Featured Research Review

ENVIRONMENTAL HEALTH PROJECT
DEFENDING PUBLIC HEALTH SINCE 2012

Exploring the Potential for Fossil Fuel Air Pollution to Alter Gene Function

Monti, P., Biganzoli, E., Bollati, V. (2025). Impact of air pollution and occupational inhalation exposures on neurodegenerative disorders: An epigenetic perspective. *iScience*, *28*(7), 112825. https://doi.org/10.1016/j.isci.2025.112825

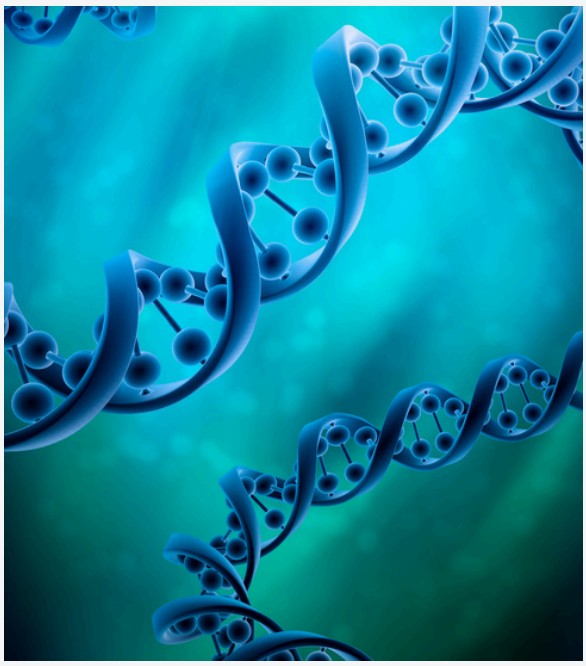
September 2, 2025

Terms to Know:

- Epigenetics/epigenome: Epigenetics is the study of how behaviors and the environment affect the way genes function. These outside influences may determine which genes get turned "on" or "off," which can have long-term health impacts in the body. "Epigenome" refers to all these changes.
- Biomarker: A substance or condition in the body that indicates a particular condition, disease, or environmental exposure.
- DNA methylation: a process in gene expression where methyl groups attach to a specific part of a DNA molecule, turning the gene "on" or "off." This epigenetic process regulates which proteins are produced, influencing development and cellular function.
- Histone proteins: provide structural support to chromosomes by wrapping around DNA, and are another way for gene expression to be turned "on" or "off."

Fossil Fuel Air Pollution and Epigenetics

Frontline communities, advocacy groups, and researchers have known for decades that air pollution from fossil fuel production adversely affects human health. Polluting emissions from oil and gas operations—fine particulate matter ($PM_{2.5}$), volatile organic compounds (VOCs), nitrogen oxides (NO_x), ozone, and numerous others—have been linked to respiratory illnesses, cancer, adverse pregnancy outcomes, cardiovascular disease, and a wide host of health impacts. With the expansion of oil and gas production expected to accelerate in the coming years, the risk of adverse health effects on a wide range of individuals is likely to increase.



info@environmentalhealthproject.org | 724.260.5504

View more of EHP's Featured Research Reviews here.

Featured Research Review

ENVIRONMENTAL HEALTH PROJECT
DEFENDING PUBLIC HEALTH SINCE 2012

According to the U.S. Energy Information Administration (EIA), shale gas production has expanded rapidly across the United States over the past two decades, transforming the country into one of the world's leading shale gas producers. Hydraulic fracturing, commonly referred to as "fracking," has been central to this growth. Starting in 2007, the EIA began reporting shale gas production separately from oil and gas as a whole. Their statistics indicate that shale gas production increased from 1.9 trillion cubic feet in 2007 to nearly 28 trillion cubic feet in 2021.

Photo courtesy of FracTracker Alliance.

Today, shale gas operations are active in more than 25 states, with major production hubs in Texas, Pennsylvania, Louisiana, West Virginia, Ohio, New Mexico, Oklahoma, North Dakota, and Colorado. Many operators that engineered this expansion initially claimed it would bring economic benefits to some regions, but such claims have been debunked, and areas with heavy fracking have largely seen economic contraction. More concerning have been the widespread public health impacts, environmental degradation, and long-term climate-changing effects.

The continued increase of dangerous industry emissions is likely. At the same time, a growing body of research, including dozens of robustly supported oil and gas health impact studies, suggests another concerning development in exposure to industry pollution: epigenetic alterations. The epigenome is a collection of compounds that act on DNA and regulate gene expression, instructing the genome on what to do and when to do it. These "instructions" can be influenced by external environmental factors, meaning what we are exposed to can affect our DNA. Alterations in how genes are expressed can have serious health consequences, from disrupting the functioning of our body's cells and tissues to suppressing cancer-fighting genes.

Air pollution, particularly from shale gas and oil development, is a potent environmental stressor capable of modifying DNA methylation patterns, altering histone structure and disrupting small RNA expression (Panni et al., 2016). These changes influence how genes are turned "on" or "off" and may act as early biomarkers of chronic diseases, including neurodegenerative disorders (NDs).

Featured Research Review

ENVIRONMENTAL HEALTH PROJECT
DEFENDING PUBLIC HEALTH SINCE 2012

New Research Survey Identifies Link Between Air Pollution and Epigenetics

A newly published literature review by Monti et al. (2025) outlines the emerging evidence linking air pollution exposure to neurodegenerative disease (ND) risk via the epigenome. The NDs examined include Alzheimer's disease and Parkinson's disease, which are projected to increase globally due to modifiable environmental risk factors, such as inhaled pollutants, not just demographic aging. The paper points to the neurotoxic properties of complex air pollution mixtures that can include PM, VOCs, heavy metals, and other hazardous gases, as well as the ability for ultrafine particles less than 0.1 microns in diameter (roughly the size of a virus) to cross the blood-brain barrier.

The paper also discusses changes in how our genes are activated, also known as epigenetic modifications, which appear to be one of the main ways that air pollution affects brain health, according to the authors' survey of the literature. These changes do not alter the DNA sequence itself, but they do influence how genes behave in response to environmental stressors, including pollution. For example, repeated exposure to fine particulate matter $PM_{2.5}$ was shown to change how genes involved in inflammation and the development of Alzheimer's disease are expressed. The authors found in other studies that VOCs and airborne heavy metals can disrupt small molecules in the body called non-coding RNAs, which help control brain function and memory-related proteins. Long-term pollution exposure can interfere with how DNA is "packaged" in cells; this insight was determined through observed changes to histones, the proteins that help organize genetic material. Changes to histones can increase brain inflammation and damage nerve cells.

The study authors identified another pathway in their review: air pollution can affect DNA methylation. DNA methylation is the process that determines which genes do or do not get expressed. Air pollution can affect this process, which can lead to important genes being activated or suppressed, potentially leading to respiratory diseases, cardiovascular problems, metabolic disorders, and even cancer development.

Moreover, this paper explains that epigenetic effects were observed well before any signs of memory loss, disease, or other health effects manifested. This observation

suggests that these conditions may be the consequence of exposure to pollution before symptoms appear; however, the observation also suggests that pollution-related epigenetic changes, if detected, could serve as early warning signs for disorders such as Alzheimer's and Parkinson's diseases.

Despite significant advances in the research on this subject, the review highlights several gaps in the literature. As with many research areas, longitudinal human studies were found to be scarce, and most of the research studies examined were either short-term animal experiments or cross-sectional population studies in older adults, in which health impacts were already realized. The review also looked only at particulate matter and a few metals, likely because other influences are not as well studied, despite many other compounds having been detected in brain tissue. Further, one of the suggestions from the literature, examining histone changes, is challenging with current technology. Further research, particularly the influence of one's total environment on health, is required to fully understand this complex interplay.

Conclusion

The findings reviewed by Monti et al. (2025) draw attention to critical implications of fossil fuel air pollution's role in environmental justice and occupational health. Workers and residents near oil and gas infrastructure are disproportionately exposed to neurotoxicants such as benzene, toluene, formaldehyde, and diesel exhaust. Many of these agents are known to cross the blood-brain barrier or induce systemic inflammation, setting off biological cascades that affect brain function and long-term neurological health.

This paper illustrates a new and concerning pathway through which oil and gas–related air pollution can shape human health. Epigenetic changes to the brain and immune system may be influenced by environmental exposure, particularly in communities situated near industry activity.

Featured Research Review

ENVIRONMENTAL HEALTH PROJECT
DEFENDING PUBLIC HEALTH SINCE 2012

To learn more about this study, explore these links:

Burnett, R., Chen, H., Szyszkowicz, M., Fann, N., Hubbell, B., Pope III, C. A., ... & Cohen, A. (2018). Global estimates of mortality associated with long-term exposure to outdoor fine particulate matter. *Proceedings of the National Academy of Sciences, 115*(38), 9592–9597. https://doi.org/10.1073/pnas.1803222115

Colborn, T., Kwiatkowski, C., Schultz, K., & Bachran, M. (2011). Natural gas operations from a public health perspective. *Human and Ecological Risk Assessment, 17*(5), 1039–1056. https://doi.org/10.1080/10807039.2011.605662

Disavino, S. (2024). *US natural gas drillers to lift 2025 output, reversing year of cuts*. Reuters. https://www.reuters.com/markets/commodities/us-natural-gas-drillers-lift-2025-output-reversing-year-cuts-2024-11-21/

Environmental Health Project. (2025) *Health Impacts of Shale Gas Development: A Collection of Research*. https://www.environmentalhealthproject.org/_files/ugd/a9ce25_db081f0233164f1e93da7d87aa03ad38.pdf?index=true

Kalenik, S., Zaczek, A., Rodacka, A. (2025). Air Pollution-Induced Neurotoxicity: The Relationship Between Air Pollution, Epigenetic Changes, and Neurological Disorders. *International Journal of Molecular Sciences, 26*(7):3402. https://doi.org/10.3390/ijms26073402

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), 412–417. https://doi.org/10.1289/ehp.1306722

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. *Science of the Total Environment, 424,* 79–87. https://doi.org/10.1016/j.scitotenv.2012.02.018

Moore, L.D., Le, T., Fan, G. (2012). DNA methylation and its basic function. *Neuropsychopharmacology, 38, 23–38.* https://doi.org/10.1038/npp.2012.112

Ohio River Valley Institute. (2025). *Frackalachia Update 2025*. https://ohiorivervalleyinstitute.org/frackalachia-update-2025/

Panni, T., Mehta, A. J., Schwartz, J. D., Baccarelli, A. A., Just, A. C., Wolf, K., Bind, M. A. (2016). Genome-wide analysis of DNA methylation and fine particulate matter air pollution in three study populations: KORA F3, KORA F4, and the Normative Aging Study. *Environmental Health Perspectives, 124*(7), 983–990. https://doi.org/10.1289/ehp.1509966

Rotman, D. (2025). AI could keep us dependent on natural gas for decades to come. *MIT Technology Review.* https://www.technologyreview.com/2025/05/20/1116272/ai-natural-gas-data-centers-energy-power-plants/

U.S. Energy Information Administration. (2022). *Shale Gas Production.* https://www.eia.gov/dnav/ng/ng_prod_shalegas_s1_a.htm

Zhang, Y., Sun, Z., Jia, J., Du, T., Zhang, N., Tang, Y., Fang, Y., Fang, D. (2021). Overview of histone modification. *Histone Mutations and Cancer. Advances in Experimental Medicine and Biology,* vol 1283, 1-16. https://doi.org/10.1007/978-981-15-8104-5_1

info@environmentalhealthproject.org | 724.260.5504

View more of EHP's Featured Research Reviews here.