Development of a WRF-based Urban Canopy Model for the Greater Salt Lake City Area

Proposed by:

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1 SCOPE OF WORK

1.1 Abstract

Continued urban growth in the greater Salt Lake City metropolitan area has changed land surface properties and resulted in continued development of an urban canopy over the greater Salt Lake area (GSLA). This canopy refers to impacts on local meteorological conditions due to increased profiles of building structures and anthropogenic heating. These changes in turn impact local pollutant reactions and transport. This is particularly relevant in the GSLA due to the high levels of summertime ozone and wintertime $PM_{2.5}$ along the Wasatch Front. The influence of existing urban canopies can be observed, but accurate forecasting of weather interactions with urban areas and impacts of future urban growth require predictive modeling. Modeling can be used to fill in measurement gaps and to better understand the correlation between urban growth characteristics, meteorological properties, and ozone and $PM_{2.5}$ concentrations. Improved understanding of urban growth impacts can inform future growth planning and resulting health impacts.

This two-year project will utilize state-of-the-science meteorological modeling with land use descriptions of the GSLA to characterize impacts of urban growth on local meteorological conditions. These modified ground to atmospheric properties can then be used with state-of-the-science air quality models such as EPA's Community Multi-scale Air Quality (CMAQ) model to predict ozone and $PM_{2.5}$ behavior. This project will: 1) develop a current meteorological model of the GSLA which accounts for urban canopy impacts based on publicly available software; 2) use this model to predict impacts on local air temperature, humidity, and wind velocities for changing land use conditions, i.e., urban growth; and 3) document model methodology and usage so air quality modelers can use existing or self-developed future results for additional urban growth and air pollutant assessments.

1.2 Basis and Rationale

Despite significant efforts to reduce air pollutant emissions over several decades, the greater Salt Lake City metropolitan area (GSLA) does not fully meet federal air quality standards related to $PM_{2.5}$ and ozone concentrations. This is in part due to challenging geographic and meteorological conditions, but is also due to increasing population growth and urbanization in the GSLA. Primary pollutant sources in the GSLA are from mobile transportation sources and residential homes, both of which increase with increasing population. Pollutant levels are further exacerbated by the urban canopy effect (in analogy to vegetative canopies such as forests), which can increase pollutant formation and retention due to higher air temperatures and modified wind velocity patterns in urban areas. As increasing population drives residential, industrial, and commercial urban growth, the impact of the urban canopy effect increases. This effect can be described in more detail as follows.

Urbanization results in land changes which reduce surface evaporation and latent heat fluxes (Akbari & Kolokotsa, 2016). Urban building structures affect the momentum, turbulence, and thermal exchange between the urban surfaces and the atmosphere. Changes in land use affect the surface roughness and energy balance of incoming solar radiation and outgoing terrestrial radiation (Huang, Huang, Yang, Fang, & Liang, 2019; Li & Zhou, 2019). The interaction between surface characteristics, planetary boundary layer (PBL), and physical processes in the atmosphere affect the urban climate. These processes are in turn impacted by urban growth (Berardi, 2017; Roberge & Sushama, 2018). The heating and air temperature effects can be assessed using land surface and air temperature measurements, but an accurate spatial and temporal representation of the surface to lower atmosphere meteorological impacts requires modeling (Jato-Espino, 2019).

Current air quality modeling relies on mesoscale meteorological models to predict local air temperatures, wind velocities, and land use characteristics. The large scale of these models often results in lack of refinement for meteorological conditions and pollutant sources. Impacts of urbanization can be lost in this lack of refinement. While a detailed treatment of flow around individual buildings is beyond the scope of what can be represented in a mesoscale model, bulk effects of the urban canopy can be represented in urban canopy models (UCMs) (Jandaghian and Berardi, 2020). Figure 1 shows a schematic relating an UCM to urban energy and flow behavior. These mesoscale models have been used to study the relative influence of various surface physical characteristics on the meteorological processes in the atmosphere and to evaluate the dynamic and thermal effects of urban properties (Doan, Kusaka, & Nguyen, 2019; Jandaghian & Akbari, 2018; Jandaghian, Touchaei, & Akbari, 2017). These models provide important properties used in detailed air quality calculations (i.e., pollutant reactions and transport), and thus provide a way to predict the impact of urban growth on pollutant levels.

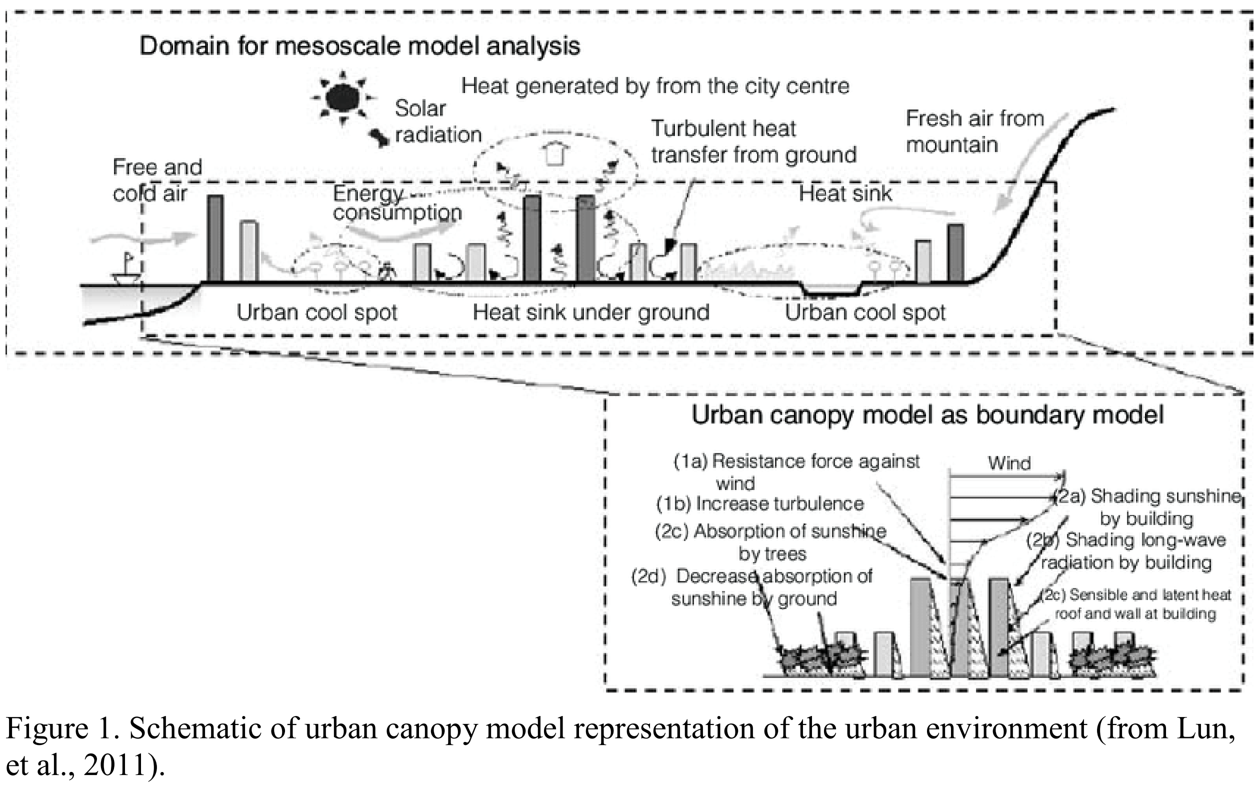


Figure 1. Schematic of urban canopy model representation of the urban environment (from Lun, et al., 2011).

The Utah Division of Air Quality (UDAQ) through topic VI of the current RFP seeks improved urban canopy modeling of the GSLA to enhance understanding of urban growth impacts on air pollutants in the GSLA. A model well suited for this type of study is the Weather Research and Forecasting model (WRF), which calculates mesoscale meteorological conditions for urban climates. Note that WRF does not directly calculate pollutant concentrations, but provides key properties (e.g., temperatures, wind velocities) used by chemical transport models (e.g., CMAQ) to compute pollutant formation, mixing, and transport. Previous modeling of the GSLA urban canopy was conducted using WRF in 2011 by AER (Nehrkorn, et al., 2011). That work was focused on characterizing the urban canopy for CO_2 measurement studies, but provides a modeling approach that can be adapted for this work.

The proposed work will: 1) develop a WRF meteorological model of the GSLA which accounts for urban canopy effects; 2) use this model to illustrate impacts on local air temperature, humidity, and wind velocities for two urban growth scenarios; and 3) document model methodology and usage so air quality modelers can use existing or self-developed future results for improved urban growth and air pollutant assessments. This research has three notable benefits. First, this model is based on publicly available software widely used by atmospheric modelers. Instead of having a proprietary model or results from a more narrowly focused modeling study, developing an urban canopy model and documenting the modeling approach based on this software will enable current and future application with multiple researchers. Second, focusing this work only on meteorological modeling, rather than coupling it with a specific chemical transport model, reduces project scope and cost while providing a more generally applicable tool. Third, illustration of impacts related to urban growth scenarios will identify specific needs for better defined land use properties and measurement studies. In summary, successful completion of this research work will provide a model and methodology that can play a significant role in understanding current urban canopy behavior and guiding future urban planning policy.

1.3 Technical Approach

The overall goal of this low-cost, focused program is to develop a WRF-based meteorological model of the GSLA that accounts for urban canopy effects and can provide inputs to downstream air quality models such as CMAQ (the EPAs premier air quality modeling software). Thus this project will provide an enabling tool that multiple researchers can use in multiple air quality and urban growth studies, rather than a single focused WRF-CMAQ air quality study. This goal will be achieved via the following three technical tasks and a fourth project management task.

1) Develop a WRF model for the GSLA that includes urban canopy calculations.
2) Evaluate meteorological changes based on two urban growth scenarios.
3) Document model usage to enable assessment of additional urban growth scenarios.

<u>Task 1 – Develop WRF-based Urban Canopy Model for the GSLA</u>

Task 1.1 – Model Development

The objective of this task to develop a WRF-based model for the GSLA that includes urban canopy effects. This model will provide adjusted wind velocity, air temperature, and humidity levels as outputs, which can be used as inputs to air quality prediction tools such as CMAQ. The current version of WRF (v4.1) has three urban canopy models (WRF-UCMs) built in – a slab model, a single layer model, and a multi-layer model. The UCMs serve as a boundary condition for planetary boundary layer calculations. The slab model is considered to have insufficient resolution to accurately represent urban canopy effects, and is used only when minimal land use data is available for inputs. The single-layer model represents urban geometry by considering street canyons as well as walls, roofs, and roads (Jandaghian and Berardi, 2020). The single-layer model considers a single orientation of the two-dimensional approximation of the streets. It evaluates the various urban classes with different thermal properties and provides an accurate estimation for sensible heat fluxes by assuming the wind distribution in the canopy. The horizontal wind is presumed to be vertically distributed as a combination of logarithmic and exponential functions. The model calculates the radiation trapping effects for multi-reflections in urban geometry and accounts for the fraction of albedo and vegetation on roofs, walls, and grounds. It estimates the anthropogenic heat as a fixed temporal profile that is added to the sensible heat flux from the street canyon.

The multi-layer urban canopy model, also named Building Effect Parameterization (BEP), is designed to capture direct interaction of buildings with the planetary boundary layer. It accounts for three-dimensional urban surfaces and for the vertical exchange of heat, moisture, and momentum. The multi-layer model provides the most vertical resolution at increase computational cost, but depends on the quality of vertical property data provided. The differences between the single-layer and multi-layer models are shown schematically in Figure 2. The multi-layer model has not shown significant improvements in simulation accuracy in several studies (Holt and Pullen 2007), so only the slab and single-layer models will be assessed for this work. The multi-layer model will be considered if the simpler models prove inaccurate.

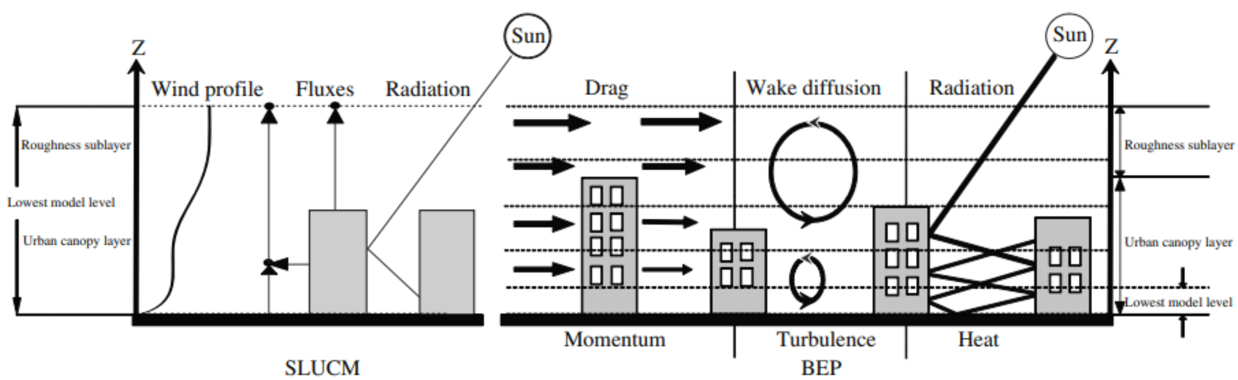


Figure 2. A schematic of the single-layer UCM (left) and the multi-layer building effect parameterization (BEP) models (right) (from Chen, et al. 2011).

WRF has previously been used in a different location for this type of modeling, and the same inputs used in that study are proposed here (Jandaghian and Berardi, 2020). The initial and boundary conditions will be taken from the North American Regional Reanalysis (NARR) (Mesinger et al., 2006). The unified NOAH land-surface model (NOAH-LSM) will provide skin (surface) temperatures, surface sensible and latent heat fluxes as lower boundary conditions for the meteorological model. Land use will be taken from the USGS 24-category data set. The

Mellor-Yamada-Janjic scheme (Janjic, 2002) will be used with the Eta similarity theory to estimate the planetary boundary layer. The Goddard scheme (Chou & Suarez, 1999) and the Rapid Radiative Transfer Model - RRTMG (Iacono et al., 2008) will be used for shortwave and longwave radiations, respectively. Lin's (2011) and Grell's (2002) schemes will be used for microphysics and cumulus models, respectively. The positive-define advection of moisture, scalars and turbulent kinetic energy will be activated to improve model stability. Table 1 summarizes the setting and the physical parametrizations planned to be applied in the WRFV4.1 model. In order to take full advantage of the UCM's capabilities, it is important to incorporate high resolution urban land use data into the WRF model treatments where the UCM is applied. High resolution urban land use data allows the UCM to better represent inputs such as urban geometry, skin temperatures of urban infrastructure, and friction velocity. As part of the model inputs, the land use types representing three urban classifications (low-intensity residential, high-intensity residential, industrial/commercial) available in the National Land Cover Database (NLCD) will be used. The default urban property inputs will be adjusted to account for Salt Lake City building and street characteristics.

Table 1
Selected settings and physical parameterizations applied in the WRF-UCMs.

Category	Option used
Microphysics	Lin Scheme
Shortwave Radiation	Goddard
Longwave Radiation	Rapid Radiative Transfer Model
Land surface model	Unified NOAH land surface model
LULC data	USGS 24-class
Planetary boundary layer physics	Mellor-Yamada-Janjic Scheme
Cumulus parameterization	Grell 3D
Advection scheme	Runge–Kutta third order

Dr. Adams is currently leading two research programs using WRF and CMAQ for modeling dust events (funded by UDAQ and NSF, respectively). As part of this, his research group has previously installed and run WRF4.1 for several time periods and so are familiar with operation of the most recent version of the software and its documentation. As an example, Figure 3 compares WRF predicted air temperature and wind velocity vectors for northern Utah at 4:00 am April 12 and 4:00 am April 13, 2017 as a weather front was moving through Utah. Note the distinct changes in temperature and flow patterns as the warming front moved through over this 24-hour period.

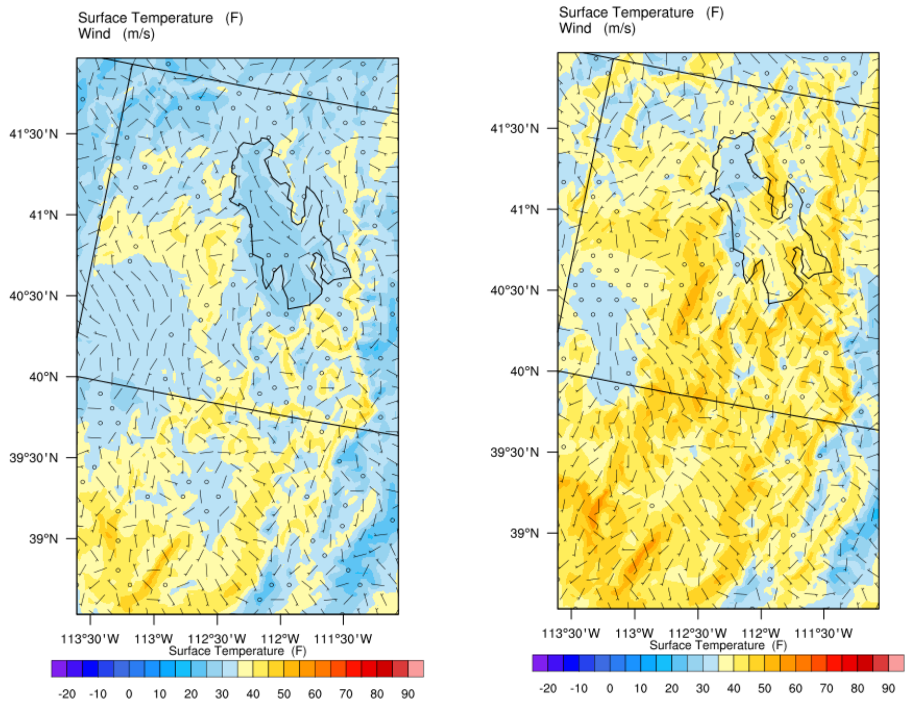


Figure 3. WRF 2-m air temperature and wind velocity predictions on 10-km grid for northern Utah at 4:00 am April 12, 2017 (left) and 4:00 am April 13, 2017 (right).

Task 1.2 – Comparison to Measured Data

Each aspect of the urban canopy model has approximations based on the spatial and/or temporal resolution of available land use type and meteorological conditions. These contribute to inaccuracies in the overall predictions. Measurement data, although limited, is useful for calibrating model results given various model assumptions. This task will use two measurement sets to help assess the performance of WRF in the GSLA environment. The first is the Vertical Transport and Mixing (VTMX) field experiment dataset from 2000. The VTMX was a multi-institutional campaign that was conducted in the vicinity of Salt Lake City during October 2000 (Doran et al., 2002) and provided data for verifying upper air properties in WRF models. Wind, temperature, and humidity data were taken at the north end, south end, and center of the valley. This data has been used previously with WRF to guide selection of model configurations appropriate to the GSLA (Nehrkorn, et al., 2011, Nehrkorn, et al., 2013). Although older, this data is one of the most complete data sets of this type and provides useful spatial resolution for comparing model predictions at several horizontal (near surface) and vertical positions. Model inputs will be modified to account for the circa 2000 period by using older NLCD land use data. Results will focus on comparisons between measured and predicted air temperatures and wind velocity profiles over 24-hour periods. Expected computational resolution is 1-2 km.

The VTMX data will be compared to three WRF models: 1) WRF with no UCM, 2) WRF with the slab UCM, and 3) WRF with single-layer UCM. Each of the WRF models will use the same land use data, mesh resolution, meteorological boundary conditions, and numerical model settings. Model and measurement comparisons will be based on air temperatures and wind velocities. In cases showing consistent differences between model and measurement data, model urban properties (within the UCM) will be adjusted to improve model accuracy. Potential changes include adjusting land use types at a coarse scale and adjusting individual land use type properties, e.g., road widths and building heights, at a property level. Once acceptable WRF-UCM predictions are established, results from the two WRF-UCM models will be compared to WRF results without the UCM for the same time periods to illustrate the differences in air temperature, humidity, and wind velocities when accounting for urban canopy impacts. Results will be compared at several locations and elevations in the GSLA. Comparison of results with observed data will identify differences in UCM model accuracy and suggest the best UCM model to represent the GSLA.

The second comparison will be based on the limited measurement set maintained by Hoch based on the 2015-2016 Salt Lake Valley $PM_{2.5}$ Pollution Study sponsored by UDAQ (Hoch, 2016). This is a much more limited data set, but will provide a few comparison points from a more recent time frame consistent with an evolved GSLA urban footprint. Land use properties will be updated to reflect conditions at this period. If this data proves insufficient for model comparison, an alternate set of meteorological data will be sought from literature or from databases maintained by the state of Utah or the University of Utah. Simulations from both the slab and single-layer WRF models will be compared to the observed data. It is expected that differences between the models will show trends consistent with the VTMX year 2000 cases.

<u>Task 2 – Evaluate Meteorological Changes Due to Urban Growth</u>

This task will use the WRF-UCM model to show the impact of changes to urban growth on GSLA meteorological conditions, and by implication, ozone and $PM_{2.5}$ concentrations. First, a baseline WRF-UCM case based on the most accurate UCM model from Task 1.2 will be developed. Weather conditions from one of the previous conditions in Task 1.2 will likely be used to save time, but land use and city properties will be updated to the most recent data available, including modifications to the Great Salt Lake shoreline (which has changed over the past 5-10 years). From this baseline, two “what-if” scenarios will be studied. The first will include a transition of a region immediately south of the Salt Lake City downtown area from residential to fully industrial/commercial. This represents a scenario where an older urban and residential area would be renewed for commercial space similar to existing downtown Salt Lake City. This would essentially double the size of the existing downtown area. The second scenario will include the transition of a significant amount of low intensity residential or rural land to high intensity residential land use type. This represents continued conversion of more rural or lightly residential areas in the south and west Salt Lake Valley to higher density residential with some localized commercial areas (e.g., Sandy/Draper area). Each study will compare air temperature, humidity, and wind velocity elevation profiles at several GSLA locations before and after the urban growth. The project manager will confirm these “what-if” scenarios with UDAQ personnel prior to this work so that UDAQ can focus the results on a different growth scenario if desired.

These “what-if” scenarios will illustrate the utility of the modeling tool and serve as a guide on how to use the model for urban planning inputs. This modeling exercise will also guide future research needs by identifying land use properties that are poorly defined or resolved.

For convenience, Table 2 lists all proposed WRF simulations to be conducted as part of the project.

Table 2. Proposed WRF Simulations.

Modeling Scenario	Description
WRF-2000	WRF with no UCM, VTMX (year 2000) conditions
WRF-slab-2000	WRF with slab canopy model, VTMX conditions
WRF-single-2000	WRF with single-layer canopy model, VTMX conditions
WRF-slab-2015	WRF with slab canopy model, 2015 conditions
WRF-single-2015	WRF with single-layer canopy model, 2015 conditions
WRF-UCM-baseline	WRF with “best” UCM, 2000 or 2015 weather, ~2020 land use and city props
WRF-UCM-Scen1	WRF baseline with growth scenario 1
WRF-UCM-Scen2	WRF baseline with growth scenario 2

Task 3 – Document Model Methodology and Usage

Too frequently, the results of modeling studies are used for a single report or publication, but the full details and/or models needed to replicate the results are not provided. As a result, future researchers must “start from scratch” when developing the same or similar models. This results in significant wasted resources. The objective of this task is to provide sufficient documentation on the setup and usage of the publicly available WRF-UCM model that subsequent researchers can follow these steps to recreate results of this study, and more importantly quickly adapt the model to produce results from additional scenarios that can be used as inputs to standard air quality models such as CMAQ. This documentation will include software versions, numerical settings used in the urban canopy models (see for example, Table 1), land use type properties, and property adjustments for the GSLA. Equally valuable will be step-by-step instructions on how to set up and run the WRF-UCM. These usage details are usually omitted from technical publications, making replication of results difficult. The outcome of this task will be instructions and information that would allow a WRF user to create and run an urban canopy model of the GSLA, recreate existing results, and create new outputs based on variations to model inputs.

Task 4 – Project Management

Prof. Adams will be the point of contact for the project and will be responsible for program management. Specific management tasks to be completed include:

- Coordination of project technical tasks with research students.
- Management of project budgets and coordination with university Grants and Accounting office to ensure timely invoicing to UDAQ.
- Timely submission of 1-2 page Quarterly Reports for the duration of the program.
- Presentation of project results at Air Quality: Science for Solutions conference.
- Submission of the Final Report with 90 days of project completion.
- Coordination of Data Sharing for project results within 8 months of project end.

1.4 Expected Outputs and Outcomes

Successful completion of this program will provide:

- A WRF-UCM model suitable for predicting meteorological properties in the GSLA that account for urban canopy effects.
- A comparison of WRF predictions without UCM and with the slab and single-layer canopy models.
- A calibration of WRF-UCM model predictions for the GSLA based on comparison with limited air property measurements in the GSLA.
- Predicted impacts on meteorological properties in the GSLA of two "what-if" urban growth scenarios.
- Documentation describing model methodology, settings, and usage sufficient to allow future researchers to use the public WRF software to replicate project model results and to conduct similar assessments of urban canopy impacts.

The results of this research will provide a natural platform from which to perform future air quality studies using the EPA CMAQ code. Dr. Adams' research group is currently using WRF results with CMAQ to model dust events, so have experience linking WRF outputs to CMAQ inputs using current versions of these codes. Performing air pollutant studies based on current urban properties and future urban growth scenarios would be a natural follow on to this project.

1.5 Deliverables

The following will be the key project deliverables:

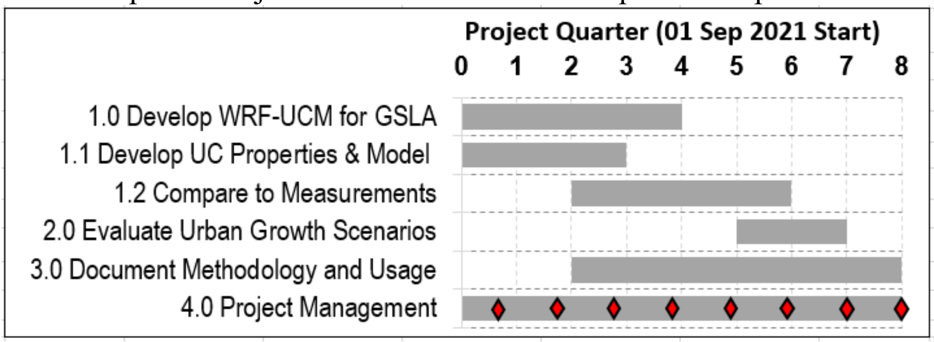
- 1-2 page quarterly reports describing the project's progress toward stated objectives.
- A final Project Report submitted within 90 days after the project completion. Report format and contents will be as outlined by the project RFP and contract.
- Copies of slides or posters from presentations at Air Quality: Science for Solutions conferences.
- Summary of simulation results from the model adjustment/calibration task. Results will be in the form of graphs, tables and color plots. Model input and output files will be shared with UDAQ via a portable hard disk drive (due to large file sizes).
- Summary of simulation results from the urban growth scenarios. Results will be in the form of graphs, tables and color plots.
- PDF files containing documentation of the modeling methodology and model inputs including numerical settings and land use properties. These will be included in the final Project Report.
- Summaries of model case inputs and predicted results will be shared via the UDAQ website within 8 months of the project completion.

The project manager will work with UDAQ personnel to define appropriate formats to share the simulated data so they are of use to future researchers and policy makers.

1.6 Schedule

Table 3 shows the expected schedule for each of the project tasks. The proposed project will commence September 1, 2021 and conclude August 31, 2023. The red diamonds on the Project Management task indicate Quarterly Report milestones.

Table 3. Proposed Project Schedule. Diamonds Represent Report Milestones.



2 BUDGET

Table 4 shows the budget summary for the project, including UDAQ cost and cost-share contributed by BYU. The budget reflects a work effort of 24 months. Table 5 shows the budget breakout and justification for each of the project tasks. Total UDAQ project cost is $59,411. Cost-share of $50,339 is provided by donated faculty time during fall and winter academic semesters, student wages supported by an internal BYU mentored research grant, and the reduction in university indirect rate from the normal 50% to the required 10% rate. Equipment costs of $1,000 are included to purchase portable data drives to transport the (large file size) WRF simulation results to UDAQ. Total project cost is $109,750. Costs to participate in the Science for Solutions conference are expected to be minimal, so no travel cost is included.

Table 4. Proposed Project Budget Summary.

Cost Category	Costs
Personnel	$ 39,000
Benefits	$ 3,192
Tuition	$ 12,000
Equipment	$ 1,000
Total Direct Costs	$ 55,192
Indirect Costs	$ 4,219
UDAQ Total	$ 59,411
Cost-Share Total	$ 50,339
Grand Total	$ 109,750

Table 5. Detailed Project Budget and Justification.

Cost Item	Hours	$/hr	Personnel	Benefits	Indirect	Total
Task 1 - Model Development						
Adams Salary (1)	66.7	75	5,000	1,520.00	652.00	7,172
Adams Salary Cost-share (2)	66.7	75	5,000	2,480.00	3,740.00	11,220
Graduate Student Wage	1,000	16	16,000	-	1,600.00	17,600
Graduate Student Cost-share (5)	500	16	8,000	-	800.00	8,800
Grad Student Tuition (3)			9,200	-	-	9,200
Undergraduate Wage	42	12	500		50.00	550
Undergraduate Cost-share (5)	83	12	1,000		100.00	1,100
Task 2 - Growth Scenarios						
Adams Salary (1)	26.7	75	2,000	608.00	260.80	2,869
Adams Salary Cost-share (2)	26.7	75	2,000	992.00	1,496.00	4,488
Graduate Student Wage	500	16	8,000	-	800.00	8,800
Grad Student Tuition (3)			2,200	-	-	2,200
Undergraduate Wage	83	12	1,000	-	100.00	1,100
Task 3 - Documentation						
Adams Salary (1)	13.3	75	1,000	304.00	130.40	1,434
Adams Salary Cost-share (2)	13.3	75	1,000	496.00	748.00	2,244
Graduate Student Wage	125	16	2,000	-	200.00	2,200
Grad Student Tuition (3)			600	-	-	600
Undergraduate Wage	83	12	1,000		100.00	1,100
Equipment - computer storage			1,000		-	1,000
Task 4 - Management						
Adams Salary (1)	33.3	75	2,500	760.00	326	3,586
Adams Salary Cost-share (2)	33.3	75	2,500	1,240.00	1,870	5,610
Project Subtotals			$ 52,000	$ 3,192	$ 4,219	$ 59,411
Wage-based Cost-Share			$ 19,500	$ 5,208	$ 8,754	$ 33,462
Add'l University Cost-Share (4)						$ 16,877
Total Effort			$ 71,500	$ 8,400	$ 12,973	$ 109,750
Total Direct Costs						$ 55,192
Total Indirect Costs						$ 4,219
Total Project Cost						**$ 59,411**
Matching Funds						$ 50,339
Grand Total						$ 109,750
Cost Detail						
1) Summer salary has benefit rate of 30.4%						
2) Winter salary (cost-share) has benefit rate of 49.6%						
3) Tuition based on 6 credit hrs for fall and winter semesters, 3 credit hrs (thesis) for summer						
4) Based on difference between standard university indirect rate of 50% and required rate of 10%						
Indirect rate is 10% on all items except tuition and external consultant (pass through)						
5) Additional student wages paid from university mentored research grant						

3 PERSONNEL ROLES AND RESPONSIBILITIES

Dr. Bradley Adams (PI), Associate Professor of Mechanical Engineering at Brigham Young University, will provide project management, oversee reporting, coordinate the research of his graduate and undergraduate students, and conduct research into modification of the WRF-UCM input files to better represent GLSA urban properties. Although Dr. Adams is relatively new to meteorological modeling, he has over 25 years of experience developing and applying modeling tools to predict air pollutant formation and assess different control technologies. He has managed over $8M in R&D programs for the US Department of Defense, Department of Energy, and EPA. He has experience with the current WRF software from his work as co-PI on two current air quality projects related to WRF and CMAQ modeling of dust events (sponsored by UDAQ and NSF, respectively). This experience will enable a faster transition to use of the WRF urban canopy models.

The graduate student will have primary responsibility for developing WRF-UCM input files using various property databases, running WRF-UCM calibration cases, and post-processing results. They will also research Salt Lake City urban properties for use in calibration and growth scenarios, run WRF-UCM growth cases and post-process results. They will work with the undergraduate student on finding data to define the growth scenarios, update the Great Salt Lake shoreline geometry, and formalize methodology and usage documentation. Having a graduate and undergraduate student compile the documentation on software usage will ensure instructions are thorough enough to guide users inexperienced in running WRF-UCM.

The undergraduate student will assist the graduate student in identifying GSLA-relevant urban property data, including data for urban growth scenarios. They will assist with post-processing and summarizing prediction results and completing model usage documentation.

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Jandaghian, Z., Touchaei, A. G., & Akbari, H. (2017). Sensitivity analysis of physical parameterizations in WRF of urban climate simulations and heat island mitigation in Montreal. Urban Climate, 24, 577–599.

Janjic, Z. (2002). Nonsingular implementation of the Mellor-Yamada level 2.5 scheme in the NCEP meso model. Camp Springs, MD: National Centers for Environmental Prediction.

Jato-Espino, D. (2019). Spatiotemporal statistical analysis of the Urban Heat Island effect in a Mediterranean region. Sustainable Cities and Society, 46, 101427.

Li, X., & Zhou, W. (2019). Spatial patterns and driving factors of surface urban heat island intensity: A comparative study for two agriculture-dominated regions in China and the USA. Sustainable Cities and Society, 48, 101518.

Lin, Y., & Colle, B. A. (2011). A new bulk microphysical scheme that includes riming intensity and temperature-dependent ice characteristics. Monthly Weather Review, 139, 1013–1035.

Lun, I., Mochida, A., Ooka, R. (2011). Progress in Numerical Modelling for Urban Thermal Environment Studies. Advances in Building Energy Research 3(1):147-188.

Mesinger, F., Dimego, G., Kalnay, E., Mitchell, K., Shafran, P. C., Ebisuzaki, W., Jovic, D., Woollen, J., Rogers, E., Berbery, E. H., Ek, M. B., Fan, Y., Grumbine, R., Higgins, W., Li, H., Lin, Y., Manikin, G., Parrish, D., & Shi, W. (2006). North American regional reanalysis. Bulletin of the American Met. Society, 87(3), 343–360.

Nehrkorn, T., Henderson, J., Leidner, M., Mountain, M., Eluszkiewicz, J., McKain, K., Wofsky, W. (2013). WRF Simulations of the Urban Circulation in the Salt Lake City Area for CO_2 Modeling. Journal Applied Meteorology and Climatology, 52 (2), pp. 323-340.

Nehrkorn, T., Henderson, J., Leidner, M., Ellis, M., Maher, A., Eluszkiewicz, J. (2011). Modeling the urban circulation in the Salt Lake City area using the WRF urban canopy parameterization. Allwine-Doran Retrospective of the Special Symposium on Applications of Air Pollution Meteorology, January 2011.

Roberge, F., & Sushama, L. (2018). Urban heat island in current and future climates for the island of Montreal. Sustainable Cities and Society, 40, 501–512.

Appendix – Principle Investigator CV

Bradley R. Adams

360-I Engineering Building
Brigham Young University
Provo, UT 84602
801-422-6545; brad.adams@byu.edu

Education

Ph.D., Mechanical Engineering Dissertation: *Computational Evaluation of Mechanisms Affecting Radiation in Gas- and Coal-fired Industrial Furnaces*; Advisor: Philip J. Smith	University of Utah	1993
M.S., Mechanical Engineering	Brigham Young University	1985
B.S., Mechanical Engineering Minor: Mathematics	Brigham Young University	1984

Employment

- ***Associate Professor****, Dept. Mechanical Engineering, Brigham Young University, (2015 - present)*
  Taught undergraduate courses in Heat Transfer, Global Leadership, Professional Skills, Senior Design, graduate courses in Compressible Flow and Combustion. Served on department course committees and External Relations committee. Mentored undergraduate and graduate student researchers in radiative heat transfer, combustion systems, air quality modeling.

- ***President****, Reaction Engineering International, Salt Lake City, Utah (2000 - 2015)*
  Led a technical consulting firm with an internationally recognized expertise in combustion and environmental solutions, ~$4M in annual revenues. Managed $8M in combustion-related R&D programs for US DOE, DOD, EPA, and NSF. Coordinated R&D programs and consulting projects for commercial clients in the power generation, petrochemical and material processing industries. Projects focused on using computer simulations and/or pilot-scale testing to evaluate combustion performance and air pollutant control strategies for large-scale furnaces. Oversaw development and application of new simulation tools for prediction of ultra-low NOx emissions in pyrolysis furnaces, mercury speciation in coal-fired power plants, and heat transfer and steam circuit behavior in combustion systems.

- ***Vice President****, Engineering Analysis, Reaction Engineering Intl., Salt Lake City, UT (1998-2000)*
  Managed REI analysis/modeling division with responsibility for Environmental Technologies and Performance Optimization groups.

- ***Manager****, Applied Technologies, Reaction Engineering Intl., Salt Lake City, UT (1997-1998)*
  Managed projects for modeling industrial combustion applications including work for power generation, chemical process and metallurgical industries; responsible for project proposals, schedules, budgets and technical results.

- ***Senior Engineer****, Reaction Engineering International, Salt Lake City, Utah (1992-1997)*
  Conducted R&D to improve REI simulation tools with an emphasis on heat transfer, NOx predictions and balance of plant impacts in coal-fired combustion systems; used CFD modeling tools to improve performance, reduce air-borne emissions and assess technology impacts in industrial combustion systems.

- ***Instructor****, Department of Chemical Engineering, University of Utah, Salt Lake City, Utah (1992)*
  Taught undergraduate heat transfer course, ranked in top 20% of Engineering College instructors in student evaluations.

- ***Consultant**, Reaction Engineering International, Salt Lake City, Utah (1991)*
  Analyzed differences in deposition and NOx levels between slurry-fired and dry coal-fired turbine combustor; evaluated effects of multiple burners and urea injection on NOx levels in a gas-fired utility boiler.

- ***Research Assistant**, Computational Fluid Dynamics Laboratory, University of Utah (1991-1992)*
  Conducted research of radiative heat transfer mechanisms in industrial gas- and coal-fired furnaces including turbulence-soot-radiation interaction; implemented domain decomposition techniques to improve computational efficiency of combustion software.

- ***Consultant**, Los Alamos National Laboratory, Los Alamos, New Mexico (1990)*
  Analyzed transient heat transfer characteristics of materials in a waste storage container to determine possibility of explosion and solid waste combustion.

- ***Research Assistant**, Combustion Computations Laboratory, Brigham Young Univ. (1989-1990)*
  Conducted research of radiative heat transfer mechanisms in industrial furnaces including improved radiation property models; implemented and evaluated vectorization techniques to improve computational efficiency of combustion software.

- ***Staff Member**, Optical Systems Engineering, MIT Lincoln Laboratory, Lexington, MA (1987-1989)*
  Led projects to analyze the thermal performance of a high-energy laser system, aircraft-based cryogenic cooling system and satellite-based electronics package using experimental prototypes and CFD-based simulations; served as Group Representative on committees responsible for procurement of division mini-supercomputer and workstations; evaluated and procured heat transfer and CFD analysis codes for Group use.

- ***Engineer**, Corp. Mechanical Engineering, GenRad, Concord, Massachusetts (1984-1986)*
  Responsible for structural, thermal and acoustical analysis of three new products; developed computer codes for optimizing acoustical and thermal packaging of electronics systems.

Professional Associations and Awards

- Dept. of Mechanical Engineering Most Influential Faculty Award, Brigham Young University Fulton College of Engineering, 2019
- Member American Society of Mechanical Engineers (ASME), 1985-present
- Senior Member American Institute of Chemical Engineers (AIChE), 2011-present
- Member American Flame Research Committee (AFRC), 2006-2015
- "Most Important, Original, and High Quality Paper," Asia-Pacific Conference on Combustion, The Combustion Institute, 1999

Journal Articles (at Brigham Young University)

Vaughn, A., Leete, K., Gee, K., **Adams, B.**, Downing, J. (2020) "Evidence for nonlinear reflections in shock-containing noise near high-performance military aircraft," *Journal of the Acoustical Society of America (in review)*

Thatcher, C., **Adams, B.** (2021) "Impact of Surface Reflection on Microbial Inactivation in a UV LED Treatment Duct," *Chem. Eng. Sci.,* 230, doi.org/10.1016/j.ces.2020.116204

Gunnarsson, A., Andersson, K., **Adams, B.,** Fredriksson, C. (2020) "Discrete-Ordinates Modelling of the Radiative Heat Transfer in a Pilot-Scale Rotary Kiln," *Energies*, 13, 2192; doi.org/10.3390/en13092192

Schroedter, T., **Adams, B.,** Tuia, J., Fry, A. (2020) "Development of a High Pressure Dry Coal Feed System for a 100 kWt Oxy-Coal Reactor," *J. Energy Resour. Technol.*, 142(7): 072304, doi.org/10.1115/1.4046602

Williams, T., **Adams, B**., (2020) "A Dimensionally Adaptive Technique for Computationally Efficient Cylindrical Discrete Ordinates Radiation Calculations," *J. Quant. Spectrosc. Radiat. Trans.* 243, doi.org/10.1016/j.jqsrt.2019.106819

Gunnarsson, A., Andersson, K., **Adams, B.,** Fredriksson, C. (2020) "Full-Scale 3D-Modelling of the Radiative Heat Transfer in Rotary Kilns with a Present Bed Material," *Intl. J. Heat Mass Trans*. 147, doi.org/10.1016/j.ijheatmasstransfer.2019.118924.

Williams, T., **Adams, B**., (2019) "Dimensionally adaptive techniques for computationally efficient discrete transfer radiation calculations," *J. Quant. Spectrosc. Radiat. Trans.* 233, 67–75, doi.org/10.1016/j.jqsrt.2019.05.007.

Adams, B., Hosler, T. (2019) "Pressure and particle property impacts on radiation in oxy-coal combustion," *Fuel* 239, 667–676, doi.org/10.1016/j.fuel.2018.11.042.

Tree, D., Tobiasson, J., Egbert, S., **Adams, B.** (2019) "Measurement of Radiative Gas and Particle Emissions in Biomass Flames," *Proc. Combust. Inst*. 37 (4), 4337-4344, doi.org/10.1016/j.proci.2018.06.221.

Tobiasson, J., Egbert, S., **Adams, B.**, Tree, D. (2018) "An Optical Method for the Measurement of Combustion Gas Temperature in Particle Laden Flows," *Exp. Therm. Fluid Sci.* 98, 704-711.

Adams, B., Tobiasson, J., Egbert, S, Tree, D. (2018) "Determining Total Radiative Intensity in Combustion Gases Using an Optical Measurement," *Energy Fuels* 32 (2), 2414–2420.

Smith, J., **Adams, B.,** Jackson, R., Suo-Anttila, A. (2017) "Use of RANS and LES Turbulence Models in CFD Predictions for Industrial Gas-fired Combustion Applications," *Industrial Combustion, Journal of the International Flame Research Foundation*, Article 201607, ISSN 2075-3071.

Other Articles and Conference Proceedings (at Brigham Young University)

Williams, T., **Adams, B.** (2019) "Improvement of Computational Efficiency for Discrete Ordinate Radiation Calculations Through the Use of Dimensionally Adaptive Mesh Techniques," Paper #915-0088, *Western States Section of the Combustion Institute - 2019 Fall Technical Meeting*, Albuquerque, NM.

Adams, B., Schroedter, T. (2019) "Modeling Pressurized Dense Phase Coal Fluidization and Transport," POWER2019-1874, *Proceedings of the ASME 2019 Power Conference,* POWER2019, July 16-18, Snowbird, Utah. (peer reviewed)

Gunnarsson, A., Andersson, K., **Adams, B.** (2019) "Heat Transfer Modelling of Industrial Rotary Kilns for Iron Ore Pelletizing," Paper #159, *The 44th International Technical Conference on Clean Energy (Clearwater Clean Energy Conference)*, Clearwater, Florida.

Adams, B., Schroedter, T., Tuia, J., Fry, A. (2019) "Modeling and Bench-scale Testing of a High Pressure Dry Coal Feed System for Oxy-combustion," Paper #139, *The 44th International Technical Conference on Clean Energy (Clearwater Clean Energy Conference)*, Clearwater, Florida.

Williams, T., **Adams, B.** (2019) "Discrete Transfer Radiation Calculations with a Dimensionally Adaptive Mesh," Paper #77, *The 44th International Technical Conference on Clean Energy (Clearwater Clean Energy Conference)*, Clearwater, Florida.

Williams, T., **Adams, B.** (2019) "Improvement of Computational Efficiency for Discrete Transfer Radiation Calculations Through the Use of Dimensionally Adaptive Mesh Techniques," 11th US National Combustion Meeting, March 24-27, Pasadena, CA.

Gunnarsson, A., Andersson, K., **Adams, B.** (2018) "Full Scale 3D-Modelling of the Radiative Heat Transfer in Rotary Kilns with a Present Bed Material," Paper #50, *The 43rd International Technical Conference on Clean Energy (Clearwater Clean Energy Conference)*, Clearwater, Florida.

Hosler, T., **Adams, B.** (2018) "Particle Property Impacts on Radiation in a Pressurized Oxy-Coal Combustor," Paper #49, *The 43rd International Technical Conference on Clean Energy (Clearwater Clean Energy Conference)*, Clearwater, Florida.

Schroedter, T., **Adams, B.** (2018) "Modeling Transport of Pressurized Dense Phase Coal," Paper #48, *The 43rd International Technical Conference on Clean Energy (Clearwater Clean Energy Conference)*, Clearwater, Florida.

Gunnarsson, A., Andersson K., **Adams, B.** (2018) "3D-Modelling of the Radiative Heat Transfer in Rotary Kilns with a Present Bed Material," *Eurotherm 110, Computational Thermal Radiation in Participating Media VI*, Cascais, Portugal. (peer reviewed)

Adams, B. (2017) "Mitigation of Airborne Pollutants in Coal Combustion, Use of Simulation," *Fossil Fuels*, *Encyclopedia of Sustainability Sci. Technol.*, 2nd Ed., Springer, ISBN 978-1-4939-2775-3, DOI 10.1007/978-1-4939-2493-6_959-1. (invited)

Smith, J., **Adams, B.,** Jackson, R., Suo-Anttila, A. (2017) "RANS vs LES CFD for Gas-fired Combustion Equipment Analysis," *AFRC 2017 Industrial Combustion Symposium*, Houston, TX.

Hosler, T., **Adams, B.** (2017) "Impact of Particle Properties on Radiative Heat Flux in an Oxy-Coal Reactor," Paper # 29OT-0033, *Western States Section of the Combustion Institute - 2017 Fall Technical Meeting*, Laramie, WY.

Schroedter, T., **Adams, B.** (2017) "Modeling a Pressurized Coal Feed System," Paper # 29OT-0031, *Western States Section of the Combustion Institute - 2017 Fall Technical Meeting*, Laramie, WY.

Williams, T., **Adams, B.** (2017) "A Fast-Running Simulation Tool for Axisymmetric Oxy-Coal," Paper # 29CC-0032, *Western States Section of the Combustion Institute - 2017 Fall Technical Meeting*, Laramie, WY.

Adams, B., Fry, A., Tree, D. (2017) "Technology Development for a Pressurized Dry Feed Oxy-Coal Reactor – Program Overview," *The 42nd International Technical Conference on Clean Energy (Clearwater Clean Energy Conference)*, Clearwater, Florida.

Adams, B., Sperry, R. (2017) "Impact of Computational Mesh on CFD Combustion Predictions," Paper 40b, 2017 Spring Meeting and 13th Global Congress on Process Safety, AIChE, ISBN: 978-0-8169-1098-4.

Conference Presentations (at Brigham Young University)

Lawless, Z., **Adams, B.** (2020) "Modeling Current and Future Windblown Dust Events In Utah Using CMAQ 5.3.1," Utah Department of Air Quality: Science for Solutions 4th Annual Conference, Provo, UT

Williams, T., **Adams, B.** (2019) "Comparison of Robustness of Discrete Transfer and Discrete Ordinate Radiation Calculations on Computationally Efficient Dimensionally Adaptive Meshes," presentation at *IMECE Fall 2019*, Salt Lake City, UT.

Adams, B., Fry, A., Tree, D. (2019) "Advancing Pressurized Oxy-Coal (POC) Combustion for Power Generation – Program Update," Abstract #75, *The 44th International Technical Conference on Clean Energy (Clearwater Clean Energy Conference)*, Clearwater, Florida.

Adams, B., Fry, A., Tree, D. (2018) "Technology Development for a Pressurized Dry Feed Oxy-Coal Reactor: DE-FE0029157 – 2018 Program Update," 2018 NETL CO2 Capture Technology Project Review Meeting, Pittsburgh, PA.

Houghton, L., **Adams, B.,** Fry, A., Gunnarsson, A., Andersson, K. (2018) "Radiometer Measurements in High Pressure Flames: System Design, Sensors and Calibration," Abstract #78, *The 43rd International Technical Conference on Clean Energy (Clearwater Clean Energy Conference)*, Clearwater, Florida.

Adams, B., Fry, A., Tree, D. (2018) "Technology Development for a Pressurized Dry Feed Oxy-Coal Reactor – Year 1 Update," Abstract #47, *The 43rd International Technical Conference on Clean Energy (Clearwater Clean Energy Conference)*, Clearwater, Florida.

Adams, B., Tobiasson, J., Egbert, S., Tree, D. (2018) "Total Radiation Intensity from Combustion Gas Measurement," Abstract #130, *The 43rd International Technical Conference on Clean Energy (Clearwater Clean Energy Conference)*, Clearwater, Florida.

Green, A., **Adams, B.** (2018) "Simulating Coal Transport with Carbon Dioxide," University Conference on Undergraduate Research, Cedar City, Utah.

Adams, **B.**, Hosler, T., Fry, A. (2018) "Impact of Particle Properties on Radiative Heat Flux in a Pressurized Oxy-Coal Combustor," 2nd International Workshop on Oxy-Fuel Combustion, February 14-15, Bochum, Germany.

Houghton, L., **Adams**, **B.**, Fry, A., Gunnarsson, A., Andersson, K. (2018) "Measuring Radiation From High Pressure Oxy-Coal Flames," 2nd International Workshop on Oxy-Fuel Combustion, February 14-15, Bochum, Germany.

Adams, B., Fry, A., Tree, D. (2017) "Technology Development for a Pressurized Dry Feed Oxy-Coal Reactor – Program Overview," *The 42nd International Technical Conference on Clean Energy (Clearwater Clean Energy Conference)*, Clearwater, Florida.

Research Grants and Contracts (at Brigham Young University)

"Dust in the Critical Zone from the Great Basin to the Rocky Mountains," NSF, $199,053, 9/1/20 – 8/31/25.

"Development of a UVC LED Intensity and Pathogen Destruction Model," NKFG Corporation, $78,000, January 1, 2020 – September 30, 2021.

"Characterizing Air Quality Impacts from Exceptional Events along the Wasatch Front," Utah Department of Air Quality, $75,000, August 1, 2019 – June 30, 2021.

"Modeling Impacts of Exceptional Dust Events on Wasatch Front Air Quality," BYU College of Engineering SEED Funding, $12,500, Jan 1, 2019 – Dec 31, 2019.

"Development of Enabling Technologies for a Pressurized Dry Feed Oxy-Coal Reactor," DOE Contract DE-FE0029157, $1.41M ($1.1M DOE), Co-PI with Andrew Fry, Oct 1, 2016 – Sep 30, 2019.

Graduate Student Advisement (at Brigham Young University)

Cole Thatcher	MS	Brigham Young University	2020 – present
Zach Lawless	MS	Brigham Young University	2019 – present
Donald Peterson	MS	Brigham Young University	2019 – present
Ty Hosler	MS	Brigham Young University	2019 – present
Todd Williams	PhD	Brigham Young University	Graduated 2020
Taylor Schroedter	MS	Brigham Young University	Graduated 2018

Undergraduate Student Advisement (at Brigham Young University)

James Thomas	BS	Brigham Young University	2020 - present
Hailee Dyer	BS	Brigham Young University	2020 - present
Ariel Green	BS	Brigham Young University	2020 - present
Dunstan Chi	BS	Brigham Young University	2020 - 2020
Cameron Van Dyke	BS	Brigham Young University	2020 - present
Cole Thatcher	BS	Brigham Young University	2018 – 2020
Peter Kasper	BS	Brigham Young University	2019 – 2019
Robert Jensen	BS	Brigham Young University	2019 – 2019
Scott Gardner	BS	Brigham Young University	2018 – 2019
Ty Hosler	BS	Brigham Young University	2017 – 2018
Ariel Green	BS	Brigham Young University	2017 – 2018
Ryan Sperry	BS	Brigham Young University	2016 – 2017

Thesis/Dissertation Committee Advisement (at Brigham Young University)

Rajarshi Roy	PhD (Andrew Fry, Chemical Engineering)	2019 – present
Teagan Nakamoto	PhD (Andrew Ning, Mechanical Engineering)	2019 – present
Alex Newell	MS (Steve Gorrell, Mechanical Engineering)	2019 – present

Nicole Burchfield	MS (Andrew Fry, Chemical Engineering)	Graduated 2020
Ashton Jessup	MS (Dale Tree, Mechanical Engineering)	Graduated 2020
Adrian Gunnarsson	PhD (Klas Andersson, Chalmers University)	Graduated 2019
Scott Egbert	MS (Dale Tree, Mechanical Engineering)	Graduated 2019
Aaron Skousen	MS (Dale Tree, Mechanical Engineering)	Graduated 2019
Cody Carpenter	MS (Dale Tree, Mechanical Engineering)	Graduated 2019
Alex Josephson	PhD (David Lignell, Chemical Engineering)	Graduated 2018
Brent Reichman	PhD (Kent Gee, Physics)	Graduated 2018
Michael Farnsworth	MS (Scott Thomson, Mechanical Engineering)	Graduated 2018
John Tobiasson	MS (Dale Tree, Mechanical Engineering)	Graduated 2017

Professional Service (at Brigham Young University)

- Mentor, Research Mentorship, Fulton College of Engineering, Brigham Young University, 2020-2021
- Mentor, Research Mentorship for Women, WE@BYU, Fulton College of Engineering, Brigham Young University, 2017-2018
- Reviewer for *ASME IMECE, Combustion Science and Technology, Energy & Fuels, Fuel, Fuel Processing Technology, Heat and Mass Transfer, International Journal of Heat and Mass Transfer, Journal of Thermal Science and Engineering, Symposium of The Combustion Institute* (2015 – present)
- Conference Committee, The International Technical Conference on Clean Energy ("Clearwater Clean Energy Conference") (2013 – present)
- Committee Member, ASME Fuels and Combustion Technologies (FACT) (2019 – present)
- Academic Liaison, American Petroleum Institute (API) Subcommittee on Heat Transfer Equipment (SCHTE) Fired Heater Consensus Group (2015 – 2019)
- API Fired Heater Research Consortium (2016 – 2019)
- Organizer and Chair, Session on Radiative Heat Transfer, The 44th International Technical Conference on Clean Energy (June 2019)
- Organizer and Chair, Session on Radiative Heat Transfer, The 43rd International Technical Conference on Clean Energy (June 2018)
- Reviewer, Proposed Alternative NOx Control Technologies, PacifiCorp (August 2017)
- Chair, Session on Coal and Biomass, Western States Section of the Combustion Institute (WSSCI) Fall Technical Meeting (October 2017)
- Chair, Session on Solid Combustion/Flame Spread, Western States Section of the Combustion Institute (WSSCI) Fall Technical Meeting (October 2015)
- Chair, Session on Ignition, Ash Deposition, Trace Elements Partitioning, 5th Oxyfuel Combustion Research Network Meeting, Wuhan, China (October 2015)

University Service (at Brigham Young University)

- Member, External Relations Committee, Mechanical Engineering Department (2015-present)
- Member, ME EN 231 Leadership in a Global Context Course Committee (2018-present)
- Member, ME EN 340 Heat Transfer Course Committee (2015-present)
- Chair, ME EN 393 Professional Skills Course Committee (2016-2019)
- PhD Qualifying Exam Committees for Thermodynamics and Heat Transfer (2015-present)
- Reviewer, Engineering and Technology College ORCA proposals (2017)
- Executive Committee, Advanced Combustion Engineering Research Center (ACERC) (2016-present)
- Judge, 3-Minute Thesis competition (2016, 2020)

Courses Taught (at Brigham Young University)

- Graduate Compressible Flow (ME EN 510) – F15, F16, F17, F19
- Graduate Combustion (ME EN 522) – W21
- Undergraduate Heat Transfer (ME EN 340) – W16, W17, W18, Sp18, F18, Sp19, Sp20
- Professional Skills (ME EN 393) – F16, W17, F17, W18, F18, W19
- Leadership in a Global Context (ME EN 231) – W20, F20, W21
- Job Finding (ME EN 495) – W20, W21
- Mentored Projects (497R) – F16, W17, F17, W18, F18, W19, F19
- Capstone Senior Design (ME 475/476) – F18, W19, F19, W20

Invited Lectures and Seminars (at Brigham Young University)

- "Overview of R&D in Industry," BYU Graduate Student Seminar, March 25, 2019.
- "Overview of R&D in Industry," BYU Graduate Student Seminar, March 12, 2018.
- "What is an Engineer?" Mountain Ridge Jr. High School, December 7, 2017.
- "Combustion Research Opportunities in the Petrochemical Industry," API 2015 Fall Refining and Equipment Standards Meeting, SCHTE Fired Heater Consensus Group, November 16, 2015.
- "Result of High-Flame Temperature Oxy-Combustion Tests at the 15 MW_{th} Test Facility and its Application to Refineries" (with Jupiter Oxygen Corp) at 5th Oxyfuel Combustion Research Network Meeting, Wuhan, China, October 28, 2015.

Professional Development Activities

- Unconscious Bias Workshop: From Awareness to Action, Utah Women & Leadership Project, 2019
- Seminar, Assessing Learning & Behavior, Brigham Young University, 2018
- Short Course, Responding to Writing, University Writing, Brigham Young University, 2018
- BYU Career Engagement Conference, Brigham Young University, 2018

Major Research Grants and Contracts (before Brigham Young University)

"Characterizing Impacts of High Temperatures and Pressures in Oxy-Coal Combustion Systems," DOE Contract DE-FE0001247, $1.57M, ($1.25M DOE), June 2015 (left before completion).

"CFD Modeling of Oxy-coal Combustion in a New Modular Boiler Concept," Jupiter Oxygen Corporation, $80K, January 2014.

"Characterization of Oxy-combustion Impacts in Existing coal-fired Boilers," DOE Contract DE-NT0005288, $3.9M ($3.1M DOE), October 1, 2009 – September 30, 2013.

"Development of a Graphics-based Convection Design Package," Shaw Energy and Chemicals, $340K, April 2011.

"Radiation Modeling in Oxy-Coal Fired Boilers," Vattenfall R&D, $58K, March 2010.

"CFD Modeling Study of MPCRF Combustor," EPA Contract EP08C000261, $40K, August 2008.

"Development of a Corrosion Management Methodology for Coal-fired Boilers," Ohio Coal Development Office Grant CDO-D-01-15, $654K, 2003 – 2005.

"Scramjet Combustor Simulations Using Reduced Chemical Kinetics For Practical Fuels," AFRL/PRKA Contract F33615-01-2124, $726K, May 2001 – March 2004.

Professional Service (before Brigham Young University)

- Chair, Session on Air Toxics, The 39th International Technical Conference on Clean Coal & Fuel Systems, June 2014
- Chair, Session on Mercury Control, The 38th International Technical Conference on Clean Coal & Fuel Systems, June 2013
- Chair, Session on Use of Modeling Tools for Technology Assessment, The 37th International Technical Conference on Clean Coal & Fuel Systems, June 2012
- Chair, Session on Oxy-Fuel Technology IV – Understanding Oxy-Combustion Impacts, The 36th International Technical Conference on Clean Coal & Fuel Systems, June 2011
- Co-Chair (with Karen Eriksson), Session 05C on CFD Modeling and Experimental Validation, 1st International Oxyfuel Combustion Conference, Germany, September 2009
- Organizing Committee, AFRC 2008 Spring Meeting, May 2008
- Chair, Session on Utility Industry Combustion Research and Development Needs, AFRC 2008 Spring Meeting, May 2008
- Organizing Committee, Applied Combustion Technology: Problem Solving for the Utility and Process Industries, Brigham Young University, May 2005

Professional Short Courses Taught (before Brigham Young University)

- "SO_3 and Hg Emission Mitigation Strategies from Coal-fired Boilers," Reaction Engineering International, Salt Lake City, Utah, (with Connie Senior, Jost Wendt, Scott Evans, Volker Schmid) March 2006.
- "Emissions Mitigation from Coal-Fired Boilers: Strategies for SO_3 Control," Clean Air Engineering, Palatine, Illinois, (with Connie Senior, Scott Evans, Jim Wright) November 2006.
- "Emissions Mitigation from Coal-Fired Boilers: Strategies for Hg Control," Clean Air Engineering, Palatine, Illinois, (with Connie Senior, Scott Evans, Jim Wright) November 2006.
- "VFURN CFD Modeling," Chinese Petroleum Corporation, Chiayi, Taiwan, March 1999.

Invited Lectures and Seminars (before Brigham Young University)

- "Current Trends in the U.S. Power Generation Industry," Pusan National University Combustion Seminar, University of Utah, Salt Lake City, Utah, June 28, 2013.
- "Challenges for U.S. Power Generation Industry," Korean Electric Power Research Institute, Daejeon, Korea, June 13, 2008.
- "The State of Computer Simulation Capabilities for Coal-Fired Systems," US-China Conference on Combustion Technology, Park City, Utah, May 7-9, 2007.
- "Emissions Mitigation from Coal-Fired Boilers Strategies for SO_3 and Hg Control," REI Environmental Compliance Seminar, Chicago, Illinois, November 14-16, 2006.
- "Mercury Emissions and Controls for U.S. Coal-fired Utility Boilers," Conference on Mercury Emissions Control Technologies for Stationary Pollution Sources, Taipei, Taiwan, November 19, 2003.
- "NOx Modeling Overview," HuaDian Power International, Jinan, China, November 21, 2003.
- "Career Seminar - Preparing for Work after Graduation," University of Utah Department of Chemical & Fuels Engineering, November 13, 2001.

Journal Articles (before Brigham Young University)

Fry, A., **B. Adams**, A. Paschedag, P. Kazalski, C. Carney, D. Oryshchyn, R. Woodside, S. Gerdemann, and T. Ochs (2011) "Principles for Retrofitting Coal Burners for Oxy-combustion," *International Journal of Greenhouse Gas Control*, Vol. 5, Supp. 1, pp. S151-S158.

Fry, A., **B. Adams**, K. Davis, D. Swensen, S. Munson, and W. Cox (2011) "An Investigation into the Likely Impact of Oxy-coal Retrofit on Fire-side Corrosion Behavior in Utility Boilers," *International Journal of Greenhouse Gas Control*, Vol. 5, Supp. 1, pp. S179-S185.

Tang, Q., Denison, M., **Adams, B**., and Brown, D. (2009) "Towards Comprehensive Computational Fluid Dynamics Modeling of Pyrolysis Furnaces With Next Generation Low NOx Burners Using Finite-rate Chemistry," *Proceedings of Combustion Institute*, Volume 32, Issue 2, pp. 2649-2657.

H-P Wan, C-S Yang, **B.R. Adams**, S.L. Chen (2008) "Controlling LOI From Coal Reburning In A Coal-Fired Boiler," *Fuel*, 87, pp. 290–296.

Wu, K.-T., H.T. Lee, C.I. Juch, H.P. Wan, H.S. Shim, **B.R. Adams**, S.L. Chen (2004) "Study of Syngas Co-Firing and Reburning in a Coal Fired Boiler," *Fuel*, Vol. 83, pp. 1991-2000.

Harding, N.S., **Adams, B.R**. (2000) "Biomass as a reburning fuel: a specialized cofiring application," *Biomass and Bioenergy,* Vol. 19, Elsevier, pp. 429-445.

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