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Impacts of Onshore Oil and Gas Development: Managing Societal and Environmental Risks

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This note provides highlights from a one-day CSIS workshop held April 26, 2017, with government, state regulators, industry, and policy experts exploring ongoing efforts to minimize and manage upstream environmental, health, safety, and societal risks associated with U.S. onshore oil and gas production. The workshop was the second in a three-part workshop series, with the first part covering key issues concerning the role of U.S. tight oil production in global markets and the final installment to target global natural gas markets.

Executive Summary

Over the past decade, tight oil and shale gas output in the United States has rapidly risen from next to nothing to account for the majority of U.S. oil and natural gas production. A critical component for prudently developing these onshore resources relates to addressing concerns regarding societal and environmental risks. Three such fundamental concerns include efforts to:

- Protect and manage water resources
- Reduce methane emissions
- Monitor and manage induced seismic events

Given these concerns, the workshop focused on determining how well industry, local and state regulators, and the federal government are managing these risks, sharing best practices, and effectively mitigating any adverse outcomes related to U.S. onshore production. The role of technology and the effectiveness of both regulatory change and operational best practices were also examined. This workshop built upon previous research conducted by the CSIS Energy and National Security Program and published in a 2013 report *Realizing the Potential of U.S. Unconventional Gas Resources*. In the five years since that report was written the process of producing shale gas and tight oil resources has changed in several important ways driven by the desire to reduce cost, improve well productivity and recovery, and manage the environmental and social impacts of production. Key takeaways include:

Water

- Water resource availability and conditions vary widely and regionally. States and local communities have made advancements in regulation to protect local water resources—although the regulatory environment is still not uniform, as is the data collection with respect to spills.
- Companies have made advancements in the chemistry and processes around reuse of produced water in drilling operations to reduce overall water consumption, but economic and logistical challenges still exist.

Methane

- Certain states and companies have taken leadership roles in measuring and managing methane emissions, but for a variety of reasons not all companies and states prioritize methane capture to the same extent.
- More data is needed to understand the stochastic nature of methane releases and determine how best to ensure that emissions capture from oil and gas operations is improved.

Seismicity

- Seismic risk is a function of both geologic conditions and operational practices. In these states that have prioritized reducing induced seismic events, diagnostic tools and regulatory and other best practices have combined to reduce the incidence of induced seismic events from water disposal and hydraulic fracturing.
- Not all states and companies take the same approach to managing induced seismicity issues and problems tend to arise when heightened activity takes place near fault zones.

Societal

- Companies and local communities are still grappling with how to achieve optimal resource development while minimizing adverse effects on local communities.
- Service companies, by virtue of the cross-cutting role they play, can often facilitate technology transfer and improve operational practices across basins, but achieving a basin or community-wide solution is often complicated.
- Despite operational and technological progress, failure to manage these issues effectively will continue to create public concern for onshore oil and gas development.

Oil and Gas Development and Water Resources

The management of water resources utilized in developing onshore oil and gas reserves has become a key concern for fundamentally obvious reasons. Primarily these concerns relate to the fact that fresh water sources support our entire ecosystem and in turn the continued functioning of the economy. Concerns have also arisen for less obvious reasons related to the sourcing of available water, transport, storage, the impact that the use of water has on local communities, recycling, treatment, reuse, disposal and, in some areas, the link between disposal and induced seismicity.

Hydraulic fracturing is a water-intensive way to produce oil and gas, but water quantity and access issues are highly dependent on the local environment.

Today, hydraulic fracturing processes use approximately 1000 gallons of water per linear foot of horizontal well. An average of 5–6 barrels of water is used for every barrel of crude oil produced; however, in certain cases, use can be as high as 30 barrels. Due to the location and concentration of the wells, this use of water in the hydraulic fracturing process can have a significant impact on the water cycle, leading, in some geographic locations, to significant losses in typical surface water cycles.

The overall use of permitted water withdrawal by the industry has continued to fall since the shale boom began, but withdrawal is becoming concentrated.

While these figures represent large volumes of water use, hydraulic fracturing represents a small amount of overall freshwater use. During the height of the shale boom, 20 percent of permitted take of water was utilized by the industry. Taking into consideration the declines in drilling activity in 2016, along with the strides made in several states to recycle water, the total withdrawal of permitted water use is estimated to be below 5 percent. That said, with the move to longer laterals (current frack lengths are now in the 12,000- to 15,000-foot range), a single well today is effectively three to five times the size of those when the shale boom began (though the number of wells in terms of surface footprint has declined); the use of water, especially within particular regions, is therefore becoming more concentrated. Ten years ago a typical frack job utilized some 3–5 million gallons per well. However, with the longer laterals being drilled, we are now typically seeing 12–15 million gallons per well and in certain cases this figure can be as a high as 25 million gallons.

In Texas, hydraulic fracturing accounts for only 0.5 percent of total state water use. However, with the majority of wells concentrated within confined regions of the Eagle Ford and the Permian, water usage is a decidedly more local issue. In the Eagle Ford (South Texas), drilling activity in some counties accounts for over 50 percent of total water use. For regions that are arid or have experienced recent droughts, the issue of use and reuse of water becomes a larger concern.

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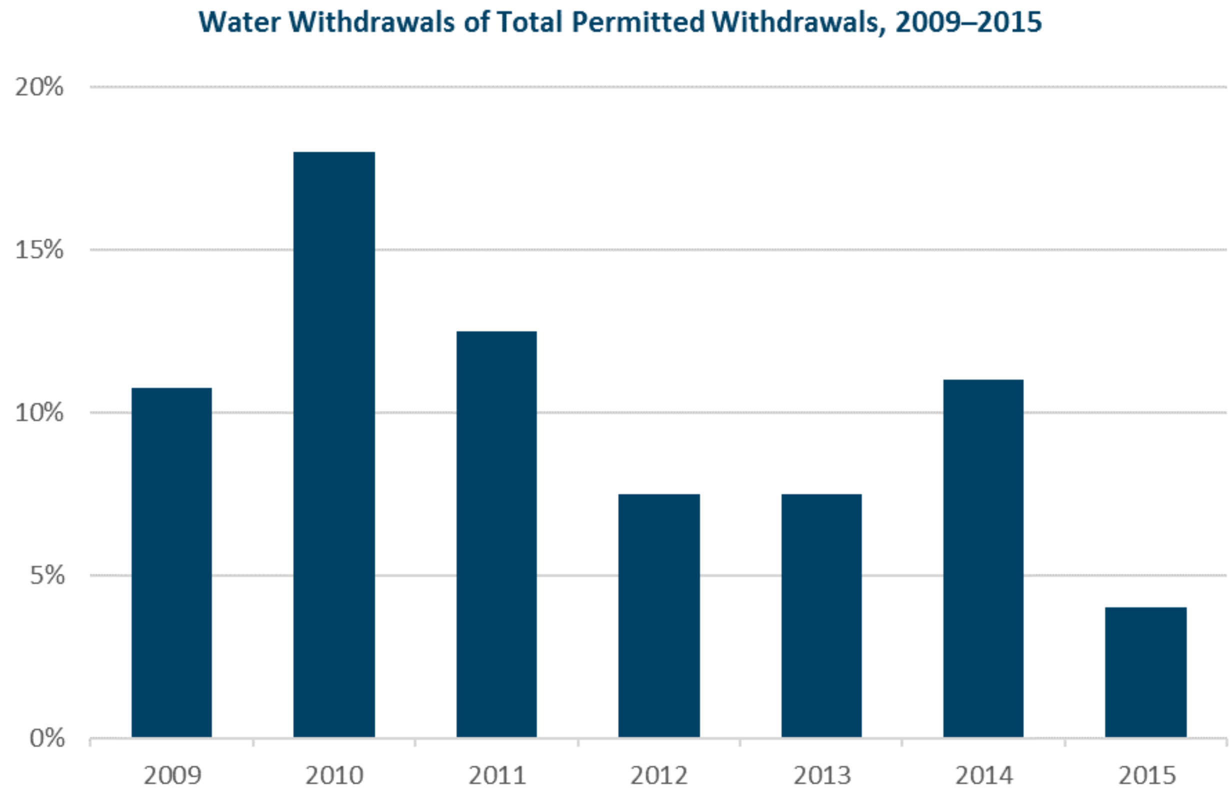

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Source: Adapted from Resources for the Future (May 2017)

Recent U.S. Geological Survey (USGS) studies suggest that unconventional oil and gas development is currently not a significant source of contamination of fresh water sources.

Apart from the effects that sourcing water can have on the local and regional water cycle, another key concern is related to the possible contamination of freshwater sources. This includes brine spills, as well as how waste water produced from the hydraulic fracturing process (which often contains chemical fracturing fluids, stray gas, and leaks from casings) is handled, treated, and ultimately effectively and safely disposed of. Prevention of contamination to ground water aquifers from drilling operations can be managed through proper well design, casing, and ensuring well integrity. Regulation and industry protocols have worked to incorporate best practices in this regard, but high-profile incidents of groundwater contamination still influence public perception of the effective management of this issue.

Options for treating, recycling, and reusing water make sense in certain places but obstacles exist.

Concerns related to fresh water availability, as well as costs associated with disposal, have led some producers to increasingly look for economic ways to treat, recycle, and reuse water or find alternatives to water for fracking operations. The reuse of water in certain circumstances can reduce the level of community impacts, and may also represent an opportunity for cost reductions by operators. However, where ample amounts of water are available, there are often compelling economic reasons why recycling is unpractical. First and foremost, as alluded to earlier, the overall use of water in fracturing is small when compared to availability of the resource in most regions. Furthermore, in the United States, mineral rights are privatized and so it is often the case that the sale of water represents a significant source of income for surface owners. Probably the most significant barrier to increased use of recycled water, however, is that operators face economic and logistical challenges, with filtration and retreatment processes often required before reuse can occur, meaning that for certain operations, treatment, recycling, and reuse is significantly more expensive than simply sourcing new water. However, at the back end, limited or costly disposal operations can also serve to encourage recycling. The increasing level of evidence tying waste water disposal, under certain conditions, to induced seismicity may also serve to encourage greater levels of recycling.

Where economically feasible, it is important that the reuse of water is encouraged in the hydraulic fracturing process to minimize impacts on freshwater sources, particularly in those regions prone to drought.

In some areas of the country treatment is economically viable, especially when the water has sufficiently low levels of total dissolved solids after it is utilized in the fracturing process, thus allowing for reuse by the operator or by other sectors. In those areas, treatment and reuse is more likely to be adopted to minimize the disruptions on the water cycle and to reduce the levels of freshwater use. Where it is not possible, permitted Class II injection wells are used. As discussed in the final section, the wells can be monitored and regulated for seismic proclivities and operational practices to minimize seismic risk. A reduction in the use of freshwater by the industry may help to reduce the level of perceived risks associated with the effects of proximity and intensity of drilling. One study showed that in areas where water wells provide fresh water to residents, there is a correlation between lower property values and proximity to heavy drilling operations, leading the researchers to identify a concern over groundwater contamination, although factors such as noise pollution and congestion may also affect values.

As the reuse of water continues to rise within the industry, it is important that related issues such as spills and leaks continue to be addressed.

Recycled water use is on the rise and is becoming more and more feasible as new methods are developed to address high-salinity water, and as portable technologies are advanced, which help to alleviate logistical issues. Cost is once again the primary barrier to reusing produced water (due to salinity, contaminants, etc.) but increasingly the economics make sense. The increased use of brackish water is particularly important in those regions prone to drought. For example, fracturing operations in the Mississippian Lime now use 100 percent produced water because of the highly arid region and the high probability of drought. It should be noted, however, that the increased use of brackish or produced water gives rise to other issues that need to be addressed including the need for segregated storage, handling, and transport. In such instances, increased use of brackish water can also lead to a rise in contaminated water spills and leaks. The reporting standards in place for addressing issues related to contamination and spills vary between states, which complicates the process of monitoring root causes and identifying sources on a national level. The reporting of brine spills standards has a one-barrel threshold in North Dakota, but in other states, such reporting standards are set at a higher threshold. Consequently, there are concerns that the precise scale of the spill problem is not well known.

As development continues, water transportation and logistics also present challenges.

Another major issue that requires further attention is that of transportation. In certain basins of the country, there is a need for backbone infrastructure to support the transport and storage of large volumes of water. However, this often runs into difficulties even in the areas where this is warranted because there are no eminent domain rights for water infrastructure. In some cases, specific areas would benefit from "basin wide" planning practices in terms of water sourcing, transport, storage, recycling, and use. Such efforts, however, are often frustrated by the sheer number of producers, drillers, and wells. This partially leads to habitat fragmentation and exacerbates the overall problem concerning the need to more effectively monitor the use of water and incentivize efficiencies in its use.

Regulators and operators have stepped up efforts to improve water protection and management, but heterogeneity persists.

While all parts of the water cycle are regulated, the standards vary between jurisdictions (quite considerably in some cases) based on water availability and infrastructure. The issue is primarily addressed at the state level and so permitting standards with respect to water withdrawal and reporting of brine spills vary along with the likes pf pre-drilling water testing, fracture fluid disclosure requirements, casing and cementing depth regulations, and pit regulations to name but a few.

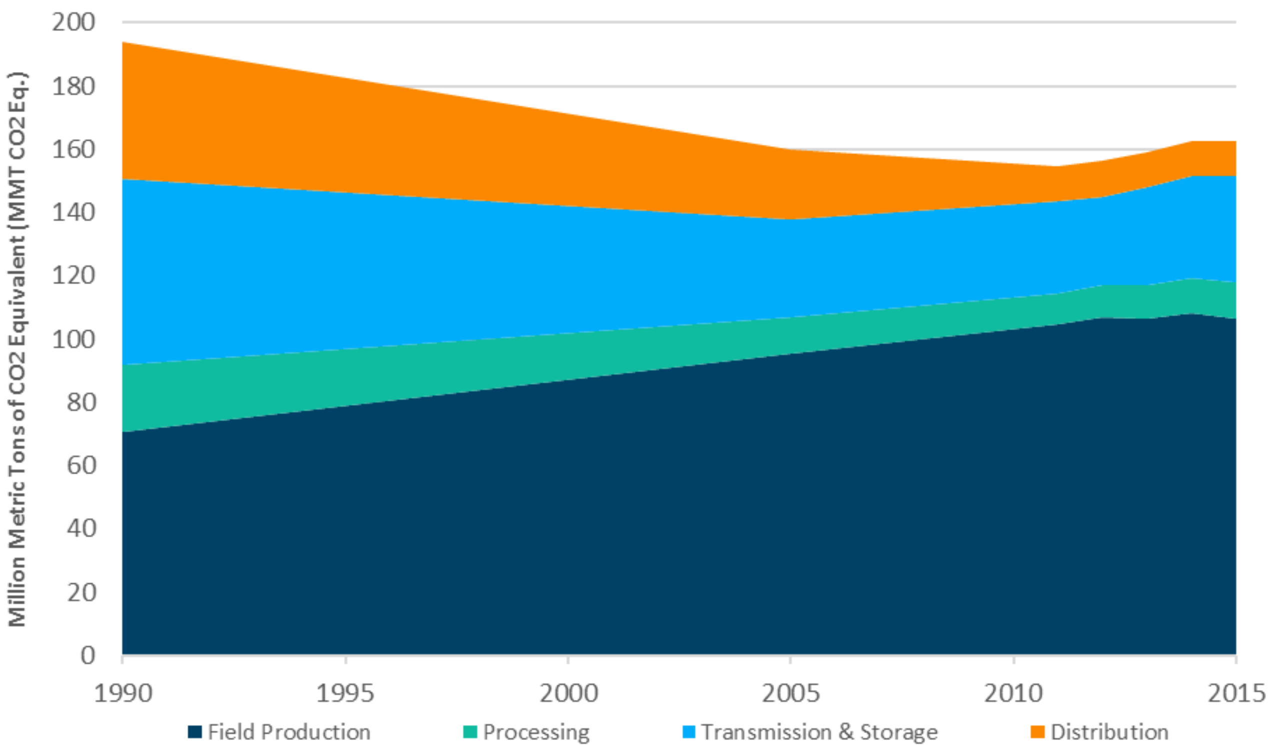
The advancement of technology and new chemistries is continuing to make the reuse of water a more viable option for the industry.

In an attempt to mitigate adverse impacts on the water cycle, some industry operators have sought to deploy best practices. While extended laterals have increased the use of water per well, several operators have significantly enhanced their efficiency of use. As technology continues to advance, reducing surface impacts through increasing the reuse of water is becoming more economically viable. Furthermore, several operators have developed new techniques to work with high-salinity water, which is also allowing for greater reuse. As operators further develop these technologies and techniques, an emphasis has also been placed on monitoring the movement of water and reducing risks of spills. However, this practice is not uniform across the industry and so measures encouraging further uptake in these activities are important.

Managing and Reducing Methane Emissions

As U.S. onshore oil and gas production has risen over the last decade, with increased climate-related concerns, the issue of managing methane emissions from the oil and gas sector has become a concern for regulators and operators alike, as the industry now accounts for approximately one-third of total methane emissions. Methane is emitted not just in the exploration phase but all along the oil and gas supply chain, with over a third of emissions associated with processing, distribution, transmission, and storage. However, the scope and stringency of methane regulation or industry management are still subject to questions and opinions, which vary on the reasoning for reducing methane emissions as well as the potential cost implications of doing so. As such, regulation of methane emissions is still an open question for many within the industry. For some producers, the added cost of managing methane emissions is not worth the expense. For others, reducing methane is worthwhile because of the economic incentive and concerns related to reputational damage of the industry, as well as the role of natural gas as a "transition fuel" if emissions are not effectively managed along the value chain.

U.S. Methane (CH_4) Emissions from Natural Gas Systems, 1990 – 2015



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Source: Adapted from U.S. Geological Service Data (May 2017)

Reducing methane emissions is important for both environmental and economic reasons.

Concern over methane emissions first arose in relation to safety, and more recently in connection with climate change. While methane has a much shorter half-life then carbon dioxide, it is a more potent greenhouse gas (and accounts for approximately 15 percent of anthropogenic greenhouse emissions globally). As U.S. oil and natural gas production has risen, the United States has also made significant strides in reducing greenhouse gas emissions. While fugitive methane emissions are viewed

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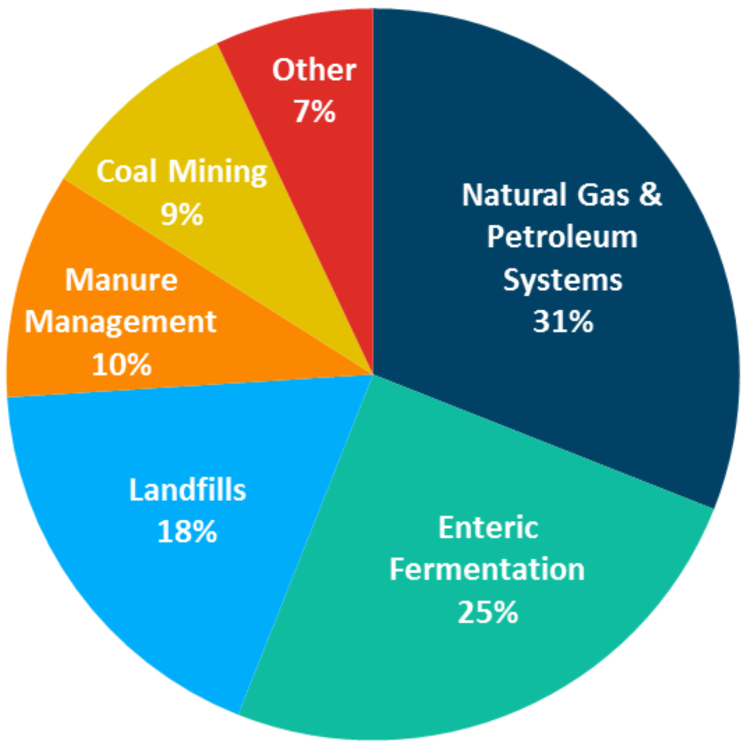
by many as an environmentally harmful side effect of oil and gas production, this methane is the same natural gas that producers are trying to develop and sell. Consequently, one of the leading economic justifications for reducing methane emissions is that oil and gas companies would generate additional revenue by capturing more of the resource they are developing. This is an important point for those who reject the environmental reasons for capturing methane emissions but take a conservation-minded approach to resource development.

U.S. Anthropogenic Methane Emissions by Sector in 2015



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Source: Adapted from Environmental Protection Agency Data (May 2017

Regulatory measures and new monitoring technologies have made strides in recent years.

With increased levels of data through improved monitoring, recent EPA studies now suggest that emissions from oil and gas operations are greater than originally thought. In fact, lack of data is part of the reason that methane management languished as an issue. Despite this uncertainty (discussed below) new federal rules under the previous administration and pilot projects to test diagnostic technologies have set a new course of action for monitoring potential emissions and the operationality of new oil and gas infrastructure. Several states have also individually risen to the challenge by implementing their own comprehensive frameworks to reduce emissions. These include California, Colorado, Ohio, and Pennsylvania. Finally, at the international level the United States has committed, along with Mexico and Canada, to cut methane emissions from the oil and gas industry by up to 45 percent below 2012 levels by 2025. However, some of the federal regulations set forth by the Obama administration are currently under review by the Department of Interior and the Environmental Protection Agency to ensure that they do not unduly impede the development of domestic energy resources. In fact, the EPA has already implemented a stay on portions of the 2016 New Source Performance Standards for the oil and gas industry, which included methane emission standards.

Some industry players are acting to address methane emissions, but better data can improve these efforts.

Recognizing the intent for regulation to reduce methane emissions as much as possible, some operators appear to be meeting or exceeding the standards required of them by deploying further means to tackle this issue. As a result, we are increasingly seeing voluntary efforts being made by operators to deploy upstream leak detection and repair programs, as well as upgrading or replacing equipment to ensure reductions. Other steps include measures to continuously improve their understanding of operational emissions, to further engineer vented emissions out of facilities and processes, to improve methods utilized in locating fugitive emissions and fixing leaks, to partner with mid-stream operators for efficient gathering and processing, and to further innovate for economic solutions. In fact, several operators have already actively engaged with the Department of Energy (DOE) to collaborate on improving measurement and have taken further proactive steps toward mitigating root causes. These strides in deploying the measures have not only been made to gain first-mover advantages, but have also come as a result of the issue being increasingly viewed as one of waste, with the capture of methane becoming more economically viable as technologies advance (even with lower prices).

The nature of the problem of methane emissions in the oil and gas industry today is a stochastic one, with a small group of operators accounting for the bulk of emissions.

With a small number of operators accounting for a significant proportion of emissions, it has been suggested that the focus of further regulation should be solely directed toward eliminating those "super emitters" in the industry. While useful, this approach may or may not be effective in preventing new emission sources from cropping up. Alternatively, some commentators have suggested that if it is economic to capture methane emissions, then the industry will eventually adapt toward engaging in this activity and self-regulate. The counter argument here, however, is that in the absence of effective regulation, "better economics" alone will not guarantee capital deployment to reduce waste.

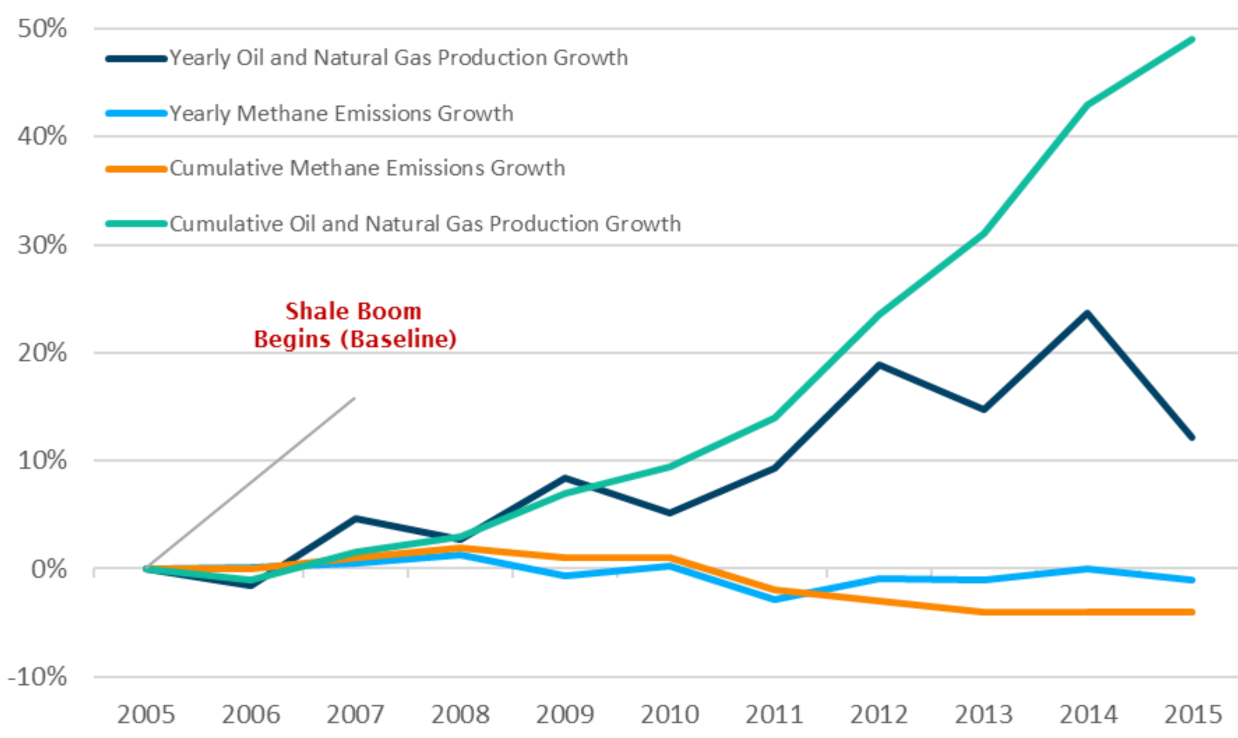
More data can improve mitigation techniques and avoid a "can't manage what you don't measure" situation.

An increasing number of studies examining this issue point to the importance of improved data collection and analysis to effectively address the challenge of methane emission reduction. With incomplete data, emissions may be going unaddressed. As such, cooperation and collaboration with the Department of Energy by all players involved in the market is of critical importance to improve the quality of data. Furthermore, many are now calling for operators to focus their efforts on developing more preventative, predictive, and ultimately proactive maintenance measures, to install corrective actions aimed at tackling root cause failure. Adopting these approaches could represent a more cost-effective means of tackling emissions rather than relying on reactive or remedial action. As such, calls have been made to further efforts to encourage the development and use of new technology and practices in addressing this challenge, while also enforcing regulations set at the federal level to set a minimum standard for late adapters.

While U.S. natural gas production has risen by over 50 percent since 2005, overall methane emissions have fallen. Nonetheless there are still significant opportunities for further reductions to be made.

Despite the enormous rise in production of natural gas, methane emissions from natural gas systems specifically have risen by less than 2 percent from 2005 levels when the shale boom began. Some of the lowest-cost opportunities to reduce methane emissions are found in the oil and gas industry. Due to the stochastic nature of the problem, individual episodes can alter the trajectory of emissions reduction; and as emissions occur at multiple stages along the value chain, there appears to be ample room for improvement.

U.S. Oil and Natural Gas Production and Methane Emissions Growth, 2005–2015



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Source: Adapted from Energy Information Administration and Environmental Protection Agency Data (May 2017)

Managing and Reducing Induced Seismic Events

Since the onset of the unconventional oil and gas revolution over a decade ago, the rate of seismic activity has increased in several producing states, most notably in Oklahoma. Induced seismicity falls into three main categories of activity: injection based, geothermal based, and depletion based. Induced seismic activity caused by the development of onshore oil and gas falls into the injection-based category, where large amounts of water are pumped underground in the production and post-production waste water disposal phases of development. The injection of water leads to increased levels of fluid pressure below the surface and can alter subsurface stresses, which in turn can produce seismic activity in areas where preexisting fault lines lie. In the central United States, the number of earthquakes of level 3 magnitude or greater has risen from less than 50 in 2008 to over 1,000 in 2015, with nearly 3,000 earthquakes of level 3+ magnitude recorded in total from 2009 to May 2017. As such, the impacts of onshore oil and gas development in terms of induced seismicity have become, for a number of communities, a major area of concern.

The evidence now indicates that induced seismicity is primarily, but not solely, a water disposal issue.

While there are examples of the process of hydraulic fracturing itself, under certain conditions, inducing seismic activity, a growing body of evidence consistently suggests that the primary cause of induced seismic activity in the United States has been related to the practice of injecting saline waste water into disposal wells. As such, the consensus now is that induced seismic activity in the oil and gas industry of magnitude 3 and above is primarily linked to water disposal operations. The reason is that waste water wells typically operate for longer durations and inject greater volumes of fluid than the process of hydraulic fracturing itself. Waste water wells are typically located at deep levels, where sandstone or other porous formations are found, which when combined with these large quantities of salt water over an extended period of time in areas where preexisting fault lines lie can cause induced seismicity. As such, induced seismic activity from waste water disposal is not an issue that is entirely unique to the hydraulic fracturing business, but rather a general issue for the oil and gas industry as well as other activities that involve disposing of large volumes of waste water under pressure.

Oklahoma has now surpassed California as the most seismically active state (in terms of the number of earthquakes of 3+ magnitude) in the lower 48 because of the dramatic rise of induced seismic events from increased waste water disposal.

There are over 35,000 salt water disposal wells in the United States and up to a million barrels a month are injected into some of these wells. In some cases, this activity has been going on for years. That said, the incidence of seismic events nationwide is actually quite small with recent activity concentrated in only a few areas of Oklahoma, Ohio, Colorado, and California. In fact, most induced seismicity is now occurring in Oklahoma, with 90 percent of the over 1,000 earthquakes that occurred in central United States in 2015 being accounted for by that one state. Before 2009 Oklahoma was a relatively quiet zone in terms of seismic activity but it is now one of the most seismically active regions in the world. The rise in the number of earthquakes in Oklahoma caused by waste water injection was particularly dramatic because of the geology of the region, where the Arbuckle rock formation is found.

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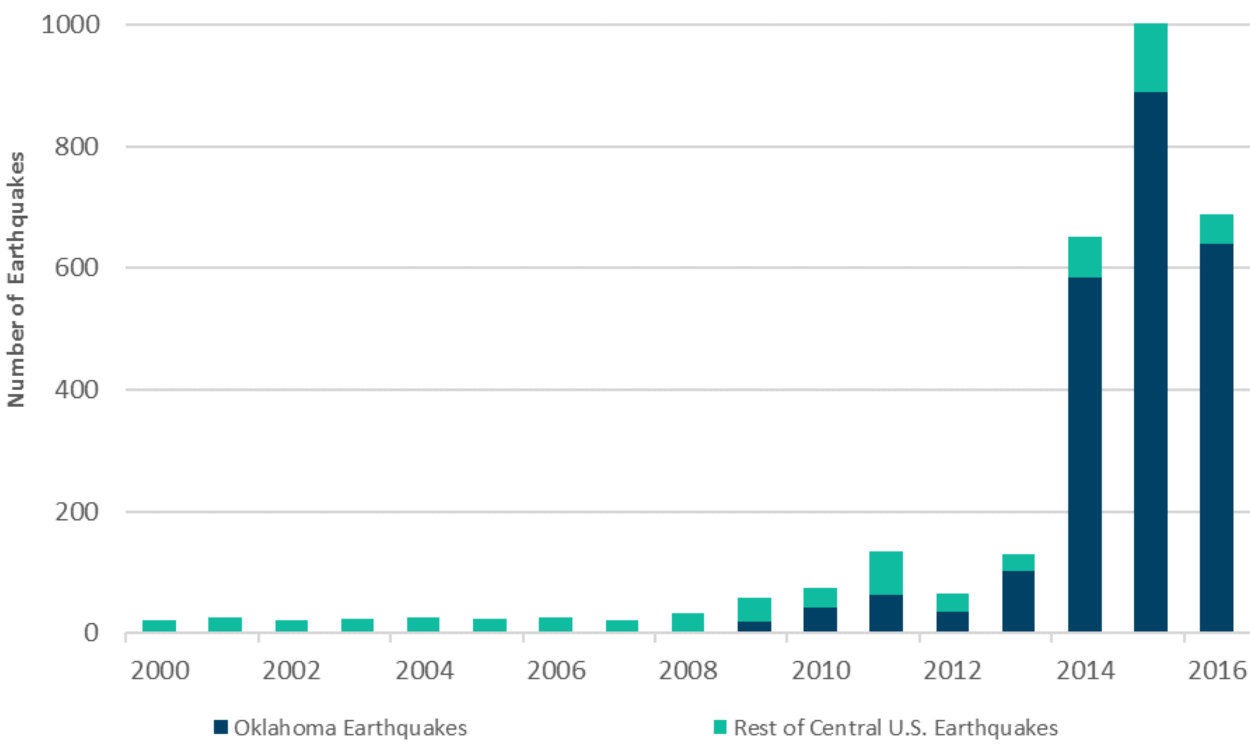
Given the differences in subsurface conditions and oil and gas operations, states are taking the lead in managing induced seismicity issues.

The upsurge in Oklahoma's seismic activity prompted state policymakers and regulators to act to address the attendant concerns. In 2015, Governor Mary Fallin requested that the industry make voluntary cutbacks in waste water injection activity. But it was the 5.8 magnitude earthquake in Pawnee (September 2016) that triggered the issuance of emergency orders for cutbacks in waste water disposal. The earthquake rate has since fallen by approximately 30 percent from 2015 to 2016, due to the combination of the decline in activity following the oil price collapse and the requested cutbacks. Induced seismic activity has continued to decline in 2017. However, three of the four magnitude 5 and above earthquakes since 2009 occurred last year. Furthermore, despite the continuing decline, the earthquake rate is still estimated to be at level far beyond historical averages, and local community as well as insurance industry concerns are growing.

Magnitude 3+ Earthquakes in Oklahoma and Rest of Central United States, 2000 – 2016



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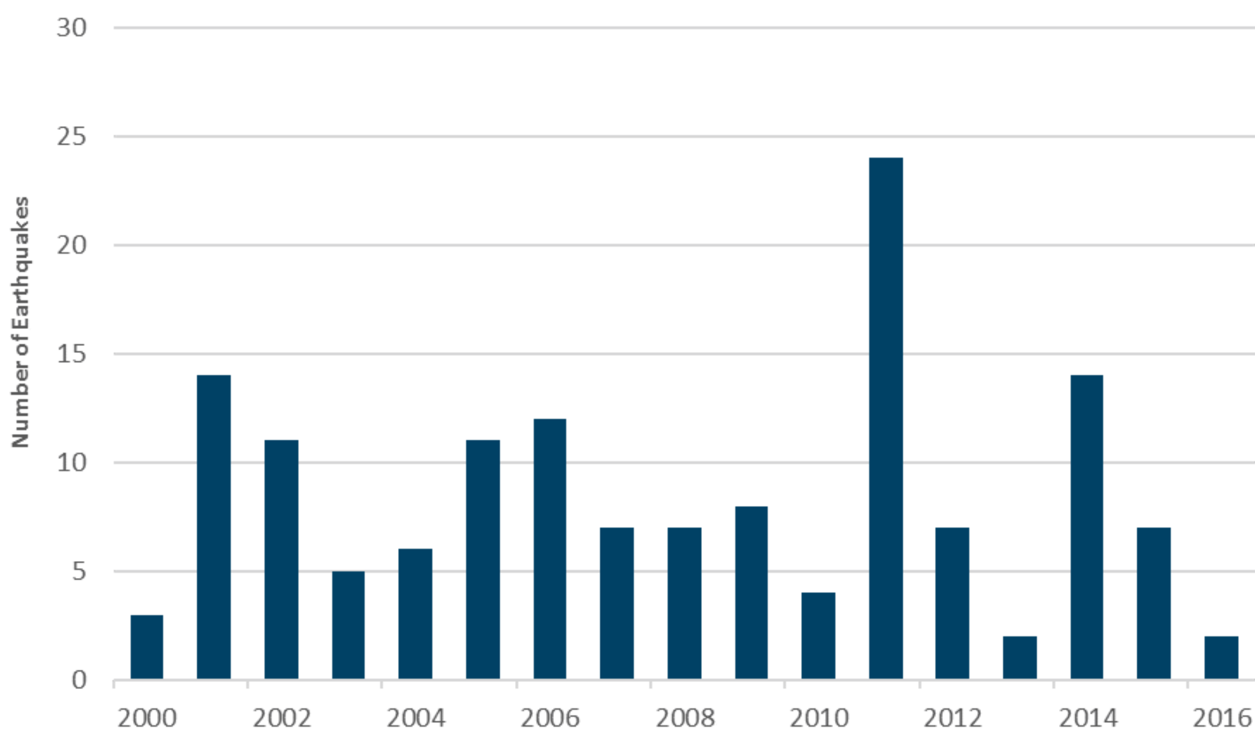
Source: Adapted from U.S. Geological Service Data (May 2017)

Induced seismicity caused by the oil and gas industry is not confined to Oklahoma, with increased levels of activity also recorded in, but not limited to, Arkansas, Colorado, Kansas, New Mexico, Ohio, and Texas.

While most of the recent induced seismic activity in the United States has been occurring in Oklahoma, it is not entirely confined to this region. Another example where induced seismic events have occurred is Colorado, where seismicity has increased primarily due to the rise of activity in Paradox Valley, the Raton Basin, and Greeley. While an induced sequence of seismic events in Greeley began in 2013, regulatory action appears to have reduced the rate of events. However, two 5+ magnitude earthquakes have occurred in the Raton Basin alone since 2005 and regulatory actions have yet to be taken to directly tackle this issue. Another state where induced seismicity has occurred is Ohio. The Ohio Department of Natural Resources has, however, been very responsive in taking action to address the issue by introducing permitting conditions for injection wells and has heavily invested in monitoring diagnostics and early warning systems.

Magnitude 3+ Earthquakes in Colorado, 2000 – 2016



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Source: Adapted from U.S. Geological Service Data (May 2017)

Ohio represents a case in point where early intervention and proactive measures have likely led to cost savings and reduced public concerns surrounding induced seismicity.

In Ohio, Governor John Kasich set a goal that no more injection-related seismic events should be felt and so regulators devised a system to achieve that objective. The state now maintains a real-time information system that monitors seismicity, traceable to individual wells. The data is used to alert companies if their operations are found to be inducing seismicity. If operators do not adjust their activity accordingly, operations will be shut down until they can figure out the root cause and address

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the issue. The investment that Ohio has made in implementing the infrastructure necessary to monitor seismicity, as well as the implementation of strict standards has likely saved the state considerable time, money, and public angst by tackling root causes before they became serious issues like those seen in Oklahoma.

An increasing number of states are now considering or have already enacted regulations to address seismic concerns. These include Oklahoma, Kansas, Ohio, Texas, California, Arkansas, and Colorado. To facilitate this process, USGS and the Environmental Protection Agency (EPA) have published guidelines surrounding the key risks associated with induced seismicity, which include total volume of water injected, the rate of injection, the depth of injection, the proximity of the injection to faults, and conduits to crystalline basement rock. The EPA guidelines, along with the efforts by the USGS in this area (with their earthquake monitoring and statistical analysis) are helping regulators and industry alike to better mitigate risks of inducing seismic activity.

In some regions, industry is working with regulators and academia to better understand regional seismicity and improve practices.

Some operators are making strides in minimizing risks associated with induced seismicity, often going beyond the remits of state legislation in developing diagnostic techniques and deploying best practices. For example, several operators have teamed up with TexNet Research and the Center for Integrated Seismicity Research (TexNet – CISR) to collaborate on detecting, cataloging, and characterizing seismicity in Texas. This has helped operators to understand fault-triggering mechanisms in the state and to mitigate risks associated with their activity. This partnership has also allowed for the seismogenic potential of basins in the state to be assessed. This assessment can then be factored into an operator's decision whether to engage in activity in that area. This partnership has also invested in research efforts to improve fluid disposal operations and to better communicate data, knowledge, and risk. This is just one example of a number of ongoing initiatives in the industry that should be further encouraged to help minimize induced seismic hazards and mitigate risks.

In a similar fashion to the water and methane issues outlined earlier, the collection and monitoring of data along with prescriptive and performance-based standards is of key importance to address root causes before they become major issues that have potentially dangerous implications. The need for effective monitoring of data as well as regulatory standards in producing regions is becoming increasingly important as the industry enters a period where global oil and gas markets are rebalancing. With the recent price increase, a rise in activity levels of onshore oil and gas development has already been recorded across U.S. basins and so the risk of increased levels of induced seismicity has also risen. Consequently, it is important that standards or best practices be adopted to mitigate this risk.

Conclusion

This note examined a limited set of environmental, health, safety, and societal concerns associated with onshore oil and gas development in the United States. The risks associated with properly managing water resources, fugitive methane emissions, and induced seismicity in the development of onshore resources are at the forefront of these concerns. With the onset of the shale revolution over a decade ago, addressing the risks associated with each of these areas has markedly improved from when the boom began, thanks to state and federal regulations, as well as the initiative of certain operators within the industry. While progress has been made, in certain areas of the country issues persist while other associated risks within these areas have arisen as production continues to increase. Furthermore, the areas of water, methane, and induced seismicity represent only three such risks of overall environmental, health, safety, and societal concerns associated with onshore oil and gas development in the United States. For these reasons, continuous improvement in efforts of data collection and the monitoring of this data, as well as continued research efforts, are critical components in ensuring that issues are effectively identified and addressed in a timely and effective manner by regulators and operators alike in order to ensure the prudent development of these onshore resources.

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