Monitoring and Modeling to Evaluate Community Exposures to Air Pollutants from Unconventional Oil and Gas Development

BACKGROUND

The rapid expansion of unconventional oil and natural gas development (UOGD) has given rise to concerns about potential effects on human health from a wide range of potential exposures to chemical and nonchemical agents, but knowledge gaps about these exposures remain. HEI Energy, therefore, issued *Request for Applications E20-1* in August 2020 to better understand the nature, extent, and frequency of potential exposures related to UOGD on air quality and noise.

Dr. Lea Hildebrandt Ruiz, University of Texas at Austin, was one of three investigators funded under this Request for Application. Hildebrandt Ruiz and colleagues developed a TRAcking Community Exposures and Releases (TRACER) model to assess exposures to air pollution from UOGD and to inform future health studies. The original scope of work focused on the Eagle Ford Shale region in Texas. The project was later expanded to the Permian Basin in New Mexico and the Marcellus Shale region in Ohio, Pennsylvania, and West Virginia.

APPROACH

The investigators used a combination of monitoring and modeling approaches at various study sites to assess the quality of the TRACER model, which they advanced and refined from an existing model for methane emissions. The TRACER model combined emissions modeling with dispersion modeling to assess exposure to various air pollutants from UOGD. The capabilities of the preexisting model were expanded from modeling emission and dispersion of methane from single UOGD well pads to assessing population exposures from multiple well pads.

The study team conducted detailed mobile and fixed-site monitoring campaigns over 3 months across two seasons in the Eagle Ford Shale in 2023 and over 2 weeks in the

> ### What This Study Adds
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> - The study includes extensive monitoring and modeling across three oil and gas regions in the United States: Eagle Ford Shale, Permian Basin, and Marcellus Shale.
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> - The investigators developed a model (the TRACER model) to assess exposures to air pollution from oil and gas development and inform future health studies. The model included additional sources of emissions, regional-scale modeling, a broad suite of pollutants, and evaluation for the purpose of exposure assessment in future health studies.
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> - Ethane concentrations were affected by oil and gas development emission sources up to 50 km away in modeling. The study reported typically high correlations between ethane and other volatile organic compounds from different exposure models and with direct observations. CALPUFF appeared to be the best-performing model in reducing bias for ethane.

Permian Basin in the spring of 2024. They used advanced instrumentation, such as mass spectrometry, which provided high-resolution data, including measurements of real-time volatile organic compounds. A suite of air pollutants was examined, including particulate matter, nitrogen oxides, and numerous air toxics. Noise was measured as well.

The investigators conducted extensive modeling in the Eagle Ford and Marcellus Shale regions, which included developing improved UOGD emissions estimates, dispersion modeling for primary pollutants, and chemical transport modeling for secondary pollutants. The investigators expanded the Methane Emission Estima-

tion Tool to create the TRACER model. The expanded model included updated emissions from additional UOGD sources, improved the spatial and temporal resolution of UOGD emissions, and broadened to a suite of nonmethane pollutants of concern for human health. The investigators applied the TRACER model to estimate emissions from individual wells and coupled the emissions with an air pollution dispersion model (CALPUFF) to estimate air pollution concentrations of ethane at receptor sites in the Eagle Ford Shale. For the modeling, they used an approximate 200 km × 200 km domain centered on the Karnes City monitoring site — located in the center of the Eagle Ford Shale — using data on more than 20,000 oil and gas wells. They focused on ethane in these analyses, which, in the Eagle Ford Shale region, is emitted almost entirely by oil and gas operations.

A similar type of TRACER modeling was also conducted in the Marcellus Shale region, although the UOGD emissions estimates were aggregated over 4 km × 4 km grid cells. Further, the investigators used a chemical transport model (CAMx) to examine the importance of detailed spatial and temporal allocation of nitrogen oxides emissions from hydraulic fracturing on predicted ozone formation in the Eagle Ford Shale. They developed various scenarios that differed in the number of wells being fractured and the duration of the fracturing process.

Lastly, the investigators compared various approaches with increasing levels of complexity to estimate exposure to UOGD in Karnes County in the Eagle Ford Shale, including various air pollution dispersion models (e.g., CALPUFF and AERMOD) and inverse distance weighting. They assessed model performance by comparing model predictions with Karnes City monitoring site data, with a focus on ethane. Many features of the modeling were further explored, such as the influence of meteorology and emissions variability.

KEY RESULTS

The investigators found that ambient concentrations of air pollutants in UOGD regions showed strong diurnal variation, with (short-term) peak concentrations occurring during late night and early morning hours. However, mean concentrations of various air pollutants and noise from the entire UOGD measurement campaigns in Eagle Ford Shale and Permian Basin were generally low and did not exceed the National Ambient Air Quality Standards concentrations (and other health-related guidelines). Caution is warranted because the measurements and the short-term health standards and guidelines have different averaging times.

With extensive modeling of the Eagle Ford Shale, the study team found that mean and peak ethane con-

centrations were affected by UOGD emission sources up to 50 km away. This influence was highly variable and depended on whether the nearest UOGD sources were upwind from the site and whether stable atmospheric conditions with low wind speeds occurred, which may facilitate peak concentrations.

Further, the study team found high variability in emission factors of volatile organic compounds across UOGD locations. Similarly, the study team reported nitrogen oxide emission rates from hydraulic fracturing from specific wells at specific times varied by two to three orders of magnitude across the scenarios. The improved emissions estimates might have led to increased estimated ozone formation in the Eagle Ford Shale region — a region with abundant biogenic volatile organic compounds.

Hildebrandt Ruiz and colleagues reported high correlations (>0.7) across different exposure models for ethane and five other volatile organic compounds, except for the inverse weighting model without meteorological data. Regarding ethane, CALPUFF appeared to be the best-performing model for reducing bias between model predictions and observational data, but it is also the most computationally intensive model. Of the less computational-demanding models, AERMOD was the best performing.

INTERPRETATION AND CONCLUSIONS

In its independent review of the study, the HEI Energy Review Committee thought the study presented a comprehensive approach to evaluating air pollution from UOGD. The broad scope of the study, detailed monitoring campaigns, and use of state-of-the-art instrumentation that provided high-resolution data were its strengths. Other strengths were the extensive modeling efforts, including the development of improved UOGD emissions estimates, dispersion modeling, and chemical transport modeling.

Although the Review Committee broadly agreed with the investigators' conclusions, the report had some limitations that should be considered when interpreting the results. The Committee thought the lack of discussion, integration, and synthesis across the many parts of the study was a missed opportunity to maximize the study's impact and limited the generalizability of the findings. The lack of integration might stem partly from the study's history because mobile monitoring in the Permian Basin and modeling in the Marcellus Shale region began after other aspects of the research had already started. The Review Committee recommends three areas of future work: application of the TRACER model in the Permian Basin, one of the most productive UOGD regions in the United States; a more thorough evaluation of the TRACER model beyond mainly ethane; and expansion of research

efforts to other potential chemical and nonchemical exposures related to UOGD, in addition to air pollution.

Overall, the Review Committee thought the study findings and the TRACER model would be of broad interest and value to a wide audience, such as resource managers, state and federal policymakers, UOGD industry practitioners, research scientists, and local communities.