HEI

Energy Research Program

WORKSHOP SUMMARY:

UNDERSTANDING POPULATION-LEVEL EXPOSURES ASSOCIATED WITH ONSHORE DEVELOPMENT OF OIL AND NATURAL GAS FROM UNCONVENTIONAL RESOURCES

July 11-12, 2018

Health Effects Institute
75 Federal Street, Suite 1400
Boston, MA 02210, USA
+1-617-488-2300
www.healtheffects.org

CONTENTS

1. INTRODUCTION

The Health Effects Institute (HEI) hosted the first of two research planning workshops in Denver, CO on July 11-12, 2018. At the workshop, a diverse group of stakeholders helped to inform HEI's planning strategy for research to better understand potential population-level exposures associated with onshore development of unconventional oil and natural gas resources. This report provides a summary of discussions at the workshop along with background information about the HEI Energy Research Program ('the Program').

2. HEI'S ENERGY RESEARCH PROGRAM

The purpose of the Program is to identify and conduct high priority research on the potential population exposures and health effects associated with onshore development of oil and natural gas from unconventional resources (UOGD)[1]. With development of these resources projected to continue, alongside growing efforts to switch to renewables and conserve energy, a source of high-quality, impartial science is needed to support decisions about how best to ensure protection of population health.

To define and oversee the Program in collaboration with HEI staff, HEI empaneled a multidisciplinary Energy Research Committee (the "Committee"):

- George Hornberger, Vanderbilt University, Director, Vanderbilt Institute for Energy & Environment, Nashville, Tennessee (Chair)
- Shari Dunn-Norman, Missouri University of Science and Technology, Rolla, Missouri
- Elaine M. Faustman, University of Washington–Seattle
- Howard Hu, University of Washington School of Public Health and University of Michigan School of Public Health
- Judy S. LaKind, LaKind Associates, LLC, Catonsville, Maryland, and Adjunct Faculty, University of Maryland–Baltimore
- Armistead (Ted) G. Russell, Georgia Institute of Technology, Atlanta
- Stefanie Ebelt Sarnat, Emory University, Atlanta, Georgia

The Committee consists of internationally recognized experts in one or more subject areas relevant to the Committee's work, have demonstrated their ability to conduct and review scientific research impartially, are independent of sponsor organizations, and have been vetted for conflicts of interest.

The Committee has been charged with reviewing the literature on potential human exposure and health effects of UOGD and research planning to address important knowledge gaps, culminating in the issuance of a competitive Research Solicitation for population-level exposure research to be funded by HEI. To ensure that only the highest quality studies receive funding for research, the Committee will carefully review proposals for technical quality and relevance, vet investigators for potential bias and conflicts of interest that might interfere with the integrity of the scientific work and interpretation of results and monitor research progress at key intervals. The Committee's oversight ends when investigators complete the research and submit their final report, which is then independently reviewed in detail by a separate HEI Energy Review Committee.

[1] In this report, UOGD is defined as operations associated with development of shale and other tight resources using horizontal wells combined with multistage hydraulic fracturing during well pad development (e.g., exploration, site preparation, drilling, well completion, management of wastes), production (e.g., extraction, gathering, and processing of oil and gas, management of wastes), and post-production (e.g., well closure, site reclamation).

HEI makes the results from all literature reviews and original research – both positive and negative – publicly available at no charge and provides summaries written for a general audience. HEI expects results from this research program to be used by government officials, communities, industry, environmental and public health organizations, and other stakeholders to inform policy development.

3. A Workshop to Inform HEI's Research Planning

HEI hosted the workshop to help inform its planning for population-level exposure research associated with UOGD. The workshop provided a venue for participants to hear expert presentations, discuss the exposure-related literature, and share recommendations for research to address important knowledge gaps in the literature.

3.1 Meeting Participants

Hosted by HEI staff and HEI's Energy Research Committee, the workshop brought together a wide range of stakeholders. Speakers and other meeting participants represented sponsor organizations, federal and state government, industry, academia, environmental and public health nongovernmental organizations, community organizations, and foundations. HEI sought the participation of individuals with diverse expertise, experience, and perspectives about UOGD to ensure that the Committee is aware of relevant research as well as their ideas for research prioritization. Meeting participants engaged in a productive exchange with the Committee and other meeting participants about HEI's plans for population-level exposure research, its review of the exposure literature, and future research challenges and opportunities.

3.2 Workshop Overview

Participants heard from expert speakers, participated in breakout sessions, and had the opportunity to view posters on relevant research. Discussion at the workshop focused on five charge questions (Table 1). Expert speakers addressed topics relevant to the charge questions, including exposure assessment, industry trends, regulatory trends, air quality and water quality literature, and human health risk assessment. During the breakout groups, participants answered two questions related to the charge questions: (1) What criteria should be used to prioritize research recommendations and (2) What potential human exposure would you study and where if you were given $2 million for research?

This report and other information from the Workshop agenda are available at www.hei-energy.org.

Table 1. Workshop Charge Questions

1.	What does the literature tell us?
2.	What does the literature not tell us?
3.	What are your recommendations for criteria for prioritizing research?
4.	What are your recommendations for population-level exposure research?
5.	What are your recommendations for further literature review and data analysis before the September workshop to help in defining research priorities?

4. Summary of Presentations

The Committee heard presentations broadly summarizing the literature on UOGD industry practices, environmental impacts of UOGD, and efforts to quantify human exposure and risk associated with UOGD.

4.1 INTRODUCTION

Representatives of HEI and the Committee presented an overview of the Energy Research Program and its scope, the Committees' approach to reviewing literature and planning for exposure research, and the role of the workshop in HEI's planning for research.

Dr. Shari Dunn-Norman, a petroleum engineer and member of the Committee, described the scope of the Committee's review, explaining the specific UOGD operations being assessed by the Committee. She discussed the challenges and considerations associated with studying potential exposures related to UOGD, such as distinguishing among sources of exposure, whether UOGD, conventional oil and gas development, or other sources and accounting for rapidly changing industry practices that may affect the potential for exposure. Her presentation elicited discussion among workshop participants about air emissions from UOGD, with some commenting on the variability in emissions across development fields and sometimes even individual wells.

Dr. Dunn-Norman answered questions about the Committee's tour of oil and gas operations in Weld County, Colorado. Members visited a well pad with six wells, a Generation 1 well pad site, in which each well had a separator and storage tank, and a Generation 4 well pad site, in which multiple wells share a separator and storage tank. Dr. Dunn-Norman answered questions about production levels in conventional versus unconventional development and variability in air emissions.

4.2 EXPOSURE ASSESSMENT LITERATURE

This session provided an overview of exposure assessment research conducted to date in occupational and community settings and from the perspectives of government, industry, and academia.

CAPT Bradley King, National Institute for Occupational Safety and Health (NIOSH)

CAPT King summarized NIOSH research on occupational exposures in the upstream oil and gas industry and strategies for reducing exposures through elimination, substitution, and engineering controls. The Committee has been charged with reviewing community exposures rather than worker exposures to UOGD; however, community exposure assessment might be informed by occupational exposure assessment, if only to represent an upper bound of possible exposure. For this reason, CAPT King was asked to summarize research on occupational exposures, despite this type of exposure being outside the scope of the Energy Research Program.

He began by describing the most severe risk that workers face, summarizing findings from NIOSH's Fatalities in Oil and Gas (FOG) database. Based on data in FOG, between 2014 and 2016, the leading cause of oil and gas worker fatalities was transportation, followed by contact injuries, explosion or fire and exposures involving alcohol, drug poisoning, or harmful substances.

CAPT King provided an overview of NIOSH's research to better understand chemical exposures among UOGD workers. The goals of the research include: 1) identifying processes and activities where chemical exposures could occur; 2) characterizing potential exposures to vapors, gases, particulates and fumes (e.g., solvents, diesel particulate, crystalline silica, acids, metals, aldehydes, and possibly other chemicals identified during the study); 3) depending on results of the field effort, recommending safe work practices and/or proposing and evaluating exposure controls (to include engineering controls, substitution, and personal protective equipment).

Specific NIOSH research projects have focused on respirable crystalline silica, volatile organic compound (VOC) mixtures, and diesel particulate matter. NIOSH evaluated respirable crystalline silica exposures at eleven hydraulic fracturing sites between 2010-2011, studying workers expected to be exposed to the

highest concentrations (i.e., sand mover operators and transfer-belt operators). NIOSH reported personal breathing zone concentrations significantly above occupational limits, and Dr. King described examples of on-site dust controls and NIOSH risk communication efforts).

NIOSH has also investigated UOGD worker exposure to hydrocarbon gases and vapors during manual tank gauging and sampling. NIOSH recommends several mitigation strategies to address these thief hatch emissions such as alternative tank gauging procedures so that workers do not have to routinely open hatches, risk communication, and proper use of supplied air respirators. Exposure to hydrocarbon gases and vapors can also occur during fluid transfer (e.g., to trucks), and NIOSH recommends using vent lines to direct hydrocarbon gases and vapor away from the work zone and potential ignition sources.

To understand worker exposure to diesel particulate matter (DPM) emissions, NIOSH has collected area and personal breathing zone samples to quantify DPM concentrations during drilling, hydraulic fracturing, and servicing of wells. No occupational exposure limits have been established for DPM, so NIOSH compared concentrations to a State of California limit for elemental carbon (EC). Five of forty nine personal breathing zone concentrations exceeded the California limit, with concentrations associated with sand mover and transfer belt operators, blender and chemical truck operators, and water transfer operators during hydraulic fracturing operations. NIOSH recommendations to reduce DPM exposures include locating diesel-driven pumps away from well pads, use of alternative fuels and advanced emission control technologies, and risk communication and worker training.

Based on its research to date, NIOSH recommends further study of occupational exposure to chemicals associated with UOGD and appropriate mitigation strategies to reduce health risk.

Q&A Session. CAPT King answered questions about whether NIOSH plans to conduct further assessments on occupational exposure to chemicals beyond what he described in his presentation. He indicated that NIOSH was open to discussion about additional research. He further noted that the occupational exposures discussed in his presentation cannot be extrapolated to non-occupational exposures. In answering questions about silica exposure, CAPT King stated that NIOSH has not examined different silica size fractions, and that NIOSH has developed a research agenda that considers technology to reduce silica exposure. When asked about the companies that partner with NIOSH in its research, CAPT King responded that they are typically industry leaders in research and environmental health and safety.

Dr. John Adgate, Colorado School of Public Health

Dr. Adgate summarized research on community exposures near UOGD. He provided his perspective on key exposures related to UOGD and how they vary by region, specific UOGD operations, number of nearby wells and temporally when operations are intermittent. Dr. Adgate highlighted how exposure has been quantified in studies to date and provided his recommendations for how they should be assessed in future research.

Dr. Adgate's list of key exposures included air pollution from methane, non-methane hydrocarbons (NMHC), including benzene, toluene, ethylbenzene, and xylene (BTEX), hazardous air pollutants (HAPs), particulate matter (PM), black carbon, polyaromatic hydrocarbons (PAHs), and ozone; water pollution from methane, NMHCs, BTEX, metals, and naturally occurring radioactive material (NORM); noise, light, and vibration; traffic; and catastrophic risk (e.g., explosions). Dr. Adgate spent the balance of his presentation focusing on potential exposures associated with air quality and noise impacts near UOGD.

He summarized the air quality literature and noted data showing concentrations of HAPs increasing with the density of UOGD and diurnal variation in concentrations of some HAPs with higher concentrations during nighttime hours. He remarked that air sampling often involves use of central monitoring locations to quantify 24-hour average air concentrations that represent relatively large areas and typically do not account for the proximity of human populations. Fewer studies used shorter averaging times to quantify any peak exposures and sampled near residential areas.

Dr. Adgate described noise as an important exposure related to traffic and pad activities, He explained that sound walls have limited efficacy and multi-well pads and related infrastructure, such as compressors, can be associated with elevated noise levels. Dr. Adgate co-authored a study of noise near UOGD, and he summarized the number of noise measurements during the day and night that exceeded a threshold at which noise "may cause annoyance and can be detrimental to health."

Dr. Adgate presented some strategies for measuring exposure in future studies. He recommended nested longitudinal studies to explore variability among seasons, years, operators, and locations. He suggested starting with a central site and including residential sampling, personal sampling, and biomonitoring focused on BTEX, NHMCs, Black Carbon, PM, ozone, and noise. Additionally, future study designs should explore both long-term exposure and short-term exposure, nesting longitudinal studies across years, seasons, and locations to explore variability.

Q&A Session. Dr. Adgate responded to questions about the feasibility of using exposure biomarkers in a fetal outcome study, methods to distinguish between background exposures and UOGD exposures, and specific chemicals that investigators will target in future exposure studies, including those involving biomonitoring and air quality monitoring. In response to an inquiry about why silica was not included on Dr. Adgate's list of exposures of concern for study, he noted that silica is primarily of concern for occupational studies except in locations where sand mining occurs. He also described the difficulty in accounting for multiple co-exposures (e.g., noise, vibration, other emissions) in a single study.

4.3 Industry Trends and Related Research

This session summarized trends in UOGD practices, particularly as they pertain to air emissions, and research at a well pad test site, with the goal of providing important background understanding about the factors that can influence the potential for human exposures and effects.

Dr. Adam Pacsi, Chevron Energy Technology Company

Dr. Pacsi provided an overview of major equipment associated with UOGD and its emissions, control technologies, and regulation. He also discussed whether the body of research on methane emissions from UOGD might inform research on other chemical emissions.

The United States Environmental Protection Agency (EPA) regulates emissions from constructed, modified, or reconstructed facilities, including controls and operational practices targeting volatile organic compound (VOC) emissions. In addition to regulating emissions from UOGD-specific equipment, EPA engine emission regulations dictate performance requirements on new engines for a model year and mandate retirement of older engines over time and replacement with lower emitting models. Federal regulations often intersect with state requirements and operator voluntary programs, many of which aim to reduce emissions, such as those from tanks, venting, pneumatic controllers, and leaks.

Dr. Pacsi summarized efforts to inventory UOGD sources of air emissions, citing specific efforts to develop emission inventories for nitrogen oxides (NOx) and VOCs, which influence ozone formation.

Publicly available emissions inventory data provide limited precision for UOGD operations dispersed over a relatively large area, but they can be helpful in capturing inter-basin variation in emissions sources from some processes and equipment. More limited emission inventory data are available for hazardous air pollutants. The Pennsylvania Department of Environmental Protection requires annual reporting of HAPS emissions, the Texas Council on Environmental Quality's Barnett Shale Special Emission Inventory, and various state regulations require individual site emission estimates in their permits.

Dr. Pacsi also discussed lessons learned from methane emission research and its application to the study of other chemical emissions. Methane studies might reflect sources in addition to UOGD. For those that isolate UOGD sources, the ratio of methane to other chemical species is variable such that simple scaling is not likely to be meaningful. Therefore, methane is not expected to be a good surrogate for other chemicals emitted by UOGD operations. Based on his work with methane emission research, Dr. Pacsi recommends studies that use multiple measurement methods and compare among basins, noting that developing an understanding of spatial and temporal variations in emissions and operations is key for putting the results in context.

Q&A Session. In response to questions from workshop participants, Dr. Pacsi explained that the variability in the results he presented are due to the conditions under which measurements were taken; therefore, his results may not be generalizable beyond those conditions. In responding to inquiries about data availability, Dr. Pacsi stated that all the data presented in his talk are publicly available, but that accessibility of data on source categories and air quality varies by state.

Dr. Michael McCawley, West Virginia University School of Public Health

Dr. Michael McCawley presented on the Marcellus Shale Energy and Environment Laboratory (MSEEL). MSEEL is a long-term project centered on a UOGD well pad field site, which represents a collaboration among West Virginia University, The Ohio State University, National Energy Technology Laboratory, Northeast Natural Energy, and Schlumberger. MSEEL has the dual goals of improving recovery efficiency and minimizing environmental implications. Environmental implications are being explored with the characterization of solid wastes (e.g., drill cuttings), characterization of liquid wastes over time (e.g., produced water), and changes in air quality.

Early findings for drill cuttings revealed that radioactivity levels were within West Virginia Department of Environmental Protection standard of 5 pCi/g above background and they are not hazardous under federal and state solid waste rules. The MSEEL project is also characterizing the inorganic, organic and radiochemistry composition of produced water, distinguishing between components originating from hydraulic fracturing fluid and formation water, which, together, comprise the produced water. Dr. McCawley reported that produced water composition differed from hydraulic fracturing fluid composition, with increasing concentrations of total dissolved solids (TDS) and ^{226}Ra and ^{228}Ra in the years following well completion.

Dr. McCawley also reported on MSEEL air quality monitoring for methane, particulate matter, and carbon dioxide among other chemicals. He reported increasing concentrations with decreasing distance from UOGD operations and highlighted important variables potentially influencing these concentrations (i.e., specific UOGD activities underway at the time of sampling and the well pad's location in a valley subject to thermal inversions). To better understand air emissions and their movement in the atmosphere, MSEEL team members are considering use of magnesium as a tracer that can be linked to UOGD operations. Dr. McCawley also described methods being developed to assess the impact of UOGD-related truck traffic on human exposures.

Q&A Session. In response to a workshop participant, Dr. McCawley confirmed that the MSEEL project employs an upwind sampling site. In addition, he discussed their possible use of magnesium as a tracer, explaining that magnesium is associated with both crustal dust and diesel emissions and can be used as a tracer of either source. In answering a question about the diesel technology use in UOGD operations, Dr. McCawley indicated that operators use diesel technology for hydraulic fracturing, off-road diesel generators, and on-road diesel trucks. He elaborated that the type of trucks depends on those used by the operator's subcontractors.

4.4 Regulatory Trends and Related Research

Panelists provided a variety of perspectives on trends in the regulation of UOGD. The session moderator, Mr. Robert O'Keefe, asked the panelists to address several topics: How can the scientific community do research that is policy-relevant? How do regulators deal with the rapidly changing landscape of UOGD? Which research gaps should be addressed by future workshops and research?

Dr. Michael Honeycutt, Texas Commission on Environment Quality (TCEQ)

Dr. Honeycutt underscored the demands on regulators to follow regulatory and technology trends related to UOGD. He explained that Texas regulators implement changes in response to these trends that are supported by high quality scientific literature. Regulatory trends across states vary depending on numerous factors such as geography and density of operations. He noted that, in general, it is difficult to marry research data with the information necessary for regulators to write effective rules and regulations. Dr. Honeycutt emphasized the need for scientific research that involves collection of data most useful for regulators.

Ms. Martha Rudolph, Colorado Department of Public Health and Environment

Ms. Rudolph categorized regulatory trends into three categories: knowns, known unknowns, and unknown unknowns. Ms. Rudolph defined knowns as the actions that state regulators take in response to federal-level regulations and well understood issues of concern in UOGD operations (e.g., spill prevention). States take unique approaches to the implementation of federal regulations, depending on their resources and needs. Ms. Rudolph defined known unknowns as the general knowledge that the regulatory community currently has about potential exposures, such as to benzene in air, and health impacts from UOGD, but without the specific knowledge necessary to define appropriate setback distances between UOGD and residences, schools, and other sensitive areas. Ms. Rudolph stated that unknown unknowns involve the general fear that people have about UOGD and the adverse effects that it might cause. Regulators need to be cognizant of these fears and work with the public and industry to address concerns in a satisfactory way, even as efforts continue to improve the understanding of potential exposures and effects and ways to protect surrounding communities.

Ms. Nichole Saunders, Environmental Defense Fund

Ms. Saunders focused her comments on regulation of produced water. She described several regulatory issues associated with produced water, stemming from a lack of understanding about its composition and general knowledge needed to properly regulate its management. Most produced water today is injected into disposal wells; however, induced seismicity and other factors are driving changes in the management of produced water. Reuse of produced water for various purposes has gained much interest; however, Ms. Saunders described a need for more information about produced water composition, toxicity, and mobility in the environment under various reuse scenarios to make informed regulatory decisions about this reuse.

Q&A Session. Workshop participants used the question and answer period to make several comments in reaction to the panel's presentations. Participants talked about the decline in public confidence in science when the message changes with each new study and the opportunity to increase confidence when the

public has opportunities for involvement in community-based participatory research. Participants also noted the value of FracFocus for identifying chemicals used in UOGD operations but also the knowledge gaps related to the composition of produced water composition and the toxicity of its components.

4.5 Air Quality Literature

This session focused on the collection, analysis, and interpretation of air quality data collected near UOGD operations in Colorado and Texas.

Dr. David Allen, University of Texas at Austin

Dr. Allen discussed emissions from upstream oil and gas operations in the United States and important questions to consider when using emission rate data in health assessments. He explained that UOGD is a source of various emissions, such as air toxics, greenhouse gases, and ozone and particulate matter (PM) precursors (e.g., VOCs and NOx). His presentation focused on the variability in temporal patterns of emissions, composition of emissions, and transformation of emitted chemicals following release to the environment.

Dr. Allen reported that temporal patterns are difficult to characterize because most emission inventories provide annual emission estimates, but emissions vary over finer time scales (e.g., hourly, daily, and weekly) and across the multi-year life of a well, which includes well pad construction, drilling, completion, and production. The composition of emissions vary widely as a function of specific UOGD operations or equipment and geologic variation in resource composition (e.g., oil, wet gas, and dry gas). Much remains to be learned about variability in emissions.

Dr. Allen also described work to understand chemical transformation of emissions that can occur near points of release to the atmosphere. He discussed a recent study that involved the collection of 12 samples of flowback wastewater from separators and storage tanks in the Permian Basin, evaporated aliquots into an environmental chamber, added oxidant precursors and NOx, and observed particulate matter formation.

Dr. Allen provided his recommendations for laboratory and field-based research to address knowledge gaps about air emissions. He described the value of field campaigns conducted across the full life of a well in regions that are selected based on target compounds of interest. Key features of the research would include coordination with local operators to obtain data describing their operational activities during the sampling program and comparison of the field study observations with data inventories representing the study location at the time of the field sampling program. Laboratory research could complement field work with testing of carefully collected field samples of well fluids.

Q&A Session. Dr. Allen answered questions about variability in ozone formation across regions and operations. In answering an inquiry about the availability of data on fracturing fluid composition and whether components have been detected in air, Dr. Allen remarked that scientists have much information about these components, but they are not necessarily reflected in air emissions data. He used chlorinated biocides to illustrate one reason for this apparent discrepancy, indicating that they can be transformed by pressure and heat in the subsurface environment. He elaborated on his teams' efforts to measure emissions during flowback and liquid unloadings (i.e., removal of accumulated fluids from wells to maintain production) and explained that all the data are publicly available. He further described efforts to identify sources of methane, especially those emitting at high rates relative to other UOGD equipment and operations.

Dr. Jeffrey Collett, Colorado State University

Dr. Collett presented on emissions and near-field dispersion of air toxics from oil and gas drilling and completions in Colorado. He presented the results of his research, which has three primary objectives: quantifying emissions of chemical compounds from oil and gas operations, characterizing the dispersion of chemical compounds in the atmosphere downwind from operations, and producing a public, high quality emissions dataset.

Dr. Collett's team at CSU has characterized air toxics, ozone precursors, and methane emissions in the Denver-Julesburg and Piceance Basins of Colorado. The team has also studied the regional impacts of UOGD on air quality, including PM formation and haze, in Boulder, Wyoming and Bakken, North Dakota. Dr. Collett presented the results of this work measuring emissions, defined as the amount of material emitted by an activity per unit of time. Concentrations are easier to measure than emissions, but they provide information only for a single place and time. Emissions data can be used to develop a dispersion model that can be used to predict concentrations for other times and places.

Dr. Collett's team has collected activity-specific emissions data on methane and VOCs in the Colorado Front Range. His measurements revealed that overall, the highest concentrations occur closest to operations and decrease with increasing distance away from operations. For activity-specific emissions, benzene emissions were highest during flowback and liquids load out (i.e., occurs when a mixture of oil and gas liquids are transferred from storage tanks to a truck). Based on this research, Dr. Collett concluded that long-term average concentration increases attributable to UOGD at Colorado setback distances are typically modest compared to health-protective criteria levels.

Additionally, Dr. Collett suggested that future research should consider short-term exposures because the highest emissions come from activities of relatively short duration, such as the flowback period, and exposures during periods of atmospheric stability when poor dispersion and limited vertical mixing can produce higher concentrations.

Q&A Session. Dr. Collett responded to an inquiry about adding other chemicals to his research program. He explained that adding chemicals to an emissions study would involve field work and analyses similar to what he described for his own research but with some variation in methods between methane and non-methane hydrocarbons. When asked about how Dr. Collett's research team was able to estimate diurnal concentrations, he responded that diurnal concentrations were simulated under different meteorological conditions using dispersion models. In addition, his research team plans to use a mobile unit to identify and track plumes at night with a goal of assessing emission scenarios during which human exposures might be at their highest.

Dr. Tiffany Bredfeldt, Texas Commission on Environmental Quality

Dr. Bredfeldt presented their strategy to assess air concentrations near UOGD in the Barnett Shale region, where there the public has been concerned about effects on human health and welfare. TCEQ has employed several techniques to characterize air quality impacts, including infrared cameras and flyovers, emissions inventories, mobile monitoring trips, field investigations, and fixed-site monitors. TCEQ's sampling campaigns utilize handheld equipment to scan possible emissions sources. Additionally, TCEQ collects "short-term" air samples (grab samples or 30-minute canister) and analyzes the samples by gas chromatography followed by mass spectrometry. During these sampling campaigns, field investigators record additional details integral to understanding potential exposure scenarios. In total, TCEQ has collected approximately 6,300 samples in the Barnett Shale region, with some additional samples collected in the Eagle Ford Shale region. Carbonyls, NOx, and sulfur compounds have not been detected at concentrations of concern with the short-term samples. Additionally, less than 5% of VOC canister samples exceeded health- or odor-based comparison values. TCEQ concluded that most issues

documented by the sampling campaign arose from human error or mechanical failures and could have been prevented by increased diligence. In addition to its monitoring program, TCEQ has worked to address public concerns. Over time, it has reduced the time required to respond to complaints and has involved citizens in its air monitoring program. Dr. Bredfeldt concluded by summarizing questions that TCEQ aims to answer in the future. For example, TCEQ will review air quality trends in relation to specific sources and citizen complaints and assess whether their short-term air samples might reflect long-term trends.

Q&A Session. Dr. Bredfeldt informed the audience that the TCEQ monitoring analysis is an ongoing project, and that the data are publicly available, but that they are not evaluating citizen responses to the research, but she reported a decrease in the number of complaints since TCEQ released its report. Dr. Bredfeldt also commented that TCEQ is working with industry to implement best management practices and minimize the human error that led to air quality issues identified with its sampling program.

4.6 Water Quality Literature

The water quality literature session focused on surface water, ground water, and produced water research, with an emphasis on the potential for human exposure to UOGD-related chemicals in these media.

Dr. George Hornberger, Vanderbilt University and Chair of HEI Energy Research Committee

Dr. Hornberger moderated the session, beginning with his overview of potential pathways of exposure to UOGD-related chemicals. According to Dr. Hornberger, potential pathways can arise from spills, wellbore failures, diffuse upward transport, or transport by way of faults or artificial pathways, such as abandoned wells. He admonished participants not to interpret simple schematics of rock as indicative of geological uniformity because, in reality the geology is variability, and this variability in turn influences fluid transport. He offered three questions of interest:

- How can pathways for contaminant migration be identified?
- What are the speeds of contaminant migration along the pathways?
- How do geochemical reactions affect the concentrations and nature of the contaminants transported?

Dr. Hornberger recommended that these questions be addressed in the framework of the Kaplan-Garrick risk triplet, which consists of three questions: 1) what can go wrong? 2) what are the consequences? And 3) how likely is it? He explained that the ideal approach to assessing risk to groundwater quality, identifying potential fluid migration paths, and obtaining data needed to understand the potential for human exposure is to monitor groundwater quality before, during, and after UOGD.

Dr. Isabelle Cozzarelli, United States Geological Survey

Dr. Cozzarelli presented on recent research on surface and ground water quality conducted by the USGS in areas with UOGD operations. This research addresses several of the research needs identified by a multiagency collaboration with the United States Department of Energy, The United States Department of the Interior, and the United States Environmental Protection Agency. It is designed to increase knowledge about the composition of oil and gas associated materials, the potential pathways by which they are released to the environment, how they might affect ecological health, and how they might result in people being exposed.

Dr. Cozzarelli presented on several ongoing research efforts related to UOGD and water quality. One such project evaluated the impacts of activities related to a wastewater disposal facility on stream water

quality and sediment biogeochemistry. The research did not assess the health of aquatic organisms, but study results indicated the potential for adverse biological effects attributable to endocrine disrupting activity in surface waters and altered microbial communities and nutrient cycling in downstream sediments. Another USGS study aimed to identify and characterize the fate and transport of constituents released in a wastewater spill in North Dakota. Indicators of UOGD waste were detected in surface water, and their transport distances and persistence were site-specific. People might be exposed to it through drinking water or recreation. Barium and radium were found to accumulate in the riverbed sediments and flood plain soils.

Dr. Cozzarelli presented strategies that USGS intends to implement to better understand UOGD operations. These include advancing tools for investigating alterations in the environment at the regional and national scale, considering exposure to both conventional and unconventional development, advancing non-invasive water quality and biological effect monitoring, and assessing whether chemical disturbances and persistence might lead to adverse health effects by combining evidence from chemistry, toxicology, and epidemiology.

Q&A Session. Dr. Cozzarelli responded to inquiries about the circumstances behind the releases to surface water that her research team studied, and methods were used to distinguish conventional produced water from unconventional produced water in the samples taken at the site discussed in her presentation. Dr. Cozzarelli cautioned that her team does not draw a strong distinction between conventional produced water and unconventional produced water because many constituents are the same and, at this point, most operations involve development of unconventional resources.

Dr. Cloelle Danforth, Environmental Defense Fund

Dr. Danforth presented work conducted by the Environmental Defense Fund (EDF) to address research gaps in the detection, composition and transformation of chemicals in produced water and their implications for human exposure and health. EDF continues to examine what is known about the toxicity of produced water, beginning with an extensive literature review to identify chemicals in produced water from onshore oil and gas operations and to categorize them with respect to the hazard they might present if exposure occurred. EDF extracted toxicity information from EPA's Comptox Chemistry Dashboard, and they collected from a variety of sources additional information about relevant regulations, laboratory analytical methods, and other information relevant to assessing the health hazard posed by each produced water constituent. Dr. Danforth also discussed EDF's ongoing efforts to investigate the composition and toxicity of chemicals in produced water used for treating roads.

Q&A Session. Dr. Danforth answered questions about whether she has considered information on environmental fate and changing technology and industry practices in the research that she presented. In response to an inquiry about whether a single bioassay could be developed that represents an entire basin, Dr. Danforth described that the type of bioassay used should be specific to the type of produced water and how it is being reused.

Mr. Daniel Soeder, South Dakota School of Mines and Technology

Mr. Soeder presented on research needs related to UOGD impacts on groundwater quality as recommended by the National Groundwater Association. Mr. Soeder's presentation included a brief overview of the history of UOGD and the environmental impacts of drilling operations, hydraulic fracturing, and issues related to wellbore integrity. He provided examples of perceived risk versus actual risk related to leaks and spills, chemical storage, and chemical transport. Mr. Soeder summarized results from a National Groundwater Association workshop about risks to groundwater quality that are related to UOGD and the associated research needs. The risks involve stray gas (biogenic, shallow geologic, and deep thermogenic sources), contaminant mobilization into groundwater, surface spills, and chemical

transformation and fate of hydraulic fracturing fluid components in the subsurface environment. Mr. Soeder listed several research needs, including collection of baseline data before development; universal environmental indicators for shale gas development, standardized approaches to the collection and analysis of data, improved sampling and laboratory methods, collaboration with operators to gain access to field sites and data, exploration of linkages between groundwater quality and well construction practices, and increased dissemination of research findings and results.

Q&A Session. Mr. Soeder answered questions about the number of sampling locations needed to understand variability in groundwater quality and UOGD effects on it. In response, he explained the importance of designing a sampling program that contributes to an understanding of the processes leading to groundwater quality impacts. Mr. Soeder also responded to inquiries about wellbore integrity and research priorities.

4.7 Human Health Risk Assessment

The human health risk assessment session included presentations from two institutions which recently released risk assessments, Colorado School of Public Health (represented by Dr. Lisa McKenzie) and the Colorado Department of Public Health and Environment (represented by Dr. Michael Van Dyke). Given that the risk assessment had different results, the objective of the session was to compare the methodologies of the risk assessments and identify gaps that can be addressed by future risk assessments.

Dr. Lisa McKenzie, Colorado School of Public Health

Dr. Lisa McKenzie presented her research team's UOGD-related human health risk assessments (HHRAs) of acute and chronic health risks from ambient diesel-associated non-methane hydrocarbons in the Northern Front Range of Colorado. Dr. McKenzie opened her presentation by defining several risk assessment concepts, including populations at risk, hazard identification, exposure pathway, and potential non-cancer and cancer effects. She contextualized her talk with data characterizing populations living in proximity to oil and gas wells in Colorado. Next, Dr. McKenzie described the methods and results of the HHRA. She described air monitoring data from several sources, which her team used in conducting the HHRA. Dr. McKenzie described how they divided the study population into four groups, depending on their distance from the nearest oil and gas facility. The distance cut-points were based on regulatory setback distances and literature reference points (i.e., < 500 ft, >500 ft to 2,000 ft, >2,000 ft to 1 mi, and > 1 mi). Dr. McKenzie's team combined toxicity information from the California Office of Environmental Health Hazard Assessment (OEHHA) with maximum hourly concentrations to estimate acute health risk and with time-weighted average concentrations to estimate chronic health risks. Dr. McKenzie presented the acute and chronic non-cancer hazard indices and excess lifetime cancer risk results and their policy implications.

Q&A Session. Dr. McKenzie responded to inquiries about their risk assessment methods, including the chemicals that they included in their analysis, whether the concentrations used in their risk assessment considered emissions variability during flowback, diurnal variability, and whether investigators quantified the error associated with their risk estimates. She responded that they took samples during uncontrolled flowback, calculated a time-weighted average to account for diurnal concentrations, and did not quantify error. Dr. McKenzie also responded to a series of questions about how background sources were considered in her analyses. When asked why residences are located within the regulatory setback distance of 500 feet from a well pad, Dr. McKenzie explained that homes can be built within this setback distance.

Dr. Michael Van Dyke, Colorado Department of Public Health and Environment

Dr. Michael Van Dyke summarized the screening HHRA conducted by the Colorado Department of Public Health and Environment (CDPHE). He began by discussing the public concern about UOGD in Colorado, which led to the formation of the Governor's Oil and Gas Task Force. The screening HHRA

represents one of several recommendations made by the Task Force. The screening HHRA was conducted using existing air monitoring data collected in the Piceance and Denver-Julesburg Basins. To define priority chemicals for inclusion in the screening HHRA, CDPHE reviewed Colorado-specific scientific literature and data characterizing and apportioning emissions among various UOGD operations, including emission inventories. CDPHE identified 56 VOCs based on its review of 11 different datasets with air concentration data from samples that were collected between 500 and 3700 feet or more from any type of oil and gas operation between 2008 and 2017. The data sets included between 36 and 28,000 individual samples.

Health risks from chronic exposures and acute exposures were calculated using the maximum average VOC concentration and the overall maximum VOC concentration across the datasets, respectively. Dr. Van Dyke described the tiered approach used to select health guidance values from national and state-level sources and presented cancer risk and non-cancer hazard results. He noted that there is a great deal of uncertainty in the acute exposure guideline levels and acute exposure measurements.

Dr. Van Dyke reported that CDPHE is in the process of updating the screening HHRA. The updated assessment will incorporate air concentration data for VOCs that are predicted from Dr. Collett's well pad-level emissions data (see earlier presentation) combined with an air dispersion model. The updated risk assessment is expected to be complete in Summer 2018.

Q&A Session. Dr. Van Dyke responded to a question about whether he thinks epidemiology studies are needed in Colorado by saying that epidemiology studies have an important place in health research, helping us to identify uncertainty and, therefore, the questions that we need to answer to understand a given situation. Dr. Van Dyke answered a series of questions about the methodology used in the Screening HHRA. He remarked that benzene is likely the most important exposure and that CDPHE needs more information on benzene concentrations and its specific sources.

5. Participant Responses to Workshop Charge Questions

Participants were asked to respond to five workshop charge questions. This section provides their verbatim responses to each question. There responses have been categorized for clarity. In addition, participants worked in small breakout groups to discuss charge questions and report back to all participants. The oral responses provided by each breakout group are summarized in Appendix E).

Workshop Participant Verbatim Responses to:
Charge Question #1 - What does the literature tell us?

Exposure-Related

- Potential increased chance of health risks, but health impacts are limited to populations close to wells. The implication is a distance "threshold" effect, and no increased risk to residents living further than a specified distance from UOGD operations (e.g. 2 km).
- Literature indicates a wide variety of scenarios that differ by region.
- Pollutants like ozone are going to vary substantially by region and it is tough to draw general conclusions based on these regional assessments.
- There is negligible risk of frac fluid migration upwards from deep shale reservoir injection points up into shallow groundwater aquifers used for human consumption.
- Stray gas migration events are very rare.

- It is generally observed that operations recover 10-40% of the injected frac fluid volume. Unaccounted frac fluid volume is largely trapped and sequestered in the shale formation. The shale reservoirs have very low water saturations and very high capillary forces that strongly imbibe water. Only a small fraction of the imbibed water can be produced back out of the shale during production. Most of the imbibed water remains in the shale, trapped by strong capillary forces.

Health-Related

- There are health effects that are significantly above background in areas where drilling is occurring.
- There are associations between UOGD and health effects in proximity studies.
- The literature suggests health impacts to people/humans living near well sites
- Sufficient evidence to suggest the health of community members is compromised due to activities related to unconventional oil and gas development.
- Research to date has shown associations between adverse health outcomes for populations exposed to UOGD, although direct causation and mechanisms have not been demonstrated.

Workshop Participant Verbatim Responses to:

Charge Question #2 - What does the literature not tell us?

Exposure-Related

- What are the personal exposures associated with increased rates of disease, and to what extent can they be shown to be coming from the drilling activities?
- There are datasets available via a DOI that are not published and/or discussed in peer-reviewed papers, yet due to a lack of funding for the analysis and time to write these papers and get them through peer review, the data is not published in the peer-reviewed literature.
- Chemical and toxicological character of produced water.
- Environmental risks of produced water reuse (e.g., aquatic, soil/terrestrial, consumption, wildlife, ecosystem changes/impacts).
- Food safety.
- Impacts at varying distances from unconventional oil and gas development sites – in cases where there are measured emissions, are there resulting concentrations above background in ambient air, and if so, what are the sources, how far do they travel, how is this impacted by meteorological conditions and chemical properties?

Health-Related

- Whether there are chemical exposures causing health effects.
- Whether there are socioeconomic confounders or other confounders that affect the findings.
- Citizen complaints and observed health effects cannot be explained by exposure and health threshold data. Why? What are we missing?
- The role of stress.
- Characterization of dose-response.
- For the communities where health effects have been reported, exposures have not been analyzed in any level of detail.
- There is not a consistent approach for comparing risk to toxicity thresholds.
- Whether the observed proximity effect is chemical or non-chemical.
- If there is a stress effect, is stress from nearby operations, disruption of routine, or fear induced by media?

- The cause and effect between epidemiology study results and exposure (or lack thereof).
- Research on the effects of exposure to multiple pollutants at the same time.
- Are the exposure threshold data being used adequately?

Workshop Participant Verbatim Responses to:
Charge Question #3 - What are your recommendations for criteria for prioritizing research?

Consider Likelihood of Exposure or Effect

- Likelihood of exposure from sources of interest, knowledge of the effects of exposure for a given exposure level that might be expected to occur,
- Focus on most likely substances that will have a plausible health effect.
- Most ubiquitous exposures.
- Focus on actual risks rather than perceived risks.
- Should whole studies focus on water exposure? Really want to do toxicity studies on environmental. Focus on media, not source materials, specifically environmental media that has been affected by releases or development.
- Understanding exposure to air pollution is of primary importance.
- The potential for adverse health impacts seems more likely through exposures to air pollution rather than water, and therefore the emphasis on exposure assessment should be on atmospheric pathways.
- Research resources allotment ratio: four to one for air pollution versus water pollution, based on the potential severity of effects and the breadth of population affected.

Focus on Exposures that have Importance for Human Health

- Life cost of potential illness due to exposure
- Make sure the research will address the key questions about exposure and health impact affecting people living near well sites.
- Review highest exposure pathways that do not have current monitoring.
- Focus on exposures that exceed EPA regulatory levels.
- Initial focus of research: lay squarely on known pollutants that can be readily measured, with additional emphasis on those atmospheric constituents with the highest toxicity/potential for harm.
- Look to areas with higher populations.
- Focus on exposure for populations near operations over the range of UOGD activities. Be sure to address background.

Distinguish UOGD Sources and Conditions

- For an off-site (ambient) measurement study, having a contemporaneous understanding of onsite operations, the types of equipment on-site, and what (if any) abnormal conditions are present during the measurements, is vital to understanding the data.

Design Feasible and Efficient Research

- Ability to ascertain both the dose and the effect at the exposure level that might be expected to occur.
- Focus on a manageable case study approach, accepting you cannot do everything.
- Exposure should be measurable, far-reaching, be plausibly related to health endpoints, chemical and non-chemical.
- Access to sites, data, and produced water samples.

- Partnerships to leverage resources for more than a single, short term effect.

Use Existing Data

- Leverage state data and agency data to avoid repeating research.
- Reaffirm that emission inventories are developed by regulators for very specific reasons. These inventories focus on sources that impact the regulatory target. Not all emission inventories can be used or extrapolated for other purposes. Researchers must understand the methodologies that are used to calculate the emissions and how reliable those would be.
- Use available resources to assess potential community exposures. Conducting community surveys or other assessments of psychosocial stressors is complex and will not address key exposure concerns.

Informs Decision-Making

- Make sure research is actionable.
- Assist industry and regulators to understand the greatest risks (i.e. frequency and magnitude), so enhancements can be focused and impactful.

Workshop Participant Verbatim Responses to:

Charge Question #4 - What are your recommendations for population-level exposure research?

Source Attribution

- Define background conditions and source apportionment.
- Ideally, there would be a 'before' snapshot of conditions prior to development.
- Measurements of hydrocarbons (both alkanes and BTEX) that can be used to identify benzene exposure at different distances from the well with known activity, and the ability to do source apportionment of the hydrocarbons present.
- Turn emissions data into exposure estimates (e.g. dispersion modeling).

Chemical and Non-Chemical Agents and Reporting Limits/Health-based Benchmarks

- Focus on air toxics/VOCs.
- Species of interest for air sampling: BTEX, low molecular weight carbonyls, black carbon, and some alkanes (some of which have health impacts; others can serve as useful tracers for UOGD). Higher molecular weight PAHs could be important as well, though these are more difficult to detect and quantify in ambient measurements.
- Quantify role of VOC emissions in regional ozone production and the associated health effects.
- Short-term exposure to benzene should be the primary target for observations.
- Targeted and non-targeted approaches.
- Consider sensitivity to noise and odor.
- Although it may be convenient to rely on existing test methods, they may not be well-suited to providing the level of detail needed for studying the impacts. For example, to TO-15 canister methods allows for the quantification of nearly 60 VOCs, including some not expected to be generated by UOGD. This type of 'catch all' method often results in long lists of 'non-detects' – which could be indicative of the absence of many target compounds, or just that the detection limit is not optimized for the detection of all species.
- Use methods optimized to detect known emitted species at levels expected in ambient air and concentrations relevant to their health impacts; it is of limited use to have a method whose detection limit exceeds the level at which health effects are relevant since a non-detect does not indicate the absence of adverse health effects.

- Do not waste resources on detailed chemical analysis and toxicity analysis of individual impoundments.
- Define criteria a priori on exposure levels that are of concern (i.e., exceed EPA levels
- Focus on agents with defined health effects to identify whether they create hazard exposures.

Spatial and Temporal Variability of Exposure

- Focus on major plays, knowing there is variation among plays; not being able to do everything shouldn't stop you from doing something.
- Choose basins where UOGD is close to communities.
- Characterize air quality at increasing distances from wells.
- Characterize high short-term exposures vs. chronic long-term exposures.

Exposure Variability due to UOGD Operations

- Understand and map potential exposure pathways for intentional release of produced water (to land, municipal, etc.) rather than focus on spills alone as an exposure pathway.
- Understand different air quality implications of single vs. multi-well pad sites.
- The nature of emissions will change over time. Early in the process, the bulk of emissions may be associated with diesel combustion – and may be common between regions. As well start producing, emissions will be more region-specific, based on the composition of the field in question. Differences in equipment, operations, and operators' practices and cultures will also lead to variations in emissions between fields. Emissions will also vary in space within a field, in addition to time.
- Consider how new technology will impact emissions (e.g., closed loop systems may reduce on-pad emissions, but they might result in relocating emissions to a new location at the other end of the pipe).
- Research utilizing high spatial density and temporal resolution measurements should be a priority.
- Recent advances in low cost measurement technologies should be employed. The sensitivity of these methods is limited, but this may be offset by the increased temporal and spatial information provided. When paired with more limited precise and accurate methods, the value of low-cost measurements is enhanced.
- Research should be conducted on "at-risk" populations and should seek to understand spatial and temporal variability.

Exposure Monitoring Methods

- Focus on topic area 3.9.1 of the HEI Strategic Research Agenda – many of the other topic areas are being studied, but human exposure and health risk is critical here, and is an expert area for HEI.
- Personal exposure monitoring
- Exposures will be best characterized using mobile monitoring approaches which can find and measure the plume – rather than waiting for the plume to come to the monitor.
- Ambient measurements should be paired with personal exposure measurements to improve our understanding of associations between ambient levels of pollution and direct exposures. Since most of the existing measurements are ambient in nature, and these are also easier to obtain and will likely continue going forward, improving our understanding of associations between ambient pollution and personal exposure is key.
- Mixtures: a) joint environmental and social, b) air and noise, c) considers effect modification by additional exposure, d) environmental justice.
- Wastewater system: a) Characterization of communities receiving fluid (by socio-economic status and race/ethnicity), b) implications for induced seismicity.

- Limited on-site meteorology would be important to be collocated with fixed, high quality monitors, and near the well-pad/emissions source.
- Describe what has been done to date (previous research/measurement efforts) in terms of regional monitoring efforts for criteria pollutants, VOCs, and H2S; and in terms of fence line/near-field monitoring for diesel exhaust, VOCs, and H2S.

Health Outcomes

- Need to do parallel ambient air monitoring and health effects studies
- Focus on easily defined outcomes with clear and defined "exposure periods" (e.g. during pregnancy).
- Perinatal effects of exposure with follow-up during childhood, including personal dose determination for gestational period because 1) the effects will be long-term, 2) there are established biomarkers for disease, 3) exposure measurements need only be done during gestation.
- How does stress factor in?
- Effects of pollutants on sensitive populations.
- Effect of increased motor activity associated with oil and gas on the communities; a) Increased heavy vehicles, b) Oil and gas truckers have been known to drive recklessly, c) Look at accident rates and noise, not only pollutants, d) Traffic is the major and most immediate impact on the community.
- Consider night versus day exposures and consequences for health (especially based on the nighttime noise literature). Also consider mental health.

Collaboration

- TCEQ and DPWE have a lot of experience and expertise, collaboration with them would be highly beneficial.

Workshop Participant Verbatim Responses to:

Charge Question #5 - What are your recommendations for further literature review and data analysis before the September workshop to help in defining HEI research priorities?

Human Exposure-Related Research

- Methods for personal dose determination.
- Advances in monitoring equipment or techniques for determining personal dose.
- Detailed search for exposure-related data, particularly unpublished sources (e.g. states).
- Need pre-defined criteria: 1) is there a certain number of exceedances that would indicate the need for a detailed exposure study, 2) what screening level thresholds will be used to indicate the need for further study, 3) try to understand what data already exists to characterize air quality near wells.

Human Health Effects-Related Research

- Health effects monitoring.
- Location of current data (geographic – is there bias or skewed data because most research is in a few areas)?

General Research Methods

- Look at case studies of how other sectors have addressed public perceptions about risks by conducting unbiased research.
- Is it worth delving into treatment chemicals? Or just move on?
- Check economics literature – changes in housing values; check sociology literature on boomtowns.

- The primary focus should be to distill the results of the Denver meeting. Although some limited additional research may be released in the interim, and this should be evaluated, but the likelihood that new information would change recommendations based on what was known as of the July meeting.
- Seek opportunities to collaborate with state agencies on the forthcoming exposure studies.
- Work with states and agencies that have extensive data to guide future exposure research (e.g. CDPHE, TCEQ, USGS, EPA).

6. NEXT STEPS

The HEI Energy Research Program Research Planning Workshop is one in a series of workshops. The next workshop will be held in Austin, Texas on September 12-13, 2018. The focus of this workshop will be scientific and regulatory topics relevant to the assessment of potential human exposures to UOGD. After the final research planning workshop in September, the HEI Energy Research Committee will draft a Research Solicitation for release in 2019. The focus of the Research Solicitation will be population-level exposure to UOGD operations. In preparation for the September research planning workshop, HEI staff are engaged in activities to better understand the available data on human exposure to UOGD operations.

Going forward, HEI seeks recommendations for sources of data related to human exposure to UOGD operations, information about relevant ongoing research, suggestions for exposure literature for the Committee to review, information on changes to the UOGD-regulatory landscape that may affect human exposure, and changes to industry practice that may affect human exposure.

APPENDIX A

Workshop Agenda

HEI Research Planning Workshop

Understanding Population-Level Exposures Related to the Development of Oil and Natural Gas from Unconventional Resources

Denver, CO
July 11-12, 2018

WORKSHOP AGENDA

Purpose of Workshop:

The workshop provides an opportunity for the Energy Research Committee to hear from a broad range of stakeholders about their expert opinions and perspectives on the literature, important knowledge gaps, and research priorities along with the criteria used to define the priorities. The Committee will consider information received during the workshop as it conducts its own review of the literature and formulates research priorities for population-level exposure research.

With the benefit of an interdisciplinary group of experts at the workshop, HEI's Energy Research Committee expects to complete a conceptual model of potential human exposure to UOGD. The conceptual model will provide a framework for piecing together information from the literature to show what we know and where knowlege gaps remain about possible human exposure pathways, thus providing a roadmap for research planning.

Workshop Charge Questions:

(1) What does the literature tell us?

(2) What does the literature not tell us?

(3) What are your recommendations for criteria for prioritizing research?

(4) What are your recommendations for population-level exposure research?

(5) What are your recommendations for further literature review and data analysis before the September workshop to help in defining research priorities?

Workshop Chair: George Hornberger, Chair, HEI Energy Research Committee

AGENDA DAY 1 (10:30am to 5:30pm)		
TIME	**TOPIC**	**SPEAKER**
10:00-10:30	*Registration*	
10:30-11:20	**Introductions and Workshop Overview**	
10:30-10:35	Welcome	Bob O'Keefe, Vice President, HEI
10:35-10:50	Introductions	George Hornberger, Chair, HEI Energy Research Committee
10:50-11:10	Committee's Approach to Literature Review and Research Planning	Donna Vorhees, Director of Energy Research, HEI
11:10-11:20	Brief Description of Unconventional Oil and Gas Development	Shari Dunn-Norman, HEI Energy Research Committee
11:20-12:20	**Overview of Exposure Assessment Literature (Moderator: Judy LaKind)**	
11:20-11:50	NIOSH Research of Occupational Exposures in the Upstream Oil and Gas Industry *(20 min presentation followed by 10 min Q&A)*	Bradley King, NIOSH
11:50-12:20	Community Exposures Near Unconventional Oil and Gas Development *(20 min presentation followed by 10 min Q&A)*	John Adgate, Univ of CO
12:20-12:30	Discussion	
12:30-1:15	*Lunch*	

AGENDA DAY 1 (10:30am to 5:30pm)		
TIME	**TOPIC**	**SPEAKER**
1:15-2:15	**Industry Trends and Related Research**	
1:15-1:45	Overview of Air Emissions from Unconventional Oil and Gas Operations *(20 min presentation followed by 10 min Q&A)*	Adam Pasci, Chevron
1:45-2:15	MSEEL – The Marcellus Shale Engineering and Environmental Laboratory *(20 min presentation followed by 10 min Q&A)*	Mike McCawley, WVU
2:15-2:45	**Perspectives on Regulatory Trends (Moderator: Bob O'Keefe)**	
	Panel discussion with Martha Rudolph, CDPHE; Michael Honeycutt, TX CEQ; Nichole Saunders, EDF	
2:45-3:00	*Break*	
3:00-3:45	Group Exercise #1: What criteria should be used to prioritize exposure research recommendations?	
3:45-5:05	**Air Quality Literature (Moderator: Ted Russell)**	
3:45-4:15	Emissions from Upstream Oil and Gas Operations in the United States: Key Questions for Health Assessments *(20 min presentation followed by 10 min Q&A)*	David Allen, Univ TX
4:15-4:45	Emissions and Near-field Dispersion of Air Toxics from Oil and Gas Drilling, Completions, and Production in Colorado *(20 min presentation followed by 10 min Q&A)*	Jeff Collett, CSU
4:45-5:05	Barnett Shale Revisited: Plan for Exposure Assessment of Emissions from Unconventional Oil and Gas Development and Production *(15 min presentation followed by 5 min Q&A)*	Tiffany Bredfeldt, TX CEQ
5:05-5:30	Discussion; wrap up for the day; review plan for day 2	
AGENDA DAY 2 (8:00am to 12:00pm)		
TIME	**TOPIC**	**SPEAKER**
7:00-8:00	*Breakfast*	
8:00-8:10	Recap from Previous Day	
8:10-9:45 AM	**Water Quality Literature**	
8:10-8:25	Overview of Potential Water-related Human Exposures	George Hornberger, Chair, HEI Energy
8:25-8:55	Highlights from Recent Research on Surface and Ground Water Quality *(20 min presentation followed by 10 min Q&A)*	Isabelle Cozzarelli, USGS
8:55-9:15	Advancing Research on Oil and Gas Produced Water *(15 min presentation followed by 5 min Q&A)*	Cloelle Danforth, EDF
9:15-9:45	Groundwater Quality and Hydraulic Fracturing: Current Understanding and Science Needs *(20 min presentation followed by 10 min Q&A)*	Dan Soeder, SD School of Mines and Technology
9:45-10:00	*Break*	
10:00-10:40	Group Exercise #2: What potential human exposure would you study and where if you were given $2M for research?	
10:40-12:00 AM	**Human Health Risk Assessment**	
10:40-11:10	Acute and Chronic Health Risks Estimated from Ambient Non-methane Levels in Colorado's Oil and Gas Basins *(20 min presentation followed by 10 min Q&A)*	Lisa McKenzie, University of Colorado
11:10-11:40	CDPHE's Assessment of Human Health Risk *(20 min presentation followed by 10 min Q&A)*	Mike van Dyke, CDPHE
11:40-12:00	Wrap-up with next steps in research planning and opportunities for continued participation	
THROUGHOUT THE WORKSHOP		
1. Posters describing ongoing research and data will be posted in the workshop meeting room.		
2. Workshop participants can contribute their ideas and recommendations to two charts posted in the workshop meeting room:		
a. Framework of a conceptual model of exposure		
b. Chart with workshop charge questions		

APPENDIX B

Energy Research Committee Biographies

ENERGY RESEARCH COMMITTEE BIOGRAPHIES
HEI Energy Research Program

George M. Hornberger (Chair)

Dr. Hornberger is a University Distinguished Professor at Vanderbilt University, where he directs the Vanderbilt Institute for Energy and Environment and has a shared appointment as the Craig E. Philip Professor of Engineering and as Professor of Earth and Environmental Sciences. Previously he was a professor for many years at the University of Virginia where he held the Ernest H. Ern Chair of Environmental Sciences. He has been a visiting scholar at the Australian National University, Lancaster University, Stanford University, the United States Geological Survey, the University of Colorado, and the University of California at Berkeley. Dr. Hornberger's research centers on the coupling of field observations with mathematical modelling. Recognizing that water resources are under pressure from many human activities from climate change to urban development, he pursues broadly interdisciplinary research focused on coupled natural-human systems. The goal of the research is to understand how climate, groundwater, surface water, and human abstraction of water interact in complex ways. Current projects include work in Sri Lanka on adaptation to drought and in the United States on how cities evolve water conservation practices. He has published extensively, with numerous scientific papers, book chapters, and books.

Dr. Hornberger has served on numerous boards and committees of the National Academies, most recently as chair of the Committee on "Future Water Resource Needs for the Nation: Water Science and Research at the U.S. Geological Survey" and chair of the Water Science and Technology Board. He has also served other organizations, for example, he chairs the Geosciences Policy Committee of the American Geosciences Institute and serves on various committees of the Geological Society of America, the American Geophysical Union, and other organizations. In 2015, he recently completed service as the chair of the Health Effects Institute Special Scientific Committee on Unconventional Oil and Gas Development. Before that in 2013, he chaired a related National Research Council Committee on Development of Unconventional Hydrocarbon Resources in the Appalachian Basin. He previously served as an editor on several highly regarded journals. Dr. Hornberger won the Robert E. Horton Award (Hydrology Section) from the AGU in 1993. In 1995, he received the John Wesley Powell Award from the USGS. In 1999, he was presented with the Excellence in Geophysical Education Award by the AGU and in 2007 he was selected Virginia Outstanding Scientist. Professor Hornberger was elected to the U.S. National Academy of Engineering in 1996. He was also elected a Fellow of the American Geophysical Union in 1994, the Association for Women in Science in 1996, and the Geological Society of America in 2005, received the William Kaula Award from the American Geophysical Union in 2010, and the Harvie Branscomb Distinguished Professor Award from Vanderbilt University in 2017.

Dr. Hornberger holds a B.S.C.E. in Civil Engineering and an M.S.C.E. in Hydrology from Drexel University and a Ph.D. in Hydrology from Stanford University.

Shari Dunn-Norman

Dr. Dunn-Norman is Associate Professor and the former Program Head of Petroleum Engineering at the Missouri University of Science and Technology. Previously, she worked in both domestic and international assignments for the Atlantic Richfield Companies (ARCO), beginning her career as a summer field roustabout and advancing to Senior Operations Engineer at ARCO International. Dr. Dunn-Norman's research has focused on pipeline flow and leak detection, well construction for the protection of underground sources of drinking water, hydraulic fracturing, and well completions. She has over 25 years of combined academic, industrial and consulting experience in well design and well completion technology. She has published extensively, with numerous scientific papers and book chapters and co-authored a book on well construction.

Dr. Dunn-Norman is a member of the Society of Petroleum Engineers (SPE), where she has served on numerous committees. She was elected and currently serves as the National President of Pi Epsilon Tau, the Petroleum Engineering Honor Society. She is also a member and volunteer for the St. Louis Academy of Science and the Missouri Academy of Science. Dr. Dunn-Norman served on the U.S. Environmental Protection Agency Science Advisory Board 2011 Ad Hoc Hydraulic Fracturing Research Advisory Panel, which reviewed EPA's draft "Assessment of the Potential Impacts of Hydraulic Fracturing for Oil and Gas on Drinking Water Resources." For more than 20 years, Dr. Dunn-Norman has taught numerous industrial short courses about production engineering and well completions for various companies, such as Petroleum ETC, a private corporation that operates events worldwide on topics ranging from multiphase pumping and artificial lift, to hydraulic fracturing; and Petroskills, a leading world organization in all areas of oil and gas training. Dr. Dunn-Norman has received numerous awards, most recently the Society for Professional Engineers' Distinguished Member Award in 2015 and several excellence in teaching awards.

Dr. Dunn-Norman holds a B.S. in Petroleum Engineering from the University of Tulsa and a Ph.D. in Petroleum Engineering from Heriot-Watt University, Edinburgh, Scotland.

Elaine M. Faustman

Elaine M. Faustman is Professor in the Department of Environmental and Occupational Health Sciences and Director of the Institute for Risk Analysis and Risk Communication in the School of Public Health and Community Medicine at the University of Washington. Dr. Faustman's research includes quantitative risk assessment for non-cancer endpoints, molecular mechanisms of developmental and reproductive toxicity, and in vitro and molecular biological methodologies. She develops decision-analytic tools for communicating and translating new scientific findings into risk assessment and risk management decisions. Dr. Faustman directs the NIEHS/EPA-funded Center for Children's Health Research. She has served as Principal Investigator for the Pacific Northwest Center for the National Children's Study and has directed the Pacific Northwest Center for Human Health and Ocean Studies. The goals of Dr. Faustman's research are to discover the mechanisms that define susceptibility in at-risk populations and to provide linkages across disciplines. She has over 200 peer reviewed research publications and reports.

Dr. Faustman is an elected fellow of the American Association for the Advancement of Science and the Society for Risk Analysis. She has served on the USEPA Science Advisory Board. She previously chaired the National Academy of Sciences Committee on Developmental Toxicology and served as a member for the National Advisory Environmental Health Sciences Council, the National Institute of Environmental Health Sciences (NIEHS)-National Toxicology Program (NTP) Committee on Alternative Toxicology Methods, the NIEHS-NTP Board of Scientific Counselors, the National Academy of Sciences Committee on Toxicology, and the Institute of Medicine Upper Reference Levels Subcommittee of the Food and Nutrition Board. She has just completed two terms as Secretary General for the International Union of Toxicology. She is currently a member of the International Science Council World Data Systems Advisory Board. She served on the U.S. Environmental Protection Agency Science Advisory Board 2011 Ad Hoc Hydraulic Fracturing Research Advisory Panel, which reviewed EPA's draft Assessment of the Potential Impacts of Hydraulic Fracturing for Oil and Gas on Drinking Water Resources. Dr. Faustman also served on the executive boards of the Society of Toxicology, the Teratology Society, and the Society for Risk Analysis. She has served as an editor on several highly regarded journals. Dr. Faustman has been honored with numerous awards, most recently the 2016 Josef Warkany Lecturer Award from the Teratology Society, the Distinguished Achievement Award from the Society for Risk Analysis in 2014, and the University of Washington's Outstanding Teaching Award.

Dr. Faustman holds an A.B. in Chemistry and Zoology from Hope College and a Ph.D. in Pharmacology/Toxicology from Michigan State University.

Howard Hu

Howard Hu is Affiliate Professor in the Department of Environmental and Occupational Health Sciences, the University of Washington School of Public Health, as well as Adjunct Professor in the Department of Environmental Health Sciences, University of Michigan School of Public Health. Until recently, he was the founding Dean and Professor of Environmental Health, Epidemiology, and Global Health at the Dalla Lana School of Public Health at the University of Toronto (2012-2018). Previously, Dr. Hu was Professor of Occupational and Environmental Medicine at the Harvard School of Public Health and Associate Physician in the Channing Laboratory of the Brigham and Women's Hospital in Boston, Massachusetts (1990-2006), after which he was the NSF International Endowed Chair of the Department of Environmental Health Sciences and Professor of Environmental health, Epidemiology and Internal Medicine at the University of Michigan School of Public Health and Health System (2006-2012). Dr. Hu is a physician-scientist, trained as an internist, occupational and environmental medicine specialist, and epidemiologist. He founded an environmental epidemiology research group that, since 1990, has grown into a multi-institutional and international team of scientists devoted to gaining new insights into the impact of exposure to potential toxicants that are of critical importance to public health and medicine. His environmental and molecular epidemiologic research has focused on heavy metals, potential endocrine disruptors, other neurotoxicants, and carcinogens, with particular interest in exposures during sensitive life stages. Dr. Hu has published more than 300 original papers in the scientific literature, and co-authored and edited several books.

He has served on the Institute of Medicine's Board of Population Health and Public Health Practice, the Board of Environmental Science and Toxicology of the National Research Council, and on the National Advisory Environmental Health Sciences Council for the National Institutes for Health. In 2016, he was elected to Fellowship, Canadian Academy of Health Sciences. He also served as the founding medical editor of Environmental Health Perspectives, the official journal of the National Institute of Environmental Health Sciences (NIEHS). He currently serves on the Board of Directors of the Canadian Urban Environmental Health Research Consortium. Dr. Hu has received numerous awards, including most recently the Linus Pauling Lifetime Achievement Award, the Award of Excellence from the American Public Health Association, and the John R. Goldsmith Award for Outstanding Contributions to Environmental Epidemiology from the International Society for Environmental Epidemiology.

Dr. Hu holds a B.Sc. in Biology from Brown University, an M.D. from the Albert Einstein College of Medicine, and an M.P.H. and Sc.D. in epidemiology from the Harvard School of Public Health. He trained in internal medicine at Boston City Hospital and in occupational and environmental medicine at Harvard.

Judy S. LaKind

Dr. LaKind is President of LaKind Associates, LLC, an Adjunct Associate Professor in the Department of Epidemiology and Public Health at the University of Maryland School of Medicine, and a Fellow-by-Courtesy in the Department of Applied Mathematics and Statistics at The Johns Hopkins University. Dr. LaKind has taught graduate level courses at The Johns Hopkins University and the University of Maryland in risk assessment and aquatic chemistry. Previously, Dr. LaKind was a geologist at the US EPA's Office of Federal Activities, where she was responsible for the evaluation of environmental impact statements and legislative reports. She is a health and environmental scientist with expertise in exposure science, assessment of human health risks, biomonitoring, scientific and technical analysis for regulatory support, and state-of-the-science reviews. Dr. LaKind has spoken and published extensively on children's exposures to environmental chemicals, the implications of uncertainty in the risk assessment process, weighing potential risks and benefits related to chemical use (for example, use of MTBE in gasoline, glycols in de-icing formulations, and chlorination of drinking water for zebra mussel control), the presence of environmental chemicals in human milk, and time-dependence and distributional analysis of exposure.

Dr. LaKind is President of the International Society of Exposure Science. She is a founding member of the International Society for Children's Health and the Environment and is a former member of Maryland's Children's Environmental Health and Protection Advisory Council, the Lead Poisoning Prevention Commission, and the Maryland Pesticide Reporting and Information Workgroup. She is a member of the World Health Organization Survey Coordinating Committee for the WHO Global Survey of Human Milk for Persistent Organic Pollutants (POPs), the HESI RISK21 Advisory Board, and the Maryland Department of Health and Mental Hygiene (DHMH) Cancer Cluster Advisory Committee. Dr. LaKind also served on the Institute of Medicine Committee on Blue Water Navy Vietnam Veterans and Agent Orange Exposure and the US Environmental Protection Agency Science Advisory Board Panel on Perchlorate - Approaches for Deriving Maximum Contaminant Level Goals for Drinking Water. Dr. LaKind has received awards, including the 2017 Society of Toxicology Regulatory and Safety Evaluation Specialty Section Award for Best Paper Contributing to the Field of Regulatory and Safety Evaluation in Toxicology and the 2015 EPA Scientific and Technological Achievement Award Level III for "Providing Critical Models and Information Needed for Exposure and Risk Assessments of Environmental Chemicals in Infants."

Dr. LaKind holds a BA in Earth and Planetary Sciences from Johns Hopkins University, an M.S. in Geology from the University of Wisconsin, and a Ph.D. in Geography and Environmental Engineering from Johns Hopkins University.

Armistead (Ted) G. Russell

Dr. Russell is the Howard T. Tellepsen Chair and Regents' Professor at the Georgia Institute of Technology School of Civil and Environmental Engineering. Dr. Russell's research is aimed at better understanding the dynamics of air pollutants at urban and regional scales and assessing their impacts on health and the environment to develop approaches to design strategies to effectively improve air quality. He currently co-directs the NSF Sustainability Research Network "Environmentally Sustainable, Healthy and Livable Cities" project and co-directed the Southeast Center for Air Pollution and Epidemiology. His research interests include air pollution modeling, aerosol dynamics, atmospheric chemistry, combustion emissions control. He has published over 300 peer-reviewed journal articles, book chapters and major reports.

Dr. Russell is a Fellow of the American Society of Mechanical Engineering and the American Association for the Advancement of Science and is a National Associate of the National Academies. Dr. Russell was a member of EPA's Clean Air Science Advisory Committee (CASAC) and a member of the National Research Council's Board on Environmental Studies and Toxicology, and he continues to serve on associated committees. He chaired the CASAC NOx-SOx, Secondary NAAQS review panel, the Ambient Air Monitoring Methods Subcommittee, and the Council on Clean Air Compliance Analysis' Air Quality Modeling Subcommittee, and was on the Health Effects Institute's Report Review Committee. Dr. Russell has been honored with numerous awards, including the 2015 Distinguished Alumni Award from Washington State University, the 2013 Regents' Professor Award, and he was the Most Influential Individual to 2013 semifinalist for the Intel Science Talent Search.

Dr. Russell holds a B.S. in Mechanical Engineering from Washington State University, and an M.S. and Ph.D. in Mechanical Engineering from the California Institute of Technology, conducting his research at Caltech's Environmental Quality Laboratory.

Stefanie Ebelt Sarnat

Dr. Sarnat is Associate Professor of Environmental Health at the Rollins School of Public Health of Emory University. Her epidemiological research focuses on examining health effects of ambient air quality using population- and panel-based approaches. She leads large-scale time-series studies of ambient air quality and acute morbidity, using emergency department visit data as an indicator of population health. Dr. Sarnat's work on these studies focuses on assessment of ambient air pollution mixtures and metrics of extreme heat, examination of the impacts of exposure measurement error on observed epidemiological findings, and assessing exposure and population factors that may modify health risk. Her studies also include prospective panel-based designs, using detailed field investigation methods to further understand environmental exposure factors and health effects among susceptible and vulnerable populations. She has published extensively in the peer-reviewed literature and has frequently been asked to speak on exposure and epidemiological topics.

Dr. Sarnat is a member of the International Society for Environmental Epidemiology, an editorial board member at Epidemiology, and an associate editor at the Journal of Exposure Science and Environmental Epidemiology. Dr. Sarnat participated on the National Research Council's Committee on Urban Meteorology: Scoping the Problem, Defining the Need and the Health Effects Institute's Review Panel on Ultrafine Particles. She has participated as an expert reviewer of drafts of the USEPA Integrated Science Assessments for particulate matter and nitrogen oxides. She serves as the Point of Contact for Emory University as an observer organization in the United Nations Framework Convention on Climate Change process. Dr. Sarnat has been honored with several awards, most recently the Department of Environmental Health Teaching Award at Emory University and a Supporting Paper for a Level III USEPA Scientific and Technological Achievement Award.

Dr. Sarnat holds a B.Sc. in Microbiology and Immunology and a M.Sc. in Occupational Hygiene from the University of British Columbia and a Sc.D. in Environmental Health from the Harvard School of Public Health.

APPENDIX C

Workshop Speaker Biographies

HEI Research Planning Workshop

Understanding Population-Level Exposures Related to the Development of Oil and Natural Gas from Unconventional Resources

Denver, CO
July 11-12, 2018

SPEAKER BIOGRAPHIES

John L. Adgate

Dr. Adgate is Professor and Chair of the Department of Environmental and Occupational Health at the Colorado School of Public Health. His research on exposure science, risk analysis, and children's environmental health has focused on improving exposure estimation in epidemiologic studies by documenting the magnitude and variability of human exposures to chemical and biological stressors. He has taught or co-taught graduate level courses in environmental health, risk analysis, occupational safety and ergonomics, and advanced methods in exposure science. Dr. Adgate has served on multiple science advisory panels for the U.S. Environmental Protection Agency as well as National Research Council and Institute of Medicine committees exploring technical and policy issues related to residential exposure to pesticides and air pollutants, impacts of energy development, lead exposure interventions, children's environmental health, the impacts of climate change on indoor air quality. He received a BS from Calvin College, an MSPH degree in environmental science from the School of Public Health of the University of North Carolina at Chapel Hill, and a PhD degree in environmental health sciences granted jointly by the University of Medicine and Dentistry of New Jersey and Rutgers University. His current funded research focuses on the risks, health, and community impacts of oil and gas development; the impact of residential weatherization and wildfires on indoor environments; and health effects stemming from perfluoroalkyl chemical (PFAS) exposure.

David T. Allen

Dr. Allen is the Gertz Regents Professor of Chemical Engineering, and the Director of the Center for Energy and Environmental Resources, at the University of Texas at Austin. He is the author of seven books and over 250 papers, primarily in the areas of urban air quality, the engineering of sustainable systems, and the development of materials for environmental and engineering education. Dr. Allen has been a lead investigator for multiple air quality measurement studies, which have had a substantial impact on the direction of air quality policies. He directs the Air Quality Research Program for the State of Texas, and he is the founding Editor-in-Chief of the American Chemical Society's journal ACS Sustainable Chemistry & Engineering. He has developed environmental educational materials for engineering curricula and for the University's core curriculum, as well as engineering education materials for high school students. He led the development of a year-long high school engineering course, Engineer Your World, which is used in hundreds of high schools nationwide. The quality of his work has been recognized by the National Science Foundation, the AT&T Foundation, the American Institute of Chemical Engineers, the Association of Environmental Engineering and Science Professors, and the State of Texas; he was elected to the National Academy of Engineering in 2017. He has served on a variety of governmental advisory panels and from 2012 to 2015 chaired the U.S. Environmental Protection Agency's Science Advisory Board. He has won teaching awards at the University of Texas and UCLA and the Lewis Award in Chemical Engineering Education, from the American Institute of Chemical Engineers. Dr. Allen received his B.S. degree in Chemical Engineering, with distinction, from Cornell University in 1979. His M.S. and Ph.D. degrees in Chemical Engineering were awarded by the California Institute of Technology in 1981 and 1983. He has held visiting faculty appointments at the California Institute of Technology, the University of California, Santa Barbara, and the Department of Energy.

Tiffany Bredfeldt
Dr. Bredfeldt is a Senior Toxicologist at the Texas Commission on Environmental Quality where she focuses on human health risk assessment, generation of toxicity factors, and NexGen risk assessment approaches. Her office has been active in evaluating ambient air quality from a human health perspective for VOCs, PAHs, carbonyls, and metals. Her responsibilities include serving on national panels that influence the future of the use of toxicology data in human health risk assessment. A significant portion of her time is dedicated to participating in public policy and outreach events where she both represents the State of Texas and also educates the public about environmental health issues. Dr. Bredfeldt received her Ph.D. in Pharmacology and Toxicology from the University of Arizona where her research focused on the carcinogenicity of arsenic metabolites and their underlying mechanisms of action. This research into the mechanisms of arsenic-induced carcinogenesis was published in various peer-reviewed journals and was acknowledged through awards from the Society of Toxicology and the National Institute of Environmental Health Sciences (NIEHS), including the 2005 Karen Wetterhahn Memorial Award. Upon completion of her doctoral studies, she conducted postdoctoral research at the University of Texas M.D. Anderson Cancer Center, where she was the recipient of a NIEHS Ruth L. Kirschstein National Research Service Award. Dr. Bredfeldt's postdoctoral research investigated the mechanisms by which early life exposure to endocrine disrupting chemicals called xenoestrogens increased cancer risk in adulthood by modulation of epigenetic structures.

Jeffrey L. Collett, Jr.
Dr. Collett is Professor and Head of the Department of Atmospheric Science at Colorado State University. Dr. Collett's research interests include pollution processing by clouds and fogs, nitrogen deposition, aerosol chemistry, air quality impacts from unconventional oil and gas development, emissions from wild and prescribed fires, precipitation chemistry and physics, dew chemistry, bi-directional exchange of ammonia between the atmosphere and surface, regional air quality, aerosol impacts on visibility, and instrument development. Recent studies have characterized (1) emissions of air toxics, ozone precursors, and methane from specific processes (drilling, fracking, flowback, and production) associated with unconventional oil and gas development, (2) the increasing contributions of ammonia to reactive nitrogen deposition in the Rocky Mountain region and across the U.S., (3) contributions of biomass burning to reactive nitrogen and brown carbon, (4) the organic chemistry of clouds and fogs, (5) impacts of oil and gas development on fine particle and haze formation in the Bakken oil patch, (6) the role of dew as a temporary, nighttime reservoir for atmospheric ammonia, and (7) international air quality issues in China and Korea. Dr. Collett received an S.B. in Chemical Engineering from MIT and M.S. and Ph.D. degrees in Environmental Engineering Science from Caltech.

Isabelle Cozzarelli
Dr. Cozzarelli received her PhD from the University of Virginia in 1993. As a geochemist in the United States Geological Survey's Water Mission Area she conducts long-term interdisciplinary research on the environmental fate and effect of organic contaminants such as fuels and fuel waste products. She has over 100 published research papers. Throughout her career she has committed herself to mentoring students and junior scientists in the field and in her laboratory in Reston Virginia. She currently serves as Team Leader of the USGS Toxics Program project on Fate and Effects of Wastes from Unconventional Oil and Gas Development. Dr. Cozzarelli has an adjunct faculty position at Virginia Tech and was elected GSA Fellow in 2005.

Cloelle Danforth
Dr. Danforth is a Postdoctoral Science Fellow in the Environmental Defense Fund's Office of the Chief Scientist and has been working primarily with the Oil and Gas Team to minimize impacts of oil and gas development on surface and groundwater. She is currently involved in a two-pronged research effort: (1) to understand and improve oil and gas wastewater characterization techniques, and (2) to create viable,

fit-for-purpose biological treatment methodologies to remove organic constituents of concern. Dr. Danforth's research has largely focused at the intersection of microbiology and environmental engineering; meaning, she considers the role of microorganisms to meet a variety of environmental challenges and needs – primarily in the context of water and wastewater. Her work includes investigating a bacterium for bioremediation of a common groundwater contaminant and exploring reactor designs for microorganisms that are able to use electricity directly to produce fuel or fuel feedstock. This process is essentially synthetic photosynthesis and could someday be used to store intermittent energy (solar) in a form that can be used at need (liquid fuel). Dr. Danforth also spent two years working as a consulting engineer performing environmental investigations and remediation. She earned her B.S. in Engineering Science at Smith College and her M.S. and PhD in Civil & Environmental Engineering from Cornell University.

Shari Dunn-Norman
(See separate compilation of biographies for HEI's Energy Research Committee)

Michael Honeycutt, PhD
Dr. Honeycutt is the director of the Toxicology Division of the Texas Commission on Environmental Quality (TCEQ). His career at TCEQ began in 1996, and he has managed the division of 14 toxicologists since 2003. His responsibilities include overseeing (1) health effects reviews of air permit applications, (2) review of the results of ambient air monitoring projects, and (3) reviews of human health risk assessments for hazardous waste sites. Dr. Honeycutt spearheaded the updating of TCEQ's Effects Screening Levels (ESLs), or toxicity factors for chemicals. The TCEQ ESL derivation procedure has undergone two independent external scientific peer reviews and multiple rounds of public comment (http://www.tceq.texas.gov/toxicology/esl/guidelines/about.html). Dr. Honeycutt serves as a technical resource for TCEQ management and staff on issues concerning air and water quality, drinking water contamination, and soil contamination. He also serves as an expert witness in public and state legislative hearings, participates in public meetings, and has conducted hundreds of media interviews. Dr. Honeycutt is an adjunct professor at Texas A&M University, has published numerous articles in the peer-reviewed literature, serves or has served on numerous external committees, and has provided invited testimony at Congressional hearings. He was recently appointed chairman of USEPA's Science Advisory Board. Dr. Honeycutt received his Bachelor's degree and Ph.D. in Toxicology from the University of Louisiana at Monroe.

George Hornberger
(See separate compilation of biographies for HEI's Energy Research Committee)

Bradley King
Dr. King is an industrial hygienist at the National Institute for Occupational Safety and Health (NIOSH). He holds a BS in Biology from Loyola University New Orleans, an MPH in Environmental/Occupational Health from Saint Louis University, and a PhD in Environmental Health Science from Johns Hopkins University. He received his commission as an Environmental Health Officer in the U.S. Public Health Service in 2002, currently holding the rank of Captain (CAPT), and received his certification in the comprehensive practice of industrial hygiene in 2005. He joined NIOSH in 1999 in the Health Hazard Evaluation program in Cincinnati, Ohio, responding to requests from workers, employers, and union officials to evaluate occupational exposures at worksites across the country. Since 2013, he has worked in NIOSH's Western States Division in Denver, Colorado; current research interests include evaluating occupational exposures in the upstream oil and gas industry. Bradley currently serves as a Director on the Board of Directors for the American Industrial Hygiene Association.

Michael McCawley
Dr. McCawley graduated with a bachelor's degree in Zoology from George Washington University. He received his master's degree in Environmental Engineering from West Virginia University and a doctorate in Environmental Health from New York University. Dr. McCawley spent over 27 years as a Public Health Service Officer with the Centers for Disease Control and Prevention (CDC) at the National Institute for Occupational Safety and Health, studying miners' health, occupational respiratory disease, aerosol measurement and ultrafine particles. While there he worked on projects concerning exposure to wood dust, volcanic ash, diesels, coal mine dust, silica and beryllium. He retired from the US Public Health Service in 2001. He has taught at WVU since 1979, with primary interests in air pollution, aerosols and occupational health. He has developed air sampling equipment and a pulmonary function test. Recently, he has been working on issues related to Marcellus Shale drilling and mountain top mining.

Lisa McKenzie
Dr. McKenzie is an Assistant Research Professor at the Colorado School of Public Health (Colorado SPH) on the University of Colorado Denver's Anschutz Medical Campus. Her expertise is in exposure assessment, environmental epidemiology, and human health risk assessment. Dr. McKenzie's research has contributed to the understanding of how air pollutants and other exposures resulting from the unconventional development of petroleum resources may affect the public's health. Her sentinel human health risk assessment indicated the potential for respiratory, neurological, and developmental health outcomes resulting from exposure to air pollutants emitted during natural gas development. Her studies investigating associations between adverse birth outcomes and childhood cancers and proximity to oil and gas development are among the first epidemiological studies on this topic to appear in the published literature. She has testified before the United States Congress and the Denver Metropolitan Regional Air Quality Council on the public health implications of natural gas development. Prior to her current academic appointment, she was a senior scientist in the private sector leading multi-disciplinary teams of scientists across the United States in conducting human health risk assessments.

Robert O'Keefe
Mr. O'Keefe is responsible for management of key programs at HEI, including the Institute's global program to assess the health effects of air pollution in developing countries. He also provides leadership in implementing HEI's ongoing research and review programs on the health impact of particulates, ozone air toxics and other pollutants, and emerging technologies and fuels, including those driven by climate concerns. He oversaw the Institute's efforts to define and implement a program of research on Accountability, a first-of-its-kind program designed to understand the health impacts of environmental regulation. He is regularly called on to address prominent institutions, including the U.S. Congress, the European Parliament, the National Academy of Science's National Research Council and Institute of Medicine, and many other domestic and international bodies. In 2009 he was invited by the Woodrow Wilson Center to address its congressional forum as a "Scholar on the Hill." He is currently a member of the U.S. EPA's national Clean Air Act Advisory Committee and is Chair of the Board of Directors of Clean Air Asia. Before coming to HEI he served for nine years at the Massachusetts Department of Environmental Protection, as Assistant Deputy Commissioner for Policy and Program Development and as Director of Planning and Budget. Mr. O'Keefe played a significant role in gaining passage and funding for major state programs, including the Massachusetts State Superfund law, the Safe Drinking Water Program, and the design and funding of Massachusetts' implementation of the 1990 Clean Air Act amendments.

Adam Pacsi
Dr. Pacsi is an air quality and greenhouse gas emission researcher for the Chevron in the internal consulting and research division of the company. Adam is a chemical engineer by training, with a BS

from Tulane University in New Orleans and a PhD from the University of Texas at Austin. His doctoral research examined the air quality and water use changes associated with unconventional natural gas development in Texas and price-based changes in the electric power sector. For the last 3.5 years, Adam has worked with Chevron on a variety of projects related to methane emissions, environmental big data and analytics, and ambient air pollution measurement technologies.

Martha E. Rudolph
Ms. Rudolph is the Director of Environmental Programs for the Colorado Department of Public Health and Environment where she oversees the Air Quality, Environmental Health and Sustainability, Hazardous Materials and Waste Management, and Water Quality Divisions. Ms. Rudolph has been with the Department since 2007, and served as the Executive Director of the Department in 2010. In 2015/2016, Ms. Rudolph was President of the Environmental Council of States, the national non-profit, non-partisan association of state and territorial environmental agency leaders. She currently serves on the Board of Directors for the Environmental Research Institute of the States and is a co-chair of the ECOS Shale Gas Caucus. Previously Ms. Rudolph was the Chair of the ECOS Air Committee and the Vice Chair of the ECOS Planning Committee. She is a member of the Division on Earth and Life Studies of The National Academies of Sciences, Engineering, and Medicine, a state advisor for the Georgetown Climate Center, and a member of the American College of Environmental Lawyers. A graduate of the Georgetown University Law Center, Ms. Rudolph is an environmental attorney, and served for 14 years in the Colorado Attorney General's Office. She has been in private practice in Denver, and was an assistant general counsel for Kinder Morgan Inc., a natural gas and energy transportation company. Ms. Rudolph received her BA in International Affairs from the University of Colorado-Boulder and Doctor of Law degree from the Georgetown University Law Center.

Nichole Saunders
Ms. Saunders is an Attorney for EDF's US Climate and Energy Program, where she works on oil and natural gas regulation and policy. Her work is focused on minimizing impacts to water, land, and communities by improving state and federal policies and industry practices. Nichole joined EDF as a legal intern in 2013, working on water and waste issues associated with natural gas development. As a law student at the University of Tulsa College of Law, she studied sustainable energy and resources law and served as Student Editor-In-Chief of the Energy Bar Association's Energy Law Journal publication and Executive Editor of the American Bar Association's Section of Environment, Energy, and Resources Year-in-Review. Prior to earning her J.D., Nichole completed her M.S. and B.S. in Environmental Biology from Tulane University. She is a member of the State Bar of Texas and Texas Bar Association.

Daniel J. Soeder
Mr. Soeder is Director of the Energy Resources Initiative at South Dakota School of Mines & Technology in Rapid City, SD, USA. He joined SD Mines in May 2017 with eight years of experience as a research scientist at the Morgantown, WV campus of the U.S. Department of Energy (DOE) National Energy Technology Laboratory, where he investigated the environmental risks of unconventional oil and gas development, and 18 years as a hydrologist with the U.S. Geological Survey (USGS) studying groundwater contamination on the U.S. east coast, and nuclear waste isolation in Nevada. Prior to joining the USGS, he spent a decade with the Gas Technology Institute in Chicago, researching hydrocarbon production from unconventional resources. He also worked as a DOE contractor collecting and characterizing Eastern Gas Shale Project cores. He holds a BS from Cleveland State University, and an MS from Bowling Green State University (Ohio), both in geology.

Michael Van Dyke
Dr. Van Dyke is the Section Chief for Environmental Epidemiology and Occupational Health at the Colorado Department of Public Health and Environment (CDPHE). His educational background includes

a BS degree in Chemistry and Biology from the University of Southern Colorado and a M.S. and Ph.D. in Environmental Health from Colorado State University. Dr. Van Dyke has been involved with the Health, Safety, and Environmental profession for nearly 20 years. He previously worked in public health at TriCounty Health Department, occupational health for the Colorado OSHA Consultation Program, and academic research at National Jewish Health. Dr. Van Dyke's work and research has focused on occupational and environmental exposure assessment and health surveillance. He is currently the Principal Investigator for Colorado's NIOSH-funded occupational health surveillance program and Colorado's CDC-funded environmental public health tracking network. Dr. Van Dyke also manages the newly created Marijuana Health Effects unit at CDPHE that has been charged with developing surveillance methods for potential adverse effects of marijuana use.

Donna J. Vorhees

Dr. Vorhees directs the Energy Research Program at HEI. She is leading an effort to implement a Strategic Scientific Research Agenda designed to understand potential human exposures and health effects from unconventional oil and gas development and how they might be prevented or minimized. Vorhees has 25 years of consulting experience, assessing multi-pathway chemical exposures in indoor and outdoor environments, quantifying human health risks, and communicating risks to affected communities in the United States on behalf of government and private clients and internationally on behalf of the United Nations Environment Program. She serves on the U.S. EPA Board of Scientific Counselors Subcommittee on Chemical Safety for Sustainability and previously served on National Research Council committees (Health Risks of Phthalates and Sediment Dredging at Superfund Megasites), other advisory committees, and peer review panels for numerous health risk assessments prepared by the U.S. EPA, the Consumer Product Safety Commission, and Health Canada. She is Adjunct Assistant Professor at the Boston University School of Public Health where she teaches Risk Assessment Methods. Vorhees received her ScM and ScD in Environmental Health from the Harvard School of Public Health.

APPENDIX D

Workshop Participant List

HEI Research Planning Workshop

Understanding Population-Level Exposures Related to the Development of Oil and Natural Gas from Unconventional Resources

Denver, CO
July 11-12, 2018

PARTICIPANTS

^Dr. John Adgate
Professor and Chair, Environmental and Occupational Health
Colorado School of Public Health

^Dr. David Allen
Melvin H. Gertz Regents Chair, Department of Chemical Engineering
University of Texas at Austin

Dr. William Allshouse
Professional Research Assistant
Colorado School of Public Health

Mr. Bruce Baizel
Director, Energy Program, Oil & Gas Accountability
Earthworks

Ms. Allie Bamber
Environmental Toxicologist
Colorado Department of Public Health & Environment

Mr. Rodney Barnwell
Counsel – Environmental & Safety
XTO Energy Inc.

Mr. Michael Bergstrom
Senior Regulatory Advisor
Shell Oil Company

Ms. Uni Blake
Scientific Advisor
American Petroleum Institute

Dr. Daniel Bon
Mobile Lab Lead Investigator
Colorado Department of Public Health & Environment

^Dr. Tiffany Bredfeldt
Toxicologist, Toxicology Division
Texas Commission on Environmental Quality

Dr. Joan Casey
Postdoctoral Scholar, Environmental Health Sciences Division
University of California at Berkeley

Dr. Jane Clougherty
Associate Professor, Department of Environmental and Occupational Health
Drexel University

^Dr. Jeffrey Collett
Professor and Department Head, Atmospheric Science
Colorado State University

^Dr. Isabelle Cozzarelli
Hydrologist
United States Geological Survey

Dr. Elena Craft
Senior Health Scientist
Environmental Defense Fund

^Dr. Cloelle Danforth
High Meadows Post-Doctoral Science Fellow
Environmental Defense Fund

*** HEI Energy Research Committee Members
^ Speakers

Dr. Eric Daniels
Consulting Hydrogeologist
Chevron

Dr. Joost de Gouw
Senior Scientist, Cooperative Institute for Research in Environmental Sciences
University of Colorado at Boulder

Dr. Dennis Devlin
Senior Environmental Health Advisor
ExxonMobil

***^Dr. Shari Dunn-Norman**
Associate Professor, Petroleum Engineering
Missouri University of Science and Technology

Ms. Nathalie Eddy
Colorado & New Mexico Field Advocate
Earthworks

Dr. James Fabisiak
Associate Professor, Department of Environmental & Occupational Health
University of Pittsburgh

***Dr. Elaine Faustman**
Professor and Director of the Institute of Risk Analysis and Risk Communication
University of Washington

Ms. Kate Fay
Manager, Environmental & Regulatory Policy
Noble Energy

Mr. Howard Feldman
Senior Director, Regulatory and Scientific Affairs
American Petroleum Institute

Mr. Kyle Ferrar
Western Program Coordinator
FracTracker Alliance

Mr. Dick Francis
Manager, Regulatory Policy, Upstream Unconventionals – US Onshore
Shell Oil Company

Dr. George Gerton
Research Professor of Reproductive Biology in Obstetrics and Gynecology, Center for Research on Reproduction and Women's Health
Perelman School of Medicine at the University of Pennsylvania

Dr. Jessica Gilman
Research Chemist, Tropospheric Chemistry
National Oceanic and Atmospheric Administration

Dr. Andrew Glickman
Manager, Health and Product Stewardship
Chevron (Retired)

Mr. Michael Goo
Partner
AJW, Inc.

Dr. John Graham
Senior Scientist
Clean Air Task Force

Mr. Daniel Greenbaum
President
Health Effects Institute

Dr. Richard Haut
Senior Research Scientist
Houston Advanced Research Center

Dr. Detlev Helmig
Fellow and Associate Research Professor, Institute of Arctic and Alpine Research
University of Colorado Boulder

Dr. Judy Wendt Hess
Epidemiologist
Shell Oil Company

Dr. Paul Hodgins
Chief Medical Officer
ConocoPhillips

^Mr. Michael Honeycutt
Director, Toxicology Division
Chairman, EPA Science Advisory Board
Texas Commission on Environmental Quality

*** HEI Energy Research Committee Members
^ Speakers

*****^Dr. George Hornberger**
Professor of Engineering, Professor of Civil and Environmental Engineering, Professor of Earth and Environmental Sciences, and Director, Vanderbilt Institute for Energy and Environment
Vanderbilt University

Dr. Rebecca Hornbrook
Project Scientist, VOC Measurements Group
National Center for Atmospheric Research

*****Dr. Howard Hu**
Professor of Environmental Health, Epidemiology, Global Health and Medicine
University of Toronto Dalla Lana School of Public Health

^Dr. Bradley King
Industrial Hygienist
CDC – The National Institute for Occupational Safety and Health Western States Division

Dr. Robert L. Kleinberg
Adjunct Senior Research Scholar, Center on Global Energy Policy, Columbia University
Non-Resident Senior Fellow, Institute for Sustainable Energy, Boston University

Ms. Kristin Koblis
Senior Occupational Health Advisor
Noble Energy

*****Dr. Judy LaKind**
President
LaKind Associates, LLC

Dr. Karlene Lavelle
Advanced Epidemiology Associate
ExxonMobil Biomedical Sciences, Inc.

Mr. Joe Lima
Director, Environmental Sustainability
Schlumberger

Ms. Kathryn Liziewski
Research Assistant
Health Effects Institute

Ms. Erin Markovich
SSU Lead
Equinor

^Dr. Michael McCawley
Interim Chair and Clinical Associate Professor, Department of Occupational & Environmental Health Sciences
West Virginia University Health Sciences Center

Dr. Roger McClellan
Advisor
Inhalation Toxicology and Risk Assessment

^Dr. Lisa McKenzie
Assistant Research Professor, Department of Environmental and Occupational Health
Colorado School of Public Health

Dr. Tami McMullin
Program Manager and Toxicologist, Oil & Gas Health Information and Response
Colorado Department of Public Health & Environment

Dr. Jana Milford
Professor, Department of Mechanical Engineering
University of Colorado at Boulder

Mr. Tom Moore
WRAP Air Quality Program Manager
Western States Air Resources Council

Dr. Ziad Naufal
Health and Workforce Safety
Chevron

Dr. Mwangi Ndonga
Occupational Health & Industrial Hygiene Specialist
EnCana

^Mr. Robert O'Keefe
Vice President
Health Effects Institute

*** HEI Energy Research Committee Members
^ Speakers

^Dr. Adam Pacsi
Air Technology Engineer
Chevron

Ms. Kelsey Patsch
Program Associate
Claude Worthington Benedum Foundation

Dr. Gabriele Pfister
Deputy Director, Atmospheric Chemistry Observations & Modeling Laboratory
National Center for Atmospheric Research

Mr. Gordon Pierce
Program Manager, Technical Services
Colorado Department of Public Health & Environment

Mr. Wil Porche
Technical Operations Lead, Safety Security Health & Environmental
XTO Energy Inc.

Mr. Daniel Raimi
Senior Research Associate
Resources for the Future

Ms. Alejandra Ramirez-Cardenas
Research Assistant, Synergy America Contractor
CDC – The National Institute for Occupational Safety and Health Western States Division

Mr. Jason Redus
Senior Industrial Hygienist
Pioneer Natural Resources

Dr. Annette Rohr
Principal Project Manager, Air Quality and Multimedia Sciences
Electric Power Research Institute

Dr. Anna Rosofsky
Staff Scientist
Health Effects Institute

^Ms. Martha Rudolph
Director, Environmental Programs
Colorado Department of Public Health and Environment

***Dr. Armistead (Ted) Russell**
Howard T. Tellepsen Chair and Regents' Professor
Environmental Engineering
Georgia Tech

Dr. Satinder Sarang
Senior Toxicologist
Shell Oil Company

***Dr. Stefanie Ebelt Sarnat**
Associate Professor
Emory University

^Ms. Nichole Saunders
Attorney
Environmental Defense Fund

Ms. Kim Schultz
Oil and Gas Program Coordinator
The Endocrine Disruption Exchange

Dr. Rashid Shaikh
Director of Science
Health Effects Institute

Mr. Robert Shavers
Operations Manager
Health Effects Institute

^Dr. Daniel Soeder
Director, Energy Resources Initiative
South Dakota School of Mines & Technology

Dr. Kevin Teichman
Deputy Assistant Administrator for Science, Office of Research and Development
United States Environmental Protection Agency

Ms. Denise Tuck
Principal Product Champion, Production Enhancement
Halliburton

*** HEI Energy Research Committee Members
^ Speakers

^Dr. Mike Van Dyke
Branch Chief, Environmental Epidemiology,
Occupational Health & Toxicology Branch
Colorado Department of Public Health &
Environment

^Dr. Donna Vorhees
Director of Energy Research
Health Effects Institute

Dr. Kristina Whitworth
Assistant Professor, Department of Epidemiology,
Human Genetics & Environmental Sciences
The University of Texas Health Science Center at
Houston

*** HEI Energy Research Committee Members
^ Speakers

APPENDIX E

Breakout Group Exercise Summaries

ENERGY RESEARCH PROGRAM

Research Planning Meeting: Understanding Population-Level Exposures Related to the Development of Oil and Natural Gas from Unconventional Resources
July 11-12

Summary of Results-Group Exercise #1

For the first group exercise, participants were assigned to groups and asked to address the question: *What criteria should be used to prioritize exposure research recommendations?* The responses from each group were diverse; however, several common themes emerged:

- **Research population.** Investigators should focus on community-based exposure in areas where people live and on vulnerable populations.
- **Toxicity and mixtures.** Population-level exposure research should prioritize specific chemicals to study by reviewing existing chemical screening work, cautioning to not exclude chemicals with wide ranging toxicities. Studies should also consider potential multiplicity of exposure and chemical mixtures. *In vivo* and animal toxicology work can be useful models to examine potential exposure to mixtures unique to UOGD.
- **Heterogeneity across oil and gas-producing regions.** There are several factors that results in inter-regional heterogeneity in potential exposures, including: geology, geography, weather patterns, industry practices, local regulations, chemical composition of the resource, and temporality. Ideally, research should be adaptable to evolving industry practices. The research community needs to determine whether broadly generalizable studies can be done given the heterogeneity across the United States, or whether several, simultaneous multi-regional studies should be prioritized to more effectively answer research questions. Alternatively, case studies in specific regions may be more effective than attempting research that addresses heterogeneity.
- **Standardization.** Research methods and protocols should be standardized to allow for inter-study comparability. Within these standards should be use of instrumentation that allows for levels of detection that allow investigators to answer health-based questions. Following HEI's model of ensuring high-quality data, research should also undergo standard QA/QC audits and third-party data reviews.
- **Exposure characterization.** Exposure characterization studies should focus on measurable exposures (i.e., exposures that can be quantified), both chemical (e.g., VOCs) and non-chemical (e.g., noise). It would be useful to have validation studies that ground-truth current exposure assessment methods used in the epidemiology literature (e.g., distance to a well as a surrogate for exposure). Research should characterize potential exposure through multiple potential pathways, across sites, at different temporalities and distances from UOGD sites.
- **Distinguishing UOGD from non-UOGD sources (i.e., confounders).** It is difficult to potential separate UOGD exposures from background exposure and other potential sources of exposure, including conventional oil and gas development and non-UOGD related traffic. Exposure-based literature in other fields, like traffic, may have some insights on distinguishing between UOGD-related concentrations and background concentrations.
- **Source apportionment.** Source apportionment and supply chain studies would be useful to identify the specific components along the upstream oil and gas lifecycle that may lead to exposures. Results from these

studies are useful for regulators and industry as they assess emissions at specific points in the UOGD process.

- **Acute versus chronic exposure.** Research should focus on both acute and chronic exposures, and on the chemicals that are known in the literature to be associated with adverse health impacts.
- **Community concerns.** Research should consider both public concerns and expert priorities. Workshop participants disagreed about how and if both should be considered in prioritizing research.
- **Regulation.** Research topics that have already been addressed by regulation are not research priorities. Research should produce results that are actionable and useful to regulators.
- **Feasiblity.** Well-designed research should be feasible, with a well-defined timeline, budget, and scope.
- **Partnerships.** Relationships with industry partners can be leveraged to better understand differences in industry practices that may affect study results.

ENERGY RESEARCH PROGRAM

Research Planning Meeting: Understanding Population-Level Exposures Related to the Development of Oil and Natural Gas from Unconventional Resources
July 11-12

Summary of Results-Group Exercise #2

For the second group exercise, participants were assigned to groups and asked to address the question: *What potential human exposure would you study if you were given $2 million for research?* The responses from each group were diverse; however, several common themes emerged:

- **A focus on air emissions versus water contamination.** Most groups focused on air quality research, citing potential emissions to air as more critical than water contamination. Groups noted the difficulty in defining potential exposed populations and in studying probability of water contamination from accidents (e.g., wellbore integrity or a surface spill) as reasons for not prioritizing water quality research. In contrast, air emissions are part of the UOGD lifecycle under normal operating conditions. Some groups did prioritize research on groundwater monitoring and produced water.
- **Data mining.** Groups noted that given finite financial resources, researchers should consider data-mining and consolidating data to understand nationwide exposures. Leveraging existing data through data mining is a cost-effective method to determine where data gaps remain and how to prioritize future research.
- **Chemical and non-chemical agents of interest.** Groups prioritized the study of agents that are known in the literature to be associated with adverse health outcomes and that are unique to UOGD and can potentially be used as markers of UOGD emissions. These agents include BTEX (benzene, toluene, ethylbenzene, and xylene), ultrafine particulates, NO_2, and other analytes that can be applied to a source apportionment model. Some groups also emphasized not ignoring the study of chemicals for which there is limited toxicity data. Groups also mentioned including noise and odor measurements as part of exposure assessment activities.
- **Conducting epidemiology studies.** Groups discussed epidemiology study designs with prospective follow-up of large populations living in proximity to UOGD and with exposure assessments in which the agent(s) is quantified. To address heterogeneity in industry practices, emissions and populations across regions, groups suggested conducting the same epidemiological study at multiple locations to assess the impacts of heterogeneity. There was an interest in focusing epidemiology studies on perinatal outcomes, citing methodological advantages, including allowing researchers to assess the outcomes of both the mother and offspring, and that the personal sampling period is relatively short. In additional, perinatal outcomes may serve as indicators of health outcomes that have implications over the life course.
- **Exposure assessment.** Much of the discussion focused around aspects of an ideal exposure assessment study. These include: collecting time-activity data, conducting exposure assessments in proximity to communities, quantifying both acute (short-term or peak) and chronic (low-long term exposure) exposure, assessing emissions heterogeneity over space and time, examining the role of topography in fate and transport of contaminants in air, collecting data for the purposes of informing an epidemiology or risk assessment and for determining setback distances (i.e., the radius of impact).

- **Exposure assessment technologies.** Groups provided several examples of the types of instrumentation and models that they might use to conduct an exposure assessment. These include high-resolution satellite data, including aerosol optical depth data, wearable personal monitors, low-cost sensors, and paired indoor-outdoor residential sampling.
- **Perceived versus actual risk.** Groups discussed the difficulty in prioritizing research based on perceived health risk versus "actual" health risk that has been supported by previous literature.