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The Environmental and Occupational Health Impacts of High-Volume Hydraulic Fracturing of Unconventional Gas Reserves

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Abstract

High-volume horizontal hydraulic fracturing (HVHF) in unconventional gas reserves involves injecting sand and fluids into fissures within the earth's crust as a means to enhance the extraction of natural gas from deep geologic formations. This technique has vastly increased the potential for domestic natural gas production and has been promoted as a way to decrease dependence on foreign energy sources, replace dirtier energy sources such as coal, and generate new jobs and

economic development. At the same time, HVHF poses potential risks to public health and the environment, including groundwater and surface water contamination, climate change, air pollution, and worker health. This position statement relates to the entire process surrounding HVHF, including site preparation, drilling and casing, well completion, production, transportation, storage and disposal of wastewater and chemicals, and site remediation. The rapid socioeconomic changes, scale of development, and pace of extraction made possible by HVHF present potential direct and indirect health challenges through changes in vehicular traffic and community dynamics, unequal distribution of economic benefits, demands on public services, health care system effects, and increased housing costs. Thus, while natural gas extraction is a long-standing and important part of our nation's energy portfolio, the onset of HVHF in many parts of the country represents a new industrial, environmental, and land use development pattern with significant potential for impacts on public health. The public health perspective has been inadequately represented in policy processes related to HVHF. Policies that anticipate potential public health threats, require greater transparency, use a precautionary approach in the face of uncertainty, and provide for monitoring and adaptation as understanding of risks increases may significantly reduce the negative public health impacts of this approach to natural gas extraction.

Problem Statement

High-volume horizontal hydraulic fracturing (HVHF) in unconventional gas reserves (often referred to as "fracing" or "fracking") is a technology that injects solids and fluids into fissures within the earth's crust as a means to enhance the extraction of natural gas from deep geologic formations, primarily the shale, tight sands, and coal seam gas that underlie many regions of the United States.[1] This technique has vastly increased the potential for domestic natural gas production and has been promoted as a way to decrease dependence on foreign energy sources, replace dirtier energy sources such as coal, and generate new jobs and economic development. Currently, the most important unconventional natural gas reserves include Barnett (Texas), Fayetteville (Arkansas), Haynesville (Louisiana and Texas), Antrim (Michigan, Indiana, and Ohio), Marcellus (New York, Pennsylvania, and West Virginia), Bakken (North Dakota), Woodford (Oklahoma), and Eagle Ford (Texas). This position statement relates to the entire process surrounding HVHF, including site preparation, drilling and casing, well completion, production, transportation, storage and disposal of waste water and chemicals, and site remediation.

The basic technology of hydraulic fracturing has existed since the 1860s. Hydraulic fracturing involves using water mixed with sand and varied chemicals to fracture rock thousands of feet below the ground and hold these fractures open, allowing gas to seep back through the drill hole and be extracted to the surface. Recent advances in drilling technology have made horizontal drilling, particularly high-volume horizontal hydraulic fracturing, feasible.[2] Horizontal drilling allows greater access to a formation than the conventional vertical well. Horizontal drilling is particularly useful for shale formations that do not have sufficient permeability for a vertical well. Such wells are now hydraulically fractured horizontally in a number of stages.[3,4]

The economic development associated with HVHF has the potential to improve some populations' health. In terms of economic development, it is anticipated that jobs will be created to support the industry directly and indirectly. Property and

rental value will increase, adding to the tax base. Property owners will have revenue opportunities from property leases and gas royalties. As new workers enter the community, hotels, restaurants, and local businesses are expected to see revenue increases. The increase in demand will also allow many businesses to expand and hire. Through this economic development, HVHF may have indirect positive public health impacts. For example, the fees and taxes associated with gas extraction can be directed back into the local public health infrastructure such as schools, hospitals, and clinics. The fees and taxes could support medical surveillance of workers and the community and epidemiological projects as well. Increased tax revenue can also be used to hire more firefighters, emergency medical technicians (EMTs), and police officers to serve the community and handle the population and traffic increases. To the extent that individuals' improved economic status leads to better nutrition, preventive behaviors and services, and access to health care, HVHF may lead to improved public health. There are also concerns, however, that the "boom and bust" cycle typical of extractive industries will not result in long-term economic benefits and that unequal distribution of these benefits may cause community conflict.[5]

Uncertainty remains over a potential environmental benefit of HVHF that has public health implications. Natural gas is more efficient and cleaner burning than coal. When burned, natural gas releases 58% less CO2 than coal and 33% less CO2 than oil.[6] Because of that, it has been promoted as a transitional fuel to begin conversion to greener energy such as wind and solar.[7,8] Although natural gas burns more cleanly than coal, a recent study argues that replacing all of the world's coal power plants with natural gas would do little to slow global warming this century. Switching from coal to natural gas would cut the warming effect in 100 years' time by only about 20%.[9] Although a 20% decrease in warming over 100 years is significant, the consequences of the warming not prevented will have grave implications for public health. In addition, some projections suggest that obtaining natural gas through HVHF actually produces more greenhouse gas emissions than does coal production and burning.[10]

At the same time, HVHF poses potential risks to public health and the environment.[11,12] HVHF raises concerns about groundwater and surface water contamination, climate change, air pollution, and worker exposures to toxins, all of which have significant public health implications.[13] As noted by Bamberger and Oswald, "complete evidence regarding health impacts of gas drilling cannot be obtained due to incomplete testing and disclosure of chemicals…and nondisclosure agreements."[14] In addition, many uncertainties remain about the types of exposures and resulting health impacts that could be associated with HVHF.[15–17] Vulnerable populations, particularly children and low-income rural populations, are most likely to be negatively affected by HVHF. There has been some HVHF in urban areas with the potential to affect large numbers of people. Due to the rapid growth of and highly varied (based on geography, drilling practices, and cumulative impacts) emissions from HVHF, it is impossible to precisely predict exposure patterns. Nonetheless, initial evidence gathered from the rapidly growing experience with HVHF, comparisons with other activities with similar emissions, and projections based on environmental models can inform a precautionary approach to the potential environmental public health impacts of HVHF.[13] Below we outline several of the current concerns about potential health effects related to water quality and quantity, air quality, occupational exposures, and community changes.

Impacts on water quality and quantity are some of the most highly publicized environmental impacts with potential health consequences.[11,18] HVHF increases

environmental impacts with potential health consequences.[11,18] HVHF increases the amount of fresh water used by each natural gas well by as much as 100 times the quantity used in conventional drilling.[9] About 30%–50% of the fluids used in drilling return to the surface; these "flowback" and "produced" fluids may contain fracing chemicals, as well as heavy metals, salts, and naturally occurring radioactive material, from below ground. Therefore, this water must be treated, recycled, or disposed of safely (see discussion of wastewater below).[19] The initial drilling operation may consume up to 600,000 gallons of fracing fluids. Over its lifetime, an average well will require up to an additional 5 million gallons of water.[8,20] It should be noted that this is a consumptive water loss, meaning that unlike water from the shower or from a toilet, most of this water is not returned to the water cycle. Especially in areas with limited water resources, the impact of HVHF on the quantity of surface water available for other uses related to public health is a concern.

The chemicals and proppants that are added to the water used in HVHF have raised public health concerns related to surface and groundwater quality (as well as air emissions and occupational exposures, as discussed below).[2,21] Chemical additives used in fracturing fluids typically make up less than 2% by weight of the total fluid.[22] Over the life of a well, this may amount to 100,000 gallons of chemical additives. These additives include proppants, biocides, surfactants, viscosity modifiers, and emulsifiers. The chemicals vary in toxicity; some are known to be safe. However, others are known or suspected carcinogens, endocrine disruptors, or additives otherwise toxic to humans, including silica, benzene, lead, ethylene glycol, methanol, boric acid, and gamma-emitting isotopes.[22] Manufacturers of fracing fluids are allowed to protect the precise identity and mixture of the fluids under "proprietary" or "trade secret" designations. From a public health perspective, this prevents the establishment of baseline levels of a substance prior to hydraulic fracturing and documenting changes. Without this information, it is difficult to apprise the drilling contractor and the public of potential health hazards. Not knowing the components of the fluids or the mixtures inhibits testing for their presence. Drilling contractors may be expected to inject fluids containing unknown chemicals about which they may have limited understanding of the risk posed to human health and the environment.

How wastewater is handled and treated is another concern related to water quality. The disposal method of the "produced water" and brine extracted from the shale has the potential to affect the water quality of lakes, rivers, and streams; damage public water supplies; and overwhelm public wastewater treatment plants.[23] Underground injection has traditionally been the primary disposal option for oil and gas produced water.[24,25] Underground injection of wastewater began in the 1930s. Most of the early injection wells were oil production wells converted for wastewater disposal.[24] Produced water also has been treated in self-contained wastewater treatment systems at well sites and fields or through the local municipal wastewater treatment plants and commercial treatment facilities.[19] However, the quantity of wastewater needing treatment and the capacity of sewage plants to properly treat these wastes may be an issue in certain areas.[23] In some areas, wastewater has been sprayed on roads, raising concerns about contamination of surface waters.

The potential for HVHF to cause methane to seep into drinking water supplies has received considerable media attention.[9] A recent incident in Bradford County, PA, provides credence to the claim that an improperly constructed natural gas well could cause methane to migrate underground.[26] While many of the assertions regarding flammability of drinking and surface water have yet to be substantiated,

regarding flammability of drinking and surface water have yet to be substantiated, a study published by the National Academy of Sciences indicates that drinking water wells within a 1-km radius of a drilling site have 17 times higher concentrations of methane than wells outside of this radius.[15] The potential for health impacts from human exposure via drinking water is not well understood.[15,27]

Natural gas extraction is a historically dangerous industry for workers.[28] Many of the safety issues involved are well understood and regulated. However, the occupational health implications are less well understood. The rapid pace and geographic scope of expansion into remote locations inhibit monitoring of the drill sites to better understand and protect against the health risks involved.[29] There are also unique concerns associated with HVHF, such as the potential for exposure to unknown chemical constituents of fracking fluids. Another primarily occupational concern relates to the "frac sand" used as a proppant. HVHF operations typically involve hundreds of thousands of pounds of frac sand. Transporting, moving, and filling thousands of pounds of sand onto and through sand movers, along transfer belts, and into blenders generate dust containing respirable crystalline silica. The National Institute for Occupational Safety and Health (NIOSH) recently collected air samples at 11 different fracing sites in 5 different states (Arkansas, Colorado, North Dakota, Pennsylvania, and Texas) to evaluate worker exposure to crystalline silica.[30] At each of the 11 sites, NIOSH consistently found levels that exceeded relevant occupational health criteria (e.g., the Occupational Safety and Health Administration [OSHA] permissible exposure limit [PEL] and the NIOSH recommended exposure limit [REL]). At these sites, 54 (47%) of the 116 samples collected exceeded the calculated OSHA PELs; 92 (79%) of the samples exceeded the NIOSH REL. The magnitude of the exposures is particularly important; 36 (31%) of the 116 samples exceeded the NIOSH REL by a factor of 10 or more. Based on these results, hydraulic fracturing workers are potentially exposed to inhalation health hazards from dust containing silica. There may also be impacts on workers and communities affected by the vastly increased production and transport of sand for HVHF. Inhalation of fine dusts of respirable crystalline silica can cause silicosis.[31] Crystalline silica has also been determined to be an occupational lung carcinogen.[32] NIOSH concluded that there continues to be a need to evaluate and characterize exposures to these and other chemical hazards in fracing fluids, which include hydrocarbons, lead, naturally occurring radioactive material, and diesel particulate matter.[30,33]

HVHF has significant potential to impact local and regional air quality. Given the number of diesel engines used on site and truck trips required to haul equipment and supplies, air quality on and around these wells pads is likely to be affected. Levels of ozone (including wintertime ozone), PM10, and PM2.5 have been found to be elevated near gas activity.[33] Wintertime ozone caused by the release of volatile organic compounds (VOCs) mixed with conditions of sunlight and snow cover has been noted in Utah, New Mexico, and Wyoming. Hydrocarbon emissions from gas drilling activity have also been shown to be high in Colorado, where researchers found that twice as much methane was being leaked into the atmosphere from oil and gas activity than was originally estimated.[34] One study showed that residents living near well pads have a higher risk of health impacts from air emissions than those living further away.[35]

Noise and light have been cited as a health concern for residents and animals living near drilling operations.[17,36] Excessive and/or continuous noise, such as that typically experienced near drilling sites, has documented health impacts.[37] According to community reports, some nearby residents may experience deafening

noise; light pollution that affects sleeping patterns; noxious odors from venting, gases, and standing wastewater; and livestock impacts.[38] Both noise and light can contribute to stress among residents.

In addition to these environmental health threats, the rapid socioeconomic changes, scale of development, and pace of extraction made possible by HVHF present both direct and indirect health challenges. HVHF has the potential to significantly change the nature of communities, particularly rural communities.[39] There have been reports of increased crime in areas with an influx of natural gas workers.[31,40] A study conducted by the County Commissioners Association of Pennsylvania revealed that the state, among other concerns, was experiencing deficits in emergency management and hazardous materials response planning in drilling areas; courts and corrections impacts; human service burdens in areas such as drug and alcohol, domestic relations, and children and youth; and effects on affordable housing.[41] The stresses of social change, uncertainty, isolation, inadequate housing and infrastructure, and substandard services feed into the fear associated with an incoming industry such as that of natural gas.[38] Chronic psychological stress has been linked to respiratory health, both independently and in combination with air pollution exposures.[42] Therefore, social stressors, such as those seen with the changes that natural gas drilling brings to an area, may have a cumulative wear-and-tear effect on individuals' emotional and psychological well-being that is difficult to quantify but significant.

Thus, while natural gas extraction is a long-standing and important part of our nation's energy portfolio, the rapid implementation of large-scale HVHF in many parts of the country presents a new industrial, environmental, and land use development pattern with significant potential for public health and environmental effects. Public health professionals have voiced concerns about the rapid expansion of HVHF, both in communities with a long history of natural gas development and those with a more limited history.[12,13] In summary, the overall process of shale gas development made possible by unconventional approaches presents a wide range of potential environmental health concerns, including:

1. Groundwater: Underground water reserves, aquifers, and groundwater may be affected, altered, or contaminated by fracing fluids or mobilization of naturally occurring minerals, gases, or radiation.

2. Surface water pollution: Spills or improper disposal of waste or fracing fluids, erosion of soil during drill pad construction or operation, or runoff carrying leaks from machinery may pollute local surface water.

3. Wastewater treatment: Few municipal wastewater treatment plants have the capacity to properly treat produced fluids. In certain locations, deep well injection of waste fluids into class II injection wells has been implicated in inducing earthquakes.

4. Water resources: Using large volumes of fresh water for HVHF may consume a scarce commodity needed for agriculture, recreation, wildlife, environmental recharge, and drinking water supplies.

5. Air pollution: Fugitive emissions of hydrocarbons from well heads, silica sand from open frac fluid mixing stations, particulate matter emissions from machinery at drill sites, incomplete combustion from flaring, gases (e.g., VOCs and other hazardous air pollutants) from compressor stations, and the cumulative impacts

from diesel trucking may pose occupational health risks and contribute to local and regional air pollution.

6. Noise and light pollution: During drilling operations, noise and light may affect nearby residents and communities (e.g., schools), as well as domestic, farm, and wild animals. Increased truck traffic in small communities may also create nuisance levels of noise and vibrations.

7. Community wellness and mental health: Rapid social and economic changes; impacts on infrastructure, schools, jobs, and housing; and effects on the local/regional economy have the potential to cause increased stress and negative impacts on the quality of life in communities.

8. Occupational health: Gas extraction is a historically dangerous industry. Although worker safety hazards are known and understood, there are very limited data regarding occupational health hazards from exposure to the chemicals, proppants, and processes used in HVHF.

9. Local public health and health care system effects: A rapid increase in natural gas development in rural communities may result in sudden population growth, changes in the needs of the population (e.g., increases in sexually transmitted infections), and the need to deal with concerns brought in about exposure from drilling operations that overwhelms existing public health and health care systems.

10. Emergency response systems: Both the number and nature of emergency response resources needed in local communities may increase due to accidents, blowouts, or spills, both at drilling sites and during transportation of supplies and waste through rural communities. Some areas have reported inadequate emergency medical service [EMS] training and communication between drilling operators and emergency responders. Pipeline construction and maintenance is a security and safety issue that transcends state borders.

While instances of health problems have been reported in various communities where HVHF has occurred across the country, to date there has been little peer-reviewed literature on the nature or extent of these impacts. This dearth of research is due to the limited number of years HVHF has been in use and to challenges in studying health impacts. These challenges include the lack of identified unique health indicators, latency of effects, limited baseline and monitoring data, low population densities in many affected areas, and, in some cases, industry practices and nondisclosure agreements that limit access to relevant information. Understanding of health effects is further complicated by the variations in HVHF operations geographically and over time. These challenges to research are unlikely to be overcome in the immediate future. However, an increasing number of case reports, agency documents, and environmental models suggest that this process presents unique and significant health concerns.

Proposed Recommendations Statement

Despite the uncertainties surrounding the nature, distribution, and extent of health effects from HVHF, the public health community has an important role to play. Based on past experiences with emergency response, offshore oil and gas production, nonpoint sources of air and water pollution, and occupational health, public health professionals have a wealth of experience relevant to various aspects of HVHF. However, as of 2012, public health professionals have had a limited role

in policy-making, regulatory, and planning decisions regarding HVHF. Public health professionals should actively engage in the full range of decisions relevant to HVHF, from education of health care providers and local health departments to local land use policy, administrative and budgetary decisions, and state and federal air and water quality policies. Policies that anticipate potential public health threats, use a precautionary approach in the face of uncertainty, provide for monitoring, and promote adaptation as understanding increases may significantly reduce the negative public health impacts of this approach to natural gas extraction.

1. National energy policy: HVHF vastly increases the potential for extraction of domestic (as well as global) natural gas. Policies regarding HVHF should explicitly compare tradeoffs among the economic, strategic, public health, and global climatological implications of energy alternatives under different extraction scenarios over the long term. In accordance with APHA policies 20078 and 2004-06, policies with respect to domestic natural gas production should minimize the nation's greenhouse gas emissions.

2. Planning for variability, uncertainty, and change: Geological, geographic, climatological, technological, economic, social, and political differences between communities in which HVHF occurs result in widely varied potential for human health impacts. The public health community should advocate for planning and policy approaches that take into account this variability.

3. Promoting the role of public health professionals: Natural gas development is regulated under local, state, and federal land use and environmental laws. However, implementing new natural gas extraction technologies on a large scale poses potential public health threats that may not be adequately anticipated by, monitored for, or protected against by existing regulatory systems. Therefore, it is essential that public health professionals be included in deliberation of administrative, programmatic, and policy approaches to natural gas extraction at all levels of government.

4. Promulgating regulations that account for cumulative impacts and aggregate multiple sources: Individual drilling operations may not create air emissions that trigger regulation under existing environmental laws. However, the cumulative impacts of emissions may create significant public health threats for local communities or regions. Therefore, projections of aggregate emissions under expected extraction scenarios should be the basis for regulation of individual sources. Overall density and projected development over time should be considered. "Loopholes" exempting natural gas development from federal and state environmental regulations should be closed, including the Clean Water Act; the Clean Air Act; the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA); the Resource Conservation and Recovery Act (RCRA); the Toxic Release Inventory under the Emergency Planning and Community Right-to-Know Act (EPCRA); and the National Environmental Policy Act. In addition, the 2005 Energy Policy Act prevents the use of the Safe Drinking Water Act to regulate HVHF.

5. Protecting workers' health: The implementation of new natural gas extraction technologies, continual changes in the gas development industry, rapid growth of drilling operations in new areas, and variations in operations between companies pose significant challenges for occupational health. In accordance with APHA Policy No. 20106, training of local health departments, health care providers, and occupational health centers and open ongoing communication between health

occupational health centers and open ongoing communication between health professionals and the gas extraction industry are essential to protecting worker and public health.

6. Building public health capacity to monitor, regulate, and respond to HVHF in local communities: The public health workforce should be better educated about natural gas development and its potential for public health impacts. Particularly, those local public health agencies in areas of active natural gas development should receive adequate resources to support education, outreach, surveillance and monitoring, needs assessment, and prevention activities related to natural gas extraction.

7. Adopting regulations that take a precautionary and adaptive approach: Given the many uncertainties regarding the long-term environmental health impacts of HVHF, a precautionary approach should be adopted:
• In accordance with APHA Policy No. 200011, use of chemicals with unknown health effects, particularly those with the potential for long-term and endocrine-disrupting potential, should be discouraged.
• Gas development companies should be required to disclose and receive approval of the chemicals proposed in each HVHF operation (see APHA Policy No. 2002-5).
• Consistent with APHA Policy No. 20038, baseline monitoring of air quality, water quantity and quality, land resources, and human health should be conducted before drilling begins and continued throughout and after extraction operations cease.
• Development should proceed at a scale and pace that allow for effective monitoring, surveillance, and adaptation of regulation to anticipate/prevent negative health effects.
• Should negative health/environmental effects be observed, development/extraction should cease until further evidence indicates that operations can resume safely.
• Health impact assessments should be conducted at a local and regional scale prior to expansion of new approaches to natural gas development.
• More research is needed on the potential for seismic effects of disposal wells.

8. Conducting additional research: Research, modeling projections, education, monitoring, and assessment are needed on public health issues associated with shale gas extraction. Public health professionals should call on gas development companies, government agencies, and communities to share data on an ongoing basis and support additional research.

Opposing Arguments/Evidence

The natural gas industry argues that HVHF complies with existing laws and that negative public health impacts have not been conclusively shown. Many disagreements about the impacts of HVHF are due to differences in how HVHF is defined. If the definition of HVHF is restricted to the technological process of hydraulic fracturing of wells, this evidence of and potential for harm is limited. However, looking at the broader impacts of natural gas development made possible by HVHF (aggregate impacts on air, water, and communities), a wider spectrum of health problems are relevant. HVHF compliance with existing law does not guarantee that the public's health is protected should the activities be exempt or if they were not anticipated at the time of the development of the current laws and regulations. The new scope, scale, and technologies associated with HVHF have impacts not anticipated by existing laws and require new regulations and monitoring systems in order to protect public health.

monitoring systems in order to protect public health.

In addition, proponents of hydraulic fracturing maintain that the natural gas produced will improve public health by replacing coal as a domestic energy source. It is likely that replacing coal with natural gas will improve some health outcomes for end users (for example, by reducing disease related to particulate emissions downwind from coal-burning power plants). However, it may increase air quality–related health problems in HVHF production areas.

Researchers have come to different conclusions about the life-cycle greenhouse gas emissions of coal versus shale gas production. These disparities in findings stem largely from varying assumptions about how much methane escapes from gas activities and how best to calculate its life cycle in the atmosphere. Future monitoring and research may clarify the relative greenhouse gas emissions of coal and natural gas over the full life cycle of production, transportation, and use.

Action Steps

For each step recommended above, we indicate actions that should be taken, and by which external entities, to ensure that the strategy is promoted and implemented. Many new state and federal laws and regulations related to HVHF are currently being considered.[36,43] This list of actions and principles is intended to guide a public health–protective approach to regulating HVHF and should be updated as research and policy evolve.

1. National energy policy: The administration and the Department of Energy should model and include the implications of HVHF with respect to long-term greenhouse gas emissions in national energy policies.

2. Planning for variability, uncertainty, and change: All agencies at the federal, state, and local levels should share data and analyses of experiences with HVHF in other locations but should account for known local differences and the uncertainties resulting from variations in geography and other factors.

3. Increasing the role of public health professionals in policy-making, managing, and monitoring: Federal, state, and local commissions and agencies charged with regulating the natural gas industry should include strong representation by professionals with training and experience in public health. In addition, the role of local and state public health professionals in responding to public health concerns arising from HVHF should be recognized and supported accordingly.

4. Promulgating regulations that account for cumulative impacts and aggregate multiple sources: State and federal environmental regulations should be amended to close loopholes exempting natural gas activities, mandate aggregation of drilling operations within a set distance of each other as a single source under Clean Air Act regulations, and base emissions regulations on models of cumulative impacts under expected development scenarios.

5. Protecting workers' health: Companies involved in HVHF should provide training for workers and local health care providers. Industry should pay for additional monitoring, training, enforcement, and health care provider needs.

6. Building public health capacity to monitor, regulate, and respond to HVHF in local communities: Federal and state legislatures should provide adequate funding for the training and staffing of local public health agencies in areas of active

natural gas development.

7. Adopting regulations that take a precautionary and adaptive approach: Federal, state, and local environment, health, and development agencies should adopt a precautionary and adaptive approach in the face of uncertainty regarding the long-term environmental health impacts of HVHF.

8. Conducting additional research: The National Institutes of Health, the

Environmental Protection Agency, and other federal agencies should fund applied research, including health impact assessments, on the projected impacts of HVHF and potential mitigating approaches.

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