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Applying the hierarchy of controls to oil and gas development

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1. Introduction

The growth in the oil and gas development (OGD) industry has placed millions of United States (US) residents in the path of multiple hazards associated with OGD operations. In 2020, nearly 1000 000 oil and gas wells were in operation (United States Energy Information Administration (USEIA) 2022), and a 2017 analysis estimated that 17.6 million US residents lived within 1600 m (1 mile) of an active oil or gas well (Czolowski *et al* 2017). Evidence continues to mount that OGD contributes to air pollution, water contamination, noise, psychosocial stress, and health risks (Johnston *et al* 2021, Deziel *et al* 2022a). Policy makers, public health scientists, regulatory agencies, community leaders, industry, and the public continue to grapple with how to best protect communities affected by OGD hazards. In this commentary we offer a hierarchy of controls framework for weighing which approaches or combination of approaches would most effectively reduce the public health impacts of the OGD industry, with particular consideration of nearby communities.

2. The hierarchy of controls

The concept of hierarchy of controls originated from the fields of occupational health and industrial hygiene to prioritize mitigation strategies from the most to the least effective at reducing hazards to workers (National Institute of Occupational Safety and Health (NIOSH) 2015). This hierarchy is based on the premise that the best way to control a hazard is to eliminate it, and the least effective is to rely on individuals to wear protective gear. In practice, regulators and risk managers can increase protections by employing a layered or 'defense in depth' approach incorporating multiple actions, rather than selecting a single strategy (Chierici *et al* 2016).

The levels from the original occupational health framework (from the most to least protective) are (a) elimination (removal of the harmful substance or process altogether); (b) substitution (replacement with a less hazardous alternative); (c) engineering controls (the hazard remains but technology is used to limit its release or intensity); (d) administrative controls (policies that try to alter behavior to limit contact with a hazard, such as signage or limiting time spent in a hazardous area); and (e) personal protective equipment (PPE) (e.g. requiring individuals to wear clothing or equipment, such as masks, to create a barrier between the person and the hazard) (NIOSH 2015).

Extending this framework to environmental and other public health hazards offers great utility for guiding policy makers and communicating risk management strategies. In figure 1, we adapt the hierarchy of controls to reduce human health hazards, risks, and impacts from OGD activities. In contrast to the original framework, which was designed for specific hazards in workplaces, adaptation of this hierarchy to OGD reveals important distinctions when managing a complex multi-hazard source that poses threats to community members. Below, we describe the controls deployed at each level of protection in the hierarchy.

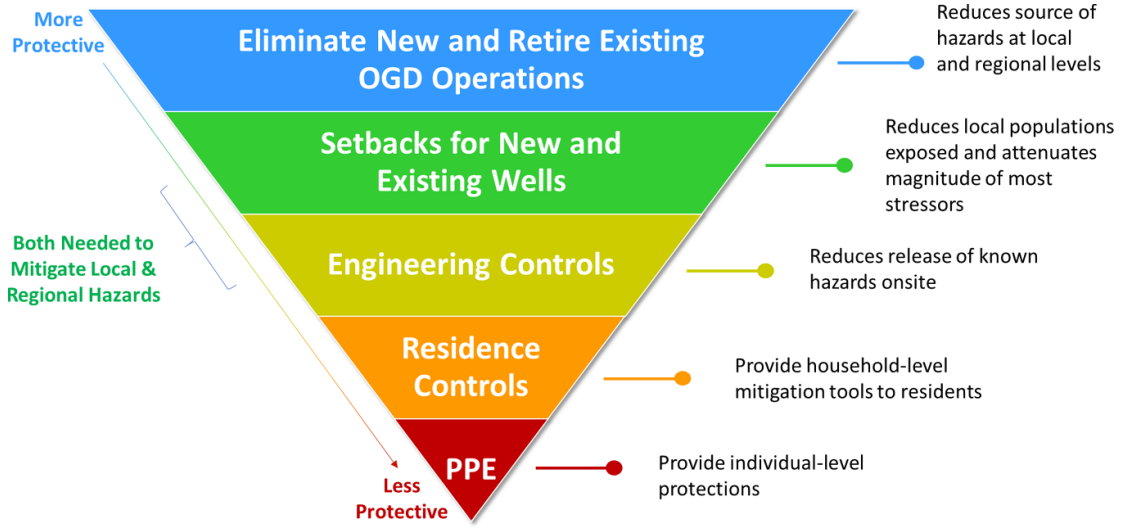

Figure 1. Hierarchy of controls to reduce public health harms from oil and gas development (OGD) activities. PPE: personal protective equipment.

2.1. Eliminate new wells and phase out existing oil and gas wells

At the top of the inverted pyramid of figure 1 is the most health protective strategy: to stop development of new oil and gas wells and phase out existing OGD activities and infrastructure with proper well plugging and environmental remediation. Placing a halt on new oil and gas wells is classified as elimination because it completely removes the hazard. Properly plugging and remediating legacy wells and ancillary infrastructure is considered substitution because the idled wells remain, but in a modified form to enhance safety.

Although most effective at protecting health, complete elimination represents a systemic shift from the status quo with substantial political, socioeconomic, and logistical ramifications. Despite these challenges, examples of elimination are occurring throughout the US. Unconventional OGD (i.e. hydraulic fracturing or 'fracking') has been eliminated in Vermont, Maryland, New York, and Washington, states which vary in available reserves. The Delaware River Basin (DRB) Commission prohibited fracking in the DRB region, which covers parts of New York, Pennsylvania, New Jersey and Delaware, in order to protect drinking water (Delaware River Basin Commission (DRBC) 2021). Because these bans are specific to fracking, they do not eliminate conventional wells or orphaned and abandoned wells. However, some municipalities are moving towards complete OGD elimination, including Los Angeles, which has approved a ban of all new conventional and unconventional oil and gas wells and a phase-out of existing wells (Los Angeles Times 2022). In addition, the bipartisan infrastructure bill passed in November 2021 allocated $4.7 billion to plug abandoned oil and gas wells across the nation (Department of Interior 2021).

2.2. Setbacks for new and existing wells

Setbacks can include the restriction of new wells and phase out of existing wells and ancillary infrastructure within health science-informed distances from sensitive receptors. Sensitive receptors include homes, schools, and other places where people live, work, and play. The utility of setbacks is based on the premise that the multiple hazards associated with OGD operations attenuate with distance, such as noise (Lamancusa 2000), odors, and health-damaging air pollutants (Turner 2020, Gonzalez *et al* 2022), and impacts to aquifers that are used for drinking water and agricultural irrigation (Domenico and Robbins 1985, Garcia-Gonzales *et al* 2019, Soriano *et al* 2020). In this application, setbacks can be considered a combination of elimination and administrative controls. Setbacks are less effective at removing exposure pathways than complete elimination because they allow OGD activities to continue. Similar to administrative controls in the occupational setting, which can limit the amount of time a worker spends in a hazardous environment (i.e. shortened shifts), people may still spend time in the setback area but less time than they would if they resided or attended school within the setback zone. To maximize effectiveness, setbacks should apply to both the OGD site and to new construction of housing or schools, the latter of which could be constructed near existing OGD wells (also referred to as a reverse setback). Additionally, exposure and health data to inform local and regional setback distance choice is limited. Because hazards attenuate at different functions of distance, it is challenging to establish

a universal setback that optimally addresses all hazards. Furthermore, because setbacks do not eliminate OGD activities, regional hazards remain. For example, setbacks do not protect against the release of fine particulate matter ($PM_{2.5}$), nitrogen dioxide (NO_2), and volatile organic compounds (Gonzalez *et al* 2022), all of which contribute to formation of secondary pollutants such as ozone or secondary particulate matter at locations far from OGD operations. Setbacks also do not prevent the release of methane or other greenhouse gases that contribute to climate change, which indirectly introduces human health risks at local to global scales. Finally, increasing distance between OGD activities and human residential communities could place OGD infrastructure closer to wildlife communities, thereby shifting the burden to ecological rather than human health impacts (Deziel *et al* 2022b). To date, 23 states have adopted or are considering setbacks that vary widely and range from 100 ft (e.g. Arkansas and New York) to 3200 ft (California) (Ericson *et al* 2020). These distances often reflect a compromise among multiple stakeholders and include both economic and public health considerations, and therefore do not generally protect public health adequately (Haley *et al* 2016).

2.3. Engineering controls

In this framework, engineering controls include deployment of technologies to capture or reduce hazards at the source, monitoring to rapidly detect leaks, and the timely repairing of new and existing wells and ancillary infrastructure. Engineering controls are typically ranked higher in the hierarchy because they can control the hazard at the source. However, in the case of OGD, we ranked engineering controls lower in the pyramid because OGD is a complex source of many potential hazards. Consequently, reliance solely on engineering controls to manage risk requires knowledge of all the hazards, availability and implementation of methods for controlling the hazards, and technologies for monitoring the effectiveness of the controls. Engineering controls could include technologies such as noise and air pollution emission mitigation controls on OGD infrastructure (e.g. sound walls, capture of emissions), particularly for those oil and gas wells nearest to residential sites and schools, and for processes associated with the highest emissions or leaks.

Leak detection and repair (LDAR) technologies have advanced in recent years (e.g. optical gas imaging) and can be effective at identifying points of air emissions releases of methane and other pollutants (Ravikumar *et al* 2020). Control for greenhouse gases such as methane may concurrently reduce co-emitted toxic or malodorous chemicals and vice versa. An example was the observed co-benefit of methane emission reduction after controlling for olfactory compounds in Alberta, Canada (Lavoie *et al* 2022). However, not all infrastructure that emits health-damaging air pollutants is methane rich and as such, LDAR focused on methane may not effectively control emissions of air toxics. Further, engineering controls can fail, and such solutions may not be available or economically feasible to handle all the complex hazards associated with OGD. Further, while the epidemiological literature clearly demonstrates that OGD is associated with multiple adverse health outcomes, such as adverse birth outcomes, respiratory disease, and mortality, the hazards and exposure pathways that contribute to these outcomes remain unclear (Li *et al* 2022, Deziel *et al* 2022a). Consequently, the effectiveness of mitigating health risks through engineering controls alone may be limited if the technologies do not control for uncharacterized hazards or exposure pathways.

2.4. Residential controls

Residential controls entail providing households with technologies and approaches to reduce hazardous exposures at home or other sensitive receptor areas, such as schools. Such controls can include water filters, light-blocking shades, sound-blocking windowpanes, air filters, and improved ventilation systems. These strategies are situated in the hierarchy between engineering controls and PPE. These protections, if used and maintained properly, may be effective at removing or reducing certain hazards indoors, where people spend a lot of time. However, this approach does not eliminate OGD hazards at the source, instead placing the burden on residents to use and maintain their own equipment. Furthermore, a complex array of devices would be needed to address the numerous known and potential hazards associated with OGD that could penetrate the home and other indoor environments. Like setbacks, residential controls do not address release of pollutants contributing to poorer regional environmental quality or climate change.

2.5. PPE

Use of PPE involves the provision of devices to reduce an individual's exposure, such as respiratory masks, ear plugs, and eye masks. PPE is the last layer of defense because it does not control the hazard. If the PPE fails, is in poor condition, worn improperly, or not worn consistently, individuals may be exposed. There is no PPE that can feasibly protect individuals against the full range of potential hazards associated with OGD. Additionally, like setbacks and residential controls, PPE does not address regional pollutant and climate change hazards.

3. Recommendations

In table 1 we summarize the advantages and disadvantages of each control type. Based on the hierarchy of controls, the most effective strategy for protecting communities from the hazards of OGD would be to

Table 1. Advantages and disadvantages of oil and gas development (OGD) control strategies from an environmental public health perspective.

Control Strategy	Description	Advantage	Disadvantage
Elimination	Eliminate new wells, properly plug existing wells, and remediate ancillary infrastructure.	Eliminates the source of nearly all environmental stressors (e.g. air and water pollutants, noise); protects local and regional populations; largest reduction in carbon emissions	May require a long-term approach due to economic, legal, political dynamics and energy reliability considerations, the need to address both conventional and unconventional wells, and the unknown location of many abandoned wells.
Setbacks	Establish a protective buffer zone between OGD hazards and sensitive receptors.	Reduces risk of exposures to populations living near OGD sites; environmental stressors are generally attenuated with increasing distance.	Setbacks alone without coupled engineered mitigation controls allow continued release of hazards. There is no universal setback that would adequately address regional air quality issues and emissions of climate-warming gases from OGD.
Engineering controls	Reduce or eliminate release of specific environmental hazards on site.	Reduces or eliminates certain hazards and therefore can have local and regional environmental public health benefits.	Tends to be disproportionately focused on air pollutant emissions and noise, and thus fails to address other pathways of exposure, including via water resources. Often not feasible to apply engineering solutions to multiple, complex hazards each requiring different control technologies (e.g. noise, air and water impacts, odors, light pollution) and lacks the important factor of safety provided by a setback when engineering controls fail.
Residence controls	Households deploy devices and strategies to reduce exposure to indoor environmental hazards at the household/school- level (e.g. water filter, light-blocking shades, air filters).	Reduces intensity of certain hazards to nearby communities at the household level.	Places burden on individuals and households to use and maintain devices properly to maximize effectiveness. Not feasible to apply devices to address numerous, complex stressors. Does not adequately address impacts of ambient air pollutant and greenhouse gas emissions from OGD on regional air quality and the climate.
Personal protective equipment	Individuals wear protective equipment to reduce exposure to environmental hazards (e.g. respiratory masks, ear plugs, eye masks).	Reduces intensity of exposure of certain hazards to nearby individuals.	Places burden on individuals to use PPE consistently and properly. May not be feasible for understudied stressors or certain environmental toxicants. Does not address impacts of air pollutant and greenhouse gas emissions from OGD on regional air quality and the climate.

eliminate all new OGD and ensure the proper plugging, decommissioning, and remediation of existing oil and gas infrastructure. However, complete elimination poses near-term challenges due to socioeconomic, energy reliability, and political considerations and therefore may require a long-term approach. In the near term, reasonably protective strategies include the layering of setbacks and engineering controls, because neither alone adequately protects populations from OGD hazards and risks. We encourage the integrated deployment of these approaches to align with the best available science and technology. Additionally, evidence-based decision-making could be improved by new research designed to elucidate the relative importance of OGD-related hazards or exposure pathways and how to mitigate them.

OGD presents a challenge for regulators due to its many hazards with varying spatiotemporal scales, dispersion patterns, and monitoring and mitigation approaches. In this application, we reached two conclusions regarding the management of risks from OGD: (a) that our modified hierarchy of controls is a useful decision-making framework that could readily be adapted to other environmental hazards; and (b) that the application of near-term and long-term approaches in this hierarchy is needed to address OGD hazards more adequately and better protect community health.

Data availability statement

No new data were created or analyzed in this study.

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