Project Summary Information Page RFP Number: EPA-OAR-OAQPS-17-03

a.) Title: Assessing Hazardous Air Pollutants (HAPS) Emitted by Residential Wood Burning in Western Washington

b.) Applicant: Olympic Region Clean Air Agency
2940 Limited Lane NW
Olympia WA 98502-6503
Principal Investigator: Dr. Odelle Hadley, Senior Air Monitoring Specialist
Tele: (360) 539-7610 x105, Fax: (360) 491-6308 Email: odelle.hadley@orcaa.org

c.) Funding requested: $359,799

d.) Total project cost: $462,899
- Includes $111,100 In-kind: equipment owned by ORCAA and WA State Dept. of Ecology

e.) Project Start: October 1st, 2017
Project End: September 30th, 2019

f.) DUNS Number: 054595004

Basis and Rationale

The Olympic Region Clean Air Agency (ORCAA) proposes to monitor hazardous air pollutants (HAPs) associated with wood combustion between October 2017 and April 2018 in Thurston County, Washington. Wood combustion emits high levels of polycyclic-aromatic hydrocarbons (PAHs), such as benzo(a)pyrene, which are highly carcinogenic[1,2] and naphthalene which causes respiratory distress and is a potential carcinogen[3]. Wood combustion also produces carbonyls like formaldehyde and acrolein[4], which cause respiratory distress and increase asthma risk[5,6]. Acetonitrile has been used as a tracer for wood combustion[7] and is also a HAP. This project will focus primarily on these five pollutants. We will analyze data, assess health risks, present our findings, and publish papers between May 2018 and September 2019.

Each winter, Thurston County woodstove emissions cause ambient PM2.5 to approach and sometimes exceed the 24-hour PM2.5 National Ambient Air Quality Standard (NAAQS). The winter PM2.5 measured in Thurston County (Lacey) is often equal to, or higher than, measurements in Tacoma and Seattle (Figure 1). Residential wood heating is more common in rural and semi-urban communities like those in Thurston County. Woodstoves and fireplaces are known to cause air quality problems in small communities [8,9] and large urban centers[8,10].

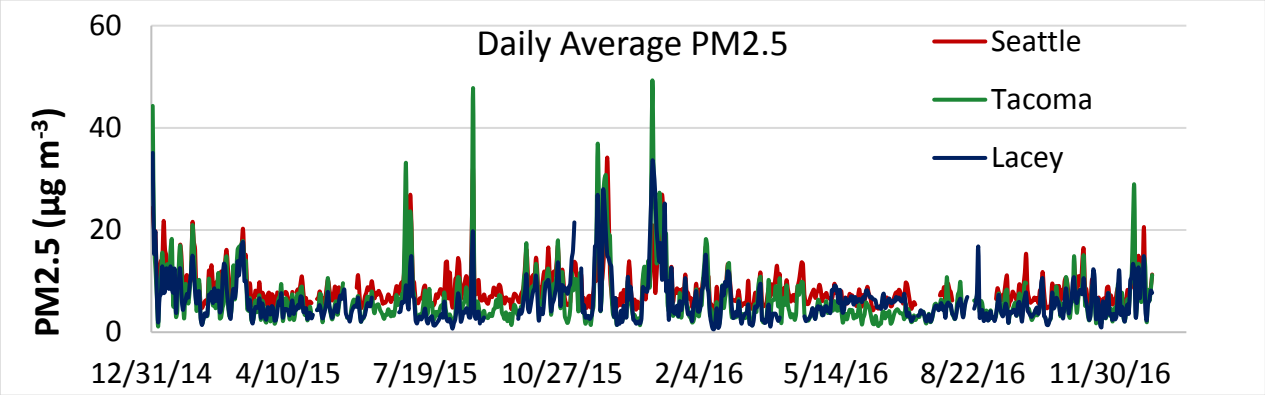

Figure 1.) Daily averaged PM2.5 during 2016 at monitoring sites in Seattle (King Co.), Lacey (Thurston Co.), and Tacoma (Pierce Co.).

ORCAA's air quality monitors track PM2.5 levels and provide warning if a region comes close to exceeding NAAQS for fine particulate. Woodstoves are Thurston County's dominant PM2.5 source in the winter and it's possible that associated gas phase toxic compounds could exceed EPA's reference concentration (RfC) for ambient exposure even when PM2.5 levels do not. Gas phase PAH concentration in ambient air is typically 2 to 3 times higher than that found in the particle phase[11]. Lighter, more volatile compounds like acrolein and naphthalene will partition almost entirely to gas phase. The U.S. EPA chronic inhalation RfC for acrolein is 0.02 µg m^{-3} [5,12]. A 2-year study conducted in Pittsburgh found mean ambient levels of acrolein exceeded the RfC by a factor of 10 in urban areas and by a factor of 3 at a rural background site[12]. Data quantifying the concentration of gas phase HAPs associated with woodstove emissions is needed to improve health risk assessments for the affected regions. Results from this study will be applicable to any community where residential wood heating presents an air quality problem.

In January 2017, ORCAA completed a saturation study in Thurston County to assess spatial and seasonal variability in ambient PM2.5. During this study, three optical particle counters (OPC - MetOne 212 profilers) were installed at various locations in the county. A fourth OPC was located at the county's permanent air monitoring site in Lacey, WA to ensure consistency between the nephelometer (Ecotech Aurora 3000) and the OPC measurements. These data showed our permanent PM2.5 monitor typically measured the highest concentrations of PM2.5 in Lacey's urban growth area (UGA). A collocated 2-wavelength aethalometer provided data allowing us to calculate the relative contributions from diesel and wood smoke to black carbon particles[13]. The highest concentrations of PM2.5 were observed in winter and predominantly associated with wood smoke[13]. A second monitoring site located in rural Thurston Co measured PM2.5 that often exceeded measurements at our suburban and urban sites.

Air sample collection and subsequent data analysis will be completed by students from The Evergreen State College (TESC). ORCAA will partner with TESC faculty to provide 2 advanced chemistry students with internships as part of their academic studies under the supervision of Dr. O. Hadley, ORCAA Senior Air Monitoring Specialist and Professor. A. Biswas, Professor. R. Schneider, and Professor C. Barlow, academic faculty at TESC (CVs attached). TESC has an excellent reputation for environmental science education and maintains modern student laboratories equipped with state of the art analytical tools available for students' use conducting independent research.

Technical Approach

The Olympic Region Clean Air Agency (ORCAA) proposes to monitor a subset of hazardous air pollutants (HAPs) commonly associated with wood smoke. The primary compounds of interest are:

naphthalene, benzo(a)pyrene, formaldehyde, acetonitrile and acrolein. These five pollutants are emitted in significant quantities during wood combustion and have been identified as having serious health risks. This project will:

1. Assess the concentration of the previously described HAPs and their relationship to elevated PM2.5 from residential wood combustion.
2. Determine if ambient levels exceed the reference concentrations (RfC) for ambient air.
3. Identify additional sources contributing significantly to these HAPs.
4. Evaluate and improve measurement methods for acrolein.
5. Provide undergraduate and graduate students with experience conducting environmental research.

24-hour (midnight-to-midnight) air samples for HAPs monitoring will be collected at Mt. View Elementary School, Lacey WA, Thurston County's air quality monitoring site since 1986. This will be the urban growth area (UGA) site. HAPs samples will be collected on Sundays and Wednesdays, between October 2017 and May 2018. This will provide data for weekdays and weekends, as burning practices may differ. Additional, concurrent, 24-hour samples will be collected at a rural monitoring site near Rochester, WA where high concentrations of PM2.5 were measured during the saturation study. Extra samples will be collected if daily PM2.5 is predicted to exceed 20 µg m^{-3} on days outside the set schedule. The following instrumentation will be installed at Mt. View Elementary and where indicated in Rochester as well.

1. A meteorological station (WD, WS, T, P, and RH) – both sites
2. Optical Particle Counter (MetOne 212 profiler) – both sites
3. A multi-wavelength aethalometer (Lacey only)
4. Carbon monoxide sampler (API 300EU) (Lacey only)
5. Ozone monitor (2b model 202) (Lacey only)
6. M903 nephelometer (proxy for PM2.5) (Lacey only)

Sample collection and analysis will follow EPA standard operating procedures for TO-11[14], TO-13[15], and TO-15[16] sampling methods. ORCAA will follow the Washington State Department of Ecology (ECY) Air Toxics Quality Assurance Project Plan (QAPP) to ensure the highest quality data reporting. Meteorological, ambient particulate data, and ambient carbon monoxide concentration will provide a context to compare and assess community scale HAPs concentrations and their relationship to PM2.5 emitted from residential woodstoves and fireplaces. ORCAA will measure fine particle concentrations with both a nephelometer and an optical particle counter (OPC) at the UGA monitoring site and an OPC at the rural site

We will use evacuated canisters equipped with flow control devices to obtain air samples for methods TO-13 and TO-15. Air flow and timing will be controlled using a PUF sampler (TE-1000, Tisch Env.) and a VOC sampler (Xontech 910). Flow rates will be checked with a certified flow meter following each sample collection. We will use a Xontech 925 for tube sample collection consistent with TO-11A sampling protocol. Canisters and relevant sample collection materials will be provided by Eastern Research Group (ERG), an independent analytical lab that will conduct sample analyses. Contracting with this lab is consistent with ECY Air Toxics QAPP. Although we are specifically interested in the previously described HAPs, ERG will analyze samples for the 93 compounds associated with the three methods. All data will be submitted to EPA's Air Quality System (AQS) database.

Students from The Evergreen State College (TESC) will perform all sample collection. ECY will provide training on standard operating procedure for sample collection. In addition to sample collection for analysis by ERG, students will collect air samples in sorbent tubes for acrolein analysis

at TESC labs. Previous studies found that Method TO-11 significantly underestimates ambient acrolein levels, while the more preferred Method TO-15 may over-predict ambient acrolein concentrations (Julie L. Swift, ERG, spoken communication)[17]. The uncertainty surrounding acrolein measurements has caused EPA to declare all acrolein data in AQS database as "unverified"[17]. Several studies have shown great improvements in more accurately measuring ambient acrolein and lowering the limit of detection to levels below EPA RfC for acrolein exposure[18,19]. We will work with our students and TESC technical staff to narrow this large window of uncertainty surrounding acrolein measurements.

Students will develop their own sample collection and analytical protocol based on previous studies[18,19] using sorbent tubes treated with pentafluorophenyl hydrazine for carbonyl samples. They will be trained and work under the supervision of Jenna Nelson, Hansina Hill, and Alberto Napuli (CV attached). Published results indicate this method improved sample collection efficiency and significantly lowered the detection limit of acrolein. Student results will be compared and evaluated against the contract lab results. TESC science students have ready access to modern chemical research instrumentation, including a 400 MHz FT-NMR spectrometer with multinuclear capability, multiple FT-IR spectrometers, two GC-Mass spectrometers, an ICP-Mass spectrometer, an atomic absorption spectrometer, a CHN analyzer, a UV/Vis-Discrete auto analyzer, a mercury analyzer and three ion chromatographs. While students will primarily use the GC/MS in their analysis, they may choose to expand on air sample analyses using additional instrumentation available at TESC.

Data Analysis

Students at The Evergreen State College (TESC) will conduct most of the data analysis under the direction and supervision of Dr. O. Hadley. We will look at the frequency distribution of HAPs concentrations through the heating season to evaluate community exposure. We will compare samples collected at the primary monitoring site in Lacey with those from the rural site to evaluate how representative the primary monitoring location is compared to the county. The correlation between HAPs concentrations and PM2.5 will be evaluated. We will look at the relationship between the different HAPS concentrations and the aethalometer and carbon monoxide data. The multi-wavelength aethalometer provides absorption characteristics of the fine particulate. Inefficient, or smoldering burns, produce brown, red, and yellow light absorbing particles[12, 19]. As burn efficiency increases, particles turn increasingly black. Inefficient combustion also increases CO levels[20]. We will analyze particle absorption characteristics in relationship to the HAPs concentration to determine how emissions change under different combustion characteristics, as indicated by particle absorption properties. Ozone measurements will provide a value on the oxidative capacity of the air during sample collection. These data will allow us to evaluate how ozone may or may not affect the ambient HAPs concentrations relative to PM2.5 and black carbon. PAHs and carbonyls are highly reactive with ozone. We will also look at the impact of ambient temperature on HAPs concentration relative to PM2.5.

Students will evaluate the accuracy and precision of the acrolein measurements. They will collect analytical data on laboratory prepared control standards, lab blanks, field samples, field blanks and analyte spiked samples to determine recovery efficiency and evaluate matrix effects. Data from ERG will be compared with the results obtained from an independent acrolein analysis using TESC laboratory facilities. Students will quantify uncertainties of the acrolein concentrations measured using EPA reference method TO-15 and compare with a new modified approach. Changes in accuracy, precision, and sensitivity will be quantified.

An additional student project will use project results to evaluate associated health risks in communities where measurements were conducted. This will be completed during the second year of

the study. All data will be checked for quality assurance following procedures outlined in the ECY Air Toxics QAPP.

Environmental Justice Impacts

The poorest communities have the highest incidences of fireplace and woodstove use for heating their homes and these homes are less likely to have certified, or pellet stoves. There is a higher likelihood that the fuel may contain construction debris, wood containing harmful chemicals, or household trash, as burning is a cheaper alternative to garbage services. All people in these communities may be adversely affected by the heating and burning practices of a few.

As previously mentioned, ORCAA operated four PM2.5 sensors in Thurston County between November 2015 and January 2016. PM2.5 peaked at all sites in the winter months. Winter average PM2.5 in Lacey, WA (6 to 10 µg m^{-3}) was on average twice that measured in West Olympia (3 to 5 µg m^{-3}). Maximum daily PM2.5 concentrations were generally 3 times higher in Lacey compared to West Olympia. Our rural monitor, located in Rochester, WA and outside the urban growth area (UGA) generally recorded PM2.5 at the same levels as in Lacey and peak concentrations were often higher. The primary sample site for this project will be at Mountain View Elementary in Lacey, WA.

Mt. View is a Title 1 school, qualifying for additional federal funds as over 40% of the families the school serves are low income. The median household income in neighborhoods surrounding Mt. View Elementary is approximately $52K, translating to about $21K per person in a household. In comparison, the median annual income in West Olympia neighborhoods is $63K or $26K per person in a household. While the median annual income for Rochester is the same as Lacey at $52K, larger families mean the per person annual income is lower at $19K. As Rochester is a rural community, the population density is less than Lacey or Olympia. The observed spikes in Rochester's PM2.5 were likely due to outdoor burning, which is prohibited in the UGA. Rochester will serve as our secondary sample collection site.

The saturation study data suggest the worst air quality in Thurston County is found in the poorest and rural communities. ORCAA regularly works with our communities to educate the public on wood burning practices and associated hazards. Results from this study will be incorporated into our community outreach in these neighborhoods. If we find HAPs concentrations exceeding EPA's RfC, the results will be used to leverage new programs assisting low income households and neighborhoods with alternatives to wood heating.

Community Collaboration and Outreach

Our primary monitoring site is located at a local elementary school, with whom we have partnered for over 20 years to monitor air quality in the community. ORCAA's board of directors, comprised of elected county and city officials, strongly endorse this project and signed a letter of support, attached to this proposal. Study results will be presented to the Lacey city council. This presentation will be filmed and broadcast on Thurston County TV and available to all county communities. Regular updates on our progress and findings will be posted on ORCAA's website and available to the public.

ORCAA is partnering with The Evergreen State College (TESC), an important educational institution in the community. This project will provide two, top level environmental students with opportunities to work on an environmental issue directly relevant to the community. TESC environmental program does not currently offer courses on air quality or atmospheric chemistry, so this project will help fill that gap. A letter of support from TESC provost's office is attached.

ORCAA regularly presents air quality information to local HOA, local fairs, and home shows, often focusing on wood heat alternatives and clean burning practices. Results from this study will be included in our wood burning mailers and brochures that are distributed throughout the community.

Environmental results: Outcomes, Outputs, Performance Measures

Outcomes

a. Determine if wood smoke emissions cause ambient HAPs concentrations to exceed EPA's RfC for public exposure.
b. Measure background HAPS concentrations and evaluate contributions from other sources relative to wood smoke.
c. Increase public awareness regarding health impacts of wood combustion and home heating and reduce exposure through education.
d. Evaluate and improve acrolein measurement methods.

Outputs

a. Addition of HAPs data to EPA's Air Quality System Database (AQS).
b. Final report on HAPs concentrations associated with ambient fine particulate from wood smoke emissions.
c. Evaluation of a new method for measuring acrolein that may reduce uncertainties, increase sensitivity, and lower the limit of detection relative to the current method.
d. 2 to 3 peer reviewed publications.

Performance Measures

All monitoring activities will be evaluated in a manner consistent with ORCAA and ECYs' current air quality monitoring programs and with ECY's Air Toxics Monitoring Quality Assurance Project Plan. ECY collects VOC and carbonyl air samples at the Beacon Hill, Seattle monitoring site. Quality assurance procedures at this site will be applied to this project. Because we will use a national contracts lab, Eastern Research Group (ERG), for the analysis, data will be submitted to AQS directly by the lab. We will evaluate data completeness monthly and ensure proper quality control audits are performed regularly (and recorded) on all equipment. ECY agreed to provide 3rd party audits on monitoring equipment at the beginning and conclusion of the project. Students working on the project will be required to submit quarterly reports on their progress. These reports will be a significant factor in credit and performance reviews of the students' progress, as well as ensuring project goals are being met in a timely manner.

Data analysis will be on-going as laboratory results are received. Data will be subjected to validation based on field records and comparison with other variables measured at the site. Sample collection protocols will be reviewed regularly and potential problems identified and solved as quickly as possible. We will set a project timeline for data collection, analysis and report writing. The timeline will be reviewed monthly and adjusted as we go forward.

Programmatic Capability and Past Performance

During the last 6 years, ORCAA has received $86,000.00 per year from EPA for operations and maintenance and $35,000 of In-kind per year for a rural NCORE site located at the Cheeka Peak Atmospheric Observatory (CPO) on Makah tribal lands above Neah Bay, Washington. The grant covers the cost of operating the site, data validation and analysis, instrument repair, and travel once a

year to EPAs air monitoring conference. The grant requires 2 reports a year: one mid-year status report and a final year-end report. Dr. Hadley is the primary operator and manager of this site. She maintains all the equipment, performs quality assurance checks, and validates data. She files interim and annual reports to EPA every year, highlighting work completed, changes to the site, and data quality assurance and completeness. Dr. Hadley recently completed a study using EPA Positive Matrix Factorization model, combined with data from the collocated IMPROVE and NCORE stations at CPO, to determine the primary PM2.5 sources at CPO, how the relative source contributions vary seasonally, and longer term trends in each source. A paper is currently under review for publication in the journal, Atmospheric Environment.

ORCAA also managed a grant to study ultra-fine particles on the Olympic Peninsula. The grant, in the amount of $515,000.00, was awarded to ORCAA by the 2013 Washington State Legislature. ORCAA partnered with Professor Dan Jaffe and Professor Joel Thornton from the University of Washington to conduct the study. The primary goal of this project was to determine how a new biomass co-generation boiler in Port Angeles could affect ultra-fine particle concentrations in the area. Data collection was conducted between January 1, 2014 and June 30, 2015. A mid-term report was submitted to the legislature October 15, 2014. The first paper was published May 2016[21]. A second paper is currently in preparation.

Dr. Hadley manages six additional ambient air monitoring sites throughout the Olympic Peninsula. She is responsible for ensuring data quality and following state QAPPs and standard operating procedures (SOP). She prepares and presents monthly reports on regional air quality to a board of directors. She regularly attends and presents her work at conferences. (See references on Pages 9-10)

Detailed Budget Narrative

	Column 1	+ Column 2	= Column 3	+ Column 4	= Column 5
Budget Categories	**Budget** 10/1/17-9/30/18	**Budget** 10/1/18-9/30/19	**Sub-Total Federal Budget** (Sum Columns 1+2)	**In-Kind**	**Grand-Total Program Budget** (Sum of Columns 3+4)
Personnel	$ 63,877	$ 18,539	**$ 82,416**	$ -	**$ 82,416**
Fringe Benefits	13,446	7,098	**20,545**	-	**20,545**
Travel	8,704	2,500	**11,204**	1,100	**12,304**
Equipment	35,000	-	**35,000**	99,000	**134,000**
Supplies	12,000	-	**12,000**	3,000	**15,000**
Contractural	157,000	-	**157,000**	-	**157,000**
Other	3,447	12,447	**15,894**	-	**15,894**
Indirect Charges	19,331	6,409	**25,740**	-	**25,740**
Totals	$ 312,805	$ 46,994	**$ 359,799**	$ 103,100	**$ 462,899**

Budget Categories	Operations & Maintenance	1st Year	2nd Year	In-Kind
Personnel	Senior Monitoring Specialist: 1st Year: Mo. $7,685 x 12/2080/hrs x 416/hrs =.20 FTE 2nd Year: Mo.$7,915 x 12/2080/hrs x 312/hrs =.15 FTE	$ 18,445	$ 14,249	
	Air Monitoring Specialist-IT: .05 FTE Mo. Salary $5,311 x 12/2080 x 104/hrs	3,187		
	Adm Srs Mgr-Accounting, payroll, budget: .05 FTE Mo. Salary $7,150 x 12/2080 x 104/hrs each year	4,290	4,290	
	TESC Students/Air Quality Specialist I: Hourly Rate: $24.33/hr x 1,560 hours	37,955		
Benefits	**R**etirement: 12.70 % (n/a to TESC) 1st Year: $25,922 x 12.70% 2nd Year: $18,539 x 12.70%	3,292	2,354	
	FICA-7.65%	5,138	1,598	
	Health Benefits @ $1,278/mo. FTE (n/a to TESC) 1st year @ .30 FTE, 2nd year @ .20 FTE	4,601	3,067	
	Labor & Industries: 1st year @ 2,184/hrs x 0.1902 2nd year @ 416/hrs x 0.1902	415	79	
Travel	Weekly site visits for operation and maintenance (2.5 x week x 30 miles x 30 weeks x $.535 mile)	1,204		
	Ecology In-House Training on Equipment at Seattle Headquarters for ORCAA Staff & TESC			1,100
	EPA National Air Monitoring Conference, Estimated Air Fare, Hotel, and Meal Per Diem for ORCAA staff, TESC student(s)	7,500	2,500	
Equipment	Sampling Sorbent Tubes	10,000		
	VOC Air Sampler (TO-15)	10,000		20,000
	Carbonyl Sampler (TO-011A)	15,000		26,000
	Optical Particle Counters (ORCAA)			7,000
	Ozone Monitor (ORCAA)			6,000
	Teledyne 300EU CO monitor			14,000
	Aethalometer			26,000
Supplies	2-Mass flow controllers	5,000		
	2-Air pumps	-		600
	2 ozone denuders	4,000		
	Miscellaneous field supplies	3,000		
	Met Stations (ORCAA)			2,400
Sub-Contracts	Eastern Research Group - Sample Analysis	145,000		
	TESC Lab Maintenance & Staff time	12,000		
Other	Rental Space @ 3% of $80,200	2,406	2,406	
	State Audit by SAO @ 3% of $9,700	291	291	
	Property Insurance @ 3% of $25,000	750	750	
	Publication Papers 2-3		9,000	
In-Direct	25% of Salaries & Benefits	19,331	6,409	-
	Annual Maintenance & Operation	$312,805	$ 46,994	$103,100
	Requested Funding	$359,799		
	Total Project Cost	$462,899		

Leveraging

ORCAA will receive approximately $47,100 in-kind funding from the Washington State Department of Ecology (ECY). ECY will provide ORCAA with toxics air samplers, sampling canisters, and sampling tubes. ECY will also provide equipment quality assurance audits at the beginning and end of the project monitoring phase. Finally, ECY will provide sample collection training to ORCAA and TESC students. A letter of support from the Department of Ecology is attached. ORCAA will contribute about $56,000 in additional monitoring equipment.

Expenditure of Awarded Grant Funds

ORCAA will follow all applicable procurement procedures, including 2 CFR 200 Uniform Administrative Requirements for Federal Awards. All equipment purchases will be made as soon as funds are available to ensure sample collection can begin on time. ORCAA staff time is accounted for and paid monthly. Each month, employees are required to fill out a time sheet that keeps track of time spent in each of ORCAA's independent regulatory programs. After all time is accounted for by program, monthly time-sheet data is transferred to an agency workload accounting spreadsheet that keeps track of total workload in each program in terms of Full-time equivalents, calculates the associated monthly cost of administering each program and determines the fee-eligible costs for each program. The accounting spreadsheet is administered by ORCAA's Accountant and serves as ORCAA's official financial record for agency programs. ORCAA's subcontractors are required to submit invoices for reimbursement monthly, or every 60 days for expenditures that are incurred, received, and are within the award period. Nearly all data collection will be completed in the first year, with analysis and reporting to be concluded in the second year. This ensures the majority of funds will be expended in the first half of the study as sample analysis accounts for a large percentage of the grant. Managing time during the reporting and analysis phase of the study will allow us to use remaining funds in a timely manner.

References

1 Bølling, A. K. *et al.* Health effects of residential wood smoke particles: the importance of combustion conditions and physicochemical particle properties. *Particle and Fibre Toxicology* **6**, doi:10.1186/1743-8977-6-29 (2009).

2 Gelboin, H. V. Benzo(a)pyrene metabolism, activation, and carcinogenesis: role and regulation of mixed-function oxidases and related enzymes. *Physiological Reviews* **60**, 1107-1166 (1980).

3 Jia, C. & Batterman, S. A Critical Review of Naphthalene Sources and Exposures Relevant to Indoor and Outdoor Air. *International Journal of Environmental Research and Public Health* **7**, 2903-2939, doi:10.3390/ijerph7072903 (2010).

4 Larson, T. V. & Koenig, J. Q. (eds Environmental Protection Agency United States & Emission Standards Division) (Research Triangle Park, NC 27712, 1993).

5 Woodruff, T. J., Wells, E. M., Holt, E. W., Burgin, D. E. & Axelrad, D. A. Estimating Risk from Ambient Concentrations of Acrolein across the United States. *Environmental Health Perspectives* **115**, 410 - 415 (2007).

6 deCastro, B. R. Acrolein and Asthma Attack Prevalence in a Representative Sample of the United States Adult Population 2000-2009. *Public Library of Science* **9**, doi:10.1371/journal.pone.0096926 (2014).

7 de Gouw, J. *et al.* Emission sources and ocean uptake of acetonitrile(CH3CN) in the atmosphere. *Journal of Geophysical Research* **108**, 4329, doi:10.1029/2002JD002897 (2003).

8 Schauer, J. J. & Cass, G. R. Source apportionment of wintertime gas phase and particle-phase air pollutants using orgainic compounds as tracers. *Environmental Science and Technology* **34**, 1821-1834 (2000).

9 Ward, T. J., P.Palmer, C., Hooper, K., Bergauff, M. & Noonan, C. W. The impact of a community-wide woodstove changeout intervention on air quality within two schools. *Atmospheric Pollution Research* **4**, 238-244 (2013).

10 Maykut, N. N., Lewtas, J., Kim, E. & Larson, T. V. Source apportionment of PM2.5 at an urban IMPROVE site in Seattle, Washington. *Environmental Science and Technology* **37**, 5135-5142 (2003).

11 Fernández, P., Grimalt, J. O. & Vilanova, R. M. Atmospheric Gas-Particle Partitioning of Polycyclic Aromatic Hydrocarbons in High Mountain Regions of Europe. *Environmental Science and Technology* **36**, 1162-1168, doi:10.1021/es010190t (2002).

12 Logue, J. M., Small, M. J., Stern, D., Maranche, J. & Robinson, A. L. Spatial Variation in Ambient Air Toxics Concentrations adn Health Risks between Industrial-Influenced, Urban, and Rural Sites. *Journal of Air and Waste Management Association* **60**, 271-286, doi:10.3155/1047-3289.60.3.271 (2010).

13 Kirchstetter, T. W. & Thatcher, T. L. Contribution of organic carbon to wood smoke particulate matter absorption of solar radiation. *Atmospheric Chemistry and Physics* **12**, 6067-6072, doi:10.5194/acp-12-6067-2012 (2012).

14 William T. Winberry, J., Tejada, S., Lonneman, B. & Kleindienst, T. (ed National Risk Management Research Laboratory Office of Research and Development) (U.S. Environmental Protection Agency, Cincinnati, Ohio, 1999).

15 William T. Winberry, J. & Jungclaus, G. (ed Center for Environmental Research Information) (Office of Research and Development, Cincinnati, OH, 1999).

16 McClenny, W. A. & Holdren, M. W. (ed Center for Environmental Research and Development Environmental Protection Agency) (Cincinnati OH, 1999).

17 Jones, M. *Data Quality Evaluation Guidelines for Ambient Air Acrolein Measurements*, <http://www.epa.gov/ttnamti1/files/ambient/airtox/20101217acroleindataqualityeval.pdf> (2010).

18 de Gouw, J. A. *et al.* Chemical composition of air masses transported from Asia to the U. S. West Coast during ITCT 2K2: Fossil fuel combustion versus biomass-burning signatures. *Journal of Geophysical Research* **109**, D23S20, doi:10.1029/2003JD004202 (2004).

19 Li, J. *et al.* Determination of gaseous carbonyl compounds by their pentafluorophenyl hydrazones with gas chromatography/mass spectrometry. *Analytica Chimica Acta* **635**, 84-93, doi:10.1016/j.aca.2008.12.041 (2009).

20 Preble, C., Hadley, O., Gadgil, A. & Kirchstetter, T. Emissions and Climate-Relevant Optical Properties of Pollutants Emitted from a Three-Stone Fire and the Berkeley-Darfur Stove Tested under Laboratory Conditions. *Environmental Science and Technology*, doi:10.1021/es5002715 (2014).

21 Gaston, C. *et al.* Online molecular characterization of fine particulate matter in Port Angeles, WA: Evidence for a major impact from residential wood smoke. *Atmospheric Environment* **130**, 99-107, doi:10.1016/j.atmosenv.2016.05.013 (2016).