Energy Research Program

WORKSHOP SUMMARY:

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

September 12-13, 2018

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CONTENTS

1. INTRODUCTION

The Health Effects Institute (HEI) hosted the second of two research planning workshops in Austin, TX on September 12-13, 2018. At the workshop, a diverse group of stakeholders helped to inform HEI's research 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 from oil and gas development 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

[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).

the research and submit their final report, which is then independently reviewed in detail by a separate HEI Energy Review Committee.

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

The Workshop provided an opportunity for a wide range of stakeholders to engage with one another and share their recommendations for research priorities and literature review. The purpose of the exposure literature review is to identify knowledge gaps based on the literature and use these gaps to generate a Research Solicitation for population-level exposure research.

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 all 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 and participated in breakout sessions. Discussion at the workshop focused around five charge questions (Table 1). Expert speakers addressed topics relevant to the charge questions, including trends and research needs in federal and state oil and gas policy and the application of data mining to UOGD-related research. During the breakout groups, participants were assigned to address one of three topical questions. Additional details on the breakout group exercises can be found in Appendix E.

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

Table 1. Workshop Charge Questions for Participants and Speakers

Charge Questions
How can existing data be leveraged to understand potential exposures from UOGD?
What potential UOGD exposures are not well understood with existing data and merit original research?
What exposure pathways and phases of UOGD should be the focus?
In conducting such research, what are your recommendations for considering regulatory, environmental, and industry-practice variability over time and across regions?
What is the value of the research for decision-makers (e.g. regulators, industry, community members, and scientists conducting research)?

4. SUMMARY OF PRESENTATIONS

4.1 INTRODUCTION

Health Effects Institute staff and the Chair of the HEI Energy Research Committee welcomed the participants and reviewed the workshop objectives and charge questions.

Mr. Robert O'Keefe

Robert O'Keefe, Vice President of the Health Effects Institute, convened the workshop and welcomed participants.

Dr. George Hornberger

George Hornberger, Chair of the HEI Energy Research Committee, introduced the members of the Committee and briefly discussed the criteria for their selection for the Committee.

Dr. Donna Vorhees

Donna Vorhees, Director of the HEI Energy Research Program, reviewed the workshop objective, charge questions, schedule, and the conceptual model of exposure that forms the basis of HEI's Energy Research Program. Dr. Vorhees emphasized that the Committee's work is intended to benefit all in society, including representatives of industry, academia, federal and state level government officials, community groups, environmental organizations, and the public.

4.2 THE COMMITTEE'S PROGRESS

HEI staff and the Chair of the HEI Energy Research Committee presented the Committee's progress on the review of the UOGD-related epidemiology literature, the UOGD-related exposure literature, and research planning.

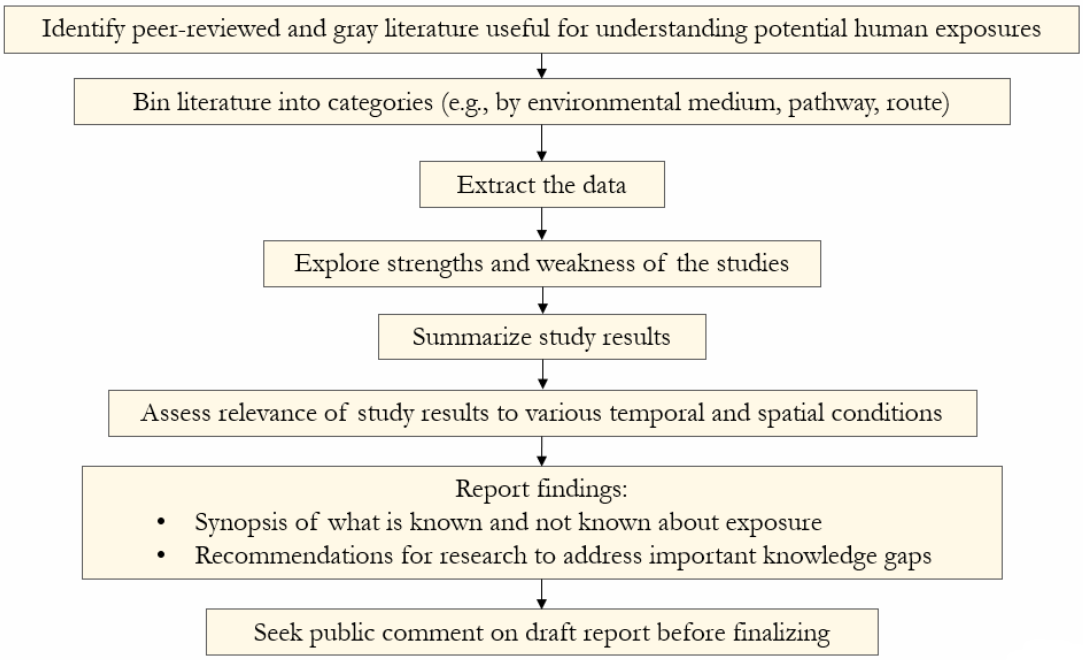
George Hornberger and HEI

Dr. George Hornberger and Dr. Donna Vorhees presented on the Committee's approach and progress. The Committee's role is to conduct literature reviews and oversee research planning, original research, and reporting of all results independently from sponsors, with widespread stakeholder engagement at key intervals. This approach is modeled after the approach HEI has used for 35 years to answer questions about air quality and health. Currently the Program is in Phase 1, which focuses on literature review and research planning. Phase 2 of the Program will focus on population-level multimedia exposure studies in multiple regions of the U.S.

Dr. Vorhees reported that the systematic review of epidemiology studies is undergoing peer review. The review of exposure-related literature is in progress, and the draft review will be released for public comment before the report is finalized. The preliminary literature review question for the exposure review is: What is known about potential UOGD-related human exposures? The Committee's approach to their review is presented in Figure 2. The Committee is surveying the existing literature to assess its utility for understanding potential human exposure to agents originating from UOGD.

Dr. Vorhees briefly summarized the activities and results of the July 2018 Workshop in Denver, Colorado. The research priorities and study design suggestions presented at that meeting are being reviewed by the Committee as it engages in the research planning process.

Figure 2. The Committee's formal approach to the exposure literature review.



Q&A Session. The question and answer session included inquiries about the scope of the review, including examination of studies about physical exposure agents, exposure-related impacts such as truck accidents and damage to property values, and prioritization for research given the scope of the review. HEI responded that physical agents are a part of Committee discussions, but that the emphasis for now is on chemical exposure due to the large associated body of literature, that secondary outcomes like truck accidents are not the focus of the review but are up for discussion, and that the Committee will develop their own set of criteria for prioritization after identifying knowledge gaps.

HEI agreed with a comment that few community-based exposure studies exist and that local communities' perceptions of whether they are at risk is a major driver for policy decisions and should therefore be considered. In response to a question on the generalizability of research, HEI responded that research funded by HEI would need to be informed by a conceptual model of exposure, as well as how operations change over time and the effects that this has on human exposure. When questioned on the need for source apportionment studies, HEI responded that several examples exist with regard to air and water in Pennsylvania, but that no single 'silver bullet' study exists.

HEI informed the audience that they are consulting with industry to understand the current state of operations and with communities and NGOs to understand the concerns about the operations. Any research team funded will need to engage effectively with communities living in study areas.

4.3 Panel Discussion: Federal and State Oil and Gas Policy – Trends and Research Needs

4.3.1 Panel Discussion

The panel discussion included six representatives from federal and state agencies that set policy for oil and natural gas operations. Panelists included Megan E. Garvey, Senior Counselor to the Regional Administrator in Region 8; Michael E. Honeycutt, Director of the Toxicology Division, Texas Commission on Environmental Quality, James C. Kenney, Senior Policy Advisor for Unconventional Oil

and Gas in the Office of Congressional and Intergovernmental Relations, United States Environmental Protection Agency (US EPA), Saba Tahmassebi, Agency Chief Engineer for the Oklahoma Department of Environmental Quality, Martha Rudolph, Director of Environmental Programs at the Colorado Department of Public Health and Environment, and Clint Woods, Deputy Assistant Administrator in the Office of Air and Radiation, United States Environmental Protection Agency.

HEI asked the panelists to address two specific talking points, sent to the panelists prior to the workshop:

1. HEI's Energy Research Committee is charged with recommending population-level research to understand potential human exposures associated with onshore unconventional oil and natural gas development in the United States. To do so, the Committee needs a clear understanding of current national- and state-level oil and natural gas regulations and guidance. For this reason, we ask each panelist to describe current oil and natural gas policy in their jurisdiction and anticipated future trends, focusing on policies most important for the protection of public health (by minimizing exposures).

2. HEI's Energy Research Committee has been charged with recommending high priority research that is relevant to policy decisions. To this end, we ask each panelist to advise the Committee about human exposure research related to unconventional oil and natural gas development that they would find most useful.

Ms. Megan Garvey, United States Environmental Protection Agency-Region 8

Ms. Megan Garvey discussed regulatory policy in US EPA Region 8 from her perspective as a former upstream oil and gas industry representative. Ms. Garvey emphasized that regional EPA staff are tasked with making decisions within the laws that Congress writes. Ms. Garvey's remarks focused on regulatory programs applicable to the oil and gas industry, including the Clean Water Act (specifically the National Pollutant Discharge Elimination System) and the Clean Air Act.

Under the Clean Water Act, states in Region 8 have the authority to run their own underground injection control programs. Produced water is an important topic in Region 8, as the Region includes three of the top 11 states producing oil and gas wastewater. Region 8 EPA has performed a critical review of their produced water permitting actions.

The Clean Air Act permits the construction of new and modified oil and gas sources. Ms. Garvey noted that, based on Clean Air Act standards, there are two ozone non-attainment areas in areas that also house oil and gas production: Denver/North Front Range and Utah. In terms of air research, Ms. Garvey mentioned that many top-down and bottom-up emission studies conclude that oil and gas emission sources contribute to a large portion of observed concentrations.

Ms. Garvey provided her perspective on the challenges associated with effective UOGD-related research. These challenges include the variability and composition of emissions and the cost, time and resources needed to measure chemical concentrations in air over short, or acute, and longer, chronic, periods.

Ms. Garvey also presented four specific factors to consider in planning for research:
1. Research should be framed and designed in a manner that is clear and concise, which are important for risk communication,
2. The best research is impartial and unbiased,
3. Remember that state and regional regulators are limited by the laws that they are charged with administering, and
4. Implementation of policy in response to research occurs primarily at the state level.

Q&A Session. Ms. Garvey confirmed that data collected by the National Pollutant Discharge Elimination System is publicly available. She also confirmed that new regulations related to green completions substantially impacted oil and gas operations.

Dr. Michael Honeycutt, Texas Commission on Environmental Quality

Dr. Michael Honeycutt presented on research recommendations related to exposure. Dr. Honeycutt expressed his view that epidemiology studies have issues with confounding and determining causality, and that it is therefore important to focus on characterizing air emissions and exposure before conducting epidemiology studies.

According to Dr. Honeycutt, for UOGD-related research to be useful, it should be focused on:

- Characterization of emission sources (e.g., battery tanks),
- Limiting the potential for background sources during sampling (e.g., traffic, conventional oil and gas development),
- Sampling durations that parallel regulatory standards,
- Frequent, stationary sampling, and
- Collection of meteorological data at sampling locations.

Dr. Honeycutt cautioned that HEI should use research dollars to collect more data and not perform a risk assessment. If HEI does conduct a risk assessment, HEI should consider that screening level benchmarks differ from actionable levels.

Q&A Session. Dr. Honeycutt confirmed that TCEQ continues its work analyzing the regional air monitoring data that it collects.

Mr. James Kenney, United States Environmental Protection Agency

Mr. James Kenney focused his remarks on regulatory efforts to address produced water, specifically EPA's study on managing produced water and the recent Memorandum of Understanding (MOU) between the State of New Mexico and EPA.

The EPA conducted a national study to understand how treatment and management of produced water can be accomplished. As part of this effort, EPA met with academics, state agencies, tribes, and other groups to get their perspectives on treatment and reuse of produced water. Common themes across these conversations included the scarcity of water resources in oil and gas producing areas and the urgency need for solutions to manage produced water. EPA will be hosting a public meeting on October 9, 2018 in Washington, DC to hear from other stakeholders on the topic of produced water, with public release of its report shortly thereafter.

The Memorandum of Understanding (MOU) between the State of New Mexico and EPA was released in April 2018. The MOU is intended to clarify the existing regulatory and permitting frameworks related to how produced water from oil and gas extraction activities can be reused, recycled, and renewed for other purposes.

Mr. Kenney presented his perspective on current data needs, including:

- Information regarding limitations of current management practices,
- Limitations and opportunities for water availability, and
- Identification of the most important produced water constituents that the EPA needs to consider and the technologies that are available for treatment.

Q&A Session. In response to a question about exposure pathways associated with produced water use, Mr. Kenney stated that in the national study, they were focusing on produced water as mandated under federal law, and that under the MOU effort, they were focusing on a range of end-uses for produced water that vary with respect to potential exposure pathways.

Mr. Saba Tahmassebi, Oklahoma Department of Environmental Quality

Mr. Saba Tahmassebi presented on the issues faced by his Agency related to produced water disposal. Oklahoma has experienced a sharp increase in induced seismic activity, and in response, Oklahoma is in the process of receiving authorization from US EPA Region 6 to manage produced water generated in the state. Mr. Tahmassebi reported that the Oklahoma Department of Environmental Quality identified several data gaps related to produced water management:

- What are the constituents of produced water?
- What concentrations are safe for discharge?
- What laboratory methods are available and adequate for produced water?
- What treatment technologies are available for produced water?

Mr. Tahmassebi also discussed the complexity of managing solids extracted from produced water, which sometimes contain naturally occurring radioactive material (NORM).

Q&A Session. Mr. Tahmassebi stated that his Agency had not yet conversed with exposure scientists at EPA about non-targeted analysis research, and that they were presently in the planning stage to determine the state of knowledge on this issue. He also informed the audience that Oklahoma had commercial injection wells in 53 counties.

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

Ms. Martha Rudolph followed up on the remarks that she delivered at the July 2019 Workshop in Denver, Colorado where she spoke about Colorado's regulations for protecting public health. Ms. Rudolph stated that existing UOGD health studies do not provide definitive answers about potential health impacts of UOGD, but regulators may be pressured into action by communities with health concerns. Some communities, such as Denton, Texas, have attempted to ban hydraulic fracturing from their municipality.

She remarked that many UOGD operators in Colorado have taken voluntary actions to decrease their impacts on the environment and surrounding communities. For example, in communities where there is concern about water quality, operators have responded by monitoring groundwater before and after UOGD.

Ms. Rudolph informed participants that since new technologies have brought UOGD operations closer to communities, regulators have been responsible for doing more to address community concerns. To this end, public health regulators have completed a screening-level human health risk assessment using data from several Colorado-based researchers, developed a system for responding to community concerns with a mobile air monitoring system, and other related actions. Ms. Rudolph emphasized the power of communicating results effectively to those who seek the information.

Q&A Session. There were no participant questions after Ms. Rudolph's remarks.

Mr. Clint Woods, United States Environmental Protection Agency

Mr. Clint Woods presented on UOGD-related trends related to EPA's oversight responsibilities under the Clean Air Act. Mr. Woods discussed trends in air pollutant concentrations, some of which have decreased since UOGD began. Despite these improvements, there has been a coincident increase in non-attainment areas. Mr. Woods reported that there is work underway to encourage voluntary efforts to reduce air

quality impacts, such as the Natural Gas STAR program. Additionally, the EPA is revisiting questions related to the National Ambient Air Quality Standards (NAAQS) as they pertain to UOGD, and he emphasized the importance of risk assessment and effective communication.

Q&A Session. Mr. Woods responded to an inquiry about inputs for calculations related to greenhouse gases.

4.3.2 Post-Panel Presentations

After the panel discussion, Workshop participants heard brief presentations related to oil and gas policy from Bruce Baizel of Earthworks and Board Member for the State Review of Oil and Natural Gas Environmental Regulations, Matt Lepore of Adamantine Energy and formerly the Director of the Colorado Oil and Gas Conservation Commission, and Alan Krupnick of Resources for the Future (RFF).

Mr. Bruce Baizel, Earthworks

Mr. Baizel presented on the State Review of Oil and Natural Gas Environmental Regulations (STRONGER), an organization that evaluates state regulations related to UOGD operations. These reviews give states information on regulatory changes or additions to improve public health. Many states have undergone both air and water-related reviews. Mr. Baizel presented some reflections on his work with communities through STRONGER, stating that while scientific research is the best way forward, many communities do not feel like they can wait for the results of a three- or four-year study. As a result, communities are working to affect policy related to setback distances. Mr. Baizel stated that the lack of health standards makes it difficult to protect health and that many communities wonder about the constituents of hydraulic fracturing fluids.

Mr. Matt Lepore, Adamantine Energy

Mr. Lepore presented on the Interstate Oil and Gas Compact Commission (IOGCC), a state-level regulatory organization that aims to promote efficient extraction of oil and gas while protecting health, safety, and the environment. From his perspective as a former regulator, there are many questions related to UOGD that cannot be answered scientifically for communities, like setback distances. He discussed the State Oil and Gas Regulatory Exchange (SOGRE), which facilitates regulator access to UOGD-related regulations from other oil and gas-producing states. The goal is for regulators to improve regulation with lessons learned in other states.

Dr. Alan Krupnick, Resources for the Future

Dr. Alan Krupnick presented on a new tool for regulators developed by RFF: the Shale Research Clearinghouse (SHARC). SHARC will be a resource that regulators and the public can use to understand the literature on public health and societal impacts of UOGD. SHARC will collect literature on both the positive and negative effects of UOGD on communities and will also showcase curated reviews that RFF has prepared on impacts, both positive and negative, which are designed for use by people living in communities affected by UOGD.

Q&A Session for Post-Panel Presentations. Dr. Krupnick informed the audience that RFF used a specific rating system to look at the broad quality of each study within the SHARC tool but not a specific set of criteria to review every single study due to lack of resources. He further explained that the SHARC tool graphically compare the quality of different studies.

Several panelists responded to a question about whether groundwater impacts are viewed as resolved. Ms. Rudolph responded that impacts on groundwater received a lot of public concern in Colorado, but that given the geology and hydrology in the region, groundwater contamination was less likely than in other

regions. She further stated that public concern had largely been overtaken by nuisance and air quality issues. Michael Honeycutt stated that wastewater was a bigger issue in Texas than air. Mr. Tahmassebi said that in Oklahoma, groundwater quality had not been studied to the same extent as it has in other regions, and that concerns about groundwater impacts focused more on quantity [of water use] than quality. Mr. Kenney replied that there had been some isolated incidences of groundwater contamination but nothing widespread, and that wastewater use for aquifer storage recharge was the bigger issue. In response to a question about whether research that provides evidence that UOGD impacts stress and subsequent health effects could affect policy, Martha Rudolph responded that it was a research gap worth pursuing. In a final question, a workshop participant asked whether existing monitoring data or the EPA hydraulic fracturing study had decreased public concern about potential groundwater contamination. This question received a unanimous 'no' from all panelists.

4.4 Data Mining: How Can We Leverage the Data that Already Exists

Experts presented on the use of data mining techniques to locate and analyze existing data related to UOGD operations. This session was formulated in response to discussion at the July 2018 workshop in Denver, Colorado about leveraging existing data sources.

Dr. Kelly Rose, National Energy Technology Laboratory

Dr. Kelly Rose of the National Energy Technology Laboratory presented on unearthing oil and gas-related data using intelligent geoinformatics. Dr. Rose's talk focused on a collaborative project with the Environmental Defense Fund to discover open source data and develop the Energy Data Exchanged (EDX) tool, an open source tool for researchers to access these data. The project included eight researchers with diverse expertise. The researchers used a SMART search to expedite the effort, developing search terms and data catalogues to create a solid foundation for the search. The search was run across a variety of search engines, including Google and Bing. SMART search has some advanced features that make finding data easier, such as the ability to use example files to prompt the search tool. The research team assigned a score to each dataset based on source and strength of spatial and temporal features. The EDX tool has a variety of applications, including evaluating the impact of oil spills, predicting oil spread, forecasting induced seismic activity, and quantifying pipeline risk in extreme weather. Dr. Rose stated that this tool is open source and will be available to the public for beta use in the coming weeks. Additional information on the EDX tool can be found here: https://edx.netl.doe.gov/. Dr. Rose informed participants that the data catalogue is expanding as more journal articles require data submission. This will lead to additional opportunities for data mining related to UOGD.

Q&A Session. There were no questions from participants following Dr. Rose's presentation.

Dr. Tao Wen, The Pennsylvania State University

Dr. Tao Wen presented on the use of geochemistry data to identify groundwater quality issues in the Marcellus region. Dr. Wen's research focuses on potential environmental impacts of anomalous methane, metals, and other organic compounds in groundwater. His research group is publishing water chemistry data online for the Marcellus production area in the Shale Network database (www.shalenetwork.org).

Dr. Wen stated that assessing the impact of shale gas development can be complicated because of coincident natural and anthropogenic sources and heterogeneity associated with water geochemistry, geology, hydrogeology, and geography. He stated that in Pennsylvania, pre-drill data are typically either not collected or not made publicly available, making it challenging to assess baseline conditions. Dr. Wen described his efforts to mine data available from the Pennsylvania Department of Environmental Protection (PADEP) and used the data along with machine learning methods to identify areas with anomalous methane concentrations in groundwater that might be indicative of a UOGD impact. He also

summarized how groundwater quality changed over time in the two Pennsylvania counties. Dr. Wen's talk concluded by discussing the advantages of machine learning to identify potentially problematic gas wells, emphasizing the need to make data publicly available to support these efforts.

Q&A Session. In response to a question on how their study accounted for data quality, Dr. Wen responded that the investigators received data in lab protocol format from PADEP consultants, and that differences in data quality may have accounted for some of the discrepancies his team observed in their work. He responded affirmatively when asked whether his team was considering natural fracture systems and other geologic features in its research.

Dr. Rebecca Hornbrook, University Corporation for Atmospheric Research

Dr. Hornbrook presented on the availability, value, and limitations of data generated by the Colorado Front Range Air Pollution and Photochemistry Experiment (FRAPPE) project. FRAPPE was designed to answer three questions:

- What and where are the relevant sources and processes that lead to the Colorado Front Range exceeding ozone standards in the summer?
- How much pollution comes into Colorado from the outside (is it something we can do something about)?
- What are the best ways to improve air quality?

FRAPPÉ was funded by the Colorado Department of Public Health and Environment, the National Science Foundation, the National Park Service, and the United States Environmental Protection Agency. The sampling campaign involved four research aircraft along with mobile vans, tower sampling stations, ground sampling stations, balloons, and satellite data. All data from the project are publicly available (https://www-air.larc.nasa.gov/missions/discover-aq/discover-aq.html).

Dr. Hornbrook stated that methane ratios provide a powerful tool for source apportionment, citing several examples such as the use of toluene-to-benzene ratios as indicators of different emission sources. Dr. Hornbrook stated that their results indicate that emissions in the Front Range exceed the 8-hour standard, with oil and gas contributing more than mobile and industrial sources. She remarked that the FRAPPÉ data has been underutilized to explore the impact of air toxics emissions and population exposure and that there is still much to be gleaned from the data, especially the VOC data set.

Q&A Session. Dr. Hornbrook informed the audience that airplane-based sampling paired with ground sampling had not been done, and that the data her team has collected has not been assessed along with satellite data. Responding to a question on what the drone sampling pattern would look like, Dr. Hornbrook stated that it would start at the top, work down and then work back up again. She described this as a "mowing the lawn" system. She informed the audience that investigators have worked to understand specific oil and gas infrastructure associated with high pollution concentration spots, considering other methane sources including livestock.

Mr. Tom Moore, Western States Air Resources Council and Mr. John Grant, Ramboll

Mr. Tom Moore of the Western States Air Resources Council and John Grant of Ramboll presented on oil and gas emission inventories and applications for estimating impacts to health and welfare. The presenters began their talk by outlining the current regulatory environment, which they described as a dated management structure under the Clean Air Act with a broad set of constructs and policies. The presenters stated that the field of oil and gas is constantly changing, spurring the need to develop a well-characterized historic base year and project future emissions given industry and regulatory trends. While technology-based control rules are passed down from the federal level, states are looking at oil and gas production sources and levels to guide their use of technology. According to the presenters, a strength of

emissions inventories is their comprehensiveness, among other attributes, where everything from the oil and gas well to the end-user of the natural gas is accounted for in the inventory. Limitations include the analysis required to develop health and welfare analyses, inconsistent data collection methods, and emission factor updates lagging behind research. Inventories are organized by process and can include criteria air pollutants and other toxicants.

Q&A Session. Mr. Moore and Mr. Grant informed the audience that, for each data point, the inventory provides the following information: whether it is represents a point or non-point source, its location, and the UOGD process associated with it. For point sources, there is also information about stack, location of stack, and parameters associated with the emission. Drs. Moore and Grant explained that emission factors are updated to the extent that they can be, and that quality assurance and quality control for the inventories is ongoing.

Dr. Alan Krupnick, Resources for the Future

Dr. Alan Krupnick presented on the use of satellite imaging to fill gaps in UOGD-related monitoring data. Dr. Krupnick's work is based on MODIS-satellite data from NASA. The satellite collects annual $PM_{2.5}$ data with a 1x1 kilometer resolution. While the use of satellite data does have the potential to address UOGD-related monitoring gaps, there are some disadvantages. For example, satellite data are not collected on cloudy days, resulting in some bias. Work to calibrate satellite data in North America is ongoing to address the various limitations. Dr. Krupnick spoke about gaps in the ground-level monitoring network in the United States, noting that monitors often are not located in areas with substantial oil and gas activity. Additionally, some monitors are timed to monitor every three days, meaning that they may not capture brief but potentially important emissions. Dr. Krupnick indicated that RFF will be working with Dr. Elaine Hill to match well locations with the satellite-derived $PM_{2.5}$ data and low birth weight data.

Q&A Session. There were no questions from participants following Dr. Krupnick's presentation.

Dr. Tami McMullin, Colorado Department of Public Health and Environment (CDPHE)

Dr. Tami McMullin presented the results of CDPHE's air quality community exposure investigations. The investigations are motivated by community reporting of symptoms. Their data show that 80% of community-reported symptoms coincided with UOGD drilling, and complaints primarily focused on odor. Additionally, most complaints were localized in communities where new UOGD is occurring, versus areas where UOGD has been ongoing for several years. According to Dr. McMullin, CDPHE's air quality investigation aimed to answer three questions:

1) What VOCs are emitted ?
2) What VOCs might be driving risk and/or reported health symptoms?
3) What exposure durations might be driving risk and/or reported health symptoms?

To answer these research questions, CDPHE has collected ~1,200 hours of continuous air concentrations in communities with UOGD.

CDPHE has performed a variety of community investigations including collecting grab samples during odor events, using a mobile lab to collect samples 1,000 feet downwind from a well pad, and running screening-level risk human health risk assessments. Dr. McMullin presented the results of CDPHE's assessment of acute and chronic health risks associated with 64 VOCs combined over various development phases (i.e., flowback, drilling, and fracturing operations). Dr. McMullin concluded that benzene monitoring is a high priority. Dr. McMullin stated that CDPHE is using data collected by researchers at Colorado State University to do prediction VOC concentrations for a probabilistic risk

assessment of every phase of UOGD operations, including the use of meteorological data to understand the distribution of potential health risks in the community. Dr. McMullin's recommendation for original research includes ground-truth screening assessments and using models to predict acute and intermittent exposures.

Q&A Session. Dr. McMullin informed the audience that drilling operations had already been in progress before sampling took place, and that at the time of sampling, CDPHE was working proactively with the local government to address community complaints. In response to a question about why flowback was contributing more organic compounds than drilling, Dr. McMullin stated that it is not unusual for these operations to cause odor, which could have triggered sampling. Dr. McMullin responded to questions about sampler placement, explaining that sampling took place 1,000 feet from the source. She further explained that CDPHE is working with operators to mitigate odors, such as those associated with diesel-based mud. A final question asked Dr. McMullin to speculate about differences in findings from recently conducted risk assessments and epidemiology studies; she responded that there are limitations associated with both approaches and that it is important to combine these efforts to improve our overall understanding.

5. Next Steps and Future Directions

This Workshop was the last in a series of research planning workshops hosted by the HEI Energy Research Committee before completing its reviews of the literature. Following the public workshop, the Energy Research Committee will meet privately to discuss the Committee's literature review and begin drafting a Request for Qualifications (RFQ). In 2019, the HEI Energy Research Committee will release the final Epidemiology Literature Review report, the draft Exposure Literature Review report, and an RFQ to commence original population-level exposure research. The draft Exposure Literature Review report will be available for public comment prior to release in its final form.

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.

For more information about HEI's Energy Research Program, refer to the Strategic Research Agenda (released November 2015) available at www.hei-energy.org.

APPENDIX A

Workshop Agenda

HEI Research Planning Workshop

Understanding Population-Level Exposures Associated with Onshore Development of Oil and Natural Gas from Unconventional Resources

Hilton Austin, 500 E 4th St., Austin, TX 78701
September 12-13, 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. This workshop is the second of two workshops. Presentations and group exercises will build on progress made at the July workshop.

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 framework of potential human exposure pathways that can serve as a roadmap for research planning.

Workshop Charge Questions:

1. How can existing data be leveraged to understand potential exposures from UOGD?
2. What potential UOGD exposures are not well understood with existing data and merit original research?
    a. What exposure pathways and phases of UOGD should be the focus?
    b. In conducting such research, what are your recommendations for considering regulatory, environmental, and industry practice variability over time and across regions?
    c. What is the value of the research for decision-makers (e.g., regulators, industry, community members, and scientists conducting research)?

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

September 12, 2018 (10:30am to 5:30pm)

TIME	TOPIC	SPEAKER
10:00-10:30 AM	*Registration*	
10:30-11:00 AM	**INTRODUCTIONS AND WORKSHOP OVERVIEW**	
10:30-10:40	Welcome	Bob O'Keefe, Vice President, HEI
10:40-11:00	Introductions	George Hornberger, Chair, HEI Energy Research Committee
11:00-11:10	Workshop Objectives and Charge Questions	Donna Vorhees, Director of Energy Research, HEI
11:10 AM -12:00 PM	**THE COMMITTEE'S PROGRESS**	
11:10-11:45	Overview of exposure literature review and research planning	George Hornberger and HEI
11:45-12:00	Discussion	
12:00-1:00	*Lunch*	
1:00-3:00 PM	**PANEL DISCUSSION: Federal and State Oil and Gas Policy - Trends and Research Needs**	
Panel Talking Points:		*Panelists (in alphabetical order):*
1. HEI's Energy Research Committee is charged with recommending population-level research to understand potential human exposures associated with onshore unconventional oil and natural gas development in the United States. To do so, the Committee needs a clear understanding of current national- and state-level oil and natural gas regulations and guidance. For this reason, we ask each panelist to describe current oil and natural gas policy in their jurisdiction and anticipated future trends, focusing on policies most important for the protection of public health (by minimizing exposures). **2.** HEI's Energy Research Committee has been charged with recommending high priority research that is relevant to policy decisions. To this end, we ask each panelist to advise the Committee about human exposure research related to unconventional oil and natural gas development that they would find most useful.		Megan E. Garvey (Senior Counselor to the Regional Administrator Region 8) Michael E. Honeycutt (Director, Toxicology Division, Texas Commission on Environmental Quality) James C. Kenney (Senior Policy Advisor for Unconventional Oil and Gas, Office of Congressional and Intergovernmental Relations, USEPA) Saba Tahmassebi (Agency Chief Engineer, Oklahoma Department of Environmental Quality) Martha Rudolph (Director of Environmental Programs, Colorado Department of Public Health and Environment) Clint Woods (Deputy Assistant Administrator, Office of Air and Radiation, USEPA)
3:00-3:30 PM	*Break*	
3:30-5:15	Group Exercise #1 followed by facilitated discussion	
5:15-5:30	*Discussion; wrap up for the day; review plan for day 2*	

September 13, 2018 (8:00am to 12:00pm)

TIME	TOPIC	SPEAKER
7:00-8:00 AM	*Breakfast*	
8:00-10:15 AM	**DATA MINING: How can we leverage the data that already exists?**	
8:00-8:25	Working smarter not harder, unearthing oil and gas data using intelligent geoinformatics	Kelly Rose (U.S. Department of Energy, National Energy Technology Laboratory)
8:25-8:45	Stalking the Wild Dataset: Informing Policy with Evidence	Kate Konschnik (Duke University)
8:45-9:05	Using Geochemistry Data to Identify Groundwater Quality Issues in Shale Gas Production Areas	Tao Wen (Pennsylvania State University)
9:05-9:25	Existing VOC Measurements from the Colorado Front Range's Oil and Natural Gas Region: Availability, Value, and Limitations	Rebecca Hornbrook (University Corporation for Atmospheric Research)
9:25-9:45	Oil and Gas Emission Inventories and Applications for Estimating Impacts to Health and Welfare	Tom Moore (Western States Air Resources Council) and John Grant (Ramboll)
9:45-9:55	Filling in the Gaps in Monitoring Data with Satellite Imaging	Alan Krupnick (Resources for the Future)
9:55-10:15	Air Quality Data from CDPHE's Community Exposure Investigations	Tami McMullin (Colorado Department of Public Health and Environment)
10:15-10:20 AM	*Brief Break before Breakout Groups*	
10:20-11:50	Group Exercise #2 followed by facilitated discussion	
11:50-12:00	Wrap-up with next steps in research planning and opportunities to comment before RFQ release	

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. When he joined the Committee, Dr. Hu served as the founding Dean 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 Associated with the Onshore Development of Oil and Natural Gas from Unconventional Resources

Austin, Texas
September 12-13, 2018

SPEAKER BIOGRAPHIES

Megan E. Garvey
Megan Garvey was appointed to her role as Senior Counselor to EPA's Region 8 Administrator in July of this year. Megan's focus is on Region 8 energy matters, NEPA and Environmental Justice. She also works closely with the Agricultural and Tribal Advisors of the Region. Before coming to EPA, Megan managed regulatory policy for an upstream oil and gas company and volunteered her time as a Commissioner on the Colorado Air Quality Control Commission. Previously, Megan worked for the State of Colorado: as an Assistant Attorney General at the Colorado Attorney General's Office (Air Quality Unit) and as the Compliance Unit Manager for the Air Pollution Control Division of Colorado's Department of Public Health and Environment. Megan started out her career practicing environmental law at a private law firm in Chicago, IL. Megan holds a B.S. in Environmental Studies from Loyola University Chicago and a J.D. from Chicago-Kent College of Law. Megan resides in Morrison, Colorado with her husband and two young sons.

John Grant
John Grant is a Managing Consultant at Ramboll where he has worked for 15 years developing emission inventory and emission control program analyses. He has developed dozens of region and project level oil and gas emission inventories and contributed to state of the science reports on oil and gas emission inventory methods and impacts. He also has extensive experience analyzing emission inventories to understand environmental tradeoffs associated with technological advancements such as vehicle and equipment electrification and adoption of emission control programs.

Michael Honeycutt, PhD
Michael 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)

Rebecca Hornbrook
Rebecca Hornbrook is a Project Scientist in the VOC Measurement Group in the Atmospheric Chemistry Observations & Modeling laboratory (ACOM) at the National Center for Atmospheric Research (NCAR) in Boulder, Colorado. Her research interests center on the atmospheric emissions and fate of volatile organic compounds (VOCs), both natural and anthropogenic. Dr. Hornbrook received her Ph.D. working with Dr. Jochen Rudolph at York University in Toronto, Canada in 2005, and has over 20 years of experience in the measurement and analysis of gas-phase VOCs. She has been involved in laboratory studies of processes involved in tropospheric oxidation of VOCs, including work she led developing the methodology for measuring stable carbon kinetic isotope effects in the reactions of non-methane hydrocarbons with OH radicals and Cl atoms. She also spent several years measuring hydroperoxy and organic peroxy radicals (HO2 and RO2) using Chemical Ionization Mass Spectrometry (CIMS), studying photochemical processes involved in VOC oxidation. In recent years at NCAR, Dr. Hornbrook has participated in the development and deployment of state-of-the-art instrumentation to measure VOCs in the atmosphere, contributing significantly to the measurement capabilities of the Trace Organic Gas Analyzer (TOGA), a fast online gas chromatograph-mass spectrometer, both in its measurement frequency and growing suite of quantified VOCs. As a member of the TOGA team, she has participated in a large number of NSF and NASA-funded field campaigns, both airborne and ground-based, including OASIS, BEACHON-ROCS, TORERO, DC3, NOMADSS, CONTRAST, FRAPPÉ, WINTER, ORCAS, and most recently, ATom and WE-CAN.

James C. Kenney
James Kenney is the Senior Policy Advisor for Unconventional Oil and Natural Gas at the United States Environmental Protection Agency. In this capacity, Jim coordinates unconventional oil and natural gas activities for the Office of the Administrator across EPA's program and regional offices. Externally, Jim works with oil and natural gas stakeholders on regulatory and policy matters to ensure responsible oil and natural gas development. Such stakeholders include: industry, trade associations, federal and state agencies, tribes, environmental non-governmental organizations (eNGOs) and the public. Within EPA, Jim's career has spanned multiple offices around the U.S., including: Denver, Colorado; Philadelphia, PA; and Washington, DC, helping him bring both a national and local perspective to his current work. Jim earned a Master of Science in Engineering and Bachelor of Science in Engineering Technology from Temple University in Philadelphia, PA. While he is an EPA Headquarters employee, Jim teleworks from Albuquerque, New Mexico where he and his family reside.

Kate Konschnik
Kate Konschnik directs the Climate & Energy Program at the Nicholas Institute for Environmental Policy Solutions at Duke University and is a Senior Lecturing Fellow at Duke Law School. Konschnik's work focuses on options for public electric utility regulation and electricity market reforms given emerging technologies and de-carbonization goals. Konschnik has also worked extensively on effective governance of unconventional oil and gas production and transport. Konschnik joined Duke from Harvard Law School, where she founded and directed the Harvard Environmental Policy Initiative and taught as a Lecturer on Law. Previously, Konschnik was Chief Environmental Counsel to U.S. Senator Sheldon Whitehouse, and an Environmental Enforcement Trial Attorney at the U.S. Department of Justice.

Alan Krupnick
Alan Krupnick is a Senior Fellow at Resources for the Future. Krupnick's research focuses on analyzing environmental and energy issues, in particular, the benefits, costs and design of pollution and energy policies, both in the United States and abroad. He leads RFF's research on the risks, regulation and

economics associated with shale gas development and has developed a portfolio of research on issues surrounding this newly plentiful fuel. Krupnick also served as senior economist on the President's Council of Economic Advisers, advising the Clinton administration on environmental and natural resource policy issues. In 2011 he was elected President of the Association of Environmental and Resource Economists and earlier that year was named an AERE Fellow.

He has served on the Editorial Boards of a number of journals. He co-chaired a federal advisory committee counseling the U.S. Environmental Protection Agency on the implementation of new ozone and particulate standards. He is a regular member of expert committees from the National Academy of Sciences, the USEPA and various Canadian government and non-governmental institutions. Krupnick also consults with state governments, federal agencies, private corporations, the Canadian government, the European Union, the Asian Development Bank, the World Health Organization, and the World Bank. He received his PhD in Economics from the University of Maryland in 1980.

His primary research methodology is in the development and analysis of stated preference surveys (such as contingent valuation and choice experiments), which include eliciting preferences for reductions in mortality risks, environmental risks, tradeoffs involved in improving community drinking water quality with respect to removal of carcinogens versus microbiological agents, and most recently, the risks from shale gas development as seen by experts and the general public.

Tami McMullin

Tami McMullin currently serves as Colorado's state toxicologist, where she also manages the Oil and Gas Health information and Response Program at the Department of Public Health and Environment (CDPHE). She leads research on community health exposures and technical evaluation of the literature on the public health effects potentially associated with oil and gas exposures. Prior to joining CDPHE, Tami worked as a toxicologist and risk assessor in the chemical industry for over a decade where she conducted regulatory testing and safety assessments. Dr. McMullin earned her Bachelor's degree in biology at the University of California San Diego and her Doctoral degree in Environmental Health and Toxicology from Colorado State University.

Charles Thomas (Tom) Moore, Jr.

Tom Moore works for the Western States Air Resources (WESTAR) Council as manager of the Western Regional Air Partnership (WRAP) air quality program, a voluntary partnership of states, tribes, federal land managers, local air agencies and the U.S. EPA, whose purpose is to understand current and evolving regional air quality issues in the context of the Clean Air Act (CAA) and the National Environmental Policy Act (NEPA). His regional analysis and planning support work is conducted through management of a series of interrelated contractor-supported regional projects for the WESTAR and WRAP membership. These diverse and complex projects cover ambient monitoring data analysis, emissions inventory preparation and analysis, regional photochemical grid modeling and source apportionment results, and satellite air quality data. He has worked extensively with both the activity and emissions estimation techniques for electrical generating units, wildland and agricultural fire emissions, oil & gas exploration and production emissions, and ozone and regional haze analysis needs and planning requirements, in support of air quality management programs across the West. A principal emphasis of his work from 2002 to the present is support of Regional Haze planning for the more than 100 Class I areas in the WESTAR-WRAP region. Key western U.S. air quality expertise includes oil & gas production emissions, wildland fire emissions and impacts, regional haze sources and transport, and impacts on the Ozone National Ambient Air Quality Standards from various sources and scales.
He has a B.S. in Physical Geography from Arizona State University in Tempe, with an emphasis on meteorological and glacier field studies, and climate data analysis projects, as well as additional graduate coursework related to air pollution and climate. He has lead numerous air pollution monitoring studies

and analysis projects, held management positions in state and local government, and worked as an environmental consultant. Before re-joining the WESTAR staff in 2013, he worked for the Western Governors' Association from 2002-13 coordinating and managing WRAP activities. From 1990 to 2001, he designed and managed air quality monitoring and data analysis activities for the Arizona Department of Environmental Quality, where he led the development and implementation of the haze monitoring networks in both urban and remote areas throughout the state. Tom also worked previously for the WESTAR from 1994-96 on an inter-agency personnel assignment, leading a WESTAR project to advise EPA on western U.S. topics and issues with implementation of the national Particulate Matter health and welfare standards.

Robert O'Keefe

Robert 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.

Kelly Rose

Kelly Rose is a geo-data science researcher with the National Energy Technology Laboratory's (NETL) Research Innovation Center. Her research at NETL is focused on using geologic and geospatial science to reduce uncertainty about, characterize and understand spatial relationships between energy, engineered-natural systems at a range of scales. Her work involves development of new data-driven methods and tools for analysis of offshore energy, oil & gas, rare earth element, groundwater, carbon storage, and geothermal systems. Rose's research interests also include development of software driven solutions to common science-data curation, discovery and inter-operability challenges. She has served on advisory committees including the Department of Interior's National Geologic and Geophysical Data Preservation Program, United Nations Environmental Programme's global outlook on methane gas hydrates, and the University of Southern California's Induced Seismicity and Reservoir Monitoring Consortiums. She is associate editor for the Journal of Sustainable Energy Engineering and is also NETL's Technical Portfolio Lead for the Advanced Offshore Energy Research Portfolio https://edx.netl.doe.gov/offshore. Rose is Principal investigator for NETL's Energy Data eXchange (EDX), an online, public and private research curation and virtual laboratory platform developed by Rose and the EDX team for DOE FE, https://edx.netl.doe.gov. Rose is co-author of 1 patented, 1 trademarked, 1 copyrighted, 10 custom tools, and more than 100 published technologies and studies. Throughout her career at NETL, Rose has had the honor of mentoring and working with more than forty-five STEM research interns and fellows. She holds geology degrees from Denison University, B.S., Virginia Tech, M.S., and Oregon State University, Ph.D.

Anna Rosofsky
Anna Rosofsky is a Staff Scientist at HEI with expertise in environmental and spatial epidemiology. Rosofsky joined HEI in 2017 as part of the Energy Research Program. In this role, Rosofsky supports technical work within and implementation of the Strategic Scientific Research Agenda to understand potential human exposure and health impacts from unconventional oil and gas development. Rosofsky recently received a Ph.D. in Environmental Health from Boston University School of Public Health, where she studied spatiotemporal patterns of ambient air pollution exposure and early-childhood health impacts. Prior to her doctoral studies, Rosofsky investigated environmental health disparities at the Center for Puerto Rican Studies and at the Mosakowski Institute for Public Enterprise. She received an M.A. in Environmental Science and Policy from Clark University.

Martha E. Rudolph
Martha 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.

Saba Tahmassebi
Saba Tahmassebi is the Agency Chief Engineer for the Oklahoma Department of Environmental Quality. For the past 25 years he has been involved in several environmental programs at DEQ. He earned his Ph.D. in engineering from University of Oklahoma, an MS in petroleum engineering from University of Southern California and a BS in chemical engineering from University of California, San Diego. He is also a university faculty member teaching engineering, environmental science and statistics courses. Saba promotes the protection of the environment and people's health through the sound application of scientific and engineering principles, adherence to environmental laws and regulations, and common-sense problem solving.

Scott Thompson
Scott Thompson has served as the executive director of the Oklahoma Department of Environmental Quality since December 2013. In that role, Thompson has implemented new approaches to environmental permitting and enforcement in Oklahoma with the goal of helping make the state more prosperous and economically viable. Prior to becoming executive director, Thompson led DEQ's Land Protection Division, where he managed a diverse set of programs, including Superfund, Brownfields, Voluntary Cleanup, and Radiation Management. Thompson has a biology degree from Central State University. He also has a master's degree in environmental science from the University of Oklahoma.

Donna J. Vorhees
Donna 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.

Tao Wen

Tao Wen received his PhD in Geology from the University of Michigan in 2017 and is currently a Postdoctoral Scholar in the Earth and Environmental Systems Institute at Penn State University. He completed his B.S. degree in Environmental Sciences at the University of Science and Technology of China in 2011. He has extensively worked on characterizing the formation and migration of natural gas (conventional and unconventional) and has assessed the environmental impacts of hydrocarbon recovery activities on water quality across a few major shale plays (i.e., Antrim Shale, Barnett Shale, and Marcellus Shale) in the U.S. During his research, Tao has blended field geology, state-of-the-art geochemical analyses, as well as emerging data mining (big data) tools in his research. More details about Tao Wen can be found at http://jaywen.com/.

Clint Woods

Clint Woods serves as Deputy Assistant Administrator in U.S. EPA's Office of Air and Radiation. Prior to joining EPA in December 2017, Clint was the Executive Director of the Association of Air Pollution Control Agencies (AAPCA), a non-profit organization of state and local air quality agencies located in Lexington, Kentucky. While with AAPCA, he was also a member of U.S. EPA's National Advisory Council on Environmental Policy and Technology. Clint previously served as a professional staff member with the Committee on Science, Space, and Technology in the U.S. House of Representatives, the Energy, Environment, and Agriculture Task Force at the American Legislative Exchange Council, and Manager of Government Affairs with the Recreation Vehicle Industry Association. He holds an MA in international commerce and policy from George Mason University and a BA from the University of Mary Washington.

APPENDIX D

Workshop Participant List

HEI Research Planning Workshop

Understanding Population-Level Exposures Associated with Onshore Development of Oil and Natural Gas from Unconventional Resources

Austin, TX
September 12-13, 2018

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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

September 12-13

Summary of Results-Group Exercise #1

For the first group exercise, participants were assigned to groups and asked to address one of three questions:

1. ***Most important information to ensure the protection of human health***: What are the most important gaps in information or data that could be filled to improve UOGD policies and regulations to protect human health and the environment? Please consider perceived or actual gaps that are important to non-governmental stakeholders or local governments. Are there opportunities for filling any of the gaps that would be enhanced by collaboration with multiple stakeholder groups (i.e., industry, academia, government, NGOs, affected communities)?
2. ***Pressing, short-term research***: What research would be most helpful to those faced with making near term decisions (e.g., regulators, industry, and community leaders) given the concerns of various stakeholders? What research needs to be conducted in the next few years that would represent an enormous missed opportunity if not conducted?
3. ***Broadly relevant research***: Which UOGD operations and potential exposures to them should be studied to provide information most broadly relevant to various locations, populations, and UOGD operational practices across the United States? What locations might be particularly useful to include in exposure research? Are there opportunities for research that would be enhanced by collaboration with multiple stakeholder groups (i.e., industry, academia, government, NGOs, affected communities)?

The responses from each group were diverse; however, several common themes emerged:

1. ***Most important information to ensure the protection of human health****: What are the most important gaps in information or data that could be filled to improve UOGD policies and regulations to protect human health and the environment? Please consider perceived or actual gaps that are important to non-governmental stakeholders or local governments. Are there opportunities for filling any of the gaps that would be enhanced by collaboration with multiple stakeholder groups (i.e., industry, academia, government, NGOs, affected communities)?*

   - **Community concerns.** Groups discussed the need to involve communities in research planning and data collection. Participants stated that communities are primarily concerned with air quality, water quality, and exposures perceived as toxic or carcinogenic. To address community concerns and protect human health, the research program should involve homeowners and concerned community members.
   - **Stress.** Groups discussed the importance of measuring stress as an exposure and outcome. There was disagreement about whether stress pathways, or other pathways, should be prioritized for study, and about the difficulty in measuring stress as compared to other pathways.

- **Spatial and temporal variability and scales.** Groups listed concentrations of chemicals in air over different phases of development and characterization of background sources among important data gaps. In particular, there are limited spatial and temporally-resolved data available in communities and other residential locations that is useful for estimating exposure. In particular, many monitoring networks do not overlap areas with both UOGD and nearby populations. To address these data gaps, the groups recommended systematic and consistent study designs across multiple locations, offering Dr. Jeff Collett's work from Colorado State University as an example.
- **Data accessibility and existing data.** Several group members mentioned that new and improved satellite data can help fill some of the air monitoring gaps and address some of the long-tail data issues common in monitoring data. Groups also discussed the need for industry-provided pre- and post-drilling air and water quality data.

2. ***Pressing, short-term research****: What research would be most helpful to those faced with making near term decisions (e.g., regulators, industry, and community leaders) given the concerns of various stakeholders? What research needs to be conducted in the next few years that would represent an enormous missed opportunity if not conducted?*

- **Air Emissions.** Multiple groups offered suggestions of pressing, short-term research characterizing air quality. Research ideas included improving the accuracy of emissions inventories, defining emissions from routine and non-routine operations, measuring noise in conjunction with air measurements, conducting fenceline monitoring and informing operators if levels of concern are detected, and monitoring air in communities. One group suggested examining data retrospectively and determining whether specific actions could be attributed to decreased emissions.
- **Produced water**. Groups discussed prioritizing research on the multiple potential exposure pathways that might occur with the expanded options for produced water management.
- **Data collection in communities.** Some groups prioritized direct, short and long-term measurements at residential properties, over centrally located monitors, which they suggest could both empower citizens and provide data to address community concerns. Other groups suggested focusing exposure studies in locations where investigators have collected data for epidemiology studies.
- **Baseline data.** Groups suggested that collection of baseline data is a priority. They suggested collecting baseline data in undeveloped areas where permits have been issued but drilling has not commenced.
- **Community involvement.** Groups emphasized that communities should be involved from the conception of a given research project to identify the research needs most pressing to them.
- **Research to support regulatory decision-making.** Groups highlighted the need to conduct research that supports regulatory decision-making. For example, a useful short-term study would focus on providing scientific evidence for setback distances.
- **Focus on known chemicals.** To conduct data in the short-term, groups suggested focusing on known chemicals with recognized toxic properties.
- **Human health research.** Other groups suggested performing human health research to determine impacts on quality of life and how regional differences in exposure may result in different health effects.

3. ***Broadly relevant research****: Which UOGD operations and potential exposures to them should be studied to provide information most broadly relevant to various locations, populations, and UOGD operational practices across the United States? What locations might be particularly useful to include in exposure research? Are there opportunities for research that would be enhanced by collaboration with multiple stakeholder groups (i.e., industry, academia, government, NGOs, affected communities)?*

- **Regulatory exceedances.** Groups noted that research on whether regulatory benchmarks are being exceeded would be broadly relevant for multiple stakeholders.
- **Population exposure.** Groups suggested that research measuring chemicals in air and water at the point of exposure, or even fenceline monitoring, would be relevant to understanding community exposures.
- **Changes over time.** Groups discussed the need for long-term sampling of air and water at the regional level to understand variability among regions and to understand how changes in technology affect releases.
- **Locations.** Several groups suggested the need for a research program conducted across multiple regions and involving multiple operators. Colorado, Pennsylvania, Texas, and North Dakota were offered as potential locations for research. Groups noted that research should occur where pre-drilling data has been collected and where UOGD is expected to continuing growing. Groups emphasized the complexity in collecting data in areas with high population density because of the presence of other background sources.
- **Collaboration.** Groups agreed that research groups should involve multiple, diverse stakeholders such as state-level organizations, communities, industry, and academics to enhance reliability and reception by both communities and regulators. Groups recommended that research teams should include researchers and state regulators. One group described the need to include different types of operators, including those involved in drilling, completions, production, battery production, and compressors.

General Discussion

Participants agreed that finding a starting place for research is difficult given the different sources and potential exposure pathways. Participants noted that a useful starting place is performing research that informs regulation. For example, rather than simply measuring chemicals in air, research should focus on establishing safe setback distances that consider different meteorological conditions. There was also discussion about the need for researchers to collaborate with industry for access to UOGD operational sits for sampling and operator-collected data. Other participants noted that partnerships with industry, researchers, and regulators are underway.

ENERGY RESEARCH PROGRAM

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

September 12-13

Summary of Results-Group Exercise #2

For the second group exercise, participants were assigned to groups and asked to address one of three questions:

1. ***Taking advantage of existing data*:** What critical research questions about exposure are most amenable to being addressed using available data? Are there data, databases, and ongoing research that the Committee may not have heard about that would help in understanding potential human exposures?
2. ***Exposure pathways*:** What are the most important exposure pathways that should be studied (an exposure pathway includes a chemical or non-chemical agent, a specific population exposed to the agent(s), and a pathway in the environment that connects them)? Is there a priority order for the studies in terms of the most pressing potential problems and the availability (or lack thereof) of pertinent data and information?
3. ***Air and water quality*:** At the last workshop, the Committee heard recommendations for research about exposures related to air quality, but fewer related to water quality. What potential human exposures related to air should the Committee consider studying? What are the potential human exposures related to water that the Committee should consider studying, whether related to exposure to groundwater, surface water, or reused flowback or produced water?

The responses from each group were diverse; however, several common themes emerged:

1. ***Taking advantage of existing data**: What critical research questions about exposure are most amenable to being addressed using available data? Are there data, databases, and ongoing research that the Committee may not have heard about that would help in understanding potential human exposures?*

- **Non-specific nature of data.** Groups remarked that much of the existing data does not point to a specific source, location, or operator of concern. For example, data collected by the state of Colorado in response to community concerns may represent the limited conditions under which samples were collected. While much of the data is general, data collected by organizations such as the Texas Commission on Environmental Quality is useful to identify air concentrations in urban environments and can be used to track emissions over the oil and gas life cycle.
- **Prioritization.** Groups remarked that existing data is useful to prioritize sources and chemicals for study.
- **Risk communication.** Groups discussed the need to interpret existing data and studies for communities and other interested stakeholders.
- **Risk analysis.** Groups mentioned that existing data can be used to conduct human health risk assessments, examining risks at variable distances from UOGD.

- **Chronic exposure.** Groups mentioned that existing data at the facility level, conducted over long periods, including boom and bust cycles, may be useful to assess chronic exposure.
- **Leak detection and repair (LDAR)data.** One group offered LDAR data as an example of existing data that could be used to identify leaks and likelihood of exposure.
- **Data gaps.** Groups discussed some of the data gaps for which existing data and research do not exist, including data from small operators in isolated areas, monitoring information that is connected to the source, and pre-drill data. Other participants mentioned that some pre-drill data exist in Pennsylvania and Ohio.

2. ***Exposure pathways***: *What are the most important exposure pathways that should be studied (an exposure pathway includes a chemical or non-chemical agent, a specific population exposed to the agent(s), and a pathway in the environment that connects them)? Is there a priority order for the studies in terms of the most pressing potential problems and the availability (or lack thereof) of pertinent data and information?*

- **Air pathway.** All groups discussed the importance of air-related exposures and ideas for studying the air exposure pathway. Groups discussed the need to conduct exposure assessment before conducting further epidemiology research. Some methodological considerations offered included measuring air quality, using both fixed off-site and onsite monitoring, at increasing distances from UOGD to identify where concentrations decline in an effort to define appropriate setback distances; collecting data over the permitting period, during different phases of development, and when different pieces of equipment are operational; conducting real-time time monitoring to detect high concentrations; and creating models to predict community exposures under different conditions.
- **Community participation.** Groups disagreed about the extent of community participation in research. Some groups saw value in community members participating in data collection and researchers engaging with community members to help prioritize pathways for research. Other groups conveyed reticence toward community involvement because data might not be collected systematically, and some community members do not want to be subjects of research.
- **Known and unknown compounds.** Some groups suggested prioritizing known compounds based on toxicity, while other groups emphasized the need to focus on unknown compounds.
- **Source identification.** Groups provided suggestions for identifying sources along the exposure pathway. They suggested using high resolution satellite data to identify leaks, conducting continuous monitoring at well pads, defining standard operating procedures and the frequency of non-routine events, and measuring at the source at a resolution that is relevant to exposure.
- **Stress.** One group prioritized pathways in the following order: air, water, psychosocial, noise, and stress. Other groups emphasized that stress and the concept of allostatic load may have a more significant impact on health than chemical exposure pathways.

3. **Air and water quality**: *At the last workshop, the Committee heard recommendations for research about exposures related to air quality, but fewer related to water quality. What potential human exposures related to air should the Committee consider studying? What are the potential human exposures related to water that the Committee should consider studying, whether related to exposure to groundwater, surface water, or reused flowback or produced water?*

- **Air quality.** Most groups agreed that the initial focus of research should be air, and that VOCs and benzene should be measured, along with secondary air pollutants.
- **Odor.** One group discussed the need for simultaneous measurement of odor and air concentrations of chemicals.
- **Water quality**. Groups suggested that assessment of water exposure pathways should focus on flowback and produced water, and that volatilization from flowback water my result in exposures

via the air pathway. Groups also discussed the need to identify chemicals of concern in produced water.

- **Risk communication.** Groups agreed that, despite the pathways selected for study, multi-stakeholder research is important, including collaboration with organizations that have a track record of strong science communication.

General Discussion

Participants discussed addressing community concerns about total risk versus focusing on what, exactly, needs to be mitigated. Participants mentioned that both sources and receptors need to be identified before conducting research, while other participants emphasized the need for biomonitoring. Participants also discussed the need for research to be useful for regulatory action and that all research should be widely communicated.