lefer, B. RappenglÃ¼ck, J. Flynn, and G. Yarwood.

DR. RANDAL S. MARTIN
Associate Research Professor
Environmental Engineering, Air Pollution
Department of Civil and Environmental Engineering
Utah Water Research Laboratory
Utah State University

EDUCATION:

B.S. Env. Eng., 1982, Montana Institute of Mining and Technology, Butte, MT
M.S. Civil and Environmental Engineering, 1989, Washington State University, Pullman, WA
PhD. Civil and Environmental Engineering, 1992, Washington State University, Pullman, WA

PROFESSIONAL EXPERIENCE:

Associate Research Professor
Associate Director, Utah Climate Center
Utah State University/Utah Water Research Laboratory, Logan, UT, 2000 - present

Assistant/Associate Professor
New Mexico Institute of Mining & Technology, Socorro, NM, 1992 - 2000

Graduate Research Assistant I & II
Washington State University, Pullman, WA 1987 - 1992

Assistant/Associate Environmental Engineer
Southern Research Institute, Birmingham, AL, 1982 - 1987

OTHER PROFESSIONAL ACTIVITIES:

State of Utah Air Quality Board, member (2017-present)
Fulbright Scholar to An-Najah National University (2018, 2019)
Air and Waste Management Association
- Chair, Higher Education Division (2003-2007; 2016-present)
- Vice-Chair, Higher Education Division (2001-2003; 2007- 2010)
- Chair, Scholarship Awards Committee (1996-2001)
- Chair, Student Affairs Committee (2000-2002)

American Geophysical Union
- Editorial Board, Earth-In Space Journal (1995-2000)

American Society of Agricultural & Biological Engineers
Association of Environmental Engineering and Science Professors
American Chemical Society
Engineers Without Borders

RESEARCH INTEREST:

Dr. Martin's research interests center around the measurement and analysis of atmospheric trace species, most notably the characterization and behavior of ambient fine particulate matter ($PM_{2.5}$ and PM_{10}), reactive hydrocarbons and related oxidation products (e.g. ozone). My expertise includes air pollution photochemistry, air quality monitoring, biogenic emissions measurements, air pollution modeling, advanced oxidation processes for gaseous pollutant control, and source particulate fractionation and measurement. Dr. Martin has been heavily involved with Utah air quality issues including studies of the Uinta Basin's wintertime ozone issues, fine particulate ($PM_{2.5}$) behavior and characteristics in the Cache Valley and along the Wasatch Front, and mobile source emissions inherent to Utah's vehicle fleet and regional conditions.

RECENT AND RELEVANT PUBLICATIONS, PRESENTATIONS, AND REPORTS

Moravek, A. et al. (2019), Wintertime spatial distribution of ammonia and its emission sources in the Great Salt Lake region, in final preparation, to be submitted to the Atmospheric Chemistry and Physics (ACP) journal Jan. 2019.

Khader, A. and R.S. Martin (2019), On-the-road testing of the effects of driver's experience, gender, speed, and road grade on car emissions, submitted to the J. Air Waste Assoc. December 31, 2018.

Dupont, R.R., J. Wiedhass, J. McLean, R. Martin, L. Allen, and C. Flint (2018), Helath Impacts of exposure to microbial chemical hazards in reclaimed wastewater used in urban agriculture, Cache Valley Utah, presented at the USDA Project Directors Meeting, Dec. 1, 2018, Chicago, IL, USA.

Ahmadi, L., K.T. Duodu, R.R. Dupont, R.S. Martin, and J.E. McLean (2018), Investigating various methods of pharmaceutical compound detection in aerosols from reclaimed water sprinkler irrigation, in the proceedings of the 11th International Conference on Irrigation and Drainage, Oct. 15-19, 2018, Phoenix, AZ, USA.

Hammond, I., R.S. Martin, P. Silva, and M. Baasandorj (2017), Wintertime ambient ammonia concentrations in northern Utah's Urban Valleys, paper A53B-2218, presented at the Fall Meeting of the American Geophysical Union, Dec. 11-15, 2017, New Orleans, LA, USA.

Baasandorj,M. et al. (2017), 2017 Utah Winter Fine articulate Study: Final Report, submitted to the Utah Division of Air Quality, March 16, 2018 (https://documents.deq.utah.gov/air-quality/planning/technical-analysis/research/northern-utah-airpollution/utah-winter-fine-particulate-study/DAQ-2018-004037.pdf)

Horel, J., E. Crosman, A. Jacques, B. Blaylock, S. Arens, A. Long, J. Sohl, and R. Martin (2016), Summer Ozone Concentrations in the Vicinity of the Great Salt Lake, Atmos. Sci. Letters, in final revision, Manuscript ID ASL-16-021.R2.

Martin, R.S. (2016), Measurement of Ambient Hydrochloric Acid near Utah's Great Salt Lake, project report submitted to P. Barickman, Utah Division of Air Quality, Apr. 2016.

Horel, J., E. Crossman, S. Arens, R. Martin, and J. Sohl, 2015 Great Salt Lake Summer Ozone Study, project report submitted to P. Barickman, Utah Division of Air Quality, Jan. 2016.

Wang, S.-Y., L.E. Hipps, O.-Y. Chung, R.R. Gillies, R. Martin (2015), Long-term winter inversion properties in a mountain valley of the western United States and implications on air quality, *J. Amer. Meteor. Soc*., Vol. 54, Dec. 2015, 2339-2352.

Moore, K.D., M.D. Wojcik, R.S. Martin, C.C. Marchant, D.S. Jones, W.J. Bradford, G.E. Bingham, R.L. Pfeiffer, J.H. Prueger, and J.L. Hatfield (2015), Particulate-matter emission estimates from agricultural spring-tillage operations using LIDAR and inverse modeling*, J. Applied Remote Sensing*, Vol. 9, 096066-1 – 0960966-23.

Moore, K.D., R. Martin, W. Bradford, C. Marchant, D. Jones, M. Wojcik, R. Pfeiffer, J. Prueger, and J. Hatfield (2015), Derivation and Use of Simple Relationships between Aerodynamic and Optical Particle Measurements, J. Environ. Eng., 141(4): 04014078.

Edwards, P.M., K. Akin, J. deGouw, W.P. Dubé, J. Gillman, D. Helmig, J.S. Holloway, B. Lerner, R. McLaren, D.D. Parrish, J. Peischl, J.M. Roberts, T.B. Ryerson, R. Martin, C. Warneke, E.J. Williams, C.J. Young, and S.S. Brown (2013), Ozone photochemistry in a natural gas basin during winter: Simulations of results from the 2012 Uintah Basin Winter Ozone Study, submitted to *Atmos. Chem. and Phys.*, 13, 8955-8971.

Moore, K.D., M.D. Wojcik, R.S. Martin, C.C. Marchant, G.E. Bingham, R.L. Pfeiffer, J.H. Prueger, and J.L. Hatfield (2013), Particulate Emissions Calculations from Fall Tillage Operations using Point and Remote Sensors, *J. of Env. Quality***,** 42(4), 1029-1038.

Moore, K.D.,E. Young, C. Gurell, M. D. Wojcik, R. S. Martin, G. E. Bingham, R. L. Pfeiffer, J. H. Prueger, J. L. Hatfield (2013), Ammonia Measurements and Emissions from a California Dairy using Point and Remote Sensors, Aug. 2013, *Transaction of the ASABE.*

CHRISTIAN LINDHJEM

Senior Managing Consultant

Dr. Christian E. Lindhjem is an expert on emissions from highway and non-road vehicles, engines and fuels. Prior to joining Ramboll as ENVIRON, Chris' work at USEPA's Office of Transportation and Air Quality included on- and off-road mobile source regulation development, emission measurements and analysis, emission control strategies and emission inventory modeling, such as regulated pollutants and chemical compositional analysis to estimate toxic and other emissions. Chris has evaluated a broad range local and national mobile source emission issues. These include emission estimates and potential emission reductions from a variety of planned or demonstrated control strategies for on-road gasoline and heavy-duty diesel vehicles, as well as off-road equipment. He works with local, regional and national officials and private clients to improve on- and off-road emission inventories for regional evaluation in addition to individual facilities, such as ports, rail yards and metropolitan areas.

CAREER

1998-Present Senior Managing Consultant
1990-1998 Engineer, U.S. Environmental Protection Agency (EPA)

- Nonroad Mobile Emissions
- Highway Mobile Emissions Model
- Engine Testing Project Management
- Clean Fuels Development

1988-1990 Research Engineer, Westvaco Corporation

EDUCATION

1983-1987 PhD, Chemical Engineering, Rensselaer Polytechnic Institute
1980-1981 MS, Chemical Engineering, University of Michigan
1976-1980 BS, Chemical Engineering; BS, Chemistry, Rose-Hulman Institute of Technology

LANGUAGE SKILLS

English, German

EXPERTISE\PROJECTS

On-Road Emission Inventories

- Managed projects to estimate metropolitan area and project level emissions estimates using the EPA MOVES, California ARB EMFAC, and European COPERT models. Managed projects to incorporate link level modeling for Chicago, Cleveland, Cincinnati, Denver, Detroit, and Atlanta including MOVES model adjustments and vehicle volume and mix of heavy and light-duty vehicles adjusted by time of data and road type. Performed evaluations of the on-road vehicle mix and vehicle weight data from Automatic Traffic Recorders to better estimate on-road emissions for EPA, Illinois, Ohio, Wisconsin, and Minnesota. Led programs to develop new strategies and uses for alternative data to evaluate on-road vehicle emissions for EPA and the Coordinating Research Council in preparation of the MOVES model. Applied the COPERT model to estimate average emissions for Middle East nations using local fleet characteristics and age and speed distributions and activity in terms of travel or fuel

CONTACT INFORMATION

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consumption. We have used vehicle emissions models to compare with real world emissions measurements from laboratory, portable equipment, remote sensing, and other studies.

On and Off-Road Mobile Source Control Strategies

- Provided detailed technical analyses and planning and day to day support of on-road and off-road mobile source control strategies for local and state government agencies including Houston-Galveston Area Council (HGAC), the East Texas Council of Governments (ETCOG), North Central Council of Governments (NCTCOG), and the Texas Commission on Environmental Quality (TCEQ). Also I have and continue to assist in revisions/updates to the mobile source emission inventory such as in Colorado, Chicago and other Midwest metropolitan regions, and Las Vegas. Provided the plan and technical guidance for the HGAC Voluntary Mobile Source Emission Reduction Program (VMEP) including marketing and online database and interactive programs, and reviews and evaluation of the Texas Emission Reduction PLAN (TERP) for the Houston Advanced Research Center (HARC).

Mobile Source Emissions Air Quality Impact Evaluation

- Providing limited and innovative plans to evaluate and mitigate mobile source emissions at a project level for specific facilities and locations. Provided technical support for estimating on-road emissions and spatial, temporal, and exhaust characteristics to evaluate air quality impacts at intersections for General Conformity and State Implementation Plans.

Chemical Constituents of Mobile Source Emissions

- I performed literature review and data evaluation of the chemical constituents including photochemically active and potential toxic components of exhaust and evaporative vehicle and offroad equipment emissions for the EPA and other clients. We estimated the emission reduction potential and impacts on air quality and toxicity from replacing diesel with biodiesel fuel in heavy-duty diesel vehicles and gasoline and diesel additives and alternative fuels.

Scientific Emissions Research and Analysis

- Performed scientific evaluation of emission modeling methods such as critically reviewing evaporative emissions estimates in MOVES and an extensive report (E-68) for the Coordinating Research Council (CRC) of EPA MOVES modeling framework. The CRC project followed and preceded work for EPA to develop and executed methods using on-board emissions monitor and laboratory data to estimate emissions from onroad and offroad vehicles and equipment using driving behavior and emissions related the physical and operating parameters of the vehicle or engine.

Off-Road Emission Inventories

- Provided service to state agencies, ports, and BNSF Railway by improving air emissions inventories from all nonroad mobile sources. Conducted in-depth locomotive and other emissions evaluations for BNSF railyards and mainline emissions in California, Chicago, and Kansas City in preparation for dispersion modeling impact analysis on the local community. For the Lake Michigan Air Directors Consortium (LADCO), a plan was developed and implemented for revising and developing activity estimates for all off-road emission sources. Prepared revised emissions inventories some categories or all nonroad (including aircraft, commercial marine, and locomotive sources) for the States of Arizona, Kansas, Texas, Arkansas, Oklahoma, Wyoming, Wisconsin, Illinois, Indiana, Michigan, Ohio, New Jersey, and the Western Regional Air Partnership (WRAP). Assisted EPA in improvements to the NONROAD model for off-road emissions estimation including for instance detailed technical comparisons of EPA and CARB models for estimating emissions from nonroad mobile sources.

Commercial Marine, Rail, and Intermodal Site Emissions Evaluations

- Conducted in depth analysis and method formulation to revise locomotive and commercial marine emissions inventories for ports and railroads, states, and national agencies. We used Automatic Information System (AIS) data to prepare grid scale emissions inventories from large ocean-going vessels commercial marine engines for the State of Texas. Also, we provided EPA similar grid level estimates by combining near port ship channels and open-ocean emissions by route. Provided detailed grid level rail locomotive emissions by rail link using national transportation links identified by GIS shapefiles for Kansas and Texas. We prepared detailed Port air emission inventories for Port of Oakland, San Francisco, and San Diego combining detailed ship, harbour craft, cargo handling equipment, drayage trucking, and rail locomotive activity.

PUBLICATIONS

2018 "Port of Oakland 2017 Seaport Air Emissions Inventory," Prepared for the Port of Oakland, September. Chris Lindhjem, Till Stoeckenius, John Grant, and Lit Chan

2017 "BNSF Locomotive Fleet Emissions," prepared for the BNSF Railway March, Chris Lindhjem and Lit Chan

2017 "Ocean-Going Tanker Vessel Lightering Emissions in the Gulf of Mexico," Prepared for the Texas Council on Environmental Quality (TCEQ) June. Timothy Sturtz, Maria Zatko, and Chris Lindhjem

2016 "Canadian Great Lakes Vessel Fleet Emissions," Lindhjem, C., T. Stoeckenius, R. Singh, A. Ai. 2016. Prepared for Canadian Shipowners Association and the Chamber of Marine Commerce, Ottawa, Ontario, Canada. December.

2016 "Transportation-Related Multi-Pollutant Emission Reduction Measures Summary," Prepared for the Houston-Galveston Area Council, October. Prepared by Christian Lindhjem and Barbara Joy

2016 "Source Apportionment of Emissions from Light-duty Gasoline Vehicles and Other Sources in the United States for Ozone and Particulate Matter," Journal of the Air & Waste Management Association, 66, 2, 98-119. Vijayaraghavan, K., C. Lindhjem, B. Koo, A. DenBleyker, E. Tai, T. Shah, Y. Alvarez, G. Yarwood.

2016 "Transportation-Related Multi-Pollutant Emission Reduction Measures," Prepared for the Houston-Galveston Area Council, October. Chris Lindhjem and Barbara Joy

2015 "Link-based Modeling Emissions Inventory of Marine Vessels (Ocean Going Vessels) in Transit and at Anchor in the Gulf of Mexico," Prepared for the Texas Commission on Environmental Quality, July. Timothy M. Sturtz, Christian Lindhjem, Lit Chan, and Greg Yarwood

2014 "Trends in On-Road Vehicle Emissions and Ambient Air Quality in Atlanta, Georgia, USA from the Late 1990s through 2009." Journal of Air and Waste Management Association, 64 (7): 808-16. Vijayaraghavan, K., A. DenBleyker, L. Ma, C. Lindhjem, G. Yarwood.

2013 "Improving Emission Estimates and Understanding of Pollutant Dispersal for Impact Analysis of Beach Nourishment and Coastal Restoration Projects." Prepared for the U.S. Department of the Interior, Bureau Ocean Energy Management (BOEM), March. Stoeckenius, T., C. Lindhjem, T. Shah.

2013 "Identification of Potential Emission Reduction Strategies for the Heart of Texas Council of Governments 6-County Area." Prepared for Heart of Texas Council of Governments, Waco, TX. DenBleyker, A., Y. Alvarez, S. Kemball-Cook, C. Lindhjem, A. Bar-Ilan, G. Yarwood.

2012 "Impact of Meteorology and Anthropogenic Emissions on the Local and Regional Ozone Weekend Effect in Midwestern US." Atmos. Environ., V57, pp 13-21, September. Koo, B., J. Jung, A. K. Pollack, C. Lindhjem, M. Jimenez, G. Yarwood.

2012, "NONROAD Growth & Activity Update." Prepared for USEPA Office of Transportation and Air Quality. August. Lindhjem, C.E, J. Grant, and L. Ma.

2012 "Effects of Improved Spatial and Temporal Modeling of On-Road Vehicle Emissions." J. Air Waste Management Assoc., 62, pp. 471-484. Lindhjem C.E. A.K. Pollack, A. DenBleyker, and S.L. Shaw.

2012 "Mobile Source Emission Models with On-Road Traffic Tunnel and Remote Sensing Measurements." J. Air Waste Management Assoc. Oct;62(10):1134-49. Fujita, E.M., D.E. Campbell, B. Zielinska, J.C. Chow, C.E. Lindhjem, A. DenBleyker, G.A. Bishop, B.G. Schuchmann, D.H. Stedman & D.R. Lawson.

ROSS L. BEARDSLEY, PhD

Senior Consultant

Ross Beardsley is a Senior Consultant at Ramboll with 6 years of experience in many aspects of air quality analysis with extensive experience in air quality modeling, atmospheric chemistry, and environmental impact analysis. He has conducted numerous air quality modeling studies ranging from single source impact assessments to global scale analyses with experience in a wide array of air quality models including CAMx, CMAQ, GEOS-Chem, HYSPLIT and AERMOD. He has implemented these models to conduct investigations of photochemical air pollutants, air toxics and air quality related values (deposition and visibility). His current and recent projects include air quality modeling and analysis for resource management plans and other regulatory applications, air quality and climate analysis under the National Environmental Policy Act, and source attribution and sensitivity analysis applications. His experience spans many industrial sectors including but not limited to mining, oil and gas (upstream and downstream), electricity generation, and transportation. In addition to air quality modeling, his technical expertise includes emission quantification, health impact assessment, programming and software development (python, R, Fortran, VBA), geographic information systems, and data analysis/visualization.

CONTACT INFORMATION

Ross L. Beardsley

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+1 (415) 8990753

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7250 Redwood Boulevard
Suite 105
Novato, CA 94945
United States of America

CAREER

2016-Present
Senior Consultant
Ramboll (formerly Ramboll Environ)

2012-2016
Research Assistant - Atmospheric Chemistry
University of Florida, Environmental Engineering Sciences Department, Florida, United States

EDUCATION

2016
PhD, Environmental Engineering Sciences
University of Florida, Gainesville, Florida, United States
2012
BS, Environmental Engineering Sciences
University of Florida, Gainesville, Florida, United States

EXPERIENCE

- Air Quality Modeling Analysis of the Salt Lake City Serious $PM_{2.5}$ Nonattainment Area. Conducted air quality modeling analysis and precursor demonstration of a $PM_{2.5}$ episode in Salt Lake City and surrounding counties in support of public comments for the attainment demonstration modeling developed by the State of Utah for the Salt Lake City $PM_{2.5}$ SIP.

- Denver 2017 State Implementation Plan Modeling. Assisted in control strategy modeling of ozone to demonstration attainment of the ozone National Ambient Air Quality Standard and analyzed relative impacts of the control of nitrogen oxides and volatile organic compounds.
- Ozone Modeling Analysis for East Texas Council of Governments. Performed CAMx source apportionment modeling to determine the impact of oil and gas development on ambient ozone concentrations in Texas.
- Rosebud Mine Area F Environmental Impact Statement (EIS). Prepared the air quality and climate and climate change sections of the EIS. Analyzed impacts to air quality and air quality related values for both direct effects due to the mine and indirect effects due to the nearby power plant. Applied a regulatory dispersion model and a photochemical grid model to characterize direct, indirect and cumulative impacts.
- Navajo Generating Station Extension Lease Environmental Assessment (EA). Prepared the air quality and climate and climate change sections of the EA. Characterized existing regional air quality and utilized existing modeling analysis to estimate potential future impacts of alternatives.
- Expanded functionality of the Electric Power Research Institutes' (EPRI) Integrated Uncertainty Assessment Tool. Expanded functionality and improved usability of the tool which estimates impacts of changes in air quality concentrations on the incidence of human health endpoints using VBA and R.
- San Antonio Ozone Health Effects Study. Performed health impact analysis of changes in atmospheric concentrations of ozone in San Antonio, Texas using the EPA's Benefits Mapping and Analysis Program.
- Carbon Bond Speciation. Updated the chemical mappings of the Carbon Bond chemical mechanism (CB05/CB6) to account for new products in version 4.5 and version 5.0 of the EPA's SPECIATE repository for processing emissions of volatile organic compounds for air quality models.

PUBLICATIONS

Vijayaraghavan, K., Libicki, S., Beardsley R. L. & Ojha, S. 2018. "Modelling of Atmospheric Mercury Deposition in India." Urban Air Quality Monitoring, Modeling and Human Exposure.

Nopmongcol, U., Beardsley, R., Kumar, N. & Yarwood, G. 2018. "Changes in United States deposition of nitrogen and sulphur compounds over five decades from 1970 to 2020." Atmos. Environ. Manuscript submitted for publication.

Beardsley, R. L. & Jang, M. 2016. "Simulating the SOA Formation of Isoprene from Partitioning and Aerosol Phase Reactions in the Presence of Inorganics." Atmos. Chem. Phys Discuss, 15, 33121–33159.

Beardsley, R. & Nedbor-Gross, R. 2015. "Development of the Florida Air Quality Modeling System (FAQMS)." Insights into Sustainable Engineering, 10.

Li, J., Jang, M. & Beardsley, R. L. 2015. "Dialkylsulfate Formation in Sulfuric Acid-Seeded Secondary Organic Aerosol Produced Using An Outdoor Chamber Under Natural Sunlight." Environ. Chem. 13(4) DOI: 10.1071/EN15129. January.

Im, Y., Jang, M. & Beardsley, R. L. 2014. "Simulation of Aromatic SOA Formation Using the Lumping Model Integrated With Explicit Gas-Phase Kinetic Mechanisms and Aerosol-Phase Reactions." Atmos. Chem. Phys., 14, 4013–4027.

Beardsley, R. et al. 2013. "Role of Sea Salt Aerosols in the Formation of Aromatic Secondary Organic Aerosol: Yields and Hygroscopic Properties." Environ. Chem., 10, 167.

PRESENTATIONS

Beardsley, R. 2018. "Modeling Single-Source Impacts to Secondary Air Pollutants." Air & Waste Management Association. Hartford, CT. June.

Beardsley, R., & Koo, B. 2018. "Development of the Korean Flexible Chemistry Editor for the Korean Air Quality Modeling System." 1st Workshop for the Development of the Korean Air Quality Forecasting System. Busan, South Korea. November.

Vijayaraghavan, K., Beardsley, R., Jung, J., Yarwood G. & Morris, R. 2016. "The Contribution of Emissions Sources and Atmospheric Deposition to Mercury in South Florida and the Everglades." Society of Environmental Toxicology and Chemistry. Orlando, FL. November.

Beardsley, R. & Jang, M. 2015. "Explicit Simulation of the Secondary Organic Aerosol Formation of Isoprene from Partitioning and Aerosol Phase Reactions." American Association for Aerosol Research Conference. Minneapolis, MN. October.

COURSES AND CERTIFICATIONS

2015. University of Florida Engineering School of Sustainable Infrastructure & Environment
Outstanding Leadership & Service Award

2014. 50th Annual Florida Section Conference of the Air & Waste Management Association (A&WMA)
- 1st Place, Team Environmental Challenge International
- 2nd Place, Graduate Student Poster

2013. 32nd Annual American Association for Aerosol Research Conference, Portland, Oregon
Student Poster Contest Winner

2012-8/2016. University of Florida, Gainesville
Graduate School Fellowship Award

2012. State of Florida
Registered Engineer In Training (E.I.T.)

MEMBERSHIPS

Air and Waste Management Association (AWMA)
2016 – Present
- Vice Chair of Professional Development for the Young Professional Advisory Council

2013-2015
- President of University of Florida A&WMA Student Chapter

TEJAS SHAH

Managing Consultant

Tejas Shah has over 15 years' experience with air pollution analyses. His expertise includes emission modeling, air quality modeling, emission inventory development, spatial analysis with GIS, database tool development, control-measure evaluation and economic impact analysis. He provided GIS support to developing oil and gas emissions inventories for current and future years in the western US for the Western Regional Air Partnership (WRAP). He has recently managed a review of available emission inventories for Mexico that are used in photochemical modeling studies of North America in which we used satellite-derived data products for sulfur dioxide (SO2), nitrogen dioxide (NO2) and natural gas flaring to evaluate spatial characterization and magnitude of the emissions inventories. Tejas has managed photochemical modeling studies for the US and other world regions in which key model inputs, such as the emission inventories and landuse inputs, depend on GIS analyses of geospatial data. Additionally, he has extensive experience using the RPOs emissions inventory, the USEPA's national emissions inventory (NEI) and the Environment Canada national inventory. Tejas' work at Ramboll includes Sparse Matrix Operator Kernel Emissions (SMOKE) processing of regional and project-level emission inventories for various oil and gas EIS projects in the Intermountain West, ozone formation studies, and regional haze modeling; preparing gridding surrogates and speciation profiles for the SMOKE model input; augmenting SPECIATE—a repository of speciation profiles; spatial analyses and preparing landuse/landcover files for the Comprehensive Air Quality Model with extensions (CAMx) and MEGAN models using GIS; and developing database tools.

CONTACT INFORMATION
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7250 Redwood Boulevard
Suite 105
Novato, CA 94945
United States of America

EDUCATION

2000-2003
MS, Chemical Engineering
Lamar University, Beaumont, Texas, United States

1996-2000
BS, Chemical Engineering
Mumbai University, Mumbai, India

SELECTED RELEVANT EXPERIENCE

SMOKE-MOVES Processing for Denver Ozone Modeling

- Developed an approach to use link-based data from TDM models as input to SMOKE-MOVES processing tool. Processed detailed vehicular activity data to prepare model-ready emissions for onroad sources. The pre-gridded activity data was input to the tool for the on-network processing and treated each grid cell and speed class as a pseudo-county. The off-network emissions were spatially allocated using surrogates developed from trip starts (start exhaust)

and trip ends (for evaporative processes) by Traffic Analysis Zone (TAZ). This approach takes advantage of detailed link-based spatial and temporal varying activity data available from the TDM model and the robust emissions calculation methodology of SMOKE-MOVES that takes into account temporal and spatial variations in meteorology and has EPA approval and support.

Allegheny County PM2.5 State Implementation Plans

- Task Manager for developing emissions input for air quality modeling to demonstrate that Allegheny County (Pittsburgh), Pennsylvania will attain the PM2.5 National Ambient Air Quality Standard (NAAQS).

BLM Colorado Air Resource Management Modeling Study (CARMMS)

- Emissions Modeling Lead for the BLM CARMMS study that assess the air quality (AQ) and air quality related value (AQRV) impacts of new federal oil and gas and other cumulative sources including non-federal O&G, mining and other regional emissions in each of the BLM Colorado Field Office planning areas, as well as the Mancos Shale area in northwest New Mexico. Air quality modeling emissions inputs were developed for high, medium and low O&G development scenarios for future years 2021 and 2025.

BLM Montana/Dakotas PGM Modeling Study

- Task Manager for developing air quality modeling emissions for the BLM Montana/Dakotas PGM modeling study to assess the AQ and AQRV impacts due to oil and gas development. The Bakken Shale formation in the Montana/Dakotas region is the most rapidly growing oil and gas development area in the U.S. Under this study, Ramboll Environ is developing a comprehensive oil and gas emissions inventory and performing base year 2012/2013 and future year 2032 modeling using the CAMx photochemical grid model.

Navajo Generating Stations (NGS) EIS Assessment

Task Manager for developing criteria and HAP emission inventory for NGS for lease extension EIS. This was the most comprehensive and complete AQ, ecological and human health assessment ever performed for an EIS.

Ozone Air Quality Modeling of the Arabian Gulf

- Managed emission inventory modeling for a confidential air quality study in the Middle East. Ramboll developed a photochemical ozone modeling system based on the Comprehensive Air quality Model with extensions (CAMx).
- Developed a comprehensive emission inventory of ozone precursors (NOx, VOC and CO) for the Kingdom of Bahrain. The inventory was compiled using publicly-available data to characterize stationary sources, mobile sources and area sources and support photochemical ozone modeling.
- Managing emission inventory modeling for a confidential study in the Middle East to assess the environmental impacts of changes to transportation infrastructure and emissions.

Air Quality and Emissions Modeling Support to EPA OAQPS

- Developed ancillary files for processing oil and gas emissions for use in the EPA's national modeling platform. Work included development and assignment of speciation profiles for WRAP Phase III oil and gas source categories, development and assignment of spatial surrogates, and preparation of inventory input files for SMOKE.

BOEM Air Quality Impacts of Off-Shore Oil and Gas Production

- Currently managing regional emissions modeling for analyzing the on-shore air quality impacts of outer continental shelf oil and gas development in the Arctic Sea near Alaska and the Gulf of Mexico. This multi-year multi-million dollar study will project future year emissions and air quality impacts and develop emission exception screening thresholds.

BLM Oklahoma-Kansas-Texas (OKT) EIS and Resource Management Plan

- Managed emissions modeling task of the BLM Oklahoma-Kansas-Texas (OKT) modeling study to assess the air quality impacts of oil and gas development and coal mines on federal and non-federal lands and other cumulative regional sources. Emissions of criteria air pollutants from predicted oil and gas development in the three-state area were developed for this study.

Western Regional Air Partnership (WRAP) Region-Wide Emissions Inventory

- Provided GIS support in developing a region-wide O&G emissions inventory for current and future years in the western US for the Western Regional Air Partnership (WRAP). It includes performing spatial analyses using ARC/GIS tools, preparing map displays using ARC/MAP and developing gridding surrogates based on O&G activities using ARC Macro Language (AML) scripts.

Development of California Emission Estimator Model (CalEEMod)

- Assisted in the development of CalEEMod - a statewide land use emissions computer model designed to provide a uniform platform to quantify potential criteria pollutant and greenhouse gas (GHG) emissions associated with both construction and operational from a variety of land use projects.

Rosebud Mine, Montana EIS

- Emissions modeling Task Manager to develop regional and project-specific emissions inputs for photochemical modeling study to assess direct effects due to the Rosebud mine and indirect effects due to the nearby power plant under NEPA.

Air Quality Assessments in Alberta, Canada

- Performed emissions modeling of regional emission inventories for North East Alberta modeling studies and North Saskatchewan Region of Alberta.

PRESENTATIONS & PUBLICATIONS

Shah, T. 2017. "Composition of Organic Gas Emissions from Flaring Natural Gas" Presented at the EPA's 2017 International Emissions Inventory Conference. August https://www.epa.gov/sites/production/files/2017-11/documents/organic_gas.pdf

Shah, T., Y. Alvarez, M. Jimenez, R. Morris, A. Brimmer and K. Lloyd. 2016. "Incorporate Traffic Demand Model Data in SMOKE-MOVES Processing for Denver Ozone Modeling" Presented at the 2016 CMAS Conference. October

Nopmongcol, U., J. Grant, E. Knipping, M. Alexander, R. Schurhoff, D. Young, J. Jung, T. Shah, G. Yarwood. 2017. "Air Quality Impacts of Electrifying Vehicles and Equipment across the United States." Environmental Science & Technology. http://dx.doi.org/10.1021/acs.est.6b04868

Karamchandani, P., R. Morris, A. Wentland, T. Shah, and J. Lester. 2017. "Dynamic evaluation of photochemical grid model response to emission changes in the South Coast Air Basin in California." Atmosphere, in review.

Collet, S., T. Kidokoro, P. Karamchandani, T. Shah, and J. Jung. 2017. "Future year ozone prediction for the United States using updated models and inputs." J. Air Waste Manage. Assoc., in review.

Vijayaraghavan, K., C. Lindhjem, B. Koo, A. DenBleyker, E. Tai, T. Shah, Y. Alvarez, G. Yarwood. 2016. "Source Apportionment of Emissions from Light-Duty Gasoline Vehicles and Other Sources in the United States for Ozone and Particulate Matter." Journal of the Air & Waste Management Association, 66, 2, 98-119. doi: 10.1080/10962247.2015.1112316.

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APPENDIX B

Relevant Project Experience

Appendix B. Relevant Project Experience

Project Title & Description	Client/Contact; Period of Performance
Utah DAQ Wintertime Ozone Modeling Enhancements. Ramboll was contracted by the State of Utah to develop and test improvements to the CAMx photochemical model to better treat the evolution of snow albedo and partitioning of NOy species under cold conditions. Both effects are very important for the proper simulation of wintertime ozone events in the oil and gas development basins of the western US.	Patrick Barickman UDAQ Salt Lake City, UT (801) 536-4008 2014 - 2015
Synthesis of Results from the Uinta Basin Winter Ozone Study. A comprehensive field study examining the meteorology and atmospheric chemistry of unusual wintertime high ozone episodes in the Uinta Basin of northeastern Utah was conducted during the winters of 2012-2013 and 2013-2014. Researchers from NOAA and several universities conducted detailed measurements during these two winter seasons as part of the Uinta Basin Ozone Study (UBOS). At the request of the Utah Division of Air Quality, Ramboll worked with the UBOS Steering Committee and the various research groups involved with the winter ozone study, reviewing results and identifying areas of special interest to the air quality regulatory community. Ramboll participated in data summary webinars, assisted with organization of two technical meetings where results of individual experiments were presented, and organized, compiled and synthesized the study results from a regulatory air quality management perspective into the final UBOS Synthesis Reports for 2013 and 2014.	Brock LeBaron Utah Div. of Air Quality Salt Lake City, UT 801-536-4006 2012-2014
Three-State Air Quality Modeling Study. Ramboll was contracted by the Western Regional Air Partnership (WRAP) to conduct the Three-State Air Quality Study (3SAQS) to perform photochemical grid modeling of the western U.S. focusing on Colorado, Utah and Wyoming. CAMx 36/12/4 km photochemical grid model (PGM) modeling was conducted for the 2008 calendar year and the results distributed and used in several NEPA air quality analysis. WRF meteorological, SMOKE emissions and CAMx and CMAQ modeling was then conducted for the 2011 calendar year. A comprehensive model performance evaluation was conducted. 3SAQS is now turning to modeling the 2014 calendar year with initial results available in summer of 2015. Ramboll also performed an ambient air monitoring network assessment for the three-state region.	Tom Moore WRAP/WESTAR Fort Collins, CO (970) 491-8837 2014 - 2017
Western States Air Resources Council (WESTAR): Three-state Monitoring Networks Assessment A team led by Ramboll performed the Monitoring Network Assessment for the Three State Air Quality Study (3SAQS) for the states of Wyoming, Colorado and Utah. The assessment was designed to guide the effective use of limited air monitoring funds to support the 3SAQS	Tom Moore WRAP/WESTAR Fort Collins, CO (970) 491-8837 2014 – 2017

Project Title & Description	Client/Contact; Period of Performance
during the 2014 – 2017 study period. Ramboll gathered information on air monitoring locations, equipment and observations together and data on emissions from current and future oil and gas developments. The data were combined into a series of GIS map overlays and analyzed to evaluate the adequacy of the existing network along with locations where additional monitoring data would be most helpful in achieving monitoring objectives.	
Denver Ozone SIP Modeling. Ramboll has been leading photochemical grid modeling for the Denver ozone SIP since 2002 under contract to the Denver Regional Air Quality Council (RAQC) with consultation from the Colorado Department of Public Health and Environment (CDPHE) Air Pollution Control Division (APCD). During 2002-2003, Ramboll used the MM5/EPS/CAMx modeling system to perform 2007 ozone attainment demonstration modeling for the Denver 8-hour ozone Early Action Compact EAC) SIP. When Denver reverted to an ozone nonattainment area in November 2008, RAQC re-hired Ramboll to lead the photochemical modeling using the MM5/SMOKE/CAMx modeling system to demonstrate ozone attainment in 2010. As a follow on to the Denver SIP modeling, Ramboll performed modeling of the 2015 and 2020 years to address compliance with the new (March 2008) 0.075 ppm 8-hour ozone NAAQS. Ramboll is continuing to work for RAQC on the latest ozone SIP for Denver.	Jerry Dilley RAQC Denver, Colorado (303) 629-5450 x240 Kevin Briggs CDPHE/APCD Denver, Colorado (303) 692-3222 2002 - Present

APPENDIX C

Letters of Commitment

RAMBOLL

December 18, 2018

Amber C. Larsen
Manager, EH&S
Salt Lake City Refinery
474 West 900 North
Salt Lake City, UT 84103

RE: Co-Funding Commitment to Ramboll's Proposal: "Investigating Sources of Ammonia Uncertainty in Modeling the Salt Lake City $PM_{2.5}$ Nonattainment Area"

Dear Marise:

Thank you for Marathon's commitment to co-fund our subject proposal in response to the Utah Department of Environmental Quality (UDAQ) Science for Solutions Research Grant – FY 2020. Your commitment is contingent upon UDAQ approving their grant for this project.

By signing and dating below, and returning to me by e-mail, Marathon agrees to contribute $25,000 towards our total proposed project budget upon contract award by UDAQ. The signed letter will be included in an Appendix to our proposal.

Please contact me if you require any additional information.

Sincerely,

/s/
Chris Emery
Senior Managing Consultant
cemery@ramboll.com
415/899-0740

Marathon Petroleum Corporation commits to co-funding in the amount of $25,000:

By: Amber Larsen

Title: Manager, EH&S, Salt Lake Refinery

Date: December 21, 2018

To: **Chris Emery**, Senior Managing Consultant
Ramboll Environment and Health
50 West Broadway, Suite 300
Salt Lake City, UT 84101
(415) 899-0740
cemery@ramboll.com

From: **Dr. Randy Martin**, consultant
3236 N 1450 E
North Logan, UT 84341
(435) 797-1585
(435) 770-9666
randy.martin@usu.edu

Date: Jan. 3, 2019

Subject: Consultant agreement for Ramboll's proposal "Investigating Sources of Ammonia Uncertainty in Modeling the Salt Lake City $PM_{2.5}$ Nonattainment Area" as submitted to the Utah Department of Environmental Quality, Science for Solutions Research Grant – FY 2020

As discussed in personal and digital communications, I, Dr. Randal S. Martin, agree to participate and commit to the consultant activities as outlined in the above referenced proposal. Specifically, I will be closely involved with accessing and analyzing local measurement data from both past and upcoming (winter and summer 2019) field studies. It should be noted that these data are all public records; however, my intimate relationship with these data will allow immediate and unique insight to the material. Specific activities will include data analysis support, assistance with measurement-model-inventory comparisons, and lending local insights and experience into the relationships between emission sources and ambient concentrations in the region.

It is anticipated that the specific tasks from the above proposal that I will be explicitly involved with include, but are not limited to:

Task 1: Characterize Model Uncertainty,
Task 2: Model Improvements,
Task 3: Emission Uncertainties, and
Task 5: Management & Reporting

This consultant agreement will be funded at a fixed cost of $15,000 to be paid at a schedule to be determined later.