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Unconventional natural gas development and public health: toward a community-informed research agenda

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Abstract

Unconventional natural gas development (UNGD) using high-volume horizontal hydraulic fracturing (“fracking”) has vastly increased the potential for domestic natural gas production in recent years. However, the rapid expansion of UNGD has also raised concerns about its potential impacts on public health. Academics and government agencies are developing research programs to explore these concerns. Community involvement in activities such as planning, conducting, and communicating research is widely recognized as having an important role in promoting environmental health. Historically, however, communities most often engage in research after environmental health concerns have emerged. This community information needs assessment took a prospective approach to integrating community leaders' knowledge, perceptions, and concerns into the research agenda prior to initiation of local UNGD. We interviewed community leaders about their views on environmental health information needs in three states (New York, North Carolina, and Ohio) prior to widespread UNGD. Interviewees emphasized the cumulative, long-term, and indirect determinants of health, as opposed to specific disease outcomes. Responses focused not only on information needs, but also on communication and transparency with respect to research processes and funding. Interviewees also prioritized investigation of policy approaches to effectively protect human health over the long term. Although universities were most often cited as a credible source of information, interviewees emphasized the need for multiple strategies for disseminating information. By including community leaders' concerns, insights, and questions from the outset, the research agenda on UNGD is more likely to effectively inform decision making that ultimately protects public health.

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Introduction

Over the past decade, new technologies have resulted in the rapid expansion of unconventional natural gas development (UNGD) in the US (1, 2). UNGD, which includes high-volume horizontal hydraulic fracturing (“fracking”), consists of extracting natural gas by injecting large volumes of fluids into shale formations. These fluids contain water, proppants, and chemicals like acids, biocides, scale inhibitors, friction reducers, and surfactants. Public attention initially focused on the implications of UNGD for domestic energy production, economic development and environmental change, but concerns have been raised about its potential impacts on human health (3–10). Researchers, decision makers, and community members have called for research to address the many uncertainties about the potential public health impacts of UNGD. In this review, we analyze these community leaders' concerns about the potential health impacts of UNGD in three eastern states, the implications for setting a research agenda that informs health-protective decision making, and effective strategies for communicating environmental public health information to affected communities.

UNGD has made it possible to extract natural gas from previously inaccessible shale formations (1). Some of these formations, like the Marcellus Shale in the northeastern US, lie in regions with limited recent experience of local gas development. The rapid expansion of UNGD has the potential to affect land use patterns as well as the economies and communities in these regions. In our assessment of community concerns and information needs, we included not only local impacts directly related to the drilling process, but also potential indirect impacts related to UNGD.

Although many communities welcome the economic growth spurred by UNGD, uncertainties about health risks have contributed to conflict, concern, and stress in some areas facing rapid growth of UNGD (11–15). Some UNGD advocates argue that it will yield health benefits due to improvements in air quality from decreased reliance on coal, and also as a result of communities' improved economic status and increased health resources. However, others contend that the process of extracting natural gas from shale deposits can result in a wide range of direct and indirect public health impacts. Universities, government agencies, and non-profit organizations are currently striving to prioritize and address these uncertainties through relevant research (3, 10).

The National Institute of Environmental Health Sciences (NIEHS) supports environmental health sciences research centers at 21 US universities, each of which has a Community Outreach and Engagement Core (COEC) responsible for promoting multidirectional communication among environmental health researchers and communities. In an effort to initiate community input into the rapidly-evolving research agenda on public health and UNGD, COECs from the University of Rochester, the University of Cincinnati, and the University of North Carolina conducted community information needs assessments in their

respective regions. At the time this assessment was conducted, each of these states (New York, North Carolina, and Ohio) was facing the potential for rapid expansion of UNGD, although Ohio was the only state with active drilling.

We interviewed local community leaders about their concerns regarding the potential health impacts of UNGD, their priorities for public health research, and insights into how ongoing research can produce credible and useful public information. In seeking to understand community leaders' perspectives in areas where UNGD was expected to expand in the future, we aimed to prospectively inform research agendas on public health and UNGD. We also explored whether community leaders' concerns varied according to their region, role in the community, or position (supportive, opposed, or neutral) on UNGD. In the course of the assessment, we gained insight into the processes through which we can engage communities and share information on an ongoing basis as research on UNGD proceeds.

Approach

We conducted 43 in-depth interviews with community leaders in the three states, focusing on community leaders, professionals, and local residents who had educated themselves about the prospect of UNGD in their regions. Interviews were conducted in 2012 and 2013, at which time UNGD had not begun in New York or North Carolina, but was expanding rapidly in parts of Ohio. A total of 48 people were interviewed (five of the interviews included two interviewees each) with 16 interviews in New York, 13 interviews in North Carolina, and 14 interviews in Ohio (Table 1). Interviews were conducted in-person or via telephone; interviews lasted up to 75 minutes and were audio-taped. The audiotapes were transcribed verbatim and coded using pre-established categories related to health concerns, research needs, information sources, and emergent themes (16–18). Transcripts were coded by two members of the research team, and differences were reconciled through discussion among the entire team. Study procedures were approved by the University of Rochester's Research Subjects Review Board (RSRB 00044034 and RSRB 00044143) and exempted from further review by the Institutional Review Boards at the University of North Carolina at Chapel Hill (IRB 12-2049) and the University of Cincinnati (IRB 2012-3161).

Initial interviewees were identified through the COECs' existing networks of community partners. This was followed by snowball sampling, in which participants were asked to suggest other interviewees who might have held different views on the prospect of UNGD in their region. Our goal was to elicit perspectives of diverse community leaders who were engaged in the issue, rather than seek a representative sample of the lay public. We included a wide range of stakeholders because we expected participants' concerns to vary based on their experiences and attitudes toward UNGD.

Analysis of transcripts indicated that saturation was reached with respect to key themes. Descriptive categories were assigned to identify participants' roles and their positions on UNGD, relying primarily on participant self-categorization (Table 1). Interviewees' self-described roles were categorized as follows: citizens/landowners (CL), environmental groups (EG), local government organizations (LGO), outreach and education professionals (OE), and public health professionals (PH). The LGO group included local government

staff, elected officials and Chamber of Commerce members. Outreach and education professionals included cooperative extension staff, members of the media, and health educators. Note that each interviewee was assigned a single role, although it was clear that many people held several roles (e.g., citizen and professional). These categories were primarily used to describe the sample and provide context for interpreting qualitative comments.

We also categorized the interviewees by their self-described “position” (opposed, neutral or supportive) on the development of UNGD in their state (Table 2). Given that “positions” were self-described, interviewees with each “position” group may have held diverse views. For example, the majority of public health and outreach/education professionals were identified as neutral, despite reporting extensive concerns and uncertainties about UNGD. This may reflect their professional training, goals, and ethical commitment to objectivity. Interviewees' self-described position on UNGD helped identify patterns of responses for further qualitative analysis and future research.

Interviewers used a semi-structured interview guide. Participants were instructed to take a broad view of health effects of UNGD, including direct health impacts from drilling sites as well as other changes in the community and environment that they might expect if UNGD increased in their region. Interviewers asked participants to reflect on both the potential positive and negative health impacts of UNGD. The interview guide included questions regarding sources interviewees had used to seek information about health and UNGD, their dominant health concerns, priorities for research needs, and opinions about sharing future research findings. For each major topic of the interview guide, we coded and tabulated the most frequent responses by interviewees' state, position on UNGD, and role. These tabulations enabled us to identify patterns and guided subsequent qualitative analysis of interviewees' in-depth responses (Table 3).

Below, we present insights from our interviews, with particular attention to concerns unique to local community leaders. These perspectives may complement experts' assessments of health risks and research needs. We illustrate these perspectives using interviewees' own words through direct quotations and tables summarizing common responses.

Throughout our analysis, we considered the differing geographic, political, and economic context in each state. At the time of the interviews, New York had been engaged in a multi-year assessment process, but had not made a decision about permitting high-volume horizontal hydraulic fracturing. However, several southern counties in central/western New York State had experienced effects (e.g., increased traffic, housing demand, and growth of businesses) related to UNGD in the adjacent areas of Pennsylvania. In North Carolina, in July 2012, the General Assembly directed state agencies to develop regulations that would govern oil and gas exploration, including the use of horizontal drilling and hydraulic fracturing, by October 2014. UNGD has been expanding in eastern Ohio since 2011 in two shale plays, namely, the Marcellus Shale and the Utica Shale (18). Thus, although interviewees' direct experiences with UNGD varied, all lived in or were adjacent to states with active UNGD that had the potential for expansion into their own area in the near future.

Community concerns about UNGD and health

Interviewees reported a wide range of public health concerns related to UNGD, generally emphasizing determinants of health rather than specific disease outcomes. Participants noted concerns about exposures through air and drinking water, cumulative impacts, uncertainties, both short- and long-term effects, and the distribution of impacts on different subpopulations. Although a majority of comments addressed potential threats to health, a number of interviews also referred to positive impacts on health. Not surprisingly, those supportive of UNGD had the fewest health concerns and were most likely to highlight positive impacts. We coded and tabulated the most frequently cited health concerns according to interviewees' state, position, and role (Table 3). This table helped guide subsequent qualitative analysis of interviewees' in-depth responses. Below, we briefly discuss five of the most significant categories of health concerns, which emerged in the interviews, namely: water, air, quality of life, public health systems, and vulnerable populations.

Water quality and quantity

Most interviews (84%) mentioned potential impacts on water as a human health concern. As one interviewee said, *“There's a whole area of water concerns from start to finish with fracking and plenty of opportunity for things to go astray, for people nearby to really be impacted”*. Contamination of drinking water (particularly in private wells) dominated the comments about water quality, with interviewees describing numerous potential threats to ground-water, including well casing failures, injection wells, and migration of chemicals through naturally-occurring fissures in shale formations or abandoned wells. The interviewees also expressed concerns about the ability of the government to adequately monitor installation of casings, the longevity of casings, or other potential threats (e.g., earthquakes) to the integrity of casings. One interviewee mentioned the potential positive impact of increased drinking water well testing prior to UNGD, stating that baseline testing may reveal pre-existing bacteriologic contamination and result in the cleanup of wells that would not otherwise have been identified.

Interviewees from all three states mentioned potential impacts on surface water, including chemical spills and improper wastewater disposal. Even several of those who were strongly supportive of UNGD acknowledged the potential for accidents: *“I think that no one disagrees with the notion that if you're handling large volumes of toxic chemicals, at some point, some of it will be spilled somewhere ... So, that's one of the certainties.”* Threats to surface water also raised concerns about trans-boundary issues, that is, even if individual landowners, localities, or states banned or tightly regulated UNGD practices in their area, they might be affected by pollution from activities in nearby jurisdictions.

Insufficient information about the composition and fate of chemicals used in hydraulic fracturing was another concern commonly raised in the context of water quality. As one Ohio resident noted, *“When these folks [UNGD companies] first started drilling... they fought tooth and nail through the courts and did everything they could to deny public knowledge, access to the ingredients, the chemicals they were using in their drilling process...right from the get-go that worried me.”* Another Ohio interviewee added, *“The*

potential health effects to us right now are unknown, simply because we do not know the total makeup of the fracking fluid.” Many interviews also mentioned naturally occurring chemicals and radioactivity from deep underground, which might be brought to the surface in the form of flowback water. They also expressed concerns about how these chemicals might interact with chemicals used in hydraulic fracturing, and how chemical storage, transport, and treatment might affect the environment.

Potential impacts of contaminated water on agriculture and wildlife were mentioned in a number of interviews, with specific concerns related to human consumption of plants or animals that came in contact with hydraulic fracturing waste or flowback water. These concerns included the well-being of farm animals, the health of consumers, and the economic impacts on farmers as well as those who depend on income from hunting or fishing. As one New York interviewee noted, *“Fishermen and sportsmen ... are very much in favor of limiting the poisoning of the rivers and the forest because that impacts their ability to not only catch healthy fish but [to] eat healthy game and fish”*.

Over half of Ohio interviewees identified water quantity as a concern, likely related to the 2012 drought in that state. As one interviewee said, *“(With) the drought in Ohio... wells ran dry... they're looking for water to be piped in for drinking, and this much water is being destroyed to serve one industry.”* However, few interviewees from other states raised this concern.

Many of the health concerns about water contamination emphasized uncertainties related to latency and permanence of impacts. Several noted that because groundwater moved slowly, contamination might not be evident for decades. As one interviewee from Ohio said, *“I haven't heard enough conversation about the health effects, you know, from any of the areas that are drilling now. You know, that's a long-term thing. In other words, if I have a problem, you might not see the effects of it for 10 years.”* Others reflected on the production, storage, and treatment of waste products generated by the shale gas extraction process. The long-term nature of potential impacts clearly affected interviewees' opinions about whether further research or regulation could adequately address their concerns about water. A New York interviewee said, *“So you could see a political situation, where the state sets up a pilot project or something, and all the wells are done with extreme caution; everything seems fine, and then they start to ramp up the development, and 25 or 30 years down the road, you've got massive groundwater contamination.”* One interviewee from North Carolina noted, *“By the time we find out what's wrong – the harm – it's already going to be done... that's what to me is wrong about this whole thing is we're all being used as guinea pigs.”* This theme of latent impacts was connected to the concern that water contamination would be long-lasting and irreversible. As one North Carolina participant stated, *“Those wells are built to last 40 years, 60 years, but this groundwater resource has been there for millions of years. And it doesn't have any capacity to clean itself. And so if you punch a hole that is going to become a conduit for contamination... you're eliminating that future resource for generations and generations and generations.”*

Air emissions

Air quality issues were also commonly mentioned (in 79% of interviews), particularly evaporation of volatile chemicals from holding ponds and fugitive emissions from wells as well as diesel emissions from trucks, mechanical equipment, and compressor stations. Overall, 63% of interviews mentioned health concerns related to truck traffic, many of which included air quality concerns (as well as increased local traffic, accidents, spills, and road damage). As one public health professional from Ohio said, *“I think that’s what people complain about the most: the noise and the traffic. Your air quality starts to go down because you’ve got so much diesel in the exhaust.”*

Silica sand, which is transported to drilling sites for use as a proppant, was also mentioned as an air quality issue, particularly with respect to inhalation risks for workers and people living near sand mining, transport, or storage facilities. An Ohio interviewee said, *“There’s a place only a mile from where I live where they’re stockpiling a lot of this [silica sand]. And you get anywhere near there on the road and there are all sorts of sand on the road. We know that silica exposure could be detrimental...I know that a worker... gets exposed so badly that the best protection equipment doesn’t protect them adequately. So I do worry about what’s happening potentially locally around storage stock piles like this.”*

In addition to local concerns, cumulative and trans-boundary impacts of air pollution were also discussed. A municipal official in New York said, *“And there’s quite a bit of concern here about what wind will come our way and what water will come our way from that drilling outside of our borders.”*

A final issue mentioned in relation to air emissions from UNGD was climate change. As one North Carolina interviewee cautioned, *“The very fact that we’re taking this stuff out of the ground without doing it within the framework of a larger management of carbon is not sustainable, and is a public health threat.”* Others noted the possibility that UNGD could mitigate climate change by replacing coal with cleaner-burning, more efficient natural gas, yet others referred to models suggesting that the total greenhouse gas emissions produced by the UNGD process might exceed those of coal production.

Quality of life and economic issues

Over half of the interviews raised one or more health concerns connected with changes in quality of life they associated with UNGD. These included specific concerns like increased traffic, housing costs, and crime rates as well as more general comments about the impacts of “boom and bust” cycles of development and loss of “rural character.” In elaborating on these potential changes, a municipal official in New York referenced *“Huge increases in substance abuses that the hospitals see. Huge increases of sexually transmitted diseases. Increases in drinking and DWIs. Increases in road accidents, trucking accidents, car accidents, pedestrian accidents. Toxic substances. All of those are a health impact of a different sort and probably more immediately prevalent than these water and air things.”* An environmental advocate in North Carolina said, *“One of the things that you’d expect in a boom-bust economy is these floods of transitory migrant workers coming in—mostly men*

without their families with them—and... you get these sort of shocking statements about, 'well, what about the sex trade and the public health dimensions of that?'"

Other interviewees expressed concerns regarding increased community conflict and stress due to UNGD. Conflict was predicted between those who supported and opposed shale gas extraction and between those who did not lease mineral rights and those who signed leases and stood to profit from UNGD. A concerned citizen in North Carolina said, *"I guess we would call it the social side of this business...that's where you have adjacent landowners who may be very good friends or may even be family members and one chooses to participate and sign an agreement with the gas company and one chooses not to participate, but you know, the traffic affects both of them."* Some interviewees described such conflict as a threat to community members' mental health.

Most interviewees recognized that community changes could have both benefits for and negative impacts on public health, and that such impacts depended on the pace and management of drilling. However, there were different opinions about what the net impacts would be. In terms of benefits, a landowner in New York who was supportive of UNGD said, *"A healthy society is also a wealthy society. You know if business is here and would be doing well people can afford to go to the doctors, afford to go to the dentists and get good healthcare... you have community centers."* A supportive Chamber of Commerce member from Ohio added, *"It's just phenomenal because some of the companies that are coming to town of course initially bring their own people with them...so those folks are either staying in the hotels, but when the hotels fill up they are looking for homes to rent... and people are renting their homes for a very good price...so it really is a win-win for everybody."*

Interviewees also recognized that the changes brought on by UNGD would have varied effects on different members of the community. One Ohio landowner stated, *"That [increase in housing demand] is great for landowners who have rental property; for those people at the bottom of the socioeconomic scale, [it is] not so great."*

Public health and health care

Several interviewees referred to specific health outcomes of concern, including endocrine disruption, developmental disorders, cancer, respiratory disorders (COPD, asthma), birth defects and miscarriage, among others. However, more interviewees mentioned cumulative changes in the health care needs of the worker and local populations as well as the challenges these changes might pose to public health systems.

More than a third of interviews mentioned specific issues related to community health systems, including emergency management services, health care system capacity, new challenges to health care providers, and the limited resources of public health agencies. Specific concerns included the need for training emergency responders who can deal with new kinds of hazards like chemical spills, explosions, and radiation. There were some interviewees who raised questions about whether the drilling companies would give emergency responders sufficient information to know what hazards might exist. For example, an environmental group member in Ohio noted, *"We had a meeting with our emergency management people here...and they say they're working in the blind because*

they don't know what chemicals are there. Now they can try to figure it out, and they can call in and get the information, but in the meantime this spill that may have occurred is going into the ground, and they don't know what it is. And they don't know whether to go near it because they don't want to hurt their people either."

Several interviewees also raised concerns about the increase in occurrences of specific diseases and the burdens imposed by UNGD workers who do not have health insurance on local health systems. Concerns related to the demographics of the new workforce (anticipated to be young single males from out of state) included increased violence and alcohol-related accidents. Others noted occupational health issues, as exemplified by an Ohio physician who mentioned drilling workers, stating that *"They do require some extra medical attention."*

Many interviewees mentioned unique challenges to health care providers, including lack of knowledge of the kinds of chemicals to which workers and residents might be exposed. Pennsylvania's Act 13 regulation, which prevented physicians from sharing information about chemical exposures (commonly referred to as the "gag rule") was noted by interviewees in all three states (19). As a concerned citizen in New York said, *"The other thing that I can't but mention...that gag rule in Pennsylvania on the doctors, that puts up such a huge red flag...why are they imposing a gag rule on the doctors?"*

Respondents in New York and North Carolina highlighted the need to better engage the public health community in decisions about UNGD. A public health representative in North Carolina said, *"Our state health director has not been invited to sit on any research or any committees or legislative committees or rule-making committees. She's been left out."* Another North Carolina interviewee said, *"Almost all of the state and federal advisory bodies have paid almost no attention to making sure that public health is well-represented on any panels...that's pretty obvious it hasn't been taken seriously."*

Concerns were also voiced in all three states about the adequacy of regulations and the capacity of government agencies to monitor and enforce regulations. *"They are radically understaffed to send inspectors out to these wells, the fracking wells and the injection wells, to do any sort of credible job. So I'd say that's a pretty big question mark,"* said an Ohio interviewee. A landowner in New York who was supportive of UNGD showed more faith in the system, but still underscored the need for active enforcement, saying that *"We're not going to avoid some of those health risks. All we can do is hope that the DEC [New York State Department of Environmental Conservation] does their job in working with protections and inspections on these sites."* A final theme was coordination among agencies. As a public health representative in New York said, *"I don't know how much the different divisions and agencies are talking to each other, but I know I would like to see more communication [among them]."*

Vulnerable populations

Participants from all three states raised issues of unequal impacts and vulnerable populations in the context of health impacts of UNGD. Several noted that residents might be affected by multiple exposures (via water and air, etc.). Interviewees representing all positions on

UNGD raised concerns about the distribution of costs and benefits, with a neutral environmental educator from New York saying, “*Well, we know in Pennsylvania... already, this is the case, there will be winners and losers and that you can expand that to economic issues, maybe health issues.*”

The most frequently identified population of concern was UNGD workers, with a number of the interviewees mentioning specific occupational health concerns. Interviewees from Ohio and public health professionals from all three states noted worker health concerns, including exposure to chemicals used in hydraulic fracturing, toxic air emissions, and silica sand. A small number of interviewees mentioned the potential for explosions, spills, and accidents involving mechanical equipment. For example, an Ohio physician noted that some areas with UNGD have seen “*blast injuries, crush injuries, 30% increase in their ER [Emergency Room] utilization.*”

Low income residents, another subpopulation of concern, were viewed as less likely to own enough land to benefit from leasing for UNGD or to own a business that would experience the positive effects of a development “boom.” Low income residents were thought to be more likely to be affected by increasing rents, reduced housing availability, or overburdened public services (e.g., emergency and health care). Interviewees also mentioned that low income landowners might feel forced to sign a lease because they needed the income; would be less likely to have the education, knowledge, or legal resources to negotiate a beneficial lease; and would be less able to take proactive steps to protect their environment and health. Other potential impacts on low income residents included limited resources to pay for baseline or long-term water quality monitoring, inability to afford health care if they were exposed to contaminants, and limited resources to relocate during times of active drilling. An advocate for rural communities in North Carolina said, “*When you talk about public health issues, what we have to talk about is the coercion of people in poverty who have no other options, who are looking for some level of financial stability.*”

In addition, some interviewees expressed particular concern for rural residents, noting that they might have no alternative source of drinking water if their wells were contaminated due to UNGD. There were also concerns about impacts on agriculture, tourism and wildlife, which may be primary sources of income for rural populations.

Summary of community concerns

Overall, the range of health concerns cited by interviewees was similar in all three states and across roles/positions. Rather than focusing on specific disease outcomes, most interviewees expressed concerns about multiple determinants of health, including air and water quality, quality of life, economic well-being and public health services. Interviewees defined the range of potential health effects very broadly, including both positive and negative changes in quality of life (including traffic, community character, economic security, conflicts between community members, stress, and boom-and-bust dynamics). Many interviewees noted the potential for cumulative effects and interactions. They also raised concerns about how these health determinants might vary widely among different regions, disproportionately affecting various vulnerable populations. Interviewees noted potential short term effects like traffic and noise, but many also expressed concerns about long-term

economic, environmental, and health consequences. Although interviewees drew strongly on reported experiences with UNGD in other states in formulating their concerns, they were also quick to note differences in geology, regulations, and past industrial contamination incidents that might result in unique impacts in their communities.

Given the small number of interviewees, we could not conclusively identify differences in the nature of concerns among community members in different states. However, our assessment suggested regional differences in participants' key health concerns that merit additional investigation. These differences may relate to past experiences with UNGD or other environmental stressors in each state. For example, only interviewees from Ohio mentioned concerns about UNGD's impacts on water quantity, likely due to the recent experience of drought in that state. Similarly, a greater proportion of Ohio interviewees talked about the role of injection wells in causing earthquakes like those that had recently occurred near Youngstown, Ohio (20–22). Interestingly, interviewees from Ohio, the only state in which UNGD was active, were least likely to mention “quality of life” and “noise/nuisance” concerns. Interviewees also showed a strong awareness that impacts may vary because of features of the local environment like the concerns about ground water in North Carolina, where aquifers are shallower than in other regions that have experienced UNGD.

The small number of interviewees and reliance on self-categorization also limited conclusions about how health concerns might vary depending on an individual's stance on UNGD and his or her role in the community. Such differences should be considered in future efforts to obtain community input on UNGD. Not surprisingly, those who identified themselves as supportive of UNGD were most likely to enumerate potential health benefits and report fewer health concerns. The concerns “supportive” interviewees most frequently expressed were related to decreased quality of life, road damage, noise/nuisance issues, and air and water quality. Public health professionals were more likely to mention worker health, agricultural or wildlife impacts and noise/nuisance, but otherwise had similar concerns to environmental groups and outreach/education professionals. None of the outreach professionals mentioned impacts on health systems vs. nearly two-thirds of environmental groups and public health professionals. These differences suggest that future efforts to track “community concerns” about health issues should include a broad range of stakeholders from different regions, with varied community or professional roles, and with different positions on UNGD.

Community-identified research needs

The second topic we focused on in interviews was how environmental public health concerns informed community leaders' priorities for future research. Research needs identified by participants were as nuanced and diverse as the health concerns they raised. Most interviewees acknowledged that additional research would help inform better decision making about UNGD. However, interviewees who were supportive of UNGD had fewer suggestions for additional health research; in fact, several explicitly noted that they believed there was already sufficient evidence demonstrating the safety of UNGD and that no further research would be needed. In addition to identifying specific research needs and types of studies, interviewees noted challenges to researching potential health impacts of UNGD.

Meanwhile, others made suggestions for structuring the research process to maximize its usefulness for informing health-protective decisions.

Research needs

A majority of research recommendations emphasized the need for baseline testing and ongoing monitoring of ambient air and water quality. A neutral resident in North Carolina stated, *“There’s a whole lot of baseline data that North Carolina should have, county by county, before it begins this process, so we’ll know...if and when fracking occur...we will know if the picture has changed.”* Interviewees also noted insufficient information on underlying geology, the fate and transport of pollutants both above and below ground, and the potential for interactions among naturally occurring and hydraulic fracturing chemicals. Better understanding of the potential for earthquakes was a focus in Ohio, where an environmental group member said, *“We have earthquakes and what’s that going to break loose? We’ve got lots of old wells and old coal mines in the area.”* In addition to identifying current environmental impacts, the need to model and predict long-term, cumulative, and interaction effects was also noted. A New York interviewee said, *“This is a big industrial activity...[it] doesn’t just happen at a factory or at one particular spot. There’s a lot of moving parts here. What happens when all these moving parts start moving together?...One of the things I think is most lacking is the cumulative impact.”*

Interviewees suggested several types of research related to direct and indirect human health impacts. Several interviewees called for epidemiologic or other health studies, with one public health representative noting *“There’s so many chemicals, there’s so many avenues of contamination. You know, water, air, land, food...we don’t have any idea...so we need long-term epidemiological studies.”*

Interviewees from all three states highlighted the value of case studies from areas with active UNGD to inform other communities about potential health impacts. One environmental advocate from North Carolina said, *“If we want to prepare the public health infrastructure...we should be looking at other communities around the country that have real boom-bust cycles.”* In addition, interviewees called for efforts to predict cumulative effects, including health impact assessment (HIA). HIA was mentioned most often by interviewees from New York as a useful tool for comprehensively evaluating health effects. Finally, the need for environmental health researchers to consider the distribution of impacts, particularly among vulnerable populations, was also noted.

Technology was likewise identified as an important area for further research. Participants wanted both more information about the impacts of existing technologies and research that can inform more health-protective approaches to UNGD. A New York landowner who was supportive of UNGD wanted to see research on methods of extraction, expressing a desire for *“research on better ways to extract...maybe less invasive, don’t use as much water.”* Similarly, an Ohio interviewee noted that, *“Maybe methods could be perfected because, when they are pushed to come up with an alternative, industry becomes pretty effective at coming up with a different way to do business.”* In particular, interviewees wanted to see research into the effectiveness of existing and alternative wastewater treatment options.

A number of interviews mentioned the need for economic research, including cost-benefit analyses, better characterization of infrastructure costs, distribution of economic benefits within a population, and the sustainability of economic development. One business owner from New York asked, “*Are these gas jobs sustainable or are they just a shot in the dark that makes a few people rich and the rest of us poor?*” A similar sentiment was expressed by an interviewee from Ohio, who said “*Property values will bump up, but in the long run, will it be good for the county? The jury's still out.*”

A final category of research needs was the demand for analyses of regulatory, policy, and institutional systems to protect public health during UNGD. Suggestions ranged from research on financing mechanisms to the extent of local government authority and eminent domain. The interviewees raised questions about what regulatory frameworks would best protect human health and whether existing laws and agency capacity were sufficient. For example, an elected official in North Carolina wondered whether local emergency responders would be adequately informed on risks associated with sites, saying that there should be “*a lot more research on...what could happen in the event of a spill... What effects could that have on...first responders in our community? What are we going to need to do to better prepare our health care professionals?*”

Research challenges

Interviewees were cognizant of a number of research challenges to informing health-protective decisions. They included lack of funding, data gaps, uncertainties, and long time frames/latent effects. Interviewees raised a set of logistical issues related to baseline monitoring, including which parameters to test, where to test, and how to pay for testing. Non-disclosure agreements and gag rules were also noted as data challenges. One interviewee asked: “*How are we going to learn what's wrong if the people affected can't talk?... Why did they even feel that was necessary, to have a gag rule on physicians?...How are you going to collect data if that sort of stuff is going on?*” One interviewee highlighted the inherent challenges of epidemiological studies, saying, “*Epidemiology takes time and money and it's a complex issue...the issue of causal inference...complex chemicals and exposure pathways... We've seen how difficult it can be to prove this kind of thing; tobacco was an example.*” Uncertainties regarding how long wells were in operation, how many were drilled at one time in an area, and the specific chemicals used at each site were also flagged as challenges to predicting future health effects of UNGD.

Research process

Interviewees' comments suggested several guidelines for how research is conducted, including transparency about funding sources, openness in sharing data, and well-defined interactions with industry. There were conflicting opinions on whether industries should sponsor UNGD research. An environmental group member from Ohio said, “*The industry needs to pay for it, you know? They ought to be volunteering to pay for it if what they are doing is so safe.*” Some interviewees recognized that although the industry may have the resources to conduct research, it may be—or may be perceived to be – biased, thus undermining the credibility of results. One participant suggested that the industry could provide funding for research and work with an oversight committee or another mechanism

that managed conflicts of interest. Other participants thought that the government should be supporting the needed health research, with one saying that it would be “*very beneficial...[if the] federal government saw this as a major issue and pulled together a stronger set of research funds for people to go after.*”

A number of the interviews raised the issue of providing public access to research data. In this context, two key barriers to research were noted, and distrust of industry underpinned both: 1) lack of transparency with respect to existing data, and 2) past instances in which industries concealed data from impacted communities and decision makers. One interviewee emphasized the need for a “*health registry for tracking symptoms and conditions*” to create a dataset which could be used in health studies.

As with health concerns, many interviewees cited opportunities to learn from areas already experiencing UNGD. However, they also noted regional differences in geology, water resources, infrastructure, economics, regulations or wastewater disposal capacities, which prevent practitioners from applying research findings from one area to another. At the same time, the interviewees acknowledged the need for efforts to synthesize and extract insights from emerging research. One educator from New York suggested the need to conduct a meta-analysis of existing studies, saying “*I think it's more research but it's also someone pulling it together and saying 'you know there's been twelve studies and here's the metadata from that.'*”

Summary of research needs

As described above, interviewees highlighted the uncertainties surrounding the nature, timing, and impacts of environmental and community changes related to UNGD. Most affirmed that additional research would help inform and improve decision making about UNGD. However, several interviewees who support UNGD suggested that there was already sufficient evidence of safety; hence, there was no need for additional research. At the same time, interviewees emphasized both the potential to learn from the experiences of other areas where UNGD was already implemented and the need to recognize unique local situations.

Interviewees likewise highlighted the challenges of investigating potential long-term health impacts. In addition, they acknowledged the complexity of modeling cumulative impacts; multiple scenarios for the location, pace and nature of drilling activities expected in their states; varied drilling practices; impacts of regulation; and changing technologies. Most of the recommendations for future research stated above were related to the environmental health determinants identified as “concerns.” However, despite the number of references to changes in quality of life, community conflict, and citizens' mental health, few interviewees called for additional research on these types of impacts. Finally, in addition to making topical research recommendations, interviewees placed a strong emphasis on how research should be conducted and communicated, including transparency about funding sources and publicly reporting research results.

Insights for communicating research on health and UNGD

The third topic explored in interviews was how community leaders interested in UNGD had obtained information on potential health effects, and which sources of information they believed to be most credible. We also sought to understand how interviewees thought new information could be communicated most effectively to community audiences in the future. University-based sources and the news media were the most commonly identified information sources (Table 4). Government agencies and the Internet were also mentioned in more than two-thirds of the interviews. Other sources of information included the oil and gas industry, environmental groups, the stories and experiences of real people (talking directly with other people about their personal stories and experiences surrounding UNGD), and community meetings.

The interviews suggested that there may be differences in information sources by state, role, and position on UNGD. For example, interviewees in Ohio were more likely to mention “the oil and gas industry” and “community meetings” as sources. Ohio was the only state in our assessment where there was active UNGD, and the industry was highlighted prominently in the news media, advertisements, and community meetings. Many interviewees from states without active UNGD noted that they tried to learn from citizens in areas experiencing UNGD. One New York resident said, *“To me one of the most valuable resources for just learning is just talking to people that are experiencing it.”* Interviewees supportive of UNGD were most likely to mention the government as a key source of information, perhaps reflecting their trust in regulatory systems.

When participants discussed the credibility of sources, many interviewees reported thinking critically about the reliability of information as well as the difficulty of finding sources they believed to be unbiased. Many indicated the potential for bias in information about UNGD, with an outreach/education professional from Ohio saying, *“You always have to consider the source, and you're always weighing the quality of the information that you are getting.”* Universities were most commonly mentioned as a credible source of information, followed closely by “government agencies”. One neutral resident from North Carolina explained this by saying *“People who have no way of profiting from whatever their information is...a lot of times are credible sources. University folk quite often are neutral in that regard, and I seem to put a lot of stock in those kinds of people and those kinds of reports that I've read.”* The process of peer-review was identified by a subset of interviewees as contributing to the quality of information. Although academic and government sources were most frequently mentioned as credible, several interviewees still expressed distrust of these sources.

In addition, industry sources were most frequently mentioned as biased. A public health professional from Ohio who was opposed to UNGD stated, *“The big point I'm making, is from the beginning, they've [oil and gas industry] used deception. If your opening ground is deception, pretending you're from Canada when you're really from Dubai, I mean, that is so classic of everything they're doing.”* However, some interviews found the industry to be a useful source of technical information, with an environmental group representative in North Carolina saying that *“We were able to find something, actually in the industry literature...in the petroleum geology literature, which turned out to be very powerful information to share*

with environmental health departments and let them understand just how much at risk wells were and how shallow our shales were and the potential implications of that. We found things in industry publications, so we reviewed industry websites as well that were often being used to make folks complacent about the technology but which we thought were relatively revealing.”

Several interviewees noted the difficulty involved in finding unbiased sources of information on UNGD. One neutral environmental group interviewee from New York noted, “*We've found it to be really very difficult to find things that don't have a fairly conspicuous bias, including in the peer reviewed literature.*” In addition, interviewees recognized the potential for bias to be introduced through reporting, with a neutral public health professional from Ohio saying, “*I want to go to the actual sources and not rely on the news media all that much because I think things get twisted.*” Finally, a number of interviewees expressed the opinion that people only believe information from sources that share their preconceived views on UNGD.

As part of the information needs assessment, the authors collected existing public education materials (information from websites, brochures, etc.) relating to the environmental and health impacts of UNGD. They found very few existing materials focused on human health. The vast majority focused on the physical process of drilling, not the broader direct or indirect potential impacts of UNGD on human populations. This initial survey suggested there is a need for more public health-focused information materials on UNGD, that are accessible to the general public.

When we asked interviewees how new research results should be shared with the public in the future, more than half suggested news media and the internet; community meetings, forums, and seminars were also frequently mentioned. Interestingly, the sources interviewees identified as credible were not necessarily those they recommended for sharing future information with the general public. This dichotomy may reflect the fact that we interviewed community leaders who had made efforts to actively inform themselves on health and UNGD. These informed community leaders may believe that they seek information differently than members of the general public, whom they see as more likely to passively receive information from the media. Overall, these responses suggested the need for multiple ways of sharing information. Successful information dissemination strategies may differ between locations and audiences.

Implications for a community-informed health research agenda

This assessment showed that community leaders defined “health effects” of UNGD very broadly, including environmental determinants of health, specific health outcomes, changes in communities' quality of life, and the long-term health effects of cumulative emissions. Interviewees identified both positive and negative community health impacts, with positive health effects most commonly associated with expected economic development. Apart from the issues of air and water pollution commonly cited in the popular media and research publications, interviewees emphasized quality of life factors like sense of community, traffic, economic development, and rural character.

Uncertainty about the risks associated with UNGD underpinned many of the interviewees' priorities for future research. In addition to studies of health effects, interviewees identified information gaps related to environmental impacts (with specific emphasis on water and air quality), UNGD technologies, economic impacts, and regulatory systems. Regional differences, potential for long-term effects, and interactions among impacts were also cited as challenges to research that could inform timely decision making.

These research priorities are similar to the range of topics addressed by recent scientific conferences and papers on research needs relating to environmental public health and UNGD (3, 10, 23, 24). However, our findings suggested different perspectives among community leaders as to what the research agenda should cover. For example, the scientific community focused on identifying disease outcomes, available data sets and testable hypotheses, whereas the community leaders we interviewed focused on research needed to inform public policy, regulations, and planning. Even those interviewees who were strongly supportive of UNGD acknowledged the potential for chemical spills and the importance of research on how best to both avoid spills and respond when such incidents occur. Interviewees also raised the need to study whether existing laws and agency capacity were sufficient to protect public health. Although community leaders agreed with researchers' calls for baseline monitoring and epidemiological studies during the course of UNGD, they also expressed concerns about using communities as “guinea pigs” in which research merely documents (instead of prevents) health impacts. The transparency of the research process and communication of results, including demands for revealing all funding sources and providing public access to data, were of great importance to community leaders.

Communities have not yet been systematically engaged in government agencies' and research institutions' efforts to develop a research agenda on the health effects of UNGD. In other situations that pose potential environmental health risks to local populations, community participation in research planning has been identified as key to reducing conflict, informing effective outreach, and conducting effective research (25–28). The growth of community-based participatory research (CBPR) in the area of environmental health reflects an increasing recognition that communities should be involved in all phases of environmental health research (29). Scholars and communities who engage in CBPR recognize that, in addition to involving residents in conducting research, it is also important to provide for community involvement in setting research agendas and framing key questions (28, 30, 31). Engaging communities in prioritizing and designing research helps assure that studies address communities' key concerns, utilize citizens' knowledge, account for local differences, and inform decision making processes. To facilitate such input, the process of setting research agendas should include the development of collaborative structures and principles for involving communities in prioritizing, funding, and conducting research as well as communicating the findings.

This assessment suggests that the UNGD environmental health research agenda is ripe for community input and involvement. Our interviews confirmed that community leaders have broad and complex concerns regarding UNGD, especially in relation to public health, implications for future well-being, and potential for global impacts. This needs assessment is a first step toward prospectively seeking communities' input in planning and conducting

research on the public health impacts of UNGD and communicating the main findings to guide all stakeholders.

Interviewees' concerns varied based on their location, role, and experiences as well as the position they held with regards UNGD. The diversity of perspectives and priorities suggests that incorporating community input into the research agenda will be a complex process. The results emerging from future research can affect individual, local, state, and national decisions about UNGD. To ensure that these decisions effectively protect public health, it is essential that the affected communities be involved throughout the process of planning, conducting, and communicating research. In order to do so, it is essential for agencies, researchers, and non-governmental groups to design systems for obtaining, integrating, and sustaining diverse community input throughout the entire UNGD health research process.

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Table 1

Role by state (number of interviews representing each role given as a percentage of total interviews from that state).

	Citizen/landowner		Environmental group		Local government		Outreach/education professional		Public health professional		Total	
	n	%	n	%	n	%	n	%	n	%	n	%
NY	6	38	5	31	2	13	2	13	1	6	2	16
NC	4	31	4	31	1	8	2	15	2	15	2	13
OH	1	7	5	36	2	14	2	14	4	29	4	14
Total	11	26	14	33	5	12	6	14	7	16	7	43

Table 2

Position on UNGD by state (number of interviews reflecting each position given as percentage of total interviews from that state).

	Opposed		Neutral		Supportive		Total	
	n	%	n	%	n	%	n	%
NY	6	38	7	44	3	19	16	16
NC	6	46	6	46	1	8	13	13
OH	8	57	4	29	2	14	14	14
Total	20	47	17	40	6	14	43	43

Table 3

Health concerns cited by interviews.

	Water quality, %	Air quality, %	Trucks, %	Quality of life, %	Health systems, %	Agriculture or wildlife, %	Traffic, %	Noise/nuisance, %	Worker health, %	Pos. health impacts, %
By state										
NY (n = 16)	81	88	56	56	38	50	6	38	13	31
NC (n = 13)	85	69	69	77	38	23	38	23	23	15
OH (n = 14)	86	79	64	29	43	36	43	14	36	21
By position										
Oppose (n = 20)	100	100	75	45	50	40	40	30	30	5
Neutral (n = 17)	82	71	59	59	35	41	18	18	24	29
Support (n = 6)	33	33	33	67	17	17	17	33	0	67
By role										
CL (n = 11)	73	55	73	64	27	36	27	27	18	36
EN (n = 14)	100	100	64	36	64	29	29	21	29	0
LG (n = 4)	50	50	50	75	0	25	25	0	0	25
OE (n = 6)	67	83	67	67	0	33	33	33	17	50
PH (n = 8)	100	88	50	50	63	63	25	38	38	25
Total (n = 43)	84	79	63	53	40	37	28	26	23	23

Table 4

Sources of information mentioned in interviews.

Source	Citing this source, % (n = 43)
University	84
News media	79
Government	70
Internet	65
Oil and gas industry	58
Environmental groups	56
Stories and experiences	49
Community meetings	44

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