

Federal Multiagency Collaboration on Unconventional Oil and Gas Research

A Strategy for Research and
Development



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Table of Contents

Introduction	2
Research Topics	7
Key Research	8
Topic 1: Understanding the Scale and Nature of U.S. Unconventional Oil and Gas Resources.....	8
Topic 2: Water Quality.....	9
Topic 3: Water Availability	11
Topic 4: Air Quality and Greenhouse Gas (GHG) Emissions	11
Topic 5: Effects on Human Health	12
Topic 6: Ecological Effects.....	13
Topic 7: Induced Seismicity.....	14
Flagship Projects	15
Next Steps.....	17
References.....	18



INTRODUCTION

This document provides a Federal Multiagency Strategy for coordinating on-going and future, high priority research associated with safely and prudently developing onshore shale gas, tight gas, shale oil, and tight oil resources (Multiagency, 2012). It identifies key questions the Agencies – the Department of Energy (DOE); Department of the Interior (DOI); and Environmental Protection Agency (EPA) – will use to guide on-going research. It also describes a process through which collaborative research will be undertaken to improve how the private sector develops these resources while protecting human health and the environment. Ultimately, the goal of research conducted under this Strategy is to provide information to assist decision-making in support of safely and responsibly developing domestic onshore unconventional oil and gas (UOG) resources for stakeholders at many levels – federal, state, tribal, and local government; within industry; and the public-at-large.

Unconventional Oil and Natural Gas Resources

America’s abundant UOG resources, which include natural gas and oil contained in tight geological formations, are vital components of our Nation’s energy portfolio. UOG development can enhance America’s energy, economic, and environmental security, and can create significant income, employment, and other economic benefits. Therefore, safely, responsibly, and efficiently developing unconventional domestic oil and gas resources plays an important role in our Nation’s energy future.

Research conducted by industry and the United States (U.S.) Government over a number of decades led to the development and commercial deployment of horizontal drilling and hydraulic fracturing technologies. The combination of these advancements and their effective application to the unique geological properties of unconventional reservoirs has dramatically increased the Nation’s technically-recoverable domestic natural gas and oil resources. At the same time, the new economics enabled by these technological innovations have greatly expanded unconventional resource production. In the case of shale gas alone, the Energy Information Administration (EIA) estimates it will account for just over one half of the total U.S. natural gas production by 2040 (EIA, 2014).

Meanwhile, the scale and nature of the technologies used to develop UOG resources have prompted concerns over potential human health and environmental impacts. Included among these concerns are such issues as water quality and availability, air quality, greenhouse gas emissions, ecosystem integrity, impacts on human health, and the prospects for inducing seismic events. Understanding these potential impacts, their relationship to national energy and environmental objectives, and how they can best be mitigated will play a significant role in enabling UOG resources to be safely and responsibly recovered and utilized, and motivates the federal research agenda.

On-going Federal Coordination

In 2011, President Barack Obama issued the *Blueprint for a Secure Energy Future*, a comprehensive plan to reduce America’s oil dependence, save consumers money, and make the Nation a worldwide leader in clean energy industries. Realizing the benefits of developing and using UOG resources in a prudent and sustainable manner is a central objective of the *Blueprint*. Accordingly, the plan identified the need for ongoing federal research that supports sound decision-making and helps ensure responsible and efficient development of domestic oil and natural gas resources. In August 2011, the Secretary of Energy Advisory Board Subcommittee

Unconventional oil and gas (UOG) refers to resources such as shale gas, shale oil, tight gas, and tight oil that cannot be produced economically through standard drilling practices.

Hydraulic fracturing, frequently described as a well stimulation technique, has been used to maximize production of oil and natural gas in unconventional reservoirs, such as shale, coalbeds, and tight sands.



on Natural Gas (SEAB, 2011) similarly highlighted the important role the federal government plays in addressing UOG research and development (R&D) needs, particularly research to support environmental protection and safety.

To further encourage federal cooperation and coordination, the President issued an executive order in April 2012 establishing an Interagency Working Group to Support Safe and Responsible Development of Unconventional Domestic Natural Gas Resources (Executive Order, 2012). In his 2013 *Climate Action Plan*, the President also called on his administration to develop a comprehensive interagency methane strategy to reduce methane emissions from a variety of sectors, including oil and natural gas. In March 2014, the Administration released a Climate Action Plan Strategy to Reduce Methane Emissions that outlines a series of voluntary actions and common-sense standards to encourage cost-effective methane emission reductions in the oil and gas sector.

Because a majority of federal UOG research activities and expertise resides collectively within the DOE, DOI, and EPA, these Agencies signed a Multiagency Memorandum of Agreement (MOA) pledging to develop a focused, collaborative and coordinated research effort addressing high-priority challenges connected to prudent UOG onshore resource development (Multiagency, 2012).

Each agency contributed senior policy and technical leaders to lead the Federal Multiagency Collaboration on Unconventional Oil and Gas Research's Steering Committee. Through this Steering Committee and the contributions of a Technical Subcommittee, comprised of scientists and engineers from DOE, DOI, EPA, and the Department of Health and Human Services (HHS),¹ the Agencies developed this Strategy for research collaboration and coordination. This effort was undertaken by building upon the subject matter expertise in each Agency; seeking input from scientists at other federal agencies and consulting with a diverse set of external stakeholders during public webinars. These public webinars were delivered over three sessions to target different audiences— academia and non-governmental organizations (NGOs); industry; and states and tribes.

In addition to producing this Strategy, the Steering Committee maintains an outreach effort, including a website². Among information on the site is the presentation used for the webinars; the MOA; the Blueprint for a Secure Energy Future; and President Obama's Executive Order. Additionally, Multiagency representatives periodically present publicly about the collaborative effort's goals and activities.

Core Competencies

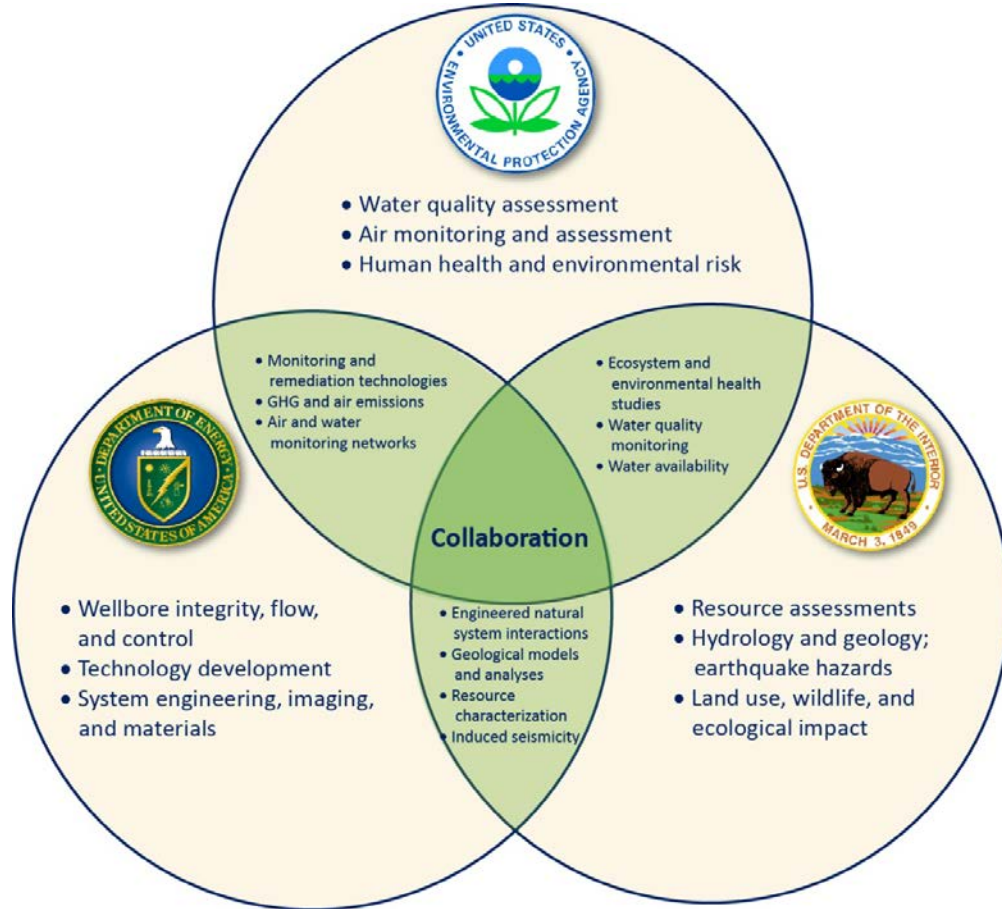
The Steering Committee acknowledges that each of the Agencies has individual expertise and core competencies (Figure 1) that can influence the effective implementation of needed R&D. Because these core competencies overlap in some areas, emphasis has been placed on a complementary approach that avoids duplication and takes advantage of inherent strengths.

¹ Other federal agencies include the U.S. Department of Health and Human Services (HHS), which includes the Centers for Disease Control and Prevention (which houses the National Institute for Occupational Safety and Health (NIOSH) and the Agency for Toxic Substances and Disease Registry (ATSDR)) and the National Institutes of Health (NIH) (which houses the National Institute of Environmental Health Sciences (NIEHS)), as well as the Department of Labor's (DOL) Occupational Safety and Health Administration (OSHA).

² The Steering Committee website is located at <http://unconventional.energy.gov>.



Figure 1: Relationships among core competencies in the area of unconventional oil and gas resources of the three federal agencies that are coordinating as part of this Strategy. In addition, the skills and cooperation of HHS and DOL, including the CDC (ATSDR and NIOSH), NIEHS, and OSHA are important for the success of the comprehensive approach outlined in the Strategy.



In developing this Strategy, the Agencies considered scientific topics relevant to prudent development of UOG resources and grouped the results into seven broad topic areas of research:

1. Scale and nature of U.S. unconventional oil and gas resources;
2. Water quality;
3. Water availability;
4. Air quality and greenhouse gas emissions;
5. Effects on human health;
6. Ecological effects; and
7. Induced Seismicity.

To help achieve the goal of Multiagency collaboration, each Agency agreed to: focus on its individual core competencies; work together on research topics, as appropriate; consistently coordinate on their individual annual research and budget processes; and join forces to coordinate with stakeholders. Among other things, this document helps communicate the coordination among key existing UOG research projects within the three Agencies and highlights remaining research needs. Although this Strategy is focused on R&D projects within the participating Agencies, the Agencies recognize that additional relevant, valuable research is ongoing elsewhere, particularly in the private sector and academia. Exhibit 1 identifies the scope of this Strategy, including what the document does and does not address.

The Federal Government's Role

To meet the challenge of responsibly developing domestic onshore oil and gas resources, including on federal lands, one key federal role is supporting relevant research that characterizes UOG resources, while simultaneously protecting human health and the environment. Fulfilling this responsibility requires the federal government to address issues related to the scale and scope of UOG development; develop consistent standards and protocols for sampling and analysis of air, water, and biological resources; analyze potential impacts on human health and the environment; encourage development and deployment of existing and innovative, new technologies and approaches that mitigate these potential risks; and support local, state, tribal, or federal level decision-making processes that enable prudent resource development.

Accomplishing these diverse but related responsibilities requires the federal government to coordinate a cross-cutting research and technology development program. The scope of essential research is broad and calls for integration and coordination across a wide range of stakeholders including scientists, engineers, industry, environmental groups, policy-makers, government agencies, NGOs, academia, and the general public.

*DOE, DOI, and EPA will use this effort to **coordinate federal research** conducted by these federal agencies. This Strategy outlines research needs and presents flagship projects that illustrate the degree and nature of coordination and collaboration that is required.*



Exhibit 1. Scope: What this document does and does not do.

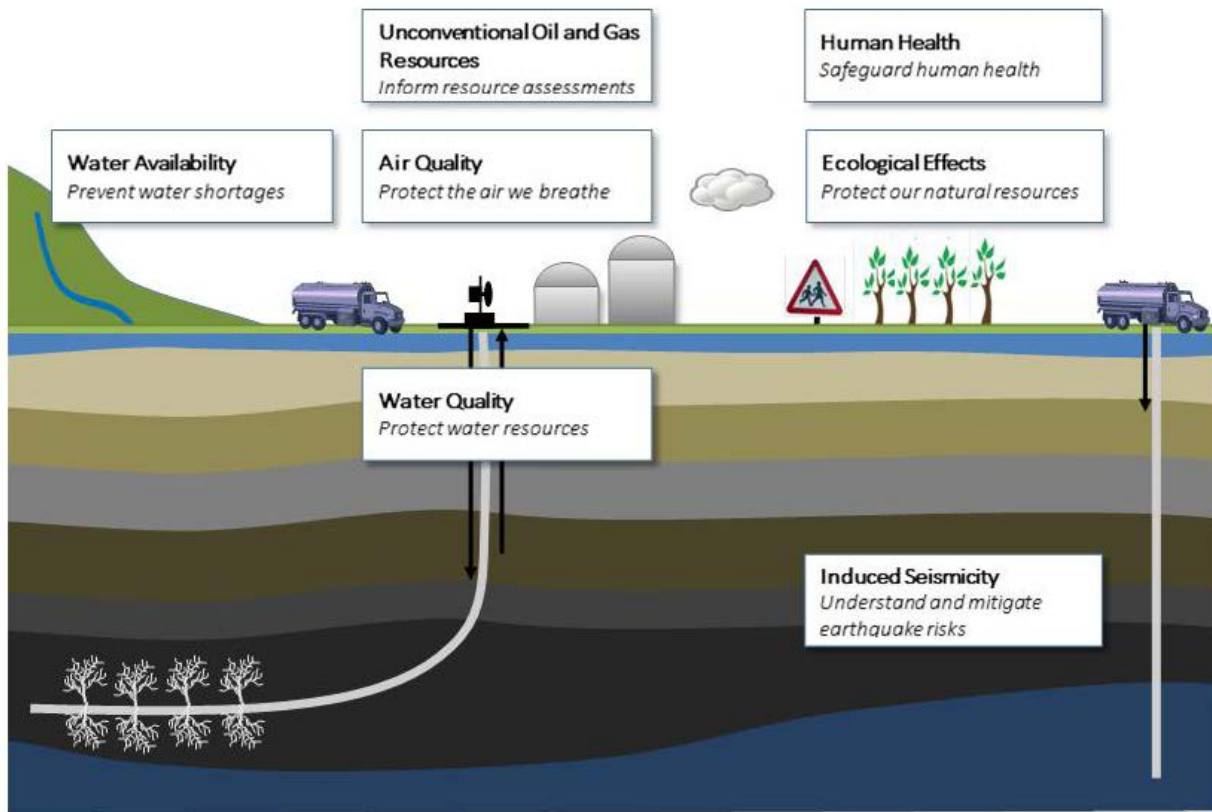
What this document does	What this document does not do
<p><i>Identifies research topics</i></p> <p>Seven broad topic areas are identified along with a discussion of the primary scientific questions within each topic.</p> <p><i>Identifies initial priorities</i></p> <p>The Strategy provides an initial prioritization of the research topics to be addressed.</p> <p><i>Defines the roles of the three Agencies</i></p> <p>The Memorandum which established this effort, laid out general areas of core competency for each of the three Agencies. This document provides further detail and establishes leadership areas for each agency. The Memorandum also noted that there will be areas for which the combined capabilities of more than one agency will be necessary to address a particular research topic. This document provides a framework for that collaboration.</p> <p><i>Establishes mechanisms for interagency cooperation</i></p> <p>Through this effort, the participating Agencies have established a Steering Committee, which is leading the coordination, and it will be a standing entity with leadership that will rotate between the three Agencies. This document provides further detail on the roles and responsibilities of the Steering Committee and steps that will be taken to ensure that research is coordinated on an ongoing basis.</p> <p><i>Proposes key flagship projects</i></p> <p>These projects are intended to delineate potential project-level work that produces outputs taking full advantage of the interagency collaboration and that addresses the major areas of public concern.</p>	<p><i>Serve as a detailed research plan</i></p> <p>The scope of this document is broad, covering diverse topics relevant to safely developing UOG resources.</p> <p><i>Provide a comprehensive analysis of ongoing research efforts across or outside of government</i></p> <p>It is critical for federal research agencies to coordinate and cooperate with their counterparts from industry, academia, and non-governmental sectors – leveraging those efforts wherever possible. While this document assesses initial research challenges, it does not provide a detailed review of efforts being carried out other than by the Agencies or a detailed literature review. Such a review will be part of subsequent research plans and will influence the scope of specific research projects that are undertaken by the federal government. While it is the federal government’s role in research to inform decision-makers and improve environmental performance, industry has different drivers, such as lowering the costs of technologies.</p> <p><i>Make regulatory recommendations</i></p> <p>This document focuses on research issues underlying the prudent development of domestic onshore UOG resources. This document does not make policy recommendations.</p> <p><i>Make recommendations for federal research beyond the scope of the Agencies on the Steering Committee</i></p> <p>There may be research topics that are undertaken by federal agencies not represented on the Steering Committee and therefore are not covered in this document.</p>



RESEARCH TOPICS

In developing this Strategy, the Technical Subcommittee considered scientific topics and associated questions relevant to safely and prudently developing onshore UOG resources and grouped the results into seven topic areas of UOG research needs (Figure 2). These key topics will subsequently be used by the Agencies to strategically coordinate existing UOG research projects as well as identify remaining R&D needs.

Figure 2: This figure depicts the seven complementary topic areas of UOG research.



- Topic 1:** Understanding the scale and nature of U.S. unconventional oil and gas resources: *What research is necessary to understand the locations of UOG and how much can be recovered? How can new or smarter deployment of existing technology enable the resource to be developed from fewer, less-impactful wells?*
- Topic 2:** Water quality: *What research is necessary to assess the impacts of UOG development on water quality? How can any potential negative impacts be mitigated?*
- Topic 3:** Water availability: *What research is necessary to understand the impacts on water resources where withdrawal may affect supply, use, and ecological health? How can the potential negative effects of water usage in UOG development be mitigated?*
- Topic 4:** Air quality and greenhouse gas (GHG) emissions: *What research is necessary to understand the potential air quality impacts from both short-term emissions and life cycle GHG emissions associated with UOG development and production? How can any potential negative effects be mitigated?*

- Topic 5:** Effects on human health: *What research is necessary to understand any potential impacts on the health of the nation’s population? How can any potential negative impacts on human health be mitigated?*
- Topic 6:** Ecological effects: *What research is necessary to understand any potential impacts to ecological systems? How can any potential negative impacts on ecosystems be mitigated?*
- Topic 7:** Induced seismicity: *What research is necessary to understand any potential for UOG-related activities to induce seismic events and to characterize any potential hazards? What can be done to mitigate any negative impacts or potential risks from these events?*

KEY RESEARCH

The following is a summary of key research developed for each of the seven topic areas. **PRIORITY RESEARCH NEEDS** have been identified for each of the topic areas along with potential products or outcomes required to meet the goal of the collaboration. These **PRIORITY RESEARCH NEEDS** represent the most critical research based on Agencies’ subject matter expertise as well as input from external stakeholders.

A key objective of this document is to define roles and responsibilities for each of the three Agencies in terms of carrying out new and existing UOG research initiatives. Consequently, specific **AGENCY ROLES** are indicated for each research need in three categories:

- Lead Agency:** Agency leads the coordination of research activities. Research need falls directly within the agency’s core competency. Agency has significant relevant experience and capabilities.
- Primary Support:** Agency has significant relevant expertise, experience, personnel, and potential resources.
- Secondary Support:** Agency has limited capabilities (i.e., individual researchers or historical programs).















The following “Priority Research Needs” summarizes the highest priority items the Agencies would address by coordinating proposed, planned, or on-going research. One example of an on-going project is EPA’s Study of Hydraulic Fracturing for Oil and Gas and Its Potential Impact on Drinking Water Resources. Additionally, while this Strategy will be used to inform budget requests, execution of specific identified priority research needs is subject to funding availability.

Topic 1: Understanding the Scale and Nature of U.S. Unconventional Oil and Gas Resources

Both geologic setting and development method are primary drivers in determining the locations and characteristics of UOG resources and the identification of the potential environmental impacts of UOG resource production. Priority research needs in this topic area include assessing the location, physical characteristics, and potential size of different UOG resources to understand the potential scale of development in different geographical areas and geologic settings. Research will assist decision makers in understanding and mitigating potentially adverse impacts of unconventional domestic energy resource development while realizing the benefits of additional energy supply.



Table 1: Priority Research Needs – Scale and Nature of UOG Resources

Priority Research Need	Agency Roles
1 Estimate Technically-Recoverable Resource (TRR): Identify where assessment is needed, gather and analyze data, and report findings.	DOE  DOI  EPA 
2 Characterize Scale/Timelines of Development: Reduce the surface and subsurface impacts of development by analyzing TRR in the context of economic factors, industry capacity, and developing technology to determine the potential intensity of future development activity.	DOE  DOI  EPA 
3 Characterize Linkages among UOG Development Processes, Variable Geology, and Pathways for Impact on Human Health and the Environment: Conduct field and laboratory studies to understand how UOG development in different reservoirs with varying geologic characteristics influence impacts on human health and the environment.	DOE  DOI  EPA 
4 Foster Technology Development for Mitigation of Impacts on Human Health and the Environment: Identify opportunities where new approaches can reduce environmental footprint of UOG development, either through smarter and smaller stimulations, more streamlined well/field development designs, or improved controls technology.	DOE  DOI  EPA 
5 Understand Long-Term Implications of UOG Development on Co-Located Subsurface Industrial Activities or Resources: Understand the impacts of pervasive change in subsurface environment resulting from natural hydrocarbon leakage on possible future large-scale activities such as carbon storage.	DOE  DOI  EPA 

Topic 1 Summary

- *Geologic setting and development method of UOG production are primary drivers of potential UOG environmental impacts.*
- *Research will help decision makers identify the likely location and development timeframe of UOG resources, which will inform decision makers on the potential harmful impacts of UOG development, while allowing the nation to better realize the benefits of additional energy supply.*

Topic 2: Water Quality
















Water quality encompasses a range of biological, chemical, and physical conditions for both surface (lakes and streams, as well as near-shore oceans) and subsurface waters (aquifers). Many public comments regarding UOG development and production reflect concern about potential water quality impacts on both ecosystems and human well-being. Priority research needs in this area include improved quantitative evaluations of contaminant pathways in water resources that can be used to assess potential human and ecological health effects.

Important additional research is needed to generate a quantitative understanding of water quality impacts over the entire cycle of UOG operations (site preparation, water acquisition, drilling, completion and fracturing, production, waste disposal, pipeline construction and site closure). Also needed is better understanding of how these impacts may vary over time and space and due to differences in UOG operations. Consequently, the goals of this research are to provide better data for evaluating impacts (e.g., ecological, human, or community effects) and to help identify best practices and new technologies for UOG operations that may help to avoid or reduce



potential adverse impacts. EPA’s Study of Hydraulic Fracturing for Oil and Gas and Its Potential Impact on Drinking Water Resources is an on-going component of the Agencies’ efforts to address these research goals.

Table 2: Priority Research Needs – Water Quality

Priority Research Needs	Agency Roles
<p>1 Determine the Impact of Well Injection (Hydraulic Fracturing Fluids and Wastewaters) and Produced Waters on Water Quality: Conduct state-of-the science assessments, review literature, review data from industry, and determine research gaps; conduct monitoring and modeling to establish driving factors for well injection-groundwater connections; and develop analytical methods for the detection of chemicals used or reported to be found in hydraulic fracturing fluids or wastewater.</p>	<p>DOE DOI EPA</p> <p>  </p>
<p>2 Assess Wellbore Integrity to Prevent and Minimize Contamination: Assess contribution of current wellbore integrity practices to risk of contamination; identify materials for improved wellbore design, construction, testing and remediation to enhance environmental performance of wellbores; apply computer models to explore the potential for gas or fluid migration from poor, incomplete, or degraded well cementing or cement failure during hydraulic fracturing in nearby wells and existing faults; and develop an “Area of Review” methodology for horizontal drilling similar to the method that is employed for vertical wells.</p>	<p>DOE DOI EPA</p> <p>  </p>
<p>3 Develop Mitigation Technologies: Develop improved technologies for water reuse and/or recycling to reduce the amount of water requiring disposal through injection or treatment technologies.</p>	<p>DOE DOI EPA</p> <p>  </p>
<p>4 Identify and Model Water Quality Changes Associated with UOG Life Cycle: Examine UOG impacts on groundwater and surface water quality; identify indicators, including tracers that can be used to document hydraulic fracturing impacts on groundwater and surface water; establish baseline monitoring for surface water and groundwater quality and stray gas; and determine the relative source contributions and environmental pathways for contaminants associated with UOG produced and flowback wastewater.</p>	<p>DOE DOI EPA</p> <p>  </p>
<p>5 Investigate the Transport and Disposition of UOG Wastewater: Inventory current wastewater volumes and disposition; study impacts of direct discharges as allowed in certain geographic areas of the country for agricultural and wildlife propagation; evaluate the efficacy of wastewater treatment technologies; develop methods to detect and quantify contaminants in UOG wastewater and receiving environmental waters; and conduct source apportionment and bromine disinfection by-product precursor studies.</p>	<p>DOE DOI EPA</p> <p>  </p>

Topic 2 Summary

- Water quality encompasses a range of biological, chemical and physical conditions for surface and subsurface waters.
- Research is needed to help understand potential impacts over the entire cycle of UOG operations, and develop best practices and mitigation technologies.








Topic 3: Water Availability

For purposes of this Strategy, the term *water availability* is used to include the amount and quality of water needed to meet human and ecosystem needs; impacts of water withdrawn from surface and groundwater systems; and water produced during the active phase of a UOG operation. Produced and flowback wastewaters are important because they can: 1) potentially be reused in hydraulic fracturing, thereby reducing total freshwater withdrawals; and 2) potentially be treated and returned to the environment, thereby potentially reducing demands on the local water budget.

This research area relates to how UOG activities may impact both the quantity and availability of water required for hydraulic fracturing, and better understand the possible impacts of ground and surface waters withdrawals on drinking water resources. As a result, it would develop information that would allow for a quantitative understanding of how water availability is impacted by UOG resources, geographic locations, methods of production, and reuse and recycling of wastewaters, as well as the technologies and approaches that optimize water use.

Table 3: Priority Research Needs – Water Availability

	Priority Research Need	Agency Roles
1	Provide Supporting Water Resources Information: Support streamgage baseline monitoring in states where UOG production is ongoing and/or planned. Collect baseline information on water resources in three case study areas (Marcellus Shale, Barnett Formation, and Bakken Shale) before, during, and after UOG operations; develop regional hydrogeologic frameworks; and identify sources of lower quality water to be used in lieu of fresh water in development activities.	DOE DOI EPA 
2	Provide Supporting Water Resources Information: Compile published information on water withdrawals, including ancillary data.	DOE DOI EPA 
3	Develop Water Budgets: Develop complete water budgets for sub-watersheds in each of the three case study areas, accounting for withdrawals, discharges to streams and groundwater, and characteristics of produced waters; provide an understanding of how much water is required to produce UOG and how the water demands are changing with increased recycling.	DOE DOI EPA 
4	Develop Predictive Tools: Develop statistical models for estimating the amount of water required for UOG operations; predict volumes of flowback fluids and produced waters.	DOE DOI EPA 
5	Develop Innovative Mitigation Technologies: Develop hydraulic fracturing technologies that require less water consumption and/or alternative waterless technologies.	DOE DOI EPA 

Topic 3 Summary

- *Water availability includes the amount and quality of water, from surface or groundwater sources, needed to meet human and ecosystem needs.*
- *Research is needed on how UOG activities impact water quantity and availability, and also to better understand possible effects of withdrawals on drinking water resources.*



Topic 4: Air Quality and Greenhouse Gas (GHG) Emissions

UOG development and operations release various pollutants into the atmosphere including particulate matter, volatile organic compounds (VOCs), such as methane and hazardous air pollutants (HAPs), as well as radon. These pollutants can impact human health, ecological resources, and the Earth’s climate. Many of the pollutants released from unconventional reservoirs are likely the same as those released from extracting oil and gas from conventional reservoirs. However, the air pollutants and their emission rates from unconventional reservoirs and the technologies associated with the development of these reservoirs remain insufficiently characterized to allow a scientifically-based evaluation of human health effects, ecological effects, and GHG emissions. In addition, UOG development has the potential to have both local (multiple wells developed from a single well pad; compressor stations) and regional (widespread exploration of UOG resources within a given shale play) impacts on air quality. Therefore, the answers to key science questions regarding air pollutant impacts require improved quantitative evaluations of emissions for use in assessments of health, ecosystem, and climate effects.

Table 4: Priority Research Needs – Air Quality

	Priority Research Need	Agency Roles
1	Air Quality Modeling: Perform preliminary air quality and dispersion modeling to evaluate potential changes.	DOE <input type="checkbox"/> DOI <input type="checkbox"/> EPA <input checked="" type="checkbox"/>
2	Source Emissions Measurements: Measure VOCs, including methane, and other HAPs from hydraulically fractured oil and gas well completions, surface impoundments, and other sources. Apply source-receptor modeling to estimate contributions from UOG activities.	DOE <input checked="" type="checkbox"/> DOI <input type="checkbox"/> EPA <input checked="" type="checkbox"/>
3	Ambient Air Measurements: Measure ambient VOC/HAP levels around wellpads, compressor stations, and distribution networks.	DOE <input checked="" type="checkbox"/> DOI <input type="checkbox"/> EPA <input checked="" type="checkbox"/>
4	Exposure Assessment: Conduct scoping evaluation of potential for exposure to VOCs/HAPs near UOG operations.	DOE <input type="checkbox"/> DOI <input type="checkbox"/> EPA <input checked="" type="checkbox"/>
5	Emission Mitigation: Assess the current capabilities of control strategies and measures to reduce emissions from UOG operations including extent of current use, costs and performance, availability and applicability, and operational benefits and challenges.	DOE <input checked="" type="checkbox"/> DOI <input type="checkbox"/> EPA <input checked="" type="checkbox"/>
6	Support Development of Engineering Controls, Technologies, and Strategies for Emissions Control during UOG Operations: Conduct measurement activities to provide information on performance of control technologies and practices; and collaborate with industry and others to move promising control concepts to demonstration stage.	DOE <input checked="" type="checkbox"/> DOI <input type="checkbox"/> EPA <input checked="" type="checkbox"/>

Topic 4 Summary

- UOG development and operations can release potentially harmful emissions into the atmosphere.
- Emission data are needed to underpin a scientific evaluation regarding possible impacts on human health, the environment, and GHG emissions.






Topic 5: Effects on Human Health

Air quality, water quality, and water availability impacts from UOG production may ultimately affect human health. Priority research needs in this area include an analysis of the available data and identification of knowledge gaps; understanding of the changes in water quality, water availability, air quality, and other environmental media; knowledge of the likely human exposures and exposure scenarios; supportive toxicology related to likely exposures; the populations and life stages susceptible to exposure, adverse physical and mental health outcomes, as well as fire and explosion hazards; and best practices for evaluating potential cumulative risks associated with multiple chemical stressors resulting from UOG development activities.

The Steering Committee recognizes that most of the research needed to address potential impacts on human health is beyond the scope of this Multiagency effort and would most appropriately be led by federal health agencies. Therefore, Table 5 does not indicate agency leads among DOE, DOI, and EPA, although the three agencies can contribute to these efforts (e.g., by performing environmental sampling). The following identified research needs were developed with input from the health agencies listed on page 3.

Table 5: Priority Research Needs – Effects on Human Health

	Priority Research Need	Agency Roles
1	Occupational Studies: Identify data and knowledge gaps for assessment of exposures and health hazards for workers. This includes the identification of contaminants of concern and prioritization of environmental pathways. As data gaps are addressed, research needs would be periodically re-prioritized.	DOE DOI EPA 
2	Toxicity Assessment: Identify known chemical, physical, and toxicological properties of chemicals used in hydraulic fracturing or found in hydraulic fracturing waste waters and air emissions. For chemicals with known structures, estimate properties using quantitative structure activity relationship methods.	DOE DOI EPA 
3	Health Studies: In coordination with partners including other federal health agencies, as appropriate, conduct health studies in the vicinity of UOG sites; synthesize a comprehensive stressor inventory; conduct temporal/spatial assessments of health conditions of concern that may be associated with UOG development and production.	DOE DOI EPA 

Topic 5 Summary

- Human health may be affected by impacts of UOG development and production on air and water quality, and water availability.
- A better understanding of the changes caused by these impacts, exposure levels, toxicity, susceptibility, and other potentially harmful outcomes, is essential moving forward.



Topic 6: Ecological Effects

Taken collectively, impacts to air quality, water quality, and water availability discussed in the previous sections can translate into a mixed set of stressors on biological communities in areas of UOG development. Additional impacts to associated ecosystems can come through land use change, habitat fragmentation or loss, increased pathways for introduction of invasive and non-native species, and noise and light pollution. Many of these types of impacts are not unique to UOG development, but the pattern, intensity and geographic context of UOG development presents a unique threat to ecological resources.

Research proposed for this topic focuses primarily on potential impacts to aquatic and terrestrial ecosystems unique to UOG development for which parallel information cannot be extracted from experiences with other development activities, particularly species of state and federal concern, and risk assessments to unique landscapes that have not been previously developed, or that affect species or ecosystems of state or federal concern that have not been previously studied. Unique UOG activities that can cause surface or groundwater contamination include high concentration of salts, produced water spills, wellbore casing failures, contamination from naturally occurring radioactive materials (NORMs), and contamination from toxic chemicals that are specifically used for hydraulic fracturing. Additionally, large water withdrawals generally required for hydraulic fracturing could alter freshwater availability and the environmental flow regimes necessary to sustain terrestrial and aquatic ecosystems and the species they support. Research would support resource protection, restoration, and mitigation activities so that land and water managers can identify risks unique to UOG development, and industry can refine best management practices to maintain and possibly restore affected habitats.

Table 6: Priority Research Needs – Ecological Effects

	Priority Research Need	Agency Roles
1	Information Gap Analysis: Review and synthesize literature, data sources, and monitoring protocols relevant to evaluating impacts of UOG on habitats, ecosystem services, aquatic life uses, migratory birds, and threatened and endangered species.	DOE <input type="checkbox"/> DOI <input checked="" type="checkbox"/> EPA <input checked="" type="checkbox"/>
2	Wastewater Toxicity Testing: Characterize and build upon the available ecological toxicity data for the chemicals in wastewaters that we project pose the greatest potential risk to ecosystems.	DOE <input type="checkbox"/> DOI <input checked="" type="checkbox"/> EPA <input checked="" type="checkbox"/>
3	Vulnerability Assessments: Identify and prioritize key geographic regions, ecosystems and their services, sensitive aquatic communities, wastewater disposal facilities, and critical wildlife habitats that have the greatest potential for impact from ongoing and potential UOG activities.	DOE <input type="checkbox"/> DOI <input checked="" type="checkbox"/> EPA <input checked="" type="checkbox"/>
4	Cumulative Impact Models: Estimate total cumulative impact of the full life cycle of UOG exploration, development, and delivery on natural resource systems of concern.	DOE <input type="checkbox"/> DOI <input checked="" type="checkbox"/> EPA <input checked="" type="checkbox"/>

Topic 6 Summary

- UOG activities can cause a wide range of impacts to ecosystems and associated species and habitats.
- Research is needed to connect air and water quality, and water availability, findings with direct exposure of flora, fauna, ecosystems, and land use change impacts.



Topic 7: Induced Seismicity

Researchers have long known about the potential of human activity for causing seismic activity, from petroleum extraction to water reservoir impoundments and fluid injection into the subsurface. Current scientific knowledge suggests changes in fluid volume and pore pressure, primarily through fluid injection, can induce seismic events. Consequently, the three stages of the UOG life cycle that could potentially cause such events to occur are: (1) during the disposal of UOG produced and flowback wastewater through deep injection wells; (2) long-term extraction of oil and gas; and, (3) the phase of hydraulic fracturing.

Although very small magnitude (microseismic) events are commonly produced by hydraulic fracturing operations, current understanding suggests that the potential risk of felt or damaging earthquakes is greatest from wastewater disposal in deep injection wells. There is a need for more data and analysis to relate UOG operations to induced seismic events, to connect these events to specific operational parameters and geologic conditions, and to develop and assess possible mitigation options for decision makers attempting to minimize seismic risks.

Table 7: Priority Research Needs – Induced Seismicity

	Priority Research Need	Agency Roles
1	Data Collection–Field and Laboratory: Identify five to ten industrial sites where background geologic site characterization and monitoring activities could be conducted; conduct geologic background and monitoring studies at several of these sites chosen for detailed assessment.	DOE <input checked="" type="checkbox"/> DOI <input checked="" type="checkbox"/> EPA <input type="checkbox"/>
2	Hazard and Risk Assessment: Analyze seismic hazard background data for multiple sites; and develop models for probabilistic hazards assessment that account for induced seismicity (IS).	DOE <input checked="" type="checkbox"/> DOI <input checked="" type="checkbox"/> EPA <input type="checkbox"/>
3	Physics-Based Model Development: Develop models for assessing the likelihood of induced seismic events and validate models with lab experiments and field data. As predictive models are developed, they must be validated and calibrated with seismic field data to demonstrate effectiveness.	DOE <input checked="" type="checkbox"/> DOI <input checked="" type="checkbox"/> EPA <input type="checkbox"/>

Topic 7 Summary

- There is the potential for induced seismic activity resulting from UOG development.
- A need exists for research that yields a better understanding of potential risks, causes and effects throughout the UOG development and production life cycle.



FLAGSHIP PROJECTS

Descriptions of six cross-cutting “Flagship Projects” have been developed to illustrate the type of collaboration and cooperation envisioned by the Steering Committee. While the Agencies are engaged in research outside of these examples, these proposed, planned, and on-going projects involve cross-cutting, multiagency, multi-disciplinary research that builds on each Agency’s core strengths and existing Agency research. Some of the Flagships examine areas where there is complementary research being conducted or where there are opportunities for significant synergy. Other projects expand on current research funded by DOE, DOI, and EPA, and address priority research needs identified in the Strategy. Finally, some of the proposed Flagships outline potential projects that the Steering Committee is considering. All of these suggested research efforts depend on available resources at the three Agencies. Envisioned are research products that would be useful to decision makers at each of the Agencies, as well as stakeholders from other federal and state agencies, tribes, industry, and the public. Descriptions of the six Flagship Projects and their projected research products are summarized below:

Flagship: Understanding Resource Volumes, Potential Scale of Future Drilling Activity, and Water Consumption in Representative Unconventional Oil and Gas Plays

Purpose: Develop approaches to better understand undiscovered UOG resources and the possible impacts of their development on the environment, especially water resources.

Products: New tools that can assess the potential intensity of future UOG drilling and water availability in priority basins.

Flagship: Study of the Potential Impacts of Hydraulic Fracturing for Oil and Gas on Drinking Water Resources

Purpose: Study of the potential impacts of hydraulic fracturing for oil and gas on drinking water resources by assessing research questions related to the five stages of the hydraulic fracturing water cycle: water acquisition; chemical mixing; well-injection; flowback and produced water; and wastewater treatment and waste disposal.

Products: An assessment of the potential impacts of oil and gas hydraulic fracturing activities on the quality and quantity of drinking water resources in the United States. The assessment is based upon extensive review of the literature, results from recently completed EPA research projects, and technical input from state, industry, and other stakeholders.

Flagship: Understanding and Managing Risks from UOG Development on Water Resources

Purpose: Address the potential for adverse effects on water quality, more broadly than just drinking water supplies, resulting from UOG operations.

Products: Peer-reviewed reports, publications, models, technology assessments, and decision tools ready for use to inform policy decisions and technical practices for protecting water resources.

Flagship: Application of Source and Remote Emission Measurement Methods to Quantification of Air Emissions from UOG Operations

Purpose: Characterize source emissions and control technology effectiveness using on-site and near-source remote methods.

Products: Sampling and measurement methods that can be used to conduct air quality characterizations from UOG operations to address impacts on local and regional air quality and potential community air toxic exposures. Conduct an assessment of the effectiveness of control technologies to mitigate air emissions.



Flagship: Water and UOG Development: Ecological Effects of Wastewater and Water Withdrawal
Purpose: Study the ecological effects of UOG development on aquatic biota, including direct effects of wastewater from UOG wells with high salt content and other chemical constituents on aquatic life.
Products: Baseline GIS layers in a representative play to support developing decision tools to locate and classify streams and riparian habitats with a high degree of potential degradation from UOG and a high propensity for restoration. Peer-reviewed publications that summarize the state of the science on potential effects of UOG on aquatic ecosystems; the development, validation, and application of suitably sensitive test species for detecting UOG effects; and describe watershed-based monitoring and assessment protocols needed to protect aquatic ecosystems from UOG impacts.

Flagship: Induced Seismicity, Implications of UOG Activities
Purpose: Improve the technical base needed both to define appropriate operational safeguards and to monitor sites effectively to minimize the potential for induced seismic events.
Products: Data to provide improved detection and location identification of seismic events at a site that is representative of produced and flowback wastewater disposal wells to elucidate key relationships between existing geologic features, injection activities, and seismic events.

NEXT STEPS

This document provides a strategy, identifies a set of priority research needs, and describes a process through which the Agencies will support relevant collaborative research to develop these resources while protecting human health and the environment. Because the Steering Committee is dedicated to a collaborative, coordinated process that takes into account the perspective and knowledge of all stakeholders, comments received will inform the future planning efforts of the three Agencies.

In the future, the Steering Committee, supported by appropriate research staff, will continue to meet on a regular basis to coordinate research efforts, and ensure that projects are implemented in a manner that maximizes public benefit and financial resource allocation. While this document initiates the process of identifying the highest priorities for research, all of the suggested research efforts depend on available resources at the three Agencies. As resources are allocated, more detailed research plans for the Flagship Projects identified in this Strategy will be prepared, describing existing literature, key milestones, required resources, funding sources, and specific outcomes.

Finally, the Steering Committee will continue to communicate with stakeholders to ensure: research conducted by the federal government addresses areas of greatest concern and impact; federal researchers appropriately leverage ongoing efforts pursued by NGOs, academia, and the private sector; and the results of federal efforts are effectively and transparently communicated to the public. The Steering Committee will continue to coordinate with external scientific communities to draw a comprehensive picture of research results and outcomes. The outputs of the multiagency research effort will expand our knowledge about UOG activities and provide information for policy decision-makers and the public to safely and responsibly develop these resources.



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