U.S. DEPARTMENT OF ENERGY

Report on the Multiagency Collaboration on Unconventional Oil and Gas Research

Report to Congress
December 2015

United States Department of Energy
Washington, DC 20585

Message from the Secretary of Energy

I am pleased to submit the enclosed report, *The Multiagency Collaboration on Unconventional Oil and Gas Research*.

The Report was prepared by the Department of Energy's Office of Fossil Energy and summarizes the accomplishments and potential next steps for the Multiagency Collaboration on Unconventional Oil and Natural Gas Research.

This Report is being provided to the following Members of Congress:

- **The Honorable Joseph R. Biden, Jr.**
  President of the Senate

- **The Honorable Paul Ryan**
  Speaker of the House of Representatives

- **The Honorable Thad Cochran**
  Chairman, Senate Appropriations Committee

- **The Honorable Barbara Mikulski**
  Vice Chairwoman, Senate Appropriations Committee

- **The Honorable Hal Rogers**
  Chairman, House Appropriations Committee

- **The Honorable Nita Lowey**
  Ranking Member, House Appropriations Committee

If you have any question or need additional information, please contact me or Mr. Brad Crowell, Assistant Secretary for Congressional and Intergovernmental Affairs, at (202) 586-5450.

Sincerely,

Ernest J. Moniz

Executive Summary

America's abundant unconventional oil and gas (UOG) resources are vital components of our Nation's energy portfolio. UOG development can enhance America's energy, economic, and environmental security; however, these resources must be extracted in a prudent manner.

The Department of Energy (DOE)—on behalf of the Multiagency Collaboration (MAC)—submits this Report to Congress detailing the accomplishments and next steps for each of seven research topics that DOE, the Department of Interior, and the Environmental Protection Agency (Agencies) identified in the multiagency UOG Research Strategy.[1] The goal of research conducted under this Strategy is to provide information to stakeholders in support of safely and responsibly developing domestic UOG resources.

The overview section of this Report highlights the major accomplishments from the three agencies. Subsequent sections provide more detail on examples of key activities, research accomplishments, examples of remaining knowledge gaps, and examples of possible next steps. The Agencies have collaborated on some of their research activities, coordinated with others**,** and shared the results of their work.

In addition to interagency communication, the Agencies also communicate the results of their work with stakeholders, including Congress, the Executive Office of the President, States, tribes, other federal agencies, industry, academia, non-governmental organizations, local officials, and the public. Throughout our outreach efforts at various venues, the MAC, has presented its research activities, results, and remaining knowledge gaps for each of the research topics identified in the Strategy.

Each research topic has been divided into three subsections: research activities overview; research results, including key accomplishments, and remaining knowledge gaps and possible next steps. Progress has been made on some of the research topics, but more research and development is needed to continue advancing the information available to decision-makers.

The following includes important research needs:

- Understanding potential impacts on water quality and availability over the entire cycle of UOG operations,
- Developing best practices and mitigation technologies for UOG development,
- Understanding the relationship between induced seismicity and UOG operations,
- Evaluating UOG-related air emissions and possible impacts on human health and the environment,

[1] http://unconventional.energy.gov/pdf/Multiagency_UOG_Research_Strategy.pdf

- Understanding the composition of UOG hydraulic fracturing fluids and/or wastewaters and potential risk,
- And understanding the environmental pathways that could lead to exposures to toxic chemicals during extraction and waste management activities.

Given congressionally appropriated resources consistent with the President's Budget requests, the Agencies look forward to working together and with others in the future.

MULTIAGENCY COLLABORATION ON UNCONVENTIONAL OIL AND GAS RESEARCH

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I. Legislative Language

This report responds to the Explanatory Statement on H.R. 83, Consolidated and Further Continuing Appropriations Act, 2015, which provides:

> Any funding in the area of hydraulic fracturing, including funding to support the proposed joint effort with the Environmental Protection Agency and the United States Geological Survey, is for research into hydraulic fracturing technologies that aims both to improve the economics and recoverability of reserves and to address the health, safety, and environmental risks of shale gas extraction. Together with EPA and USGS, the Department of Energy is directed to submit to the Committees on Appropriations of the House of Representatives and the Senate not later than 180 days after enactment of this Act an interagency detailed research plan, to include the proposed length of a collaborative study regarding hydraulic fracturing, out-year budget costs, and specific milestones and objectives.[2]

[2] Explanatory Statement Submitted by Mr. Rogers of Kentucky, Chairman of the House Committee on Appropriations Regarding the House Amendment to the Senate Amendment on H.R. 83, 160 Cong. Rec. H9307 at H9701 (Dec. 11, 2014).

II. Background

In July 2014, the U.S. Department of Energy (DOE), U.S. Department of the Interior (DOI), and Environmental Protection Agency (EPA) jointly released the *Federal Multiagency Collaboration on Unconventional Oil and Gas Research: A Strategy for Research and Development* (Strategy). The Strategy describes how the three agencies coordinate on-going and planned, high-priority research associated with safely and prudently developing onshore shale gas, tight gas, shale oil, and tight oil resources. The information generated under the Strategy can inform decision-makers and stakeholders at many levels—federal, state, tribal, and local government; industry; non-governmental organizations (NGOs); and the public—in support of responsible development of domestic onshore unconventional oil and gas resources. The Strategy identifies the key questions the Agencies use to guide their research and outlines a collaborative research process to reduce the impacts of developing these resources and protecting human health and the environment.

> "We are getting at the moment a very substantial benefit from the natural gas that we're able to produce by [hydraulic fracturing]. If we want the benefit to continue, we need to maintain the confidence of the public that this can be done in a safe and environmentally responsible way. This administration is determined to see that that happens." – John Holdren, Director, White House Office of Science and Technology Policy; May 2014

The Agencies identified seven research topics relevant to developing onshore UOG resources in a manner protective of human health and the environment. For each of these topics, priority research needs were identified taking into account the Agencies' subject matter expertise as well as input from external stakeholders.

This Report to Congress (Report) covers the Collaboration's progress to-date, with examples of research accomplishments and remaining knowledge gaps. The Agencies recognize and encourage others (e.g. industry) to contribute to addressing these research needs. This Report presents high-level information, cites reports and publications providing decision ready-science, and describes the Agencies' outreach efforts to share research results.

III. Overview

Major Accomplishments

The Agencies have a coordinated approach on planning research and sharing the results of their work. Some highlights of this coordinated approach include:

- Improved understanding of impacts on drinking water resources; data limitations preclude a determination of the frequency of impacts with any certainty.
- Reduced risk of groundwater contamination through improved wellbore design.
- Commercialized techniques in use by industry to reduce and reuse produced water.
- Improved methods for detecting wastewater spills.
- Improved understanding of the connection between increased seismic activity and UOG operations, which have informed State understanding of potential hazards.
- Enhanced methods for measuring air quality and emissions.
- Reduced ecological impacts by improving the permitting process with remote sensing techniques.
- Improved estimates of high potential UOG resources.

More detail on these and other accomplishments are described in the sections that follow.

Communication of Research Results

In addition to managing their research portfolios, the Agencies also communicate the results of their work to stakeholders, including Congress, the Executive Office of the President, States, tribes, other Federal agencies, industry, academia, nongovernmental organizations, local officials, and the public. Representatives from the Agencies have made presentations at dozens of conferences and published their research results in peer reviewed journals. These results are informing stakeholder decision-making.

For example, DOE research from its wellbore integrity portfolio highlighting foamed cement was published in the January 2015 issue of the *Journal of Petroleum Technology*. This research, performed by DOE's National Energy Research Laboratory (NETL) demonstrated that field-generated samples of foamed cement had lower porosity than lab-generated samples—confirming what cement specialists believed about the behavior of foamed cements in downhole conditions.

DOI's U.S. Geological Survey (USGS) published several peer-reviewed publications and technical reports on the potential effects of UOG activities on water quality, water availability, and ecosystems. Additionally, the USGS has released publications and products related to induced seismic events, including a comprehensive assessment of the link between thousands of

earthquakes and UOG operations, and has developed a prototype probabilistic hazard model for induced earthquakes. The USGS has also conducted assessments of undiscovered, technically recoverable UOG resources in selected basins.

Conducted at the urging of Congress, EPA's Hydraulic Fracturing Drinking Water Study has increased scientific understanding of hydraulic fracturing and produced 12 EPA technical reports and over 13 peer-reviewed research papers. EPA's study has also produced a draft assessment (*Assessment of the Potential Impact of Hydraulic Fracturing for Oil and Gas on Drinking Water Resources*) which represents a state-of-the-science integration of over 950 cited references relevant to the potential impacts of hydraulic fracturing activities on drinking water resources in the United States. (See, www.epa.gov/hfstudy) EPA worked in consultation with state and federal agencies, tribal governments, industry, non-governmental organizations, and the public in carrying out the hydraulic fracturing drinking water study and assessment Examples of EPA's public outreach related to its study can be found at http://www2.epa.gov/hfstudy/how-get-involved-epas-hydraulic-fracturing-study.

While each of these efforts highlights the individual agencies' core competencies and mission, the portfolios of the three Agencies complement each other in providing answers to the questions identified in the Strategy.

IV. Water Quality

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

Research Activities Overview

DOE is developing technologies for water reuse and recycling to reduce the amount of water requiring disposal or treatment. DOE is also assessing wellbore integrity to prevent and minimize contamination, including improving wellbore design, construction, testing, and remediation.

DOI is researching the potential impacts of UOG activities on surface water and groundwater quality. Research includes determining the baseline water quality conditions; assessing the potential for migration of methane gas and other hydrocarbons; investigating the environmental contaminants due to spills from UOG wastewater management activities, and developing geochemical methods and groundwater flow models to evaluate potential contamination of water supplies.

EPA is assessing the potential impacts of hydraulic fracturing activities on drinking water resources in the United States to improve understanding of the factors and drivers that may affect the frequency and severity of these impacts.

Research Results and Key Examples

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- **Data transparency and access.** Contributed to national database on chemicals and water used in hydraulic fracturing (FracFocus) and national well-level database that includes well level production, geology and construction through development of the National Gateway (Gateway) and the Risk Based Data Management System (RBDMS). DOE has also increased data transparency regarding fracture fluid additives, including improvements to the effectiveness of FracFocus disclosure and its usefulness for regulators, operating companies and the public. FracFocus illustrates how rapidly states can mobilize to respond to issues of public interest. In 2011, 2 states required chemical disclosure. By February 2014, over 20 states required chemical disclosure and 15 used FracFocus. Today, 24 states and the BLM require oil and gas operators to use FracFocus for chemical disclosure. An additional 4 states are now considering using FracFocus.
- **Produced water disposal reduction and product creation from by-products (i.e., salt).** Conducted pilot testing of pretreatment options to allow removal of naturally occurring radioactive material, salt crystal recovery, and re-use of produced water; created a water management model, Produced Water Treatment Beneficial Use Screening Tool,

which provides industry with tailored suggestions for water treatment and management options.

- **Water use reduction.** Supported industrial development and verified use of technologies, including water desalinization systems, ultrafiltration, and osmosis technologies; conducted field tests of filtration system that demonstrated 98.6 percent of over 600,000 gallons of produced water were reused.
- **Tools for well analysis.** Deployed geospatial analysis tools (GIS) that improve environmental assessments of water management.
- **Wellbore design improvements.** Improved operational safety and reduced risks to drinking water: developed Nanite™, a "smart" cement protocol that optimizes zonal isolation and improved leak detection tools that combine X-ray and neutron backscatter imaging techniques.

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- **Water quality study on UOG development.** Results from a surface water study from 1970 to 2010 [based on the parameters specific conductance (SC) and chloride (Cl) concentration from national, publicly available data] suggest that there have not been consistent or widespread changes in water quality in areas with increasing UOG development. Intentional or unintentional releases of produced water are a source of concern throughout the country and are often tracked using SC or CI as primary indicator constituents.
- **Wastewater spills.** Preliminary analytical results of water samples taken downstream from two alleged UOG-related spills (one in North Dakota and the other in West Virginia) suggest that accidental release of UOG wastewater can be detected in the environment by chemical and microbiological methods.
- **Variability of produced waters in wells.** In a study of 13 hydraulically fractured shale gas wells in north-central Pennsylvania (Marcellus Shale), USGS researchers found that the microbiology and organic chemistry of produced waters varied widely from well to well.
- **Methane analyses of groundwater and drinking water wells.** Analyses of groundwater in the Upper Delaware River Basin (Pennsylvania and New York) indicate the natural occurrence (pre-development) of methane is relatively low (<1 mg/L) in most samples. Other studies suggest that drinking water wells in areas near natural gas wells may have significantly higher concentrations. The analyses document the natural occurrence of methane in this region, but do not indicate whether the methane has a microbial or thermogenic origin.
- **Wastewater treatment plants as potential sources of DBPs.** USGS research of water samples collected in Pennsylvania from four sites along a large river shows that wastewater treatment plants processing waters from UOG development are potential sources of brominated disinfection by-products (DBPs) and DBP precursors

to receiving streams. Of the hundreds of known or suspected DBPs possibly created by disinfection processes, the brominated forms are among the most toxic. While these findings do not indicate an immediate threat to aquatic life or human health, the USGS study provides new data on the water quality of streams receiving discharged wastewater that can be used to inform decisions about management and treatment of produced waters.

- **Geochemistry of produced waters.** The USGS is conducting ongoing research to characterize the geochemistry of produced waters from the major oil- and natural-gas producing reservoirs in the Appalachian Basin. Results suggest that naturally occurring contaminants (e.g., radium) often are found in produced waters from Marcellus Shale gas wells.

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- **Peer-reviewed research.** As part of its Hydraulic Fracturing Drinking Water Study, EPA published over 20 peer-reviewed research papers and a Draft Assessment of the Potential Impact of Hydraulic Fracturing for Oil and Gas on Drinking Water Resources (June 2015, www.epa.gov/hfstudy).
- **Assessment of documented impacts to drinking water.** Based on available scientific data, EPA found that hydraulic fracturing activities in the United States are carried out in a way that has not led to widespread, systematic impacts on drinking water resources. While there were documented impacts to drinking water resources, the number of such impacts relative to the number of fractured wells was low. This could reflect either a rarity of impacts on drinking water resources or an underestimate of impacts as a result of data limitations.
- **Potential pathways impacting drinking water.** The assessment also identified potential ways that hydraulic fracturing activities impact drinking water resources, including:
  - Water withdrawals in areas with low water availability
  - Spills of HF fluids and produced waters (flowback and formation waters)
  - HF conducted directly into formations containing drinking water resources
  - Well integrity failures
  - Subsurface migration of gases and liquids
  - Inadequately treated wastewater
- **Independent scientific review.** EPA submitted the draft assessment to the Agency's independent Science Advisory Board to provide a rigorous, scientific peer review. The SAB process encourages public comment on the science in the assessment.

Examples of Remaining Knowledge Gaps

Examples of remaining knowledge gaps include:

- Additional baseline water quality data.
- Composition of wastewaters produced during UOG development.
- Methane data and analysis of groundwater from domestic and public water-supply wells.
- Improved well bore integrity technology development and best management practices.

Examples of Possible Next Steps

Each Agency will undertake research that is part of their core capabilities, as outlined in the Strategy. Below are possible next steps that build off of their current research portfolios.

- Assess and develop technology to help manage and treat co-produced water from oil and gas wells.
- Finalize the EPA's *Study of Potential Impacts of Hydraulic Fracturing for Oil and Gas on Drinking Water Resources*.
- Develop an improved understanding of relations among production of naturally occurring contaminants, production characteristics, and geologic features.
- Develop the capability to predict amounts of naturally occurring contaminants in produced waters.

V. Water Availability

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.

Research Activities Overview

DOE is investing in technologies that could reduce the utilization of valuable freshwater resources.

DOI methods can be used to estimate the volumes of water and sand required for UOG development. The methodology will be applied to estimate future water use in selected basins. The volume of water predicted to be produced can also be used in evaluations of potential induced seismicity from wastewater injection in deep wells.

Research Results and Key Examples

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- **Fresh water use reduction.** At least two major companies have reduced or eliminated their dependence upon fresh water through technologies that allow re-use of produced or flowback water and use of non-freshwater.
- **Technology development.** DOE has supported the verified use of technologies for treating or managing water in all parts of the hydraulic fracturing and production process, including water desalinization systems, ultrafiltration, and osmosis technologies. The addition of nanoparticles combined with surfactants can improve the performance of foam fracturing fluid mixtures, reducing the need for fresh water in those fracturing fluids.

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- **Volumes of water and sand.** New DOI methods can be used to estimate the volumes of water and sand required for UOG development. The methodology will be applied to estimate future water use in selected basins (e.g., in the Williston Basin of North Dakota).
- **Drilling methods and use of proppants, treatment fluids, additives, and water.** A national analysis of data on nearly 1 million hydraulically fractured wells and 1.8 million fracturing treatment records from 1947 through 2010 was used to identify trends in drilling methods and use of proppants, treatment fluids, additives, and water for hydraulic fracturing in the United States. This analysis illustrates the rapid expansion of water-intensive horizontal/directional drilling: an increase from 6 percent of new

hydraulically fractured wells drilled in the United States in 2000 to 42 percent of new wells drilled in 2010.

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- **Water withdrawals impact on drinking water.** In most of the counties in the United States, water used for hydraulic fracturing is less than 1 percent of total water use and consumption. Water withdrawals for hydraulic fracturing have the greatest potential to impact drinking water availability in areas with, or in times of, low water availability, exacerbated by drought, and over allocation of water.
- **Impacts of water withdrawals.** EPA researchers published a study that examined the impacts of water withdrawals in the Upper Susquehanna and Upper Colorado River Basins.

Examples of Remaining Knowledge Gaps

Examples of remaining knowledge gaps include:

- Identify alternative sources of water for UOG development to replace the use of freshwater sources.
- Deploy effective water-less and reduced-water technologies.
- Increase the number of wastewater treatment options.

Examples of Possible Next Steps

Each Agency will undertake research that is part of their core capabilities, as outlined in the Strategy. Below are possible next steps that build off of their current research portfolios.

- Develop an improved understanding of the relationship between formation characteristics, geologic characteristics, water requirements, and produced waters.
- Determine the effect of water withdrawals for UOG production on headwater streams and drinking water aquifers.
- Develop technologies and management practices for reducing fresh water demand and increasing the recycling of produced water.

VI. Induced Seismicity

UOG development in recent years has been associated with an increase in earthquake activity, especially in the central United States. There is a need for a better understanding of how this increased seismicity is related to UOG operations so that its associated seismic hazard can be reduced.

Research Activities Overview

DOE technologies are helping to produce assessments on the likelihood of past and future seismicity, and DOE research is showing that the relationship between injection and seismicity varies across different regions. DOE is identifying location-specific geologic risks and increasing transparency and access to disposal well injection volumes.

DOI research has been able to identify regions where seismicity has increased in recent years beyond what might be consistent with natural processes and has related this increased seismicity to fluid-injection activities.

Research Results and Key Examples

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- **Diagnostic and modeling tools.** DOE has assessed the likelihood and risk of induced seismicity in oil and gas operations, especially in Oklahoma, by utilizing state-of-the-art diagnostic and modeling tools. Geomechanical modeling, to evaluate Coulomb stresses, provided a valuable tool for assessing whether past seismicity may have been triggered or whether future seismicity is likely to be triggered.
- **Regional differences in injection/seismicity relationships.** A DOE study discovered that the injection/seismicity relationship was different across the regions. The UT-Austin study has implications for regulations and risk assessment/mitigation, because local surveys must be conducted to accurately determine the potential impact of injection and disposal. For example, the study found that injection triggered earthquakes in the Fort Worth Basin, whereas fluid extraction triggered earthquakes in the Eagle Ford.
- **Location-specific geologic risks.** DOE has identified location-specific geologic risks (oil, gas, and underground injection) using an integrated software tool (geoWELL).
- **Data transparency and access.** Transparency and access to disposal well injection volumes have increased through the National Gateway database, which will be made public in March 2016.

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- **Wastewater disposal.** USGS research indicates that the recent increase in earthquake activity and its seismic hazard in the central United States are primarily due to the disposal of wastewater from oil and gas production by deep injection. Large volumes of injected wastewater may be required for an earthquake response that includes events large enough to be felt, or even damaging. The magnitude of the largest induced earthquakes in some sequences correlate with the volume of injected wastewater, which consists mostly of formation brines that are co-produced with the oil or gas from hydraulically fractured unconventional reservoirs.
- **Forecasting models.** A recent USGS report outlines a preliminary set of models to forecast how hazardous ground shaking could be in the areas where sharp increases in seismicity have been recorded and describes for the first time how injection-induced earthquakes can be incorporated into U.S. seismic hazard maps. The models ultimately aim to calculate how often earthquakes are expected to occur in the next year and how hard the ground will likely shake as a result. This report looked at the central and eastern United States; future research will incorporate data from the western states as well. The report also identifies issues that must be resolved to develop a final hazard model, which is scheduled for release at the end of 2015 after the preliminary models are further examined.
- **Early identification of wells prone to inducing large earthquakes.** The vast majority of wells that inject wastewater into deep aquifers for disposal do not induce earthquakes large enough to be felt. For the tiny fraction of wells that do induce large earthquakes, however, the challenge is to identify them at early stages of injection projects in time to take corrective actions. DOI is in the process of exploring the feasibility of reducing the hazard of fluid-injection induced earthquakes in this way. That is, modest improvements to regional seismic networks in conjunction with the capability to deploy local networks rapidly can provide this early warning capability by imaging, at an early stage, buried faults that are in the process of being reactivated and likely to rupture in large-magnitude earthquakes unless adjustments to the injection operations are made.
- **Induced earthquake sequence.** The USGS has developed hydrological and geomechanical models and applied them to better understand the induced earthquake sequence extending from Oklahoma City toward the northeast. The findings included that these earthquakes were induced mostly by high-volume injection of wastewater, and that given enough time from the start of injection and sufficient crustal permeability, high-volume injection can induce earthquakes at least 30 km from the injection wells.

Examples of Remaining Knowledge Gaps

Examples of remaining knowledge gaps include:

- Understand the specifics of earthquake mechanisms resulting from deep crust injection of fluids.
- Determine the relationship between fluid injection, regional geology, and occurrence of earthquakes.
- Identify alternative wastewater disposal strategies.

Examples of Possible Next Steps

Each Agency will undertake research that is part of their core capabilities, as outlined in the Strategy. Below are possible next steps that build off of their current research portfolios.

- Identify the most important geologic and industrial factors influencing the occurrence of seismicity resulting from fluid injection at depth.
- Continue to develop methods to determine which injection wells may have a significant seismic response in time to avoid earthquakes large enough to be of concern to the public.
- Determine whether the maximum magnitude of earthquakes induced by fluid injection is limited by industrial factors such as the volume of injected fluid, or by the same factors that limit the magnitudes of natural earthquakes.

VII. Air Quality

UOG development and operations can release potentially harmful emissions – including GHGs, air toxics, and ozone precursors – into the atmosphere. Emission data are needed to determine the relationship between UOG emissions and possible impacts on human health and the environment.

Research Activities Overview

DOE has developed advanced analytical methods for air and stray gas emissions that are helping to form a baseline for other sites and entities to reconcile differences in data. DOE is helping to explain regional trends by measuring emissions over large areas. DOE has also produced a GIS-based tool that is clarifying potential impacts through improved environmental assessments.

Research Results and Key Examples

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- **Modular emissions measurement.** DOE research on estimating and measuring emissions is modular and can be applied to other sites and conditions. Accurate and consistent information on baseline conditions and measurable emissions are necessary for effective impact mitigation.
- **Statistical methods.** DOE has refined statistical methods to represent the air quality impact from Marcellus Shale drilling and fracking activities based on the field data.
- **GIS tool.** DOE has developed a GIS-based tool that clarifies potential environmental impacts from drilling through improved environmental assessments of fluids management. The tool will help operators track air toxics and greenhouse gases associated with fluids handling.
- **Natural gas resources information site.** DOE has created an information site that enables users to learn about natural gas resources available in Arkansas and explains the steps followed by natural gas development companies—from gaining access to land through sending gas to marketplace.
- **Analytical methods for air and stray gas emissions.** DOE has developed advanced analytical methods for quantifying air and stray gas emissions; this standard methodology allows different entities to reconcile differences between data.

Examples of Remaining Knowledge Gaps

Examples of remaining knowledge gaps include:

- Research and test new technologies and practices (including measurement and verification techniques) that contribute to a reduction in methane emissions in the oil and gas sector.
- Perform preliminary air quality and dispersion modeling to evaluate potential changes in concentrations of methane, particulate matter, and regional ozone associated with UOG development.
- Measure emissions from UOG development.

Examples of Possible Next Steps

Each Agency will undertake research that is part of their core capabilities, as outlined in the Strategy. Below are possible next steps that build off of their current research portfolios.

- Develop and demonstrate more cost effective technologies to detect and reduce methane emissions from natural gas infrastructure.
- Research focused on better quantifying methane emissions throughout the UOG development value chain.
- Study air emissions from UOG operations, including air toxics and tropospheric ozone precursors.

VIII. Resource Assessments

Geologic setting and development method of UOG production are primary drivers in both determining the locations and characteristics of UOG resources and identifying potential UOG environmental impacts. Research will help decision makers understand and mitigate potential harmful impacts of UOG development, while allowing the nation to better realize the benefits of additional energy supply.

Research Activities Overview

DOE is characterizing emerging shale gas plays, which include estimates for gas in place and technically recoverable resources. DOE is also improving its understanding of recovery challenges and production behavior.

DOI research assesses 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. This research assists decision makers in understanding and mitigating potentially adverse impacts of unconventional domestic energy resource development while realizing the benefits of additional energy supply.

Research Results and Key Examples

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- **Characterized shale plays.** DOE has characterized emerging Alabama shale gas plays that determined a technically recoverable resource of 70-139 Tcf.
- **Model for optimizing production.** DOE has an enhanced understanding of the Bakken shale that led to a model used by operators.
- **Optimize well fracturing.** DOE has discovered new ways to optimize fracturing and refracturing of shale wells, and thus reducing production footprint.
- **Complexly fractured rocks study.** Working alongside Lawrence Berkeley National Laboratory, Texas A&M University, Stanford University, and several industry partners, DOE has an enhanced understanding of production from complexly fractured rocks.
- **Fluid flow in tight rocks study.** Working alongside Missouri University of Science and Technology and the Colorado School of Mines, DOE has an enhanced understanding of fluid flow in tight rocks.

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- **Assessments of undiscovered, technically recoverable UOG resources.** The USGS conducted assessments of undiscovered, technically recoverable UOG resources in selected basins, including Marcellus Shale and Utica Shale in the East, Eagle Ford Shale

in TX, Bakken Shale in the Midwest (North Dakota and eastern Montana), Barnett Shale (in Texas), the Green River Shale formation (Colorado, Wyoming, and Utah), and Alaska North Slope. These assessments indicate that significant deposits of oil and gas from unconventional reservoirs occur in basins across the country. Several dozen geologic framework studies were also published that describe the petroleum systems models that support the resource assessments. DOI is increasing the understanding of the locations where resource development is likely to occur and how the development may impact water availability, groundwater and surface water quality, air quality, landscape and ecosystem changes, and induced seismicity hazards.

Examples of Remaining Knowledge Gaps

Examples of remaining knowledge gaps include:

- Continue to conduct assessments of undiscovered, technically recoverable UOG resources in priority basins.
- Develop technology that allows more efficiency from fewer, less impactful wells.
- Provide public data sets characterizing current and future resources.

Examples of Possible Next Steps

Each Agency will undertake research that is part of their core capabilities, as outlined in the Strategy. Below are possible next steps that build off of their current research portfolios.

- Conduct research to advance imaging of the subsurface in terms of geophysical and geochemical characteristics.
- Identify key geoscience issues that need to be investigated to support the nation's unconventional oil and gas resources assessments, such as petroleum geochemistry of basin-centered source rocks to support petroleum system models.
- Continue to produce three dimensional geologic frameworks in selected UOG basins to characterize geometries and physical characteristics of hydrocarbon source rocks.

IX. Ecological Effects

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 potential impacts on flora, fauna, ecosystems; and land use changes.

Research Activities Overview

DOI is conducting research of chloride toxicity related to oil and gas development and identifying species and habitats most at risk, including brook trout and freshwater mussels. Georeferenced data layers are being developed of the Marcellus and Utica Shale layers, including improved bedrock layer and federal and other protected lands and used in initial stream potential model predictions for brook trout overlying the Marcellus Shale play. An information gap analysis of published literature, data sources and monitoring protocols relevant to evaluating impacts of UOG on species and habitats is being developed through systematic review and synthesis. These efforts are helping assess the toxicological and biological contributions of UOG development to potential health risks for living systems.

Research Results and Key Examples

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- **Remote sensing imagery analysis.** USGS's analysis of remote sensing imagery is being used to better inform the permitting process so the impact on fish and wildlife habitats can be minimized.
- **Impact of major ions.** USGS's laboratory studies will be used to determine the impact of major ions associated with UOG production on aquatic species and communities for use in updated national and regional ambient water quality criteria.
- **Chloride concentration in wetlands.** Statistically modeled patterns of wetland chloride concentrations in relation to oil wells and geology explained variation in chloride concentrations and may indicate contamination from produced water.
- **Impact on aquatic species.** Results from a study in the northeastern United States suggest that ongoing development of the gas resources in the Bakken and Marcellus regions may result in significant habitat avoidance by grassland birds and range restrictions of five endemic species of terrestrial forest salamanders, respectively. Studies of other aquatic species such as brook trout and freshwater mussels indicate potential impact from hydraulic fracturing waste, including exposure to sodium chloride.

Examples of Remaining Knowledge Gaps

Examples of remaining knowledge gaps include:

- Identify what is the potential risk of novel compounds present in UOG hydraulic fracturing fluids and/or produced waters, including biocides, methane, radon, and other naturally occurring radioactive materials (NORMs), iodide, bromide, and shale-related microbes on state and federal species of concern, sensitive aquatic communities, and surrounding terrestrial and aquatic ecosystems.
- Identify the constituents and concentrations of compounds in wastewaters to determine the potential toxicity to ecological systems.

Examples of Possible Next Steps

Each Agency will undertake research that is part of their core capabilities, as outlined in the Strategy. Below are possible next steps that build off of their current research portfolios.

- Characterize the available ecological toxicity data for the chemicals in wastewaters that pose the greatest potential risk to ecosystems, including testing for water contamination from salts, NORM, and toxic chemicals that are associated with hydraulic fracturing.
- Identify and prioritize key geographic regions, organisms and their services, sensitive aquatic communities, and critical wildlife habitats that have the greatest potential for impact from ongoing and potential UOG activities.
- Develop and adapt new genetic and genomic tools for use as ecological indicators as a rapid way of detecting chemical contamination over wide geographic regions to more quickly and economically identify and contain UOG-related chemical leaks into the environment.
- Design methods and protocols related to water quality and ecological effects research so they can also be used to inform research on human exposure pathways associated with UOG activities.

X. Effects on Human Health

Human health may be affected by UOG development and production due to impacts from air and water quality, as well as from water availability. A better understanding of the changes caused by these impacts, exposure levels, toxicity, susceptibility, and other potentially harmful outcomes, is essential.

The MAC recognizes that most of the research needed to address potential impacts on human health is beyond the scope of this effort and would most appropriately be led by federal health agencies. That said, some ongoing work by the three Agencies has and could continue to contribute to addressing the human health research topic.

For example, DOI's design methods and protocols related to water quality and ecological effects can be used to conduct research on human exposure pathways associated with UOG activities. DOI research provides insight into ecological and human pathways of exposure and DOI has conducted research on baseline water quality as well as potential sources of contamination due to spills of UOG wastewater to identify potentially harmful chemicals in the environment. In addition, DOI is collaborating with colleagues in the human health community by performing field studies of environmental geochemistry that are relevant to co-located human health studies.

As part of its Hydraulic Fracturing Study, EPA assessed ways that drinking water resources are impacted and/or vulnerable to impacts from hydraulic fracturing activities. EPA collated and published available chemical, physical, and toxicological properties of chemicals used in hydraulic fracturing, which can inform potential impacts to human health.

XI. Conclusion

The MAC has made significant progress since the President issued the Executive Order "Supporting Safe and Responsible Development of Unconventional Domestic Natural Gas Resources" in April 2012[3]. Our collective research, published in journals and as reports, has resulted in a greater understanding of how UOG development may impact the environment, how to mitigate potential impacts, and how to prudently develop energy resources. The research to-date reflects substantial progress in addressing the research needs identified in the multiagency research strategy.

In this Report, the three Agencies have collaborated to identify the substantial work that is still required to fully address the research needs identified in the Strategy. Given Congressionally appropriated resources consistent with the President's Budget requests, the Agencies look forward to working together and with others in the future. Such collaboration and coordination will provide stakeholders with the necessary information to assist decision-making in support of safely and responsibly developing domestic UOG resources while protecting human health and the environment.

[3] https://www.whitehouse.gov/the-press-office/2012/04/13/executive-order-supporting-safe-and-responsible-development-unconvention