CONGRESS OF THE UNITED STATES
HOUSE OF REPRESENTATIVES

Written Testimony before the
Committee on Natural Resources
Subcommittee on Energy and Mineral Resources

Hearing entitled "*Oil and Gas Development: Impacts on the Climate and the Costs of Business as Usual*"

July 16, 2019

Seth B.C. Shonkoff, PhD, MPH

Executive Director, PSE Healthy Energy

Visiting Scholar, Department of Environmental Science, Policy and Management, University of California, Berkeley

INTRODUCTION

Chairman Lowenthal, Ranking Member Gosar and distinguished Members of the Subcommittee, it is an honor to appear before you today at this important hearing on oil and gas development and its impacts on human health and climate change.

By way of background, I am an environmental public health scientist and the executive director of PSE Healthy Energy, based in Oakland, California. PSE Healthy Energy is a multidisciplinary, nonpartisan, nonprofit research institute that studies the way energy production and use impacts public health and the environment. I also hold formal research affiliations in the Department of Environmental Science, Policy and Management at the University of California, Berkeley and at Lawrence Berkeley National Lab.

My testimony today is focused on the hazards, risks and impacts of oil and gas development and climate change on human health. My testimony is based on a strong and growing body of science supported by decades of peer-reviewed research.

There is strong scientific consensus that we are in a climate emergency and only have a limited period of time to dramatically reduce greenhouse gas emissions to avert dire economic, health, security and ecological consequences. I am in front of you today as a scientist, but also as a father with an interest in protecting the health, security and livelihoods of my children.

HAZARDS, RISKS AND IMPACTS OF OIL AND GAS DEVELOPMENT ON HUMAN HEALTH

Oil and gas development poses well-understood hazards, risks, and impacts to human health through various pathways, including through environmental media (e.g., air, water), from noise and light pollution, and kinetic injuries (e.g., vehicle and well-pad accidents). Hazards that are directly attributable to oil and gas development consist of human exposures to chemicals through inadvertent or intentional release to water, air, or soil. In this testimony I focus on what is known regarding air and water pathways and human health. While traffic, noise and light pollution are potentially important sources of hazards, for sake of brevity, they are beyond the scope of this testimony.

PSE Healthy Energy keeps track of a near-exhaustive collection of peer-reviewed studies of shale and tight gas development by topic area (e.g., health, air pollution, water pollution) in our Repository of Oil and Gas Energy Research (ROGER)[1].

An evaluation of the peer-reviewed literature on air, water and human health impacts of shale gas development published through 2015 concluded that 87% of air quality studies indicated elevated air pollutant emissions and/or atmospheric concentrations; 69% of water quality studies found associations with water quality impairment; and 84% of public health studies reviewed indicated public health hazards, elevated health risks, or adverse health outcomes (Hays and Shonkoff, 2015).

[1] Available at: https://www.psehealthyenergy.org/our-work/shale-gas-research-library/

While some of these studies had multiple findings beyond those evaluated in our review article, the fact that the majority of the research on these topics found increased risks and impacts is noteworthy.

Summary of Peer-Reviewed Science on Human Health and Distance from Oil and Gas Development

Increased risks from air pollution and elevated noise levels associated with adverse health outcomes have been observed in close proximity to oil and gas development. At 500 ft, the peer-reviewed literature suggests increased cancer risks (McKenzie et al., 2018a; McMullin et al. 2018) and elevated noise levels (Radke et al. 2017). Paulik et al. (2016) found no increased cancer risk at 500 ft, but the researchers only looked at polycyclic aromatic hydrocarbons (PAHs) rather than a wider array of pollutants identified in the literature. Elevated noise levels were also observed out to approximately 1,000 feet from compressor stations at levels at which adverse health effects, such as sleep disturbance and insomnia had been reported (Boyle et al. 2017). Additionally, a survey of experts determined that the minimum safe distance from unconventional oil and gas development is 1/4 mile (1,320 feet) and additional setbacks should be considered for vulnerable groups (Lewis et al. 2018). Hazards, risks, and impacts attributable to oil and gas development are also observed in the peer-reviewed literature at 2,500 ft and beyond, including elevated noise levels (Blair et al. 2018), adverse birth outcomes (Currie et al. 2017; Hill et al. 2018; McKenzie et al. 2014; Stacy et al. 2015; Whitworth et al. 2017; Whitworth et al. 2018), increased non-cancer and cancer risks (McKenzie et al. 2012), childhood cancer (McKenzie et al. 2017), and other acute adverse health outcomes (Weinberger et al. 2017). One small peer-reviewed industry study (Maskrey et al. 2016) found that the maximum VOC concentrations did not exceed USEPA regional screening levels beyond 2500 feet. Furthermore, studies that have evaluated increased proximity, well density, and certain activities at the well pad have also found associations with adverse respiratory, cardiovascular, perinatal, mental health, and other acute health outcomes (Casey et al., 2016; Casey et al., 2018; Koehler et al., 2018; McKenzie et al., 2018b; Rasmussen et al., 2016; Tustin et al., 2016).

To put the scale of this into context, a peer-reviewed national spatial assessment of population proximity to oil and gas development found that 17.6 million Americans live within 1 mile (5,280 ft) of an active oil and/or gas well (Czolowski et al., 2017).

Air Pollution

The California Council on Science and Technology (CCST) concluded in its independent, peer-reviewed scientific report on hydraulic fracturing and oil and gas development pursuant to California Senate Bill 4 that concentrations of health damaging air pollutants are more concentrated near oil and gas development than further away and present higher health hazard to populations in proximity to oil and gas development. As explained in the previous section, the vast majority of peer-reviewed studies that have evaluated human health as a function of distance agree with this conclusion. It should be noted that not all studies that found health impacts include *field based* measurements of air quality and air pollutant emissions, but many have included surrogates associated with air pollutant emissions such as well productivity and well density.

Studies have found that the source of these potential exposures are both from petroleum – for example, benzene and petroleum hydrocarbons – as well as volatile and air-polluting compounds added to hydraulic fracturing fluids and routine drilling and well maintenance activities, such as biocides, corrosion inhibitors and surfactants. (Stringfellow et al. 2017).

Intended (e.g. venting) and unintentional (e.g. fugitive emissions or leaks) air pollutant emissions from upstream oil and gas development can contain health-damaging air pollutants, such as hazardous air pollutants (HAPs)[2], criteria air pollutants[3], and reactive organic gases which are associated with the formation of tropospheric ozone (i.e., smog) (Shonkoff et al. 2015). Specific sources of these emissions include pumps, generators, compressors, condensate tanks venting and flaring of natural gas, dust from well stimulation and land-clearing activities, leaks from gas transfer lines and well heads, emissions from storage and separator tanks, surface impoundments and other solid and liquid waste handling methods. Air pollutant emissions also include combustion products from diesel trucks, pumps and other sources.

The majority of the oil and gas air pollution and public health studies have concluded that geographic proximity to active oil and gas development is an exposure and health impact risk factor, largely due to increased risk of exposure to air pollution associated with oil and gas development (Brown et al., 2014; Brown et al., 2015; Colborn et al., 2014; Macey et al., 2014; McKenzie et al., 2012; McKenzie et al., 2018a; Rich & Orimoloye, 2016). Many air-quality monitoring and modeling studies estimate that emissions of health-damaging air pollutants from oil and gas development are episodic and lead to degraded air quality in proximity to oil and gas development operations (Allen, 2014; Brown et al. 2015). The majority of studies that have assessed oil and gas development emissions of hazardous air pollutants (HAPs) have identified benzene, toluene, ethylbenzene and xylenes (BTEX), n-hexane, styrene, and 1,3 butadiene as emitted pollutants, although other health-relevant pollutants are found to be emitted throughout various stages of oil and gas development (Garcia-Gonzales et al., 2019) (Figure 1). The minority of studies, such as Bunch et al. (2014) – an oil and gas industry-funded study – did not find a positive correlation between proximity and air pollutant concentrations.

[2] A hazardous air pollutant (HAP), also known as toxic air pollutants or air toxics, are those pollutants that cause or may cause cancer or other serious health effects, such as reproductive effects or birth defects, or adverse environmental and ecological effects. The United States Environmental Protection Agency is required to control 187 hazardous air pollutants (USEPA, 2018).

[3] The Clean Air Act (CAA) of 1970 identified six common air pollutants of concern, called criteria pollutants. The criteria pollutants are carbon monoxide, lead, nitrogen dioxide, ozone, particulate matter, and sulfur dioxide. Criteria pollutants are the only air pollutants with national air quality standards that define allowable concentrations of these substances in ambient air.

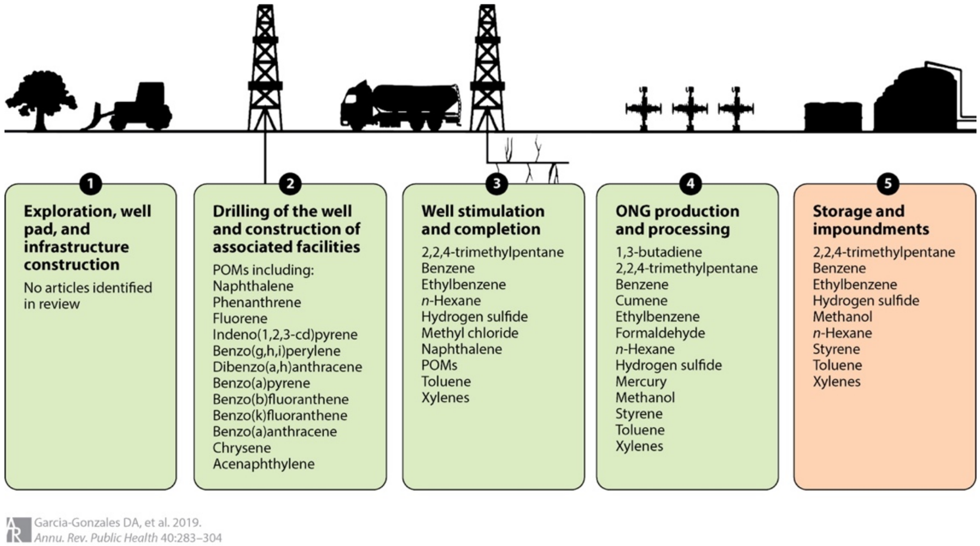

Figure 1. Hazardous air pollutant (HAP) compounds collected through primary measurements and recategorized. Abbreviations: ONG, oil and natural gas; POMs, polycyclic organic matter. *(Source: Garcia-Gonzales et al. 2019)*

With respect to criteria air pollutants, a recent analysis estimated that on a per-ton basis, the health benefits of reducing $PM_{2.5}$ precursor emissions from the oil and gas sector vary by pollutant type, and range from \$6,300 and \$320,000, while the value of reducing ozone precursors ranges from \$500 to \$8,200 in the year 2025 (Fann et al., 2018).

The peer-reviewed literature suggests that more stringent regulation is required to attenuate public health risks from exposures to air pollutants emitted from oil and gas development. First, increased emission control technologies (e.g., reduced emission completions and leak detection and repair) as was required under the Bureau of Land Management (BLM) Methane Rule prior to President Trump's Executive Order 13783 should be reinstated. These are cost-effective and critical measures to undertake. Additionally, the implementation of minimum setback distances between oil and gas development and where people live, work and play should be considered in permitting and regulatory decisions.

Water Pollution

Water is a significant component of oil and gas development. It is injected to facilitate oil and gas production and large volumes of wastewater return to the surface as *produced water* that must be managed and disposed of. Produced water is often saline and contains toxic chemicals sourced from the petroleum geological formations as well as chemicals and their byproducts that were used to facilitate production. Oil and gas development introduces a number of well-described pathways through which water can become contaminated and introduces potential for human exposure to toxic chemical constituents. The most well-described water pathways that can result in human exposures are the following:

- Compromised structural integrity of well bores (e.g., “leaky wells”) near aquifers with current or future human consumption uses
- Direct injection of hydraulic fracturing fluids or produced water into groundwater that meets the definition of an underground source of drinking water (USDW) under the Safe Drinking Water Act (SDWA) as has been done in many oil and gas producing states in the U.S. (DiGiulio et al. 2018)
- Spills and leaks of produced water and stimulation or maintenance fluids containing chemicals
- Reuse of produced water that may contain hazardous levels of chemicals for agricultural irrigation of food crops for human consumption (Shonkoff et al., 2016);
- Discharge of insufficiently treated produced water into Waters of the United States upstream of drinking water intakes
- Disposal of produced water that with hazardous concentrations of chemicals into unlined pits with hydrogeological connectivity to groundwater that is currently or could be used in the future for drinking water or other types of human consumption (CCST 2015)

Human health risks of produced water handling and reuse may be exacerbated by the presence of chemicals used for well stimulation activities (e.g. hydraulic fracturing) and routine oil and gas operations (Stringfellow et al. 2017). Numerous studies have noted the lack of chemical disclosure in oil and gas operations and lack of toxicity information available for chemical additives (Shonkoff et al. 2015; Stringfellow et al. 2017; Yost et al., 2016).

Experimental findings in the peer-reviewed literature demonstrate adverse effects to the endocrine, metabolic, and reproductive systems associated with identified and unidentified substances that comprise produced water (He et al. 2017, Kassotis et al. 2018b, 2016a, 2016b, Tasker et al. 2018). Despite insufficient information to identify and quantify specific constituents in produced water, these experimental and bioanalytical results indicate aspects of the health relevance of exposure to produced water.

CLIMATE DIMENSIONS OF OIL AND GAS DEVELOPMENT

Global climate policy is founded on the understanding that the average global temperature rise caused by greenhouse gas emissions should not exceed 2 °C above the average global temperature of pre-industrial times (UNFCCC, 2019). To meet this goal, it is estimated that a third of global oil reserves, half of gas reserves and over 80% of current coal reserves should remain unused from 2010 to 2050 in order to meet the target of 2 °C, and that development of resources in the Arctic and any increase in unconventional oil production are incompatible with this target warming limit (McGlade and Ekins, 2015).

The Intergovernmental Panel on Climate Change (IPCC) stated with high confidence that global temperature is likely to increase by 1.5°C between 2030 and 2050 if it continues to increase at the current rate. Climate models predict significant differences in regional climate conditions between present-day and global warming of 1.5°C, and between 1.5°C and 2°C. These differences include increases in mean temperature in most land and ocean regions, hot extremes in most inhabited regions, heavy precipitation in several regions, and the probability of drought and precipitation deficits in some regions (IPCC, 2018).

Oil and natural gas are fossil fuels that result in emission of greenhouse pollutants through two primary pathways: (1) emissions of carbon dioxide (CO_2) – a long-lived greenhouse gas – during the combustion of oil and gas; and (2) the accidental leakage or intentional venting of methane – the primary constituent in natural gas – to the atmosphere during oil and gas development, transmission and distribution. Methane is a potent greenhouse gas that is 87-times more potent than CO_2 over a twenty-year time horizon. Given that greenhouse gas emissions must be significantly reduced in the near-term and methane's high greenhouse gas potential within this time horizon, it is imperative to dramatically cut methane pollution right away.

A recent review paper published in *Science* that synthesized methane measurements across dozens of studies estimated that in 2015, oil and gas development released 13 million metric tons (1 metric ton = 1,000 kg) of methane to the atmosphere – a resource worth at least 2 billion dollars (Alvarez et al. 2018). This estimate is 63% higher than that estimated by EPA (Alvarez et al. 2018) and 42% of all anthropogenic methane emissions considering 18 million metric tons from all other anthropogenic methane emissions in 2015 (EPA 2017). This estimate results in a production-normalized emission rate of 2.3%, which does not incorporate substantial methane loss in natural gas distribution systems (McKain et al. 2015, Lamb et al. 2016, Wunch et al. 2016). These findings challenge the assertion that natural gas produces fewer greenhouse gas emissions than coal combustion.

While current methane emissions from oil and gas development are unacceptably high, methane emission surveys indicate that major methane reductions are readily attainable using leak detection and repair systems and other off-the-shelf emission control technologies.

Moreover, while not always the case, the control of methane from oil and gas systems will likely also control the emissions of health-damaging volatile organic compounds (VOC) and other HAPs that are health damaging. These health-damaging air pollutants are often co-mingled and co-emitted with methane. For instance, gas samples from wells in Wyoming indicate that benzene concentrations are as high as 331 part-per-million (ppm) (DiGiulio and Jackson 2016), posing hazards and potential risks to nearby populations when gas is emitted to the atmosphere. As a reference, the Reference Exposure Level (REL) for benzene is 1 part-per-billion (ppb) for an 8-hour or chronic exposure and 8 ppb for an acute exposure (OEHHA 2016).

IMPACTS OF CLIMATE CHANGE ON HUMAN HEALTH

In addition to exposure to air pollutants and risks posed by water contamination from underregulated operations, oil and gas contributions to climate change introduces climate-specific risks to human health. Climate change increases the frequency and intensity of extreme heat and weather events and causes and exacerbates droughts, sea level rise and wildfires. These changing conditions have direct and indirect impacts on the health of human populations (Figure 2).

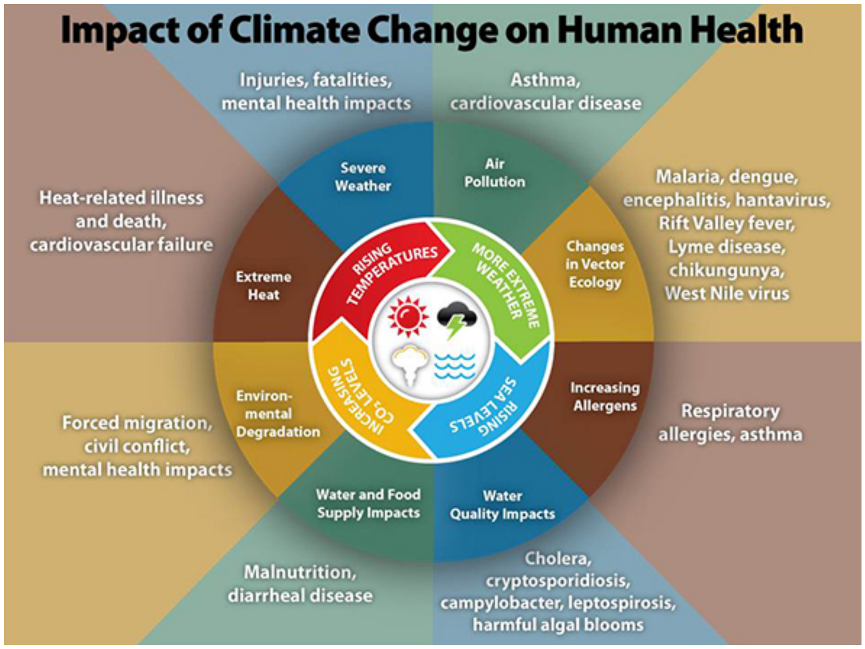

Figure 2. Direct and indirect impacts of climate change on human health.
(Source: CDC, 2014)

Direct impacts of climate change include increases in heat-related illness and death. For instance, a recent analysis concluded that achieving a 2°C and 1.5°C threshold could avoid between 70 to 1,980 and 110 and 2,720 deaths in 15 U.S. cities, respectively where reliable climate and health data are available (Lo et al. 2019).

Indirect impacts of climate change on health are numerous. For example, rising temperatures can alter geographic ranges where vectors (e.g. mosquitoes, ticks) can survive and thrive, spreading the diseases they carry (e.g. Zika virus, malaria, dengue and Lyme disease). Rising temperatures can also lengthen and worsen pollen seasons, exacerbating asthma and respiratory symptoms. Additionally, increased temperatures can increase the formation and concentration of air pollutants, like ozone which causes negative respiratory and cardiovascular health impacts.

Furthermore, extreme weather events, including droughts, wildfires, and floods, can impair water and food supplies leading to malnutrition and causing displacement and forced migration. In 2018, California experienced the deadliest and most destructive wildfire in its history, breaking records set just one year earlier during 2017's devastating fire season (CAL FIRE, 2019a; CAL FIRE, 2019b). Air pollution from the Camp Fire in Paradise (CA) traveled thousands of miles and impacted millions of Californians. In addition to the loss of life and infrastructure, the water supply in Paradise became contaminated with benzene, a known human carcinogen, as a result of the Camp Fire (Paradise Irrigation District, 2019). Mental health impacts are also expected as a result of severe weather events, damages to homes and community infrastructure, changing environmental conditions, displacement and migration.

Impacts on health will be experienced more intensely by socially and economically disadvantaged communities, and by vulnerable populations, including children, the elderly, the chronically ill and the disabled.

In the Human Health chapter of the 2014 report (Smith et al. 2014), the International Panel on Climate Change (IPCC) summarized major changes in human health predicted to occur based on climate change projections in the following ways:

- "Greater risk of injury, disease, and death due to more intense heat waves and fires (very high confidence)
- Increased risk of undernutrition resulting from diminished food production in poor regions (high confidence)
- Consequences for health of lost work capacity and reduced labor productivity in vulnerable populations (high confidence)
- Increased risks of food- and water-borne diseases (very high confidence) and vector-borne diseases (medium confidence)
- Modest reductions in cold-related mortality and morbidity in some areas due to fewer cold extremes (low confidence), geographical shifts in food production, and reduced capacity of disease-carrying vectors due to exceedance of thermal thresholds (medium confidence). These positive effects will be increasingly outweighed, worldwide, by the magnitude and severity of the negative effects of climate change (high confidence)

IMPLICATIONS OF DISMANTLING THE BLM METHANE RULE

The venting or flaring of at least some gas during oil and gas development is unavoidable. Whether during well drilling, well stimulation, exploration, production, well purging, or emergencies, some natural gas reaches the surface that cannot be easily used, sold or controlled (BLM 2018b). When this occurs, the gas either must be combusted ("flared") or released to the atmosphere ("vented"). Operators may also flare natural gas on a longer-term basis from production operations in situations where an oil well co-produces natural gas (or "associated gas") in an exploratory area or a field that lacks adequate gas-capture infrastructure to bring the gas to market (BLM 2018b).

In response to oversight reviews from the Government Accounting Office (GAO 2010) and increased flaring on Federal and Indian leases, in 2016, the U.S. Bureau of Land Management (BLM) adopted a rule entitled "Waste Prevention, Production Subject to Royalties, and Resource Conservation." The stated purpose of the this was to reduce flaring, venting, and leaks of methane – a greenhouse gas that is 86-times as strong as carbon dioxide (CO_2) over a 20-year timeframe – associated with oil and gas production on onshore Federal and Indian leases (Federal Register 2016). Another stated benefit of the rule was to reduce emissions of health-damaging volatile organic compounds (VOCs) and hazardous air pollutants (HAPs) that effect local and regional air quality (Federal Register 2016). These VOCs and HAPs include benzene, a known human carcinogen.

The 2016 BLM rule implemented reasonable, simple engineering, phased-in changes to reduce flaring, venting, and leaks during oil and gas production. One significant rescission of the 2016 rule was the removal of leak detection and repair because checking for leaks was "unnecessarily burdensome" (BLM 2018b). During the first year of implementation, repair of leaks would have reduced methane emissions by 51% and NMVOC emissions by 31% (BLM 2018b). Another requirement of the 2016 rule was to route vapor from storage tanks to a distribution line or to a combustion device. During the first year of implementation, this would have reduced methane emissions by only 4% but reduced NMVOC emissions by 41% (BLM 2018b). Changes required under the 2016 BLM rule would have reduced profit by the oil and gas industry by only 0.15% (Federal Register 2016).

The oil and gas industry (Western Energy Alliance, the Independent Petroleum Association of America) and four states (Wyoming, Montana, North Dakota, Texas) filed motions for a preliminary injunction to stay the rule which was denied in January 2017 (BLM 2018c). However, in March 2017, President Trump issued Executive Order (EO) 13783 entitled "Promoting Energy Independence and Economic Growth" to avoid "regulatory burdens that unnecessarily encumber energy production, constrain economic growth, and prevent job creation" (BLM 2018b) which initiated the process of largely rescinding the BLM rule.

In October 2017, the BLM suspended compliance with the 2016 BLM rule and in September 2018 formally rescinded virtually all portions of the BLM rule (Federal Register 2018) that would have reduced flaring, venting, and leaks during oil and gas production on Federal and Indian lands. In the Environmental Assessment (EA) for the 2018 BLM rescission of the 2016 BLM rule, the impact of the rescission on climate change was not considered because EO 13783 rescinded previous BLM references to the 2013 President's Climate Action Plan, the subsequently issued Climate Action Plan: Strategy to Reduce Methane Emissions (March 2014), and the Council on Environmental Quality's climate change guidance, entitled "Final Guidance for Federal Departments and Agencies on Consideration of Greenhouse Gas Emissions."

CONCLUSION

Oil and gas development is associated with multiple human health hazards, risks and impacts via air, water and other environmental pathways. Given that oil and gas are fossil fuels, strong scientific consensus supported by decades of peer-reviewed research has confirmed that their production and use present significant climate risks.

- While it is true that there are still some unanswered questions regarding the exact mechanisms of observed health impacts of oil and gas development, there is clearly enough information for decisionmakers to take - at a minimum - the following actions:
- First, immediately implement the cost-effective approaches to methane and health-damaging VOC emission control (for example, leak detection and repair and increased vapor recovery) as was required under the now rescinded 2016 BLM Methane Rule.

- Mandatory increased distances between where oil and gas development occurs and where people live, work, recreate and play should be considered in permitting and regulatory decisions to protect public health.

This testimony has been provided to inform the Subcommittee of the need for increased regulation of oil and gas development at the federal and state level.

Again, I wish to thank members of the Subcommittee for the opportunity to speak on the issue of the human health dimensions of oil and gas development and climate change.

SOURCES CITED

Allen, D. T. (2014). Atmospheric Emissions and Air Quality Impacts from Natural Gas Production and Use. Annual Review of Chemical and Biomolecular Engineering. https://doi.org/10.1146/annurev-chembioeng-060713-035938

Alvarez, R. A., Zavala-Araiza, D., Lyon, D. R., Allen, D. T., Barkley, Z. R., Brandt, A. R., … Hamburg, S. P. (2018). Assessment of methane emissions from the U.S. oil and gas supply chain. Science, eaar7204. https://doi.org/10.1126/science.aar7204

Blair, B. D., Brindley, S., Dinkeloo, E., McKenzie, L. M., & Adgate, J. L. (2018). Residential noise from nearby oil and gas well construction and drilling. Journal of Exposure Science & Environmental Epidemiology, 1. https://doi.org/10.1038/s41370-018-0039-8

Boyle, M. D., Soneja, S., Quirós-Alcalá, L., Dalemarre, L., Sapkota, A. R., Sangaramoorthy, T., ... Sapkota, A. (2017). A pilot study to assess residential noise exposure near natural gas compressor stations. PLOS ONE, 12(4), e0174310. https://doi.org/10.1371/journal.pone.0174310

Brown, D. R., Lewis, C., & Weinberger, B. I. (2015). Human exposure to unconventional natural gas development: A public health demonstration of periodic high exposure to chemical mixtures in ambient air. Journal of Environmental Science and Health, Part A, 50(5), 460–472. https://doi.org/10.1080/10934529.2015.992663

Brown, D., Weinberger, B., Lewis, C., & Bonaparte, H. (2014). Understanding exposure from natural gas drilling puts current air standards to the test. Reviews on Environmental Health, 29(4), 277–292. https://doi.org/10.1515/reveh-2014-0002

CAL FIRE (California Department of Forestry and Fire Protection). (2019a). Top 20 Most Destructive California Wildfires. https://www.fire.ca.gov/media/5511/top20_destruction.pdf

CAL FIRE (California Department of Forestry and Fire Protection). (2019b). Top 20 Deadliest California Wildfires. https://www.fire.ca.gov/media/5512/top20_deadliest.pdf

CDC (Centers for Disease Control and Prevention). (2014). Climate Change and Public Health - Climate Effects on Health. Retrieved July 5, 2019, from https://www.cdc.gov/climateandhealth/effects/default.htm

Casey, J. A., Wilcox, H. C., Hirsch, A. G., Pollak, J., & Schwartz, B. S. (2018). Associations of unconventional natural gas development with depression symptoms and disordered sleep in Pennsylvania. Scientific Reports, 8(1), 11375. https://doi.org/10.1038/s41598-018- 29747-2

CCST (California Council on Science and Technology). (2015). An Independent Scientific Assessment of Well Stimulation in California. Executive Summary. Available at: https://ccst.us/wp-content/uploads/2015SB4-v2ES.pdf.

Colborn, T., Schultz, K., Herrick, L., & Kwiatkowski, C. (2014). An Exploratory Study of Air Quality near Natural Gas Operations. Human and Ecological Risk Assessment: An International Journal, 0(ja), null. https://doi.org/10.1080/10807039.2012.749447

Currie, J., Greenstone, M., & Meckel, K. (2017). Hydraulic fracturing and infant health: New evidence from Pennsylvania. Science Advances, 3(12), e1603021. https://doi.org/10.1126/sciadv.1603021

Czolowski, E. D., Santoro, R. L., Srebotnjak, T., & Shonkoff, S. B. C. (2017). Toward Consistent Methodology to Quantify Populations in Proximity to Oil and Gas Development: A National Spatial Analysis and Review. Environmental Health Perspectives, 125(8), UNSP 086004. https://doi.org/10.1289/EHP1535

DiGiulio DC, Shonkoff SBC, Jackson RB. (2018). The Need to Protect Fresh and Brackish Groundwater Resources During Unconventional Oil and Gas Development. Current Opinion in Environmental Science & Health. 3:1-7. Available at: https://authors.elsevier.com/c/1Wf1I8nIePIe~Z

Fann, N., Baker, K. R., Chan, E. A. W., Eyth, A., Macpherson, A., Miller, E., & Snyder, J. (2018). Assessing Human Health PM2.5 and Ozone Impacts from U.S. Oil and Natural Gas Sector Emissions in 2025. Environmental Science & Technology. https://doi.org/10.1021/acs.est.8b02050

Federal Register. Volume 81, Number 223, Friday November 18, 2016. Department of the Interior, Bureau of Land Management. 43 CFR Parts 3100, 3160, and 3170. Waste Prevention, Production Subject to Royalties, and Resource Conservation.

Federal Resister. Volume 83, Number 36. Thursday, February 22, 2018. Department of the Interior, Bureau of Land Management. 43 CFR Parts 3160 and 3170. Waste Prevention, Production Subject to Royalties, and Resource Conservation; Rescission or Revision of Certain Requirements.

Garcia-Gonzales, D. A., Shonkoff, S. B. C., Hays, J., & Jerrett, M. (2019). Hazardous Air Pollutants Associated with Upstream Oil and Natural Gas Development: A Critical Synthesis of Current Peer-Reviewed Literature. Annual Review of Public Health, 40(1), 283–304. https://doi.org/10.1146/annurev-publhealth-040218-043715

Hays, J., McCawley, M., & Shonkoff, S. B. C. (2017). Public health implications of environmental noise associated with unconventional oil and gas development. Science of The Total Environment. https://doi.org/10.1016/j.scitotenv.2016.11.118

Hays, J., & Shonkoff, S. B. C. (2016). Toward an Understanding of the Environmental and Public Health Impacts of Unconventional Natural Gas Development: A Categorical Assessment of the Peer-Reviewed Scientific Literature, 2009-2015. PLOS ONE, 11(4), e0154164. https://doi.org/10.1371/journal.pone.0154164

He Y., Folkerts E. J., Zhang Y., Martin J. W., Alessi D. S., Goss G. G. 2017. Effects on Biotransformation, Oxidative Stress, and Endocrine Disruption in Rainbow Trout (Oncorhynchus mykiss) Exposed to Hydraulic Fracturing Flowback and Produced Water. Environmental Science & Technology 51(2), 940–947.

Hill, E. L. (2018). Shale gas development and infant health: Evidence from Pennsylvania. Journal of Health Economics, 61, 134–150. https://doi.org/10.1016/j.jhealeco.2018.07.004

IPCC (Intergovernmental Panel on Climate Change). (2018). Special Report: Global Warming of 1.5C. Available at: https://www.ipcc.ch/sr15/chapter/summary-for-policy-makers/

Jemielita, T., Gerton, G. L., Neidell, M., Chillrud, S., Yan, B., Stute, M., ... Panettieri, R. A., Jr. (2015). Unconventional Gas and Oil Drilling Is Associated with Increased Hospital Utilization Rates. PLoS ONE, 10(7), e0131093. https://doi.org/10.1371/journal.pone.0131093

Kassotis C.D., Iwanowicz L.R., Akob D.M., Cozzarelli I.M., Mumford A.C., Orem W.H., Nagel S.C. 2016. Endocrine disrupting activities of surface water associated with a West Virginia oil and gas industry wastewater disposal site. Science of the Total Environment 557-558, 901-910.

Kassotis C. D., Bromfield J. J., Klemp K. C., Meng C.-X., Wolfe A., Zoeller R. T., Balise V.D., Isiguzo C. J., Tillitt D.E., Nagel, S. C. 2016. Adverse Reproductive and Developmental Health Outcomes Following Prenatal Exposure to a Hydraulic Fracturing Chemical Mixture in Female C57Bl/6 Mice. Endocrinology, en.2016-1242. https://doi.org/10.1210/en.2016-1242

Kassotis, C. D., Nagel, S. C., & Stapleton, H. M. 2018. Unconventional oil and gas chemicals and wastewater-impacted water samples promote adipogenesis via PPARγ-dependent and independent mechanisms in 3T3-L1 cells. Science of The Total Environment. https://doi.org/10.1016/j.scitotenv.2018.05.030

Koehler, K., Ellis, J. H., Casey, J. A., Manthos, D., Bandeen-Roche, K., Platt, R., & Schwartz, B. S. (2018). Exposure Assessment Using Secondary Data Sources in Unconventional Natural Gas Development and Health Studies. Environmental Science & Technology. https://doi.org/10.1021/acs.est.8b00507

Lamb B.K., Cambaliza M.O.L., Davis K.J., Edburg S.L., Ferrara T.W., Floerchinger C., Heimburger A.M.F., Herndon S., Lauvaux T., Lavoie T., Lyon D.R., Miles N., Prasad K.R., Richardson S., Roscioli J.R., Salmon O.E., Shepson P.B., Stirm B.H., Whetstone J. 2016. Direct and indirect measurements and modeling of methane emissions in Indianapolis, Indiana. *Environmental Science & Technology* 50, 8910–8917.

Lewis, C., Greiner, L. H., & Brown, D. R. (2018). Setback distances for unconventional oil and gas development: Delphi study results. PLOS ONE, 13(8), e0202462. https://doi.org/10.1371/journal.pone.0202462

Lo YTE, Mitchell DM Gasparrini A, et al. (2019). Increasing mitigation ambition to meet the Paris Agreement's temperature goal avoids substantial heat-related mortality in U.S. Cities. *Science Advances*, 5: eaau4373, 1-9.

Lyon D.R., Alvarez R.A., Zavala-Araiza D., Brandt A.R., Jackson R.B., Hamburg S.P. 2016. Aerial surveys of elevated hydrocarbon emissions from oil and gas production sites. *Environmental Science & Technology* 50, 4877–4886.

Macey, G. P., Breech, R., Chernaik, M., Cox, C., Larson, D., Thomas, D., & Carpenter, D. O. (2014). Air concentrations of volatile compounds near oil and gas production: a community-based exploratory study. Environmental Health, 13(1), 82. https://doi.org/10.1186/1476-069X-13-82

Maskrey, J. R., Insley, A. L., Hynds, E. S., & Panko, J. M. (2016). Air monitoring of volatile organic compounds at relevant receptors during hydraulic fracturing operations in Washington County, Pennsylvania. Environmental Monitoring and Assessment, 188(7), 1–12. https://doi.org/10.1007/s10661-016-5410-4

McGlade C. & Ekins, P. (2015) The geographical distribution of fossil fuels unused when limiting global warming to 2 °C. Nature, 517, 187-190. https://www.nature.com/articles/nature14016

McKain K., Down A., Raciti S.M., Budney J., Hutyra L.R., Floerchinger C., Herndon S.C., Nehrkorn T., Zahniser M.S., Jackson R.B., Phillips N., Wofsy S.C. 2015. Methane emissions from natural gas infrastructure and use in the urban region of Boston, Massachusetts. *Proceedings National Academy of Science* 112, 1941–1946.

McKenzie, L. M., Witter, R. Z., Newman, L. S., & Adgate, J. L. (2012). Human health risk assessment of air emissions from development of unconventional natural gas resources. The Science of the Total Environment, 424, 79–87. https://doi.org/10.1016/j.scitotenv.2012.02.018

McKenzie, L. M., Guo, R., Witter, R. Z., Savitz, D. A., Newman, L. S., & Adgate, J. L. (2014). Birth Outcomes and Maternal Residential Proximity to Natural Gas Development in Rural Colorado. Environmental Health Perspectives, 122(4). https://doi.org/10.1289/ehp.1306722

McKenzie, L. M., Allshouse, W. B., Byers, T. E., Bedrick, E. J., Serdar, B., & Adgate, J. L. (2017). Childhood hematologic cancer and residential proximity to oil and gas development. PLOS ONE, 12(2), e0170423. https://doi.org/10.1371/journal.pone.0170423

McKenzie, L. M., Blair, B. D., Hughes, J., Allshouse, W. B., Blake, N., Helmig, D., ... Adgate, J. L. (2018a). Ambient Non-Methane Hydrocarbon Levels Along Colorado's Northern Front Range: Acute and Chronic Health Risks. Environmental Science & Technology. https://doi.org/10.1021/acs.est.7b05983

McMullin, T. S., Bamber, A. M., Bon, D., Vigil, D. I., & Van Dyke, M. (2018). Exposures and Health Risks from Volatile Organic Compounds in Communities Located near Oil and Gas Exploration and Production Activities in Colorado (USA). International Journal of Environmental Research and Public Health, 15(7), 1500. https://doi.org/10.3390/ijerph15071500

OEHHA (Office of Environmental Health Hazard Assessment). (2019). Toxic air contaminants. Available at: https://oehha.ca.gov/air/toxic-air-contaminants.

OEHHA (Office of Environmental Health Hazard Assessment). (2016). OEHHA Acute, 8-hour and Chronic Reference Exposure Level (REL) Summary. Available at: https://oehha.ca.gov/air/general-info/oehha-acute-8-hour-and-chronic-reference-exposure-level-rel-summary. Accessed on July 11, 2019.

Paradise Irrigation District. (2019). Water Quality Advisory – After the Camp Fire. https://pidwater.com/wqadvisory

Paulik, L. B., Hobbie, K. A., Rohlman, D., Smith, B. W., Scott, R. P., Kincl, L., … Anderson, K. A. (2018). Environmental and individual PAH exposures near rural natural gas extraction. Environmental Pollution, 241, 397–405. https://doi.org/10.1016/j.envpol.2018.05.010

Peng, L., Meyerhoefer, C., & Chou, S.-Y. (2018). The health implications of unconventional natural gas development in Pennsylvania. Health Economics, 27(6), 956–983. https://doi.org/10.1002/hec.3649

Rabinowitz, P. M., Slizovskiy, I. B., Lamers, V., Trufan, S. J., Holford, T. R., Dziura, J. D., ... Stowe, M. H. (2015). Proximity to Natural Gas Wells and Reported Health Status: Results of a Household Survey in Washington County, Pennsylvania. Environmental Health Perspectives. https://doi.org/10.1289/ehp.130773

Radtke, C., Autenrieth, D. A., Lipsey, T., & Brazile, W. J. (2017). Noise characterization of oil and gas operations. Journal of Occupational and Environmental Hygiene, 14(8), 659– 667. https://doi.org/10.1080/15459624.2017.1316386

Rasmussen SG, Ogburn EL, McCormack M, Casey JA, Bandeen-Roche K, Mercer DG, & Schwartz BS. (2016). Association between unconventional natural gas development in the marcellus shale and asthma exacerbations. JAMA Internal Medicine, 176(9), 1334– 1343. https://doi.org/10.1001/jamainternmed.2016.2436

Rich, A. L., & Orimoloye, H. T. (2016). Elevated Atmospheric Levels of Benzene and Benzene- Related Compounds from Unconventional Shale Extraction and Processing: Human Health Concern for Residential Communities. Environmental Health Insights, 10, 75–82. https://doi.org/10.4137/EHI.S33314

Shonkoff SBC, Maddalena RL, Hays J, Stringfellow W, Wettstein ZS, Harrison, R, Sandelin W, McKone, TE. (2015). Potential Impacts of Well Stimulation on Human Health in California. In: An Independent Scientific Assessment of Well Stimulation in California. California Council on Science and Technology, Sacramento, CA. Available at: http://ccst.us/publications/2015/vol-II-chapter-6.pdf

Shonkoff SBC, Domen JK, Stringfellow WT. (2016). Hazard Assessment of Chemical Additives Used in Oil Fields that Reuse Produced Water for Agricultural Irrigation, Livestock Watering, and Groundwater Recharge in the San Joaquin Valley of California: Preliminary Results. PSE Healthy Energy. September 2016. Available at: https://www.psehealthyenergy.org/our-work/publications/archive/hazard-assessment-of-chemical-additives-used-in-oil-fields-that-reuse-produced-water-for-agricultural-irrigation-2/

Smith, K.R., A. Woodward, D. Campbell-Lendrum, D.D. Chadee, Y. Honda, Q. Liu, J.M. Olwoch, B. Revich, and R. Sauerborn, 2014: Human health: impacts, adaptation, and co-benefits. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 709-754.

Stacy, S. L., Brink, L. L., Larkin, J. C., Sadovsky, Y., Goldstein, B. D., Pitt, B. R., & Talbott, E. O. (2015). Perinatal Outcomes and Unconventional Natural Gas Operations in Southwest Pennsylvania. PLoS ONE, 10(6), e0126425. https://doi.org/10.1371/journal.pone.0126425

Stringfellow, W. T., Camarillo, M. K., Domen, J. K., & Shonkoff, S. B. C. (2017). Comparison of chemical-use between hydraulic fracturing, acidizing, and routine oil and gas development. PLOS ONE, 12(4), e0175344. https://doi.org/10.1371/journal.pone.0175344

Tasker, T. L., Burgos, W. D., Piotrowski, P., Castillo-Meza, L., Blewett, T. A., Ganow, K. B., … Warner, N. R. (2018). Environmental and Human Health Impacts of Spreading Oil and Gas Wastewater on Roads. Environmental Science & Technology. https://doi.org/10.1021/acs.est.8b00716

Tustin, A. W., Hirsch, A. G., Rasmussen, S. G., Casey, J. A., Bandeen-Roche, K., & Schwartz, B. S. (2016). Associations between Unconventional Natural Gas Development and Nasal and Sinus, Migraine Headache, and Fatigue Symptoms in Pennsylvania. Environmental Health Perspectives. https://doi.org/10.1289/EHP281

United Nations Framework Convention on Climate Change (UNFCCC). (2019). The Paris Agreement: essential elements. https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement

U.S. Department of the Interior, Bureau of Land Management (BLM 2018a), Oil and Gas Statistics. Available at https://www.blm.gov/programs/energy-and-minerals/oil-and-gas/oil-and-gas-statistics

U.S. Department of the Interior, Bureau of Land Management (BLM 2018b), Waste Prevention, Production Subject to Royalties, and Resource Conservation; Rescission or Revision of Certain Requirements. Final Rule. DOI-BLM-WO310-2018-0001-EA

U.S. Environmental Protection Agency (EPA). 2017. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2015. Available at: www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2015.

U.S. Environmental Protection Agency (EPA). 2018. Technology Transfer Network - Air Toxics Web Site. Available at: https://www3.epa.gov/airtoxics/pollsour.html. Accessed on July 10, 2019.

Weinberger, B., Greiner, L. H., Walleigh, L., & Brown, D. (2017). Health symptoms in residents living near shale gas activity: A retrospective record review from the Environmental Health Project. Preventive Medicine Reports. https://doi.org/10.1016/j.pmedr.2017.09.002

Willis, M. D., Jusko, T. A., Halterman, J. S., & Hill, E. L. (2018). Unconventional natural gas development and pediatric asthma hospitalizations in Pennsylvania. Environmental Research, 166, 402–408. https://doi.org/10.1016/j.envres.2018.06.022

Whitworth, K. W., Marshall, A. K., & Symanski, E. (2017). Maternal residential proximity to unconventional gas development and perinatal outcomes among a diverse urban population in Texas. PLoS One; San Francisco, 12(7), e0180966. http://dx.doi.org/10.1371/journal.pone.0180966

Whitworth, K. W., Marshall, A. K., & Symanski, E. (2018). Drilling and Production Activity Related to Unconventional Gas Development and Severity of Preterm Birth. Environmental Health Perspectives. https://doi.org/10.1289/EHP2622

Wunch D., Toon G.C., Hedelius J.K., Vizenor N., Roehl C.M., Saad K.M., Blavier J.-F.L., Blake D.R., Wennberg P.O. 2016. Quantifying the loss of processed natural gas within California's South Coast Air Basin using long-term measurements of ethane and methane. *Atmospheric Chemistry & Physics* 16, 14091–14105.

Yost E. E., Stanek J., DeWoskin R.S., Burgoon L.D. 2016. Overview of chronic oral toxicity values for chemicals present in hydraulic fracturing fluids, flowback, and produced waters. Environmental Science & Technology 50, 4788-4797.

Zavala-Araiza D., Alvarez R.A., Lyon D.R., Allen D.T., Marchese A. J., Zimmerle D.J., Hamburg S.P. 2017. Super-emitters in natural gas infrastructure are caused by abnormal process conditions. *Nature Communications* 8, 14012.