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RESEARCH BRIEF 3

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Natural Gas Flaring Associated with Unconventional Oil and Gas Development: Potential Human Exposures

This Research Brief is part of a series of periodic updates on the literature about potential human exposures and health effects associated with unconventional oil and natural gas development (UOGD) in the United States

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Trusted Science, Clean Environment, Better Health

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TRUSTED SCIENCE, CLEAN ENVIRONMENT, BETTER HEALTH

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About HEI Energy

The Health Effects Institute (HEI) Energy is a national research program formed to identify and conduct high-priority research on potential population exposures and health effects from development of oil and natural gas from shale and other unconventional resources across the United States. HEI Energy supports community exposure research in multiple regions. To enable exposure research planning, HEI Energy conducts periodic reviews of the relevant scientific literature. Once initial research is completed, HEI Energy will assess the results to identify additional exposure research priorities and, where feasible and appropriate, health research needs for funding in subsequent years.

The scientific review and research provided by HEI Energy will contribute high-quality and credible science that supports decisions about how best to protect public health. To achieve this goal, HEI Energy has put into place a governance structure that mirrors the one successfully employed for nearly forty years by its parent organization, the Health Effects Institute, with several critical features:

- HEI Energy receives joint funding from the U.S. Environmental Protection Agency under a contract that funds HEI Energy exclusively and from the oil and natural gas industry;
- HEI Energy's independent Board of Directors consists of leaders in science and policy who are committed to fostering the public–private partnership that is central to the organization;
- HEI Energy's research program is governed independently by individuals having no direct ties to, or interests in, sponsor organizations;
- HEI Energy's Research Committee consists of members who are 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, and have been vetted to avoid conflicts of interest;
- All research undergoes rigorous peer review by HEI Energy's Review Committee;
- HEI Energy staff and committees engage in open and extensive stakeholder engagement before, during,and after research, and communicate all results in the context of other relevant research;
- HEI Energy makes publicly available all literature reviews and original research that it funds and provides summaries written for a general audience; and
- Without advocating policy positions, HEI Energy provides impartial science, targeted to make better-informed decisions.

HEI Energy is a separately funded affiliate of the Health Effects Institute (*www.healtheffects.org*).

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PURPOSE OF THIS RESEARCH BRIEF

People living near unconventional oil and gas development (UOGD)[1] can be exposed to chemical and non-chemical (e.g., noise and light) agents released to the environment from these operations. Natural gas flaring has grown in recent years across the United States (Figure 1, U.S. Energy Information Administration 2021), and most recently in Texas and North Dakota, giving rise to questions about associated exposures and possible human health effects.

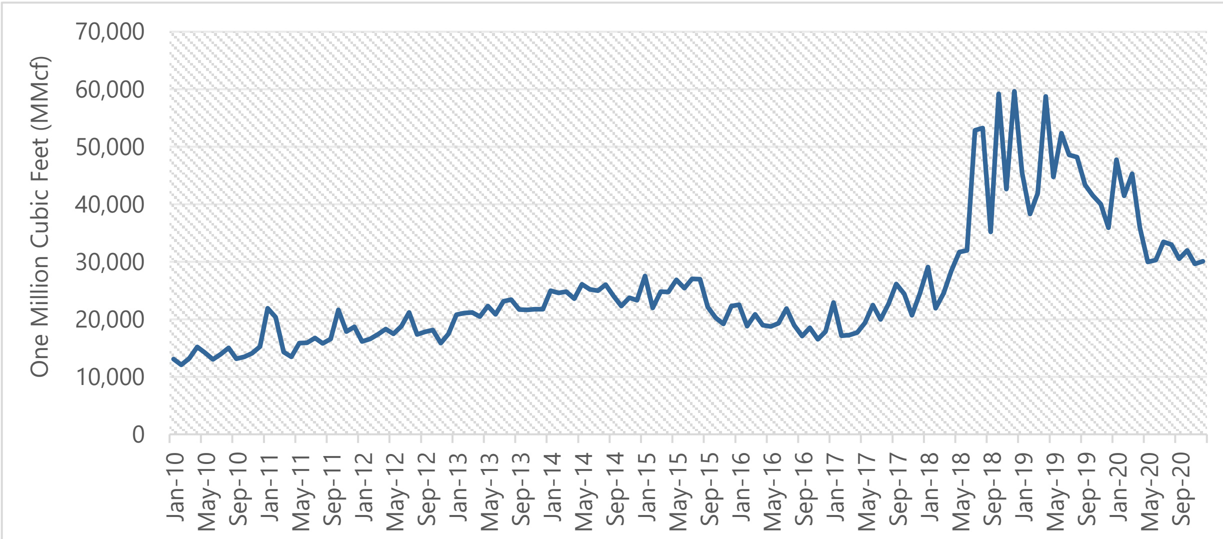

Figure 1. Natural gas vented or flared in the United States.
Data source: U.S. Energy Information Administration, 2021

This Research Brief summarizes literature characterizing emissions from flaring, assessing human exposures to flaring, and assessing potential inequalities and health effects associated with flaring. It is part of a series of Research Briefs summarizing literature about potential exposures and health effects associated with UOGD.

OVERVIEW OF FLARING

Natural gas flaring is defined as "the controlled combustion of natural gas for operational, safety, or economic reasons" (U.S. Department of Energy 2019). Flaring is used by operators during drilling and production to eliminate waste gas when there are higher rates of oil and gas production than can be marketed, as part of operations to intermittently dispose of unwanted gas, or as a safety measure (Ohio Environmental Protection Agency 2014; U.S. Department of Energy 2019; Willyard 2020). Flares can also become unintentionally unlit due to equipment malfunctions or wind, thus releasing natural gas directly into the atmosphere and not undergoing a combustion reaction (Cusworth et al. 2021).

All states with UOGD have flaring regulations, and these regulations can vary across states (U.S. Department of Energy 2019). No national regulations are currently in place (U.S. Department of Energy 2019), but EPA has proposed methane regulations with provisions about flaring (U.S. EPA 2021).

[1] UOGD refers to the development and production of oil and natural gas as practiced starting around the beginning of the 21st century through multistage hydraulic fracturing in horizontal wells.

SUMMARY OF THE REVIEW

Scope of the Review

We used the same search term and approach employed in the HEI Energy Research Committee's 2019 survey of the UOGD exposure literature (HEI-Energy Research Committee 2019) to identify publications useful for assessing potential human exposures associated with natural gas flaring. This search phrase included the term "flar*." The literature search included peer-reviewed and gray literature published between January 1, 2000 and September 3, 2021 that contributes to understanding how people might be exposed to chemical agents or non-chemical agents released directly from flaring to the environment or that assessed associations between UOGD flaring and adverse health outcomes among people living in major oil and natural gas–producing regions of the United States.

All potentially useful publications were considered whether or not the investigators set out to study human exposures. Some characterized the chemical agents associated with UOGD operations, the ways that these agents behave in the environment, the concentrations of agents in air and other environmental media, and the potentially exposed populations.

Overview of the Literature

The search returned 14 publications. Three measured or reviewed air emissions (Allen et al. 2016; Gvakharia et al. 2017; Weyant et al. 2016), two used source apportionment to attribute changes in air quality to specific UOGD operations, including flaring (Hildenbrand et al. 2016; Maskrey et al. 2016), one used flare emissions to model flare-associated changes in air quality (Olaguer 2012), three characterized flare volume and frequency for exposure assessment (Franklin et al. 2019; McDonald and Wilson 2021; Willyard and Schade 2019), two conducted epidemiology assessments to examine associations between health outcomes and exposure to flaring (Cushing et al. 2020; Willis et al. 2020), and three characterized communities living near flaring (Cushing et al. 2021; Johnston et al. 2020; Willyard 2020). All took place in Texas except for three in North Dakota (Cushing et al. 2021; Gvakharia et al. 2017; Weyant et al. 2016) and one in Pennsylvania (Maskrey et al. 2016) (Figure 2).

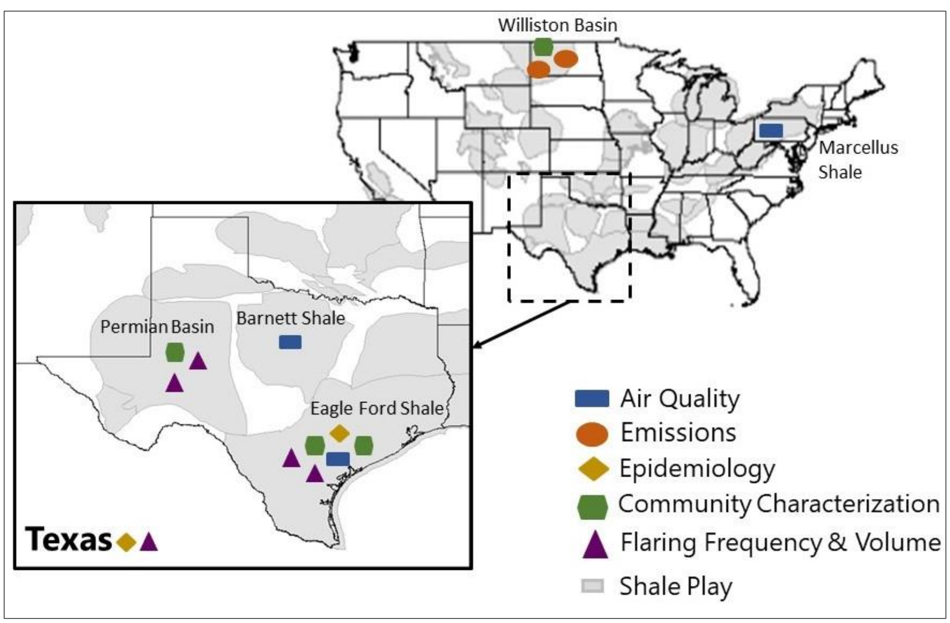

Figure 2. Flaring study locations.

The UOGD flaring literature includes three main approaches to understand the contribution of flaring to changes in air quality and exposures: measuring or modeling chemical emission rates, measuring or modeling changes in air quality, and quantifying the number of flares in various locations or volume of flares using publicly available state records or satellite data. The discussion of the flaring literature is organized in accordance with a conceptual model of exposure (Figure 3). This organization facilitates identification of links between potential UOGD sources of exposure and populations as well as and gaps in our understanding of exposures. In addition to exposure, the literature also covers health outcomes from potentially exposed communities which are also included in this brief.

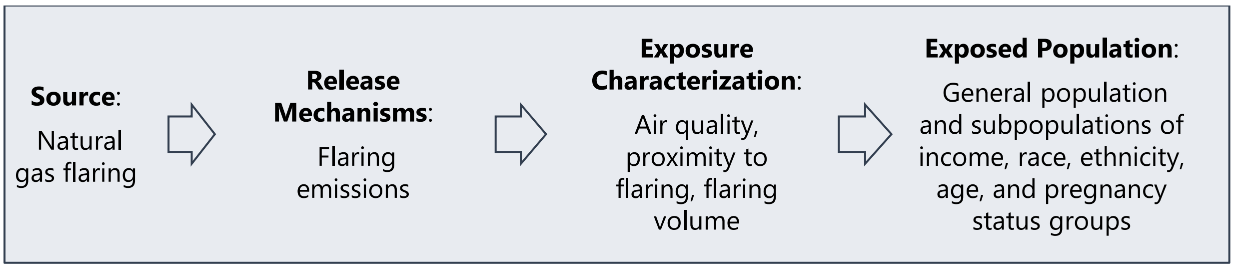

Figure 3. Conceptual model of potential exposure associated with natural gas flaring.

EMISSIONS FROM NATURAL GAS FLARING

Communities living near natural gas flares can be exposed to noise, light, and chemical emissions (Ohio Environmental Protection Agency 2014; U.S. Department of Energy 2019). Characterizing chemical emissions from flares that occur during UOGD operations is necessary to identify potential chemicals of concern for health.

The composition of flare emissions varies depending on whether the natural gas undergoes complete or incomplete combustion, or no combustion in the case of unlit flares. Much of the existing data on flaring emissions have focused on greenhouse gases, which have been collected as part of emissions inventories (Allen et al. 2016; Grant et al. 2019; Lange et al. 2014; U.S. Department of Energy 2019; U.S. EPA 2014; Zhang et al. 2020). These inventories allow for tracking of emissions and implications for climate change. Other publications have characterized chemicals of potential concern to human health, including black carbon (BC), which is also a greenhouse gas, (Allen et al. 2016; Gvakharia et al. 2017; Weyant et al. 2016) and volatile organic carbons (VOCs) (Hildenbrand et al. 2016; Maskrey et al. 2016). To our knowledge no publications quantify light or noise exposures from flaring in the United States.

Emissions Inventories

Studies have summarized data collected or modeled through the U.S. Environmental Protection Agency's (U.S. EPA) Greenhouse Gas Reporting Program and the Inventory of U.S. Greenhouse Gas Emissions and Sinks, as well as through state agencies (Allen et al. 2016; U.S. Department of Energy 2019). Allen et al. (2016) assessed whether several predictors of flaring emissions estimates (e.g., flaring emissions, volumes of flared gas, emissions per volume, or heating value of flared gas) over- or underestimate emissions of BC, carbon dioxide, and methane. The authors highlighted sources of uncertainty associated with emissions inventories data, including underreporting by operators, undercounting small flares, and estimated emissions factors based on a limited number of or outdated measurements. They underscored the need for more process-level emissions measurements to reduce these sources of uncertainty (Allen et al. 2016).

Emissions Measurements

Two studies (Gvakharia et al. 2017; Weyant et al. 2016) used aircraft in the Bakken region of North Dakota to collect airborne samples of flare plumes. They used the measurements to estimate emission factors (a value that relates quantity of chemical released into the atmosphere with specific processes [U.S. EPA 2016]) and assessed whether emission factors calculated using their measurements align with emission factors reported by the U.S. EPA and those in other inventories.

Gvakharia et al. (2017) collected measurements of ethane, methane, and BC from 37 unique flare plumes. They reported that emissions factors, calculated using their airborne measurements, varied over time for the same plume and across plumes. In examining whether wind speed or quantity of methane emissions could explain BC emission factor variability, they concluded that neither were correlated with BC emission factors. They also reported that, based on their measurements, incomplete combustion of flares is underreported to the U.S. EPA. They concluded that information about stack diameter, gas composition, and flow rate would help understand emission factor variability.

Weyant et al. (2016) collected measurements of methane, carbon dioxide, and BC from 26 unique flare plumes. Like Gvakharia et al. (2017), Weyant et al. (2016) reported that BC emission factors calculated using their measurements varied considerably within and across plumes; BC emission factors from the 26 flares varied over two orders of magnitude. Weyant et al. (2016) BC emission factors (0.36 Gg BC/year) were higher than those calculated by Gvakharia et al. (2017) (0.24 Gg BC/year). Investigators of both studies concluded that the variability in emission factors reported in their studies has implications for estimates of flaring contribution to climate change and changes in air quality.

Air Quality Changes from Flaring

Investigators have examined whether changes in air quality can be attributed to flaring during UOGD operations using dispersion modeling (Olaguer 2012) and air quality measurements combined with operational information (Hildenbrand et al. 2016; Maskrey et al. 2016).

Air Quality Modeling

One study used air dispersion modeling to predict changes in air quality attributable to flaring in the United States (Olaguer 2012). The investigators simulated unintended flare events from a natural gas facility in the Barnett region of Texas and applied a 200 meter-resolution air quality model to examine local ozone formation from releases of ozone precursors. The model included assumptions about ozone photochemistry, pollutant transport geometry and physics, meteorology, and emissions rates. They reported that flare volumes of 100,000 m^3/hr over 2 hours could affect peak ozone levels 8–16 km downwind of the flare location. The investigators concluded that flaring may be an important contributor to ozone nonattainment in major metropolitan areas near shale formations.

Air Quality Measurements

Two studies (Hildenbrand et al. 2016; Maskrey et al. 2016) conducted air quality measurement campaigns and attributed measurements to UOGD processes using information about well pad operations. Hildenbrand et al. (2016) conducted continuous mobile measurements of benzene, toluene, ethylbenzene, and xylene (BTEX) on and surrounding several well pads in the Eagle Ford region of Texas. They reported emissions from specific processes that were highly variable across well pads. At two of the six well pads, they attributed detected BTEX concentrations to flaring stations as well as condensation tanks and compressor units on the well pads. They reported that toluene was the most frequently detected chemical, and that concentrations were below limits for short-term exposures set by the Occupational

Safety and Health Administration and the National Institute for Occupational Safety and Health. They did not compare concentrations with other health benchmarks.

Maskrey et al. (2016) conducted three months of total VOC monitoring at a school and residence located within 900 m (or just over 0.5 mile) of a well pad. They also collected 24-hour passive canister samples of 62 individual VOCs (using U.S. EPA Method TO-15) during "baseline," "fracturing," "flaring," and "post-flaring" phases. Continuous total VOC monitoring occurred during specific well pad operations: pre-development (baseline), fracturing, flaring, and post-flaring. They reported that total VOC and concentrations of individual VOC measurements at the school and residence during fracturing and flaring were consistent with concentrations collected during the "baseline" period at both locations. They also performed a screening-level human health risk assessment, in which they compared measurements with U.S. EPA's subchronic (less than 7 years of exposure) Regional Screening Levels (RSLs). They reported that all RSLs were greater than maximum 24-hour concentrations of individual VOC measurements.

Flaring Location and Volume as Surrogates of Exposure

Investigators have used proximity to flares on well pads and volume of flared gas to approximate human exposures. To estimate flare location and volume, the studies either used satellite observations (Cushing et al. 2020, 2021; Franklin et al. 2019; Johnston et al. 2020; Willis et al. 2020) or publicly available data on flare location and volume that operators reported to regulatory entities (Willis et al. 2020; Willyard 2020). Other investigators used both sources of data to compare methods (McDonald and Wilson 2021; Willyard and Schade 2019).

Satellites to Estimate Flaring Location and Volume

The studies that used satellites to estimate flaring location and volume relied on data collected by the Visible Infrared Imaging Radiometer Suite (VIIRS) instrument and the Nightfire algorithm developed by the National Oceanic and Atmospheric Administration (Cushing et al. 2020, 2021; Franklin et al. 2019; Johnston et al. 2020; Willis et al. 2020; Willyard and Schade 2019). Briefly, VIIRS utilizes visible to long-wave infrared to detect combustion-related sources (Elvidge et al. 2015). To detect a natural gas flare, combustion within a certain range is selected. In addition, Nightfire can estimate emission volumes based on size and radiant heat of a combustion event (Elvidge et al. 2015).

Franklin et al. (2019) used VIIRS and Nightfire to characterize the extent of flaring in the Eagle Ford region from 2012 to 2016. They linked Nightfire outcomes with well records to characterize the types of wells where flaring was observed. They identified 43,887 oil and gas flares in the Eagle Ford region, of which 82% were associated with oil producing wells and 92% with horizontally drilled wells. In the Eagle Ford region, 5 of 49 counties accounted for 71% of total flaring. This research team applied these methods to an epidemiologic study (Cushing et al. 2020) and community inequality assessments (Cushing et al. 2021; Johnston et al. 2020), which are described below.

Flaring Volume Records Reported by Operators

Four studies used regulatory records to identify flaring volume and location for exposure assessment (McDonald and Wilson 2021; Willis et al. 2020; Willyard 2020; Willyard and Schade 2019, described below). All the studies were based in Texas where the Texas Railroad Commission (TxRRC) requires operators to report the volume of flared gas on a monthly basis (U.S. Department of Energy 2019).

Comparison of Methods to Estimate Flaring Volume

Willyard and Schade (2019) compared the data provided by the TxRRC on flaring volumes to those estimated by satellite data using VIIRS and Nightfire method for flared gas volume in the Eagle Ford and Permian regions from 2012–2015. They reported that the volumes from the VIIRS instrument were consistently larger than those reported to the TxRRC, but that temporal trends in flaring volume were similar between the two methodologies.

Comparison of Methods to Estimate Flaring Location

Another study (McDonald and Wilson 2021) compared observations of 227 flares made during helicopter fly-overs during three months of 2020 in the Permian region with a list of permitted flares from the TxRRC. They estimated 69% to 84% of the flares observed did not have permits and that 36 of the flares had an exemption to permitting requirements according to the TxRRC.

HEALTH AND COMMUNITY ASSESSMENTS

Assessment of Flaring Exposures in Epidemiology Studies

Cushing et al. (2020) used satellite data to examine associations between maternal exposure to nightly flares and birth outcomes in the Eagle Ford region of Texas (Cushing et al. 2020). In brief, they used VIIRS and Nightfire to locate nightly flares within 5 km of maternal residences and defined three exposure surrogates: (1) number of nightly flares during pregnancy for each participant within 5 km of their residence, (2) total flared area during pregnancy, and (3) inverse-distance weighting of each nightly flare observation. Willis et al. (2020) examined associations between UOGD, including flaring, and ZIP-code level pediatric asthma hospitalizations. To assess flaring exposure, they used monthly TxRRC natural gas flaring volume data from 2000 to 2010, which they geolocated and assigned to each ZIP code in the study area. More information about exposure assessment approaches and health outcome findings of both studies can be found in Research Brief 1.

Characterization of Communities Near Flaring

Three studies characterized the populations in proximity to flaring events in Texas and North Dakota. Three studies examined populations near the Eagle Ford or Permian basins in Texas (Cushing et al. 2021; Johnston et al. 2020; Willyard 2020). Johnston et al. (2020) focused solely on the Eagle Ford Basin, and Willyard (2020) looked at both of the basins in Texas. Cushing et al. (2021) characterized communities near the Permian and Eagle Ford basins as well as the Williston Basin in North Dakota. Johnston et al. (2020) examined inequalities in potential exposure between Hispanic and non-Hispanic populations, whereas the other two examined inequalities in proximity to flaring by age (Cushing et al. 2021), income (Willyard 2020), and race and ethnicity (Cushing et al. 2021; Willyard 2020).

To quantify number and volume of flares, both Cushing et al. (2021) and Johnston et al. (2020) used satellite data from the VIIRS Nightfire algorithm developed by National Oceanic and Atmospheric Administration from 2012–2020 and 2012–2016, respectively. Willyard (2020) utilized flare stack emissions and well location data reported to the TxRCC in 2012. Both Cushing et al. (2021) and Johnston et al. (2020) utilized the 2010 census data to understand the demographic make-up of communities at the census block–level, whereas Willyard used the 2010–2014 American Community Survey five-year population estimates to characterize communities.

The three studies used different approaches to assign flaring to populations of interest. Willyard (2020) examined census block–level demographic characteristics of populations located within a one-mile radius around UOGD facilities with reported flaring. In analytical models, they examined associations between venting and flaring and several predictors including: new drilling in the study year, proximity to permits filed, facility and operator oil and gas production volumes, number of violations, and the portion of the residents that belonged to various racial or ethnic groups. Johnston et al. (2020) examined census block–level demographic characteristics of populations located within a 5-km radius of observed nightly flares. Cushing et al. (2021) disaggregated census block data by assigning building footprint centroids to census blocks, and assigned population counts to each building based on census block–level data. They used this approach to account for the fact that a census block can be disproportionately large in rural areas compared to urban areas and therefore may not represent the spatial distribution of residences in a census block. They estimated exposure by counting the number of nightly flares within a radius of 3, 5, and 10 km of each building.

Overall, the studies reported that flaring was disproportionately located in proximity to communities from historically disadvantaged populations compared with other populations, thus raising questions of environmental justice. Willyard (2020) reported a positive association between the percentage of Hispanic residents at the census block–level and the odds of a UOGD facility venting or flaring. The investigator also reported increased odds of flaring or venting with increased levels of new drilling, UOGD density, oil production, new permits and violations, and household income. In this study, increased odds of flaring or venting were not associated with the percentage of Black population, population density, or proximity to a pipeline.

Johnston et al. (2020) reported that, compared with census blocks with less than 20% Hispanic residents, blocks with more than 80% Hispanic residents were exposed to a higher number of flares, but were less likely to live in proximity to any UOGD wells. Cushing et al. (2021) reported that 535,907 people in the Eagle Ford, Permian, and Williston regions lived within 5 km of a UOGD flare. By examining the percentage of age and racial ethnic groups living within 5 km of any flares, 1–9 flares, 10–99 flares, or more than 100 flares, they reported that children under five years of age were more likely to live near more than 100 flares in the Permian Basin, and that seniors were more likely to live near flares in the Eagle Ford. They also reported that Black residents were more likely to live near more than 100 flares in both the Permian and Eagle Ford regions of Texas, and that Indigenous and Hispanic communities were more likely to live near more than 100 flares in the Williston Region compared with other racial and ethnic groups.

Summary and Next Steps

This Research Brief summarizes a growing body of literature about UOGD flaring exposures and health effects. Through the studies summarized in this brief, investigators have identified uncertainties in flaring emissions rates and UOGD operator reporting of flaring volumes (Allen et al. 2016; McDonald and Wilson 2021; Willyard and Schade 2019). In addition, regulation of flaring and the industry's flaring practices continue to change and vary among states and regions (U.S. Department of Energy 2019). Future research to improve understanding of flaring emissions and associated human exposures would benefit from accounting for the influence of an evolving UOGD operational and regulatory landscape.

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HEI Energy Board, Research Committee, and Staff