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## **Strategic Research Agenda on the Potential Impacts of 21st Century Oil and Natural Gas Development in the Appalachian Region and Beyond**

HEI Special Scientific Committee on  
Unconventional Oil and Gas Development in  
the Appalachian Basin

### *EXECUTIVE SUMMARY*

A PDF of the full report is available at  
<http://www.healtheffects.org/UOGD/UOGD.htm>

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Health Effects Institute  
Boston, MA

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# EXECUTIVE SUMMARY

Unconventional oil and natural gas development is a driving force behind significant economic and energy policy shifts in the United States and the world today. Technological advances in development are substantially increasing energy supplies, while at the same time outpacing the scientific research that can answer questions about the development's potential effects. With funding from private foundations, the Health Effects Institute (HEI) convened a Special Scientific Committee to develop this impartial, multidisciplinary Strategic Research Agenda to help guide future research about potential adverse impacts<sup>1</sup> of 21st century oil and natural gas development. The Research Agenda recommends research to better understand and to prevent or minimize potential impacts on human health and well-being, communities, ecological health, and the environment. The result of the Committee's work is this Strategic Research Agenda. It was developed in response to questions raised in the Appalachian region of the United States. The questions are not unique to the region; therefore, the Research Agenda can address concerns expressed elsewhere in the United States and the world.

As used in this Research Agenda, "21st century oil and natural gas development" refers to the onshore development and production of oil and natural gas from

## Purpose and Scope of this Research Agenda

This Strategic Research Agenda is offered as an impartial, multidisciplinary guide for future research about potential adverse impacts of 21st century oil and natural gas development. The Research Agenda recommends research to better understand and to prevent or minimize potential impacts on human health and well-being, communities, ecological health, and the environment.

As used in the Research Agenda, "21st century oil and natural gas development" refers to the onshore development and production of oil and natural gas from unconventional geologic resources as practiced today, recognizing that industry practices continue to change in response to evolving technologies, regulations, and other factors. For simplicity, the term is abbreviated as "OGD" in this report.

Although the Committee recognized that OGD can generate important benefits, an in-depth analysis of such benefits was beyond the scope of our review. An equally important question also considered beyond the scope of the review is *How do potential OGD impacts compare with those from other energy sources?* Governmental agencies and other organizations are actively engaged in the complex task of evaluating various combinations of energy sources, including a consideration of their ability to meet future energy requirements and climate-change potential. The Committee has sought to answer the more focused but critical question to help inform future energy policy choices: *Which potential impacts of OGD warrant priority consideration for scientific study?*

## Overview of Recommendations

The Committee defined research questions that:

- Collectively indicate knowledge gaps; they are not findings of impacts;
- Are linked to the ultimate goal of understanding and preventing or minimizing potential impacts on human and ecological health and well-being; and
- Apply broadly to Appalachia and other regions.

## Moving Forward

In view of the importance of implementing the Research Agenda as quickly as possible, HEI has already begun outreach to key potential partners and sources of funding from government, industry and the foundation community. The Research Agenda will form the basis of a targeted HEI Research Program, which will be described in a draft Implementation Plan to be released in late 2015.

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<sup>1</sup> Throughout this Research Agenda, the term "impact" refers to adverse effects. The term "benefit" refers to positive effects.

unconventional geologic resources as practiced today, recognizing that industry practices continue to change in response to evolving technologies, regulations, and other factors. The Committee chose the term (instead of the more common “unconventional oil and natural gas development”) to reflect the Committee’s intent (1) to address the potential impacts of oil and natural gas development that involves staged hydraulic fracturing (i.e., fracturing that occurs in sequential stages along a horizontal wellbore) combined with horizontal drilling used in the Appalachian region since the natural gas boom began and (2) to reflect the possibility that these technologies will be used more widely with both conventional and unconventional geologic formations in the future. For simplicity, the term is abbreviated as “OGD” in this report.

## **MOTIVATION FOR CREATING A RESEARCH AGENDA**

Oil and natural gas development is not new to Appalachia, with hundreds of thousands of oil and natural gas wells drilled into primarily conventional geologic formations since the mid-1800s. Historically, oil and natural gas were extracted either without hydraulic fracturing or with lower volumes of hydraulic fracturing fluid. The extraction technique of staged hydraulic fracturing combined with horizontal drilling drives the current wave of development. OGD differs from previous oil and natural gas development in ways that introduce the potential for different kinds of impacts.

The use of the OGD processes in Pennsylvania began in the early 2000s and rapidly expanded to include eastern Ohio and northern West Virginia. Many people living in these regions were familiar with conventional oil and natural gas development, but not with the pace, scale, or type of the recent OGD. The industry and regulators have protocols to protect workers, neighbors, and the environment. However, given the rapid pace and technologic changes associated with OGD, knowledge of its potential impacts and whether protocols and regulations are sufficient to prevent or minimize them has, in some cases, lagged behind.

In response to shale gas development in Appalachia, various organizations — each with its own specific focus — have acted to understand, prevent, and minimize potential impacts. One of these organizations was the Pennsylvania-based Shale Gas Roundtable, composed of leaders from government, industry, academia, environmental groups, and the public (<http://iop.pitt.edu/shalegas/>). The Roundtable was formed to answer one question:

As a region, how can we most effectively and responsibly safeguard our communities and environment, grow our economy, and manage unconventional oil and gas development?

In its 2013 report, the Roundtable emphasized the need for “efforts to increase balanced research and rigorous monitoring of the possible impacts of unconventional oil and gas development.” HEI’s multidisciplinary Special Scientific Committee, which produced the Research Agenda presented here, was formed in response to this recommendation.

## **THE COMMITTEE’S REVIEW AND PRIORITIES**

To identify what is known and what is not known about potential impacts and about trends in industry practices related to impacts, the HEI Special Committee reviewed about 1,000 peer-reviewed articles and reports. Throughout its review, the Committee consulted with experts and

stakeholders to develop this integrated assessment of research needs that spans the range of topics directly and indirectly related to potential impacts on health and well-being.

The Committee recognized that OGD can generate important benefits. Agencies and others at the regional, national, and international levels are actively engaged in the complex task of evaluating various combinations of energy sources, including a consideration of their ability to meet future energy requirements and climate-change potential. The Committee has sought to answer the more focused but critical question to help inform future energy policy choices: Which potential impacts of OGD warrant priority consideration for scientific study?

The Committee evaluated the potential for impacts from the following phases of OGD:

- Development (i.e., exploration, site preparation, vertical and horizontal drilling, hydraulic fracturing, well completion in preparation for production, and management of wastes);
- Production (i.e., extraction, gathering, processing, and compression of gas; extraction and processing of oil and natural gas condensates; management of produced water and other wastes; and construction and operation of pipelines); and
- Post-production (i.e., well closure and site reclamation).

The Committee's review did not include the following:

- Inter- and intra-state oil and gas distribution networks or other pipelines and compressor stations (beyond the gathering pipelines in the field) used to transport oil or gas outside of the production area;
- The end uses of oil and natural gas (e.g., electric power generation and vehicle fuel);
- The development and production of oil and natural gas from conventional geologic formations unless they involve the use of staged hydraulic fracturing combined with horizontal drilling; and
- Potential global climate-change impacts from OGD. The Committee reviewed information about climate-forcer emissions from OGD, but did not define research needs about the contribution of these emissions to global climate change, a research topic that is already the subject of extensive research programs around the world.

The Committee defined research questions based on a review of the literature and input received during expert consultations and two public workshops. The Committee also crafted seven criteria against which to identify and judge research areas. The criteria were intended to reflect the full breadth of research topics and characteristics that might be useful for understanding and preventing or minimizing potential impacts. In addition, the Committee identified several themes that pertain to multiple research questions (Table ES-1). Throughout its deliberations, the Committee stressed the need to account properly for these cross-cutting themes in research conducted in response to the Research Agenda. The research should also contribute to an improved understanding of these themes.

Guided by a review of the literature, input from stakeholders, and its own criteria, the Committee developed 35 research questions that cover the range of topics linked to the ultimate goal of understanding and preventing or minimizing potential impacts on human and ecological health and well-being. The Committee deemed all research questions to be important topics of inquiry, although not necessarily of equal importance.

**Table ES-1. Cross-cutting themes that pertain to multiple research questions.** These cross-cutting themes should be accounted for in studies designed in response to this Research Agenda. The research should contribute to an improved understanding of these themes.

Cross-Cutting Theme	Description
Background conditions	<p>Many of the potential stressors associated with OGD have other sources:</p> <ul style="list-style-type: none"> <li>▪ Natural sources (e.g., methane from biological sources or from depth by way of migration along natural fractures)</li> <li>▪ Anthropogenic sources (e.g., conventional oil and natural gas development, orphaned and abandoned wells, active coal mines or abandoned mines, landfills, power plants, vehicle emissions, and long-range transport)</li> </ul> <p>Potential impacts attributed to OGD might have other causes:</p> <ul style="list-style-type: none"> <li>▪ Baseline ecological characteristics and baseline human health and social characteristics must be distinguished from OGD-specific impacts.</li> </ul>
Variability	<p>Several factors related to levels of stressors and potential impacts can vary considerably:</p> <ul style="list-style-type: none"> <li>▪ Spatial variability (e.g., geology, industry practice across regions, and location of OGD operations relative to surrounding communities and ecosystems)</li> <li>▪ Temporal variability (e.g., changes to industry practice over time and duration of development)</li> <li>▪ OGD facility variability (e.g., compressor stations and processing plants)</li> <li>▪ Individual variability (e.g., human and ecological exposure and susceptibility)</li> </ul>
Benefits of OGD	<p>In some cases, the potential impacts of OGD could be interconnected with potential benefits. Some examples:</p> <ul style="list-style-type: none"> <li>▪ Improvements to local infrastructure could decrease traffic injuries over the long term.</li> <li>▪ Expansion of medical facilities in response to an influx of workers could improve access to healthcare.</li> </ul>
Permitted, accidental, and unauthorized releases of stressors to the environment	<p>Stressors entering the environment might lead to potential impacts:</p> <ul style="list-style-type: none"> <li>▪ Stressors intentionally released in accordance with applicable regulations (e.g., permitted discharges to surface water, equipment emissions to ambient air, and vehicle emissions)</li> <li>▪ Stressors released through illegal or poor practices (e.g., improper waste disposal or accidental releases of fracturing fluid and other materials)</li> </ul>
Data availability and quality	<p>Ready access to high-quality OGD-related data of various kinds (e.g., chemical usage, waste composition and management, and documentation of accidents) is essential to designing useful and efficient research. Some challenges to accessibility are the:</p> <ul style="list-style-type: none"> <li>▪ Confidential nature of some information</li> <li>▪ Lack of standard analytical methods for characterizing some OGD-related wastes</li> <li>▪ Uneven documentation of some data</li> </ul> <p>Creation of standardized electronic (digital) reporting systems and databases would help facilitate ready access to OGD-related data. The Committee specifically noted the value of a standardized database to document permitted, accidental, and unauthorized releases from OGD operations.</p>

The questions collectively indicate knowledge gaps; they are not findings of impacts. They are broadly applicable to Appalachia and other regions, although the importance of the questions likely varies by region. Comparative studies among regions would be useful in understanding

how insights from one region might apply to other regions. Further, while the Committee's scope of review excluded OGD operations outside of the production area, the research questions are broadly relevant to OGD operations within and outside of production areas.

The research questions were defined relatively broadly to avoid pre-judging the specific type of research that could be performed. In this way, the Committee recognized that it does not have complete knowledge of every topic, nor can it anticipate new knowledge over the coming years. Research examples are provided for each question, but solely to aid the comprehension of the research questions.

The research questions fall into three general areas: (1) stressor and exposure characterization, (2) health and well-being assessment, and (3) evaluation of most-effective practices. The Committee recommends pursuing research in each of these areas. In

particular, questions about stressor and exposure characterization are useful in addressing questions about health and well-being. Research on management practices can help prevent or reduce impacts in advance of waiting for the results of lengthy health studies.

Although the research questions cannot be pursued at the same time, they do not need to be carried out in a linear time frame. For example, all exposures do not need to be quantified before determining relationships between exposure and biological response (although both of these components are needed before quantitatively characterizing risks). However, health studies should be based on hypotheses about plausible links between OGD-related exposures and specific health outcomes. The individual research activities can be carried out in parallel and sequenced as needed to support effective analysis of exposures, risks, and health outcomes. In fact, such a parallel and sequenced execution will be crucial to achieve results in a timely fashion.

The Committee deemed all research questions to be important topics of inquiry, although not necessarily of equal importance. Funding for research to answer these questions, like that for all scientific research, is limited. The Committee therefore used its criteria to identify 13 research questions of "overarching importance," which target a better understanding of exposure, risk,

### Highlights of the Committee's Research Recommendations

#### 35 Research Questions

- They collectively indicate knowledge gaps; they are not findings of impacts.
- They are linked to the ultimate goal of understanding and preventing or minimizing potential impacts on human and ecological health and well-being.
- They apply broadly to Appalachia and other regions.
- They fall into three general areas of research: (1) stressor and exposure characterization; (2) health and well-being assessment; and (3) evaluation of most-effective practices.
- 13 questions are identified as high priorities, although all questions are important topics of inquiry.

#### Cross-cutting Research Themes

- A number of themes should be accounted for in studies designed in response to this Research Agenda. These themes are:
  - Background conditions (i.e., levels of stressors in the environment originating from natural and anthropogenic sources other than OGD, and baseline health characteristics that need to be distinguished from potential OGD effects)
  - Variability with respect to a number of factors (e.g., geology, industry practice across regions and over time, and human and ecological exposure and susceptibility)
  - Permitted, accidental, and unauthorized releases of stressors to the environment
  - Benefits of OGD and their interrelationships with the impacts being studied
- Research should contribute to an improved understanding of these cross-cutting themes.

and effects from a broad spatial and substantive perspective. Table ES-2 lists the topics in terms of three general areas of interest, the purpose of the research, and the topics of specific research questions — 13 of overarching importance and 22 other important topics. Table ES-3 provides brief descriptions of the topics addressed by the 13 research questions.

**Table ES-2. The Committee’s prioritized research questions by topic.**

General Area of Research	Purpose	Research Topic <sup>(1)</sup>
<b>Stressor and Exposure Characterization</b>	To improve understanding of whether exposures of potential concern are occurring	<b>Topics of Overarching Importance <sup>(2)</sup></b> <ul style="list-style-type: none"> <li>▪ Chemical toxicity (human and ecological)</li> <li>▪ Emissions and air quality</li> <li>▪ Total human exposure</li> <li>▪ Water quality</li> </ul>
		<b>Other Important Topics</b> <ul style="list-style-type: none"> <li>▪ Climate-forcer emissions</li> <li>▪ Criteria air pollutants</li> <li>▪ High-emitters</li> <li>▪ Human biomonitoring</li> <li>▪ Indoor air radon</li> <li>▪ Induced seismicity causes</li> <li>▪ Water use</li> <li>▪ Water-quality diagnostics</li> </ul>
<b>Health and Well-Being Assessment</b>	To improve understanding of whether potential impacts on public and worker health, ecological health, and well-being are occurring	<b>Topics of Overarching Importance <sup>(2)</sup></b> <ul style="list-style-type: none"> <li>▪ Ecological health effects (landscape change)</li> <li>▪ Public health effects (air exposure)</li> <li>▪ Public health effects (near-term studies)</li> <li>▪ Public health effects (water exposure)</li> <li>▪ Social and psychosocial effects</li> <li>▪ Worker health effects (chemical and radiation)</li> </ul>
		<b>Other Important Topics</b> <ul style="list-style-type: none"> <li>▪ Community services and infrastructure</li> <li>▪ Community well-being and health effect interactions</li> <li>▪ Ecological health effects (chemical and radiation)</li> <li>▪ Ecological health effects (cumulative)</li> <li>▪ Public health effects (long-term studies)</li> <li>▪ Public health effects (psychological stress)</li> <li>▪ Worker health effects (noise, vibration, and physical hazards)</li> </ul>
<b>Evaluation of Most-Effective Practices</b>	To enhance practices that minimize or prevent impacts	<b>Topics of Overarching Importance <sup>(2)</sup></b> <ul style="list-style-type: none"> <li>▪ Accidental waste release</li> <li>▪ Permitted waste management</li> <li>▪ Wellbore integrity</li> </ul>
		<b>Other Important Topics</b> <ul style="list-style-type: none"> <li>▪ Air quality control</li> <li>▪ Community planning and resiliency</li> <li>▪ Ecological health effects (mitigation)</li> <li>▪ Induced seismicity prevention</li> <li>▪ Water transport</li> <li>▪ Wellbore diagnostics</li> <li>▪ Workplace organization</li> </ul>
<p><sup>(1)</sup> Within each category, research topics are listed in alphabetical order.</p> <p><sup>(2)</sup> The Committee identified 13 research questions of overarching importance, which target a better understanding of potential exposure, risk, and effects from a broad spatial and substantive perspective.</p>		

**Table ES-3. Topics addressed by the 13 research questions of overarching importance <sup>(1)</sup>.**

Research Topic	Summary
<b>Stressor and Exposure Characterization <sup>(2)</sup></b>	
Chemical toxicity (human and ecological)	Adequate toxicity information does not exist for some components of OGD fluids and wastewater. The initial goal of research would be to improve the understanding of the composition of these fluids. The goal of subsequent research would be to conduct toxicological evaluations where exposure information suggests that such evaluations would be helpful to decision-making about the protection of human and ecological health.
Emissions and air quality	OGD emissions might affect air quality. The goal of research would be to quantify the contribution of emissions from OGD to concentrations of a wide range of air pollutants.
Total human exposure	People might be exposed to a range of OGD-related health stressors, depending on the effectiveness of industry and regulatory protocols. The goal of research would be to identify these exposures and, for any of potential concern, to use rigorous methods to quantify them.
Water quality	Reports of surface water and groundwater contamination allegedly caused by OGD have garnered much public attention. The goal of research would be to quantify any contribution of OGD to short- and long-term trends in the quality of water resources.
<b>Health and Well-Being Assessment <sup>(2)</sup></b>	
Ecological health effects (landscape change)	OGD can result in physical (e.g., habitat fragmentation) and sensory (e.g., increased light) changes to landscapes. The goal of research would be to quantify the contribution of OGD to short- and long-term landscape changes and any resulting ecological risks.
Public health effects (air exposure)	Emissions associated with OGD might lead to changes in air quality. The goal of research would be to determine whether variations in OGD-related airborne exposures are associated with health effects; these studies would focus on any quantified exposures of concern from high-quality studies of potential OGD impacts on air quality.
Public health effects (water exposure)	The scientific literature and popular press reflect concern about OGD-contaminated water resources. The goal of research would be to conduct population-based studies of health effects; these studies would focus on any quantified exposures of concern from high-quality studies of potential OGD impacts on water resources.
Public health effects (near-term studies)	Uncertainty about potential short- and long-term health effects related to OGD has led to community concern. The goal of research would be to determine, through systematic research, whether nearby communities are at increased risk for health effects that might be plausibly linked to OGD-related exposures. If an increased risk is identified, further research would then investigate in greater detail how and to what extent any such health effects are attributable to OGD-related stressors.
Social and psychosocial effects	OGD might have social and psychosocial impacts. The goal of research would be to determine whether and to what extent OGD might contribute to changes in individual and community well-being.
Worker health effects (chemical and radiation)	The OGD work environment can involve various health stressors, with exposure dependent on use of health and safety protocols. The goal of research would be to characterize and identify techniques for mitigating acute and chronic exposures of potential concern that are not already addressed by industry and regulatory protocols.
<b>Evaluation of Most-Effective Practices <sup>(2)</sup></b>	
Accidental releases	OGD-related fluids and wastes can be released to the environment as a result of spills, leaks, blowouts, and other accidents. The goal of research would be to understand the nature of potential impacts from the accidental releases and how they might be prevented or reduced.
Permitted waste management	OGD generates solid and liquid wastes (e.g., produced water, drill cuttings, and drilling fluids). The goal of research would be to determine the potential for impacts from approved disposal of OGD wastes and the most-effective practices for managing the wastes.
Wellbore integrity	A tremendous amount of guidance exists to support the planning, design, and execution of well construction to prevent gas and fluids from escaping the wellbore. The goal of research would be to determine whether guidance is being broadly and effectively implemented and is sufficient to ensure the lifetime integrity of wellbores as OGD technology and practices evolve.
(1) The cross-cutting themes in Table ES-1 should be accounted for in studies designed in response to this Research Agenda. The research should contribute to an improved understanding of these themes.	
(2) Within each category, research topics are listed in alphabetical order.	

## IMPLEMENTATION OF THE RESEARCH AGENDA

This Research Agenda is intended to identify opportunities for government, industry, nongovernmental organizations, and academics to work cooperatively toward improving the understanding of potential impacts and making further advances in minimizing or preventing them. The Committee anticipates that the Research Agenda will be used by researchers and those who fund them as well as by regulators, the oil and natural gas industry, environmental organizations, public health experts, and other stakeholders to inform policy development in this important area. It also serves as a framework within which existing research efforts fit.

High-quality research can be obtained in a number of ways. Given the complex and often controversial circumstances in which OGD is taking place, implementation of the Research Agenda will be most credible to a broad range of stakeholders if it is funded and overseen in a manner that leads to research of the highest quality, impartiality, and relevance. The success of the effort will depend strongly on cooperation among government, industry, and other stakeholders to create an environment of trust in which research can be conducted and the results can be relied on to support sound decision-making. This approach depends on four elements:

- **Governance and Funding:** Governance of the research program should be independent of its sponsors or other interested parties and be managed by an impartial research organization. Core funding should be balanced with sponsorship by industry, government, and possibly foundations and other sources. Ideally, funding should be provided for institutional and long-term support in the fulfillment of the Research Agenda outlined here and for other research topics and needs as they arise.
- **High-Quality Science:** The research should be overseen by a research committee and a review committee, each composed of leading scientists in various fields relevant to the Research Agenda. Members should be vetted to ensure that the research and review of results are carried out impartially. The research committee should competitively select studies for funding. The review committee, having no involvement in the selection, design, or oversight of the studies, should comprehensively review the studies for quality and technical rigor.
- **No Advocacy:** The mission of this independent research effort should be to produce the best science needed to make better informed decisions, without advocating policy positions.
- **Communication:** The research organization should communicate results widely and transparently, make the underlying data available, and disseminate comprehensive reports — including all results, both positive and negative — to the widest possible audience at no cost.

A key challenge, given the existence of numerous research questions in a period of potentially rapid growth in OGD, will be to ensure the prompt startup of the research program proposed here, with a strong emphasis throughout on streamlining every part of the program to provide the shortest possible turnaround in obtaining answers to the key questions to protect human and ecological health. The need for timely results would also argue for relying, as far as possible, on existing research organizations to expedite implementation.

The success of this comprehensive Research Agenda will depend strongly on the identification of significant and balanced funding and careful coordination with ongoing research efforts, such as the federal Multi-Agency Collaboration on Unconventional Oil and Gas Research and the National Institute of Environmental Health Sciences. The Committee recognizes, and would hope, that elements of this Research Agenda could be taken up as priorities for funding by appropriate agencies, e.g., the National Institute for Occupational Safety and Health (NIOSH) for worker health effects, and the Department of Energy National Energy Technology Laboratory (NETL) for wellbore integrity and other topics that overlap its research portfolio (National Energy Technology Laboratory 2015).

At the same time, a number of the overarching research questions would be best implemented as part of an integrated research program that could be pursued simultaneously. In pursuit of such an integrated program, certain groups of funders from both government and industry might choose to identify a major portion of this Research Agenda for funding, such as the overarching human exposure and health topics. Such funding can provide impetus to establish a new, integrated research program to specifically address those questions.