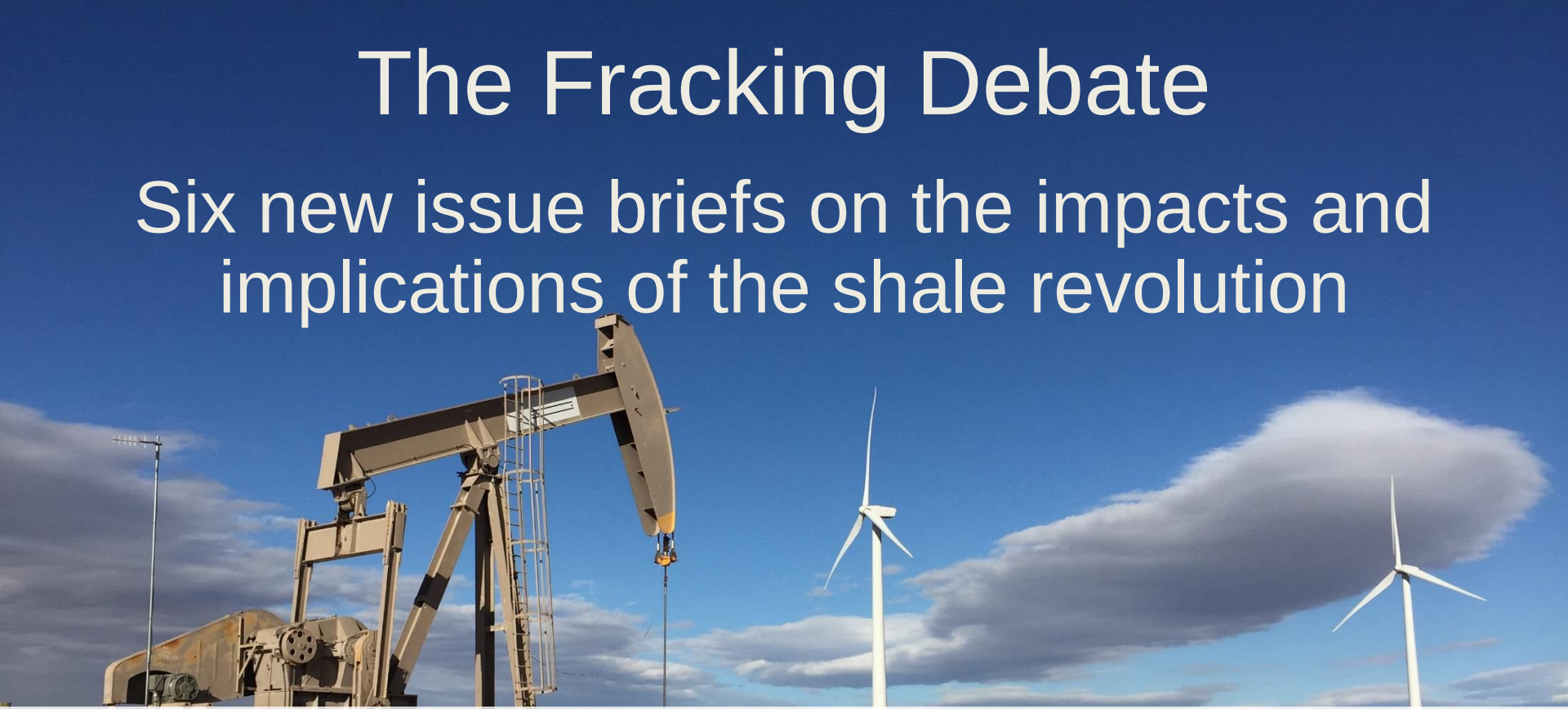
The Fracking Debate

Six new issue briefs on the impacts and implications of the shale revolution



Daniel Raimi, Alan Krupnick, and Isabel Echarte

Resources for the Future

April 25, 2018

RESOURCES FOR THE FUTURE

About RFF

- Resources for the Future (RFF) is an independent, nonprofit research institution in Washington, DC
- RFF's mission is to improve environmental, energy, and natural resource decisions through impartial economic research and policy engagement

Introduction

What is Fracking?

Does Fracking Contaminate Water?

Will Fracking Make Me Sick?

Does Fracking Cause Earthquakes?

Is There Any Regulation on Fracking?

Is Fracking Good or Bad for Climate Change?

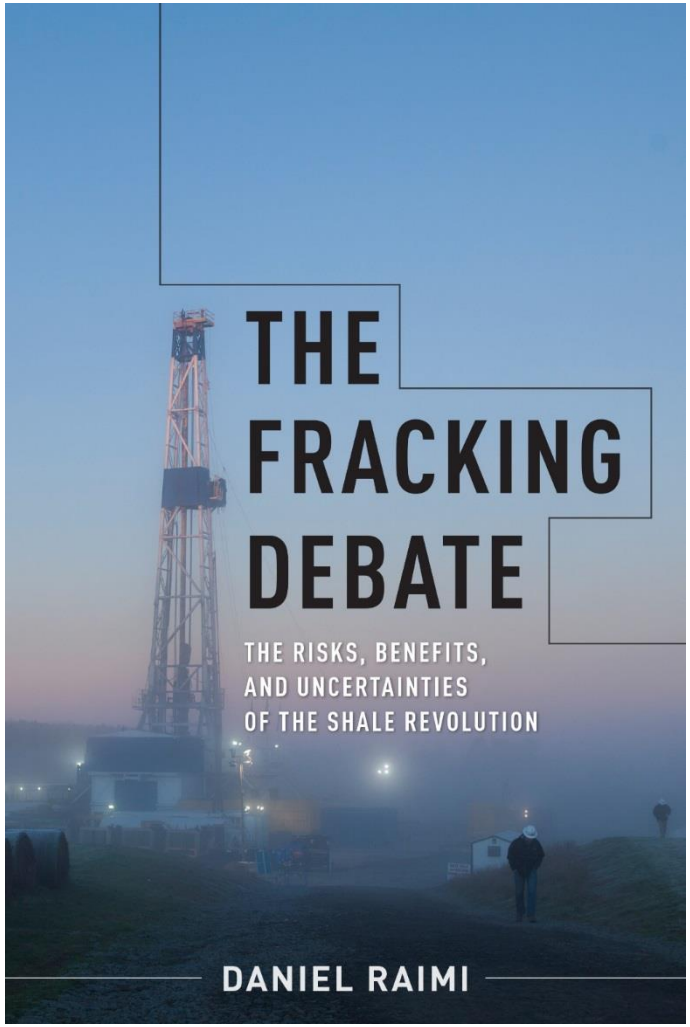
Will Fracking Make the US Energy Independent?

Is Fracking Good for the Economy?

Will Fracking Spread Around the World?

Do People Living Near Fracking Love it Or Hate it?

What's Next?



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CENTER on GLOBAL ENERGY POLICY SERIES

The Shale Revolution and Water Quality

Daniel Raimi*

One of the first, and still one of the most prominent concerns over shale development has to do with the risks to water quality from hydraulic fracturing. To date, there are very few cases—perhaps as few as one or even zero—where underground fracturing activities have credibly been linked to damage of drinking water sources. However, a number of other aspects of oil and gas development have the potential to negatively affect drinking water sources, and there are hundreds of well-documented cases of such contamination.

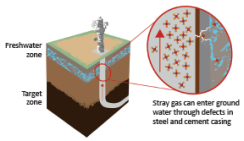
Fracking chemicals

Early concerns over the risks of hydraulic fracturing centered around the potential for proprietary chemical formulas to infiltrate drinking water sources. However, shale development typically occurs at depths far below the water table (typically 3,000 to 10,000 feet), and the likelihood of fracturing chemicals to migrate upwards into drinking water sources is extremely small. There is one case in Pavillion, Wyoming, where fracturing occurred at unusually shallow depths (roughly 1,200 feet), where researchers have gathered fairly compelling evidence of chemicals and hydrocarbons leeching into drinking water sources, possibly from underground fracturing activities and possibly from leaking wastewater storage ponds.

In another case from Bradford County, Pennsylvania, chemicals used in hydraulic fracturing have been detected in drinking water sources. Again, the pathway of contamination is not entirely clear, but a 2015 academic study hypothesized that improper gas well construction was the possible cause for the chemical 2-n-butoxyethanol migrating into a nearby drinking water source. In this case, the concentration of the chemical in question was not hazardous to human health.

Stray gas

A more common risk to water sources from oil and gas development—regardless of whether hydraulic fracturing is involved—comes from methane migration, or "stray gas." Stray gas refers to methane entering groundwater due to improper well construction, typically due to faults in an oil or gas well's steel casing or the cement that surrounds it. If concentrations of methane are high enough, water sources can become flammable, as illustrated in widely-circulated scenes in film and television. Importantly, methane can occur



RFF researchers in 2013 surveyed 215 experts across stakeholder groups on key risks. Top water-related priorities included on-site pit and pond storage, freshwater use, and wastewater management. For details, see "Pathways to Dialogue: What the Experts Say about the Environmental Risks of Shale Gas Development" (www.rff.org/research/publications/pathways-dialogue-what-experts-say-about-environmental-risks-shale-gas).

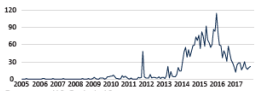
* This is one of a series issue briefs based on *The Fracking Debate: The Risks, Benefits, and Uncertainties of the Shale Revolution* (Columbia University Press, 2017) by Daniel Raimi. Raimi is a senior research associate at Resources for the Future.

The Shale Revolution and Earthquakes

Daniel Raimi*

In some states, particularly Oklahoma, oil and gas activities have led to a sharp rise in human-caused earthquakes, also known as "induced seismicity." In Oklahoma, the number of quakes registering 3.0 or greater in magnitude (the threshold where quakes are typically felt at the surface) grew dramatically through 2016. While most are too small to cause damage, several quakes of magnitude 5.0 or greater have damaged homes, businesses, and other infrastructure, though no major injuries or fatalities have been reported. This brief provides an overview of the key causes of these quakes, along with how new technologies and policies can reduce the risks.

Figure 1. Monthly count of OK earthquakes, ≥3.0M



Data source: U.S. Geological Survey

Earthquakes caused by fracturing or depletion

While many news headlines have described induced seismicity as being caused by "fracking," there are a relatively small number of cases where hydraulic fracturing has directly caused earthquakes. Researchers have identified a small number of minor quakes in Ohio, Oklahoma, Texas, and the United Kingdom where hydraulic fracturing appears to be the primary cause. However, quakes in Canada linked directly to hydraulic fracturing have registered as high as 4.6 in magnitude.

Disturbances in some cases may also be caused by oil or gas depletion. One well-documented case occurred in Long Beach, California, where parts of the city sank by more than 20 feet due to the reduced underground pressures caused by oil extraction (the problem was halted when operators began pumping water into the underground formations to maintain pressure). Many earthquakes in the Netherlands have also been linked to depletion of natural gas.

Earthquakes caused by wastewater disposal

The vast majority of growth in human-caused earthquakes associated with oil and gas development in the U.S. has been linked to the disposal of oil and gas wastewater. Every oil and gas well produces at least some wastewater—regardless of whether it is hydraulically fractured—in some cases generating 20 or more barrels of water for every barrel of oil. The water that is comingled with oil and gas deep underground is called "produced water," while water used for hydraulic fracturing that returns to the surface is known as "flowback." In most regions, produced water volumes are larger than

RFF's Alan Krupnick and Isabel Echarte published "Induced Seismicity Impacts of Unconventional Oil and gas Development," (www.rff.org/seismicityimpacts) which reviews the seismicity literature as part of a broader assessment of the impacts of fracking. Studies are generally retrospective, establishing a relationship between seismicity and oil and gas activities. Recently, some work has moved to assess the probability of future seismic events, but almost none assesses the above-ground impacts of induced seismicity.

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The Effects of the Shale Revolution on Local Governments

Daniel Raimi*

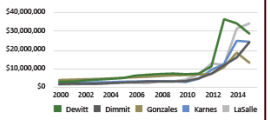
Increased natural gas and oil production has affected local government revenues and services in over a dozen U.S. states. In some locations, particularly rural regions such as the Bakken, Permian, and Eagle Ford plays, these effects have been dramatic. In other, more economically diverse and densely populated regions such as the Barnett or Denver-Julesburg plays, the effects have been more modest. This issue brief describes the impacts of the shale revolution on local governments, and highlights strategies to plan for the future.

Higher, but more volatile revenues

Local government revenues are affected by oil and gas development both directly and indirectly. In most states, local governments apply ad valorem property taxes to oil and gas property, including the oil and gas itself. Additionally, many states allocate a share of state-collected production, or "severance," taxes to local governments. Finally, local governments may lease publicly-owned land for oil and gas development, generating leasing "bonuses" and royalties.

Indirect revenues are often led by sales taxes, which increase as industry activity leads to population growth and increased economic activity. However, when drilling activity slows due to a downturn in oil or gas prices, sales tax revenues can rapidly shrink. Similarly, property taxes tied to the value of oil and gas property can be highly volatile, as the figure, which shows property tax revenues for five counties in the Eagle Ford region, illustrates. Despite this volatility (discussed in more detail below), oil and gas development has led to higher revenues for most local governments, even after the downturn in oil prices in late 2014. For many rural local governments in regions including the Bakken, Eagle Ford, Marcellus, Permian, and Utica regions, revenues have more than doubled due to oil- and gas-related revenue growth.

Property tax revenues for select TX counties



Data source: Texas Comptroller's Office

Increased demand for services

Growing oil and gas development has also increased demand for a variety of local government services. Local road networks have been the most widespread challenge, particularly for rural county governments

RFF's Alan Krupnick, Isabel Echarte, and Lucija Muehlenbachs published "Local Government Impacts of Unconventional Oil and gas Development," (www.rff.org/oilgasgov) which reviews this literature. Local public finance research finds large heterogeneity in impacts across localities, even those in the same state. Most local governments are able to meet increased demand for services and address costs related to development. Rural, undiversified areas are less able to effectively respond to these challenges.

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The Health Impacts of the Shale Revolution

Daniel Raimi*

The shale revolution has dramatically increased drilling activity in both densely and sparsely populated regions of the United States. While the industry has operated for decades in major cities such as Los Angeles, the number of communities living alongside oil and gas development has increased in states including Colorado, Pennsylvania, and Texas. This proximity, along with the specific technologies such as hydraulic fracturing used to develop shale plays, has raised concerns over the health risks of living near oil and gas production sites.

Local risks

Initial concerns over the health impacts of shale development focused on the risks of exposure to proprietary chemical formulas used in hydraulic fracturing. While some of these chemicals can be harmful if encountered in sufficient doses, risks of such exposure for the general public (though not for industry workers) are very small, and there is little to no evidence that substantial health damages have occurred through this pathway.

However, several other pathways of exposure warrant closer attention. First, spills and leaks of produced water, chemicals, or oil at the surface have the potential to damage the environment and pose risks to humans and animals in close proximity. Similarly, well failures known as "blowouts" may occur during the drilling phase, when an oil or gas well is unable to withstand internal pressures, and suffers an uncontrolled release of large quantities of liquids and gases. Although blowouts are very rare, they pose substantial health risks for workers on site and any nearby residents when they do occur.

A second risk comes from air emissions that occur during the well development, drilling, and completion process. Each of these activities requires powerful diesel engines that often run 24-hours per day for weeks or months at a time. The extent of the health effects from diesel exhaust—which includes volatile organic compounds, particulate matter, and other pollutants—depends on the level and duration of exposure. Immediate health effects include eye/nose/throat/lung irritation, headaches, nausea, and can exacerbate respiratory and cardiac diseases in sensitive populations.

Along with diesel emissions, air emissions that occur during the flowback stage—after a well has been hydraulically fractured and liquids and gases are flowing back to the surface—pose a potential risk for workers and nearby populations. These emissions include volatile organic compounds and air toxics such as ben-

RFF's Alan Krupnick and Isabel Echarte published "Health Impacts of Unconventional Oil and gas Development," (www.rff.org/oilgashealth) which reviews the health literature. Almost all studies found a positive association between fracking and at least one health outcome (e.g., low birthweight), but the literature overall produces inconsistent results for any given outcome. No study has identified the mechanism for these health impacts, and only one study reviewed was able to assess each link in the causal chain below. Overall, more research is needed to assess and characterize health impacts.

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The Economic Impacts of the Shale Revolution

Daniel Raimi*

Growth in U.S. natural gas and oil production from shale has had major economic impacts at the local, national, and international levels. These impacts have occurred through a variety of pathways, and although precisely quantifying their effects is difficult, the broad effects for the United States and for regional economies have been mostly positive to date.

Macro effects

For the U.S. economy as a whole, the shale revolution has had two major effects: reducing energy prices for consumers, and increasing the importance of the domestic oil and gas industry. For consumers, lower energy prices are a clear economic benefit. Without the shale revolution, natural gas prices—and likely oil prices—would be far higher, increasing the costs of residential and commercial heating, transportation, manufacturing, electricity, and more. These lower prices have, on average, saved each U.S. household thousands of dollars in heating, cooling, and transportation costs.

The second major effect—a larger domestic oil and gas industry—has more complex implications. In simple terms, a larger oil and gas industry means more exposure to the upside and the downside of volatile oil and gas prices (explored in more detail below). For example, oil and gas extraction grew from 0.4% of gross domestic product in 1998 to 1.7% in 2014, representing an additional $294 billion in 2014 alone, larger than the state of Arizona or the nation of Chile. However, the subsequent downturn in prices that has benefited consumers has shrunk the industry's share of GDP back to 0.9% in 2016.

Finally, reduced imports of crude oil and natural gas, coupled with recently increased exports of domestic resources, have substantially strengthened the U.S. balance of trade. However, the U.S. is still one of the world's largest importers of oil, second only to China.

Regional and local effects

The regional and local economic effects of the shale revolution have also been large. Although some studies using modeling techniques known as "input-output" analysis have over-estimated the regional economic and employment benefits of the shale boom, others using more careful techniques consistently find positive, but notably more modest, benefits in terms of both income and employment. One straightforward analysis from Pennsylvania found that counties with the largest number of Marcellus shale wells consistently outperformed their counterparts with fewer wells across metrics including employment, income, and business profits.

These economic benefits occur through a variety of pathways. First, local landowners benefit from oil and gas leases, which generate "bonus" payments and

RFF's Alan Krupnick and Isabel Echarte published "Economic Impacts of Unconventional Oil and gas Development," (www.rff.org/oilgasecon) which reviews the literature on local economic impacts of fracking. The report finds strong evidence for local employment and wage gains, though some studies initially overstated potential benefits. The literature on the long-term economic growth of areas with significant resources remains inconclusive.

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The Shale Revolution and Climate Change

Daniel Raimi*

Introduction

The shale revolution has dramatically increased U.S. production of natural gas and oil, with complex and important implications for greenhouse gas emissions. This issue brief describes the near term effects on climate change, potential longer term impacts, and the crucial role of government policies.

Short term impacts

In 2016, the U.S. energy sector emitted roughly 5,200 million metric tons of carbon dioxide, the lowest level since 1993. Numerous studies have demonstrated that the leading cause of these reductions has been the displacement of coal by natural gas in the electricity sector, where CO_2 emissions have fallen by 25% since 2007. This displacement has been led by the availability of a low cost supply of natural gas, brought about by the shale revolution.

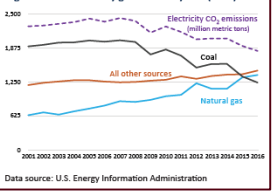
Methane emissions

The primary component of natural gas is methane which, when burned, produces heat, water, and CO_2. However, methane is also a greenhouse gas which is shorter-lived, but traps heat more effectively than CO_2. When it escapes into the air from a well, pipeline, processing facility, or any other piece of equipment, methane's impact on the climate is roughly 84 times more powerful than CO_2 over a 20-year time frame and roughly 28 times more powerful over a 100-year time frame.

If more than about 4% of the natural gas produced in the U.S. is emitted as methane (rather than being burned), the climate benefits of gas' displacement of coal disappears over a 20-year time frame. If the time frame is 100 years, the leakage rate would have to be more than 8% for natural gas to be a climate loser relative to coal.

In recent years, the U.S. EPA's estimates of domestic methane emissions have come under question, leading researchers to conduct dozens of studies to determine the amount escaping from natural gas (and oil) systems. While there is still some uncertainty, the most in-depth studies and the majority of evidence points to leakage rates in the range of 1.5% to 3.0%, well below the levels needed to negate natural gas' climate benefit over coal. Still, additional efforts to reduce methane emissions would further improve natural gas' carbon footprint.

Figure 1. Net electricity generation by fuel (TWh)



Data source: U.S. Energy Information Administration

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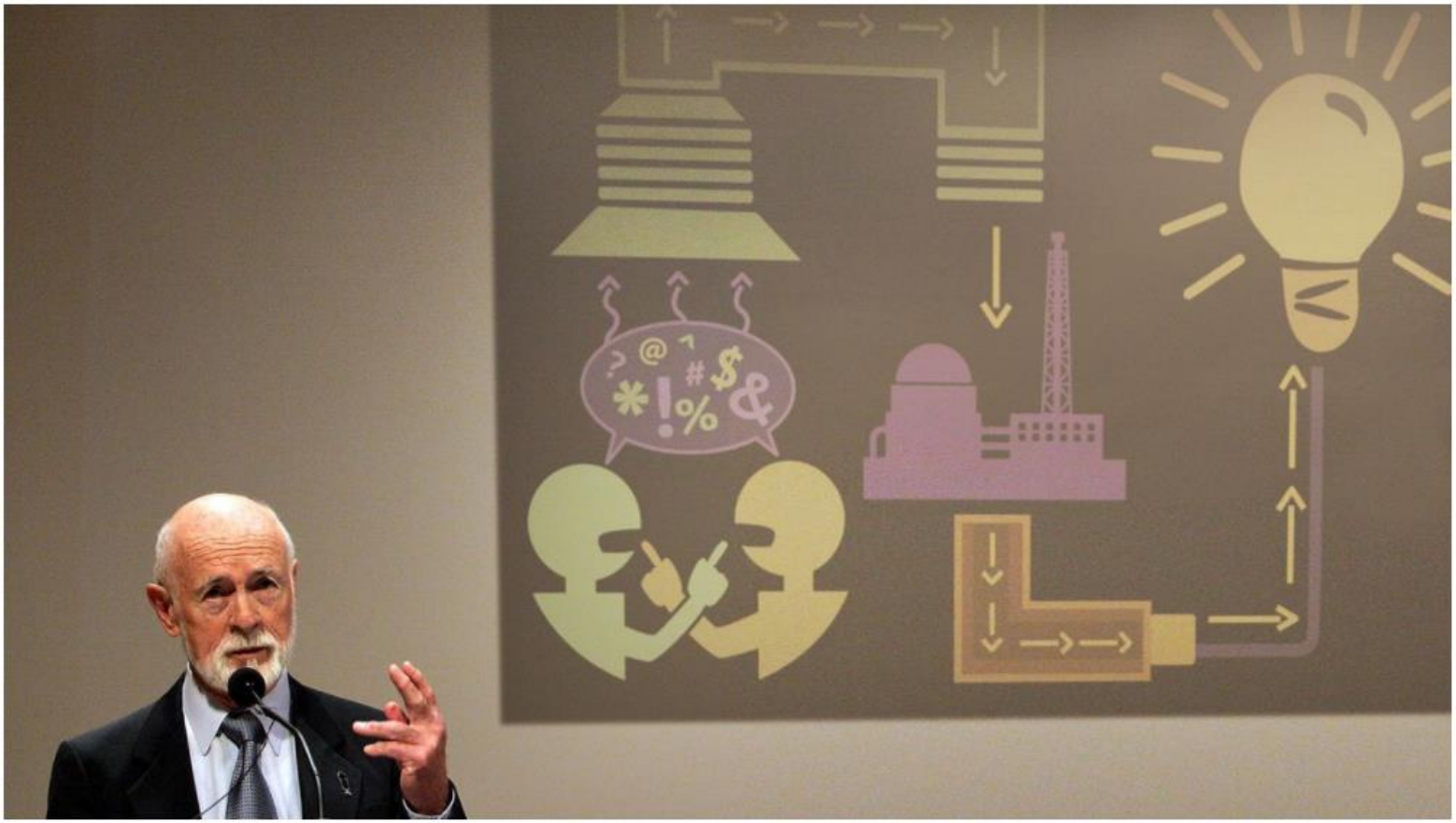
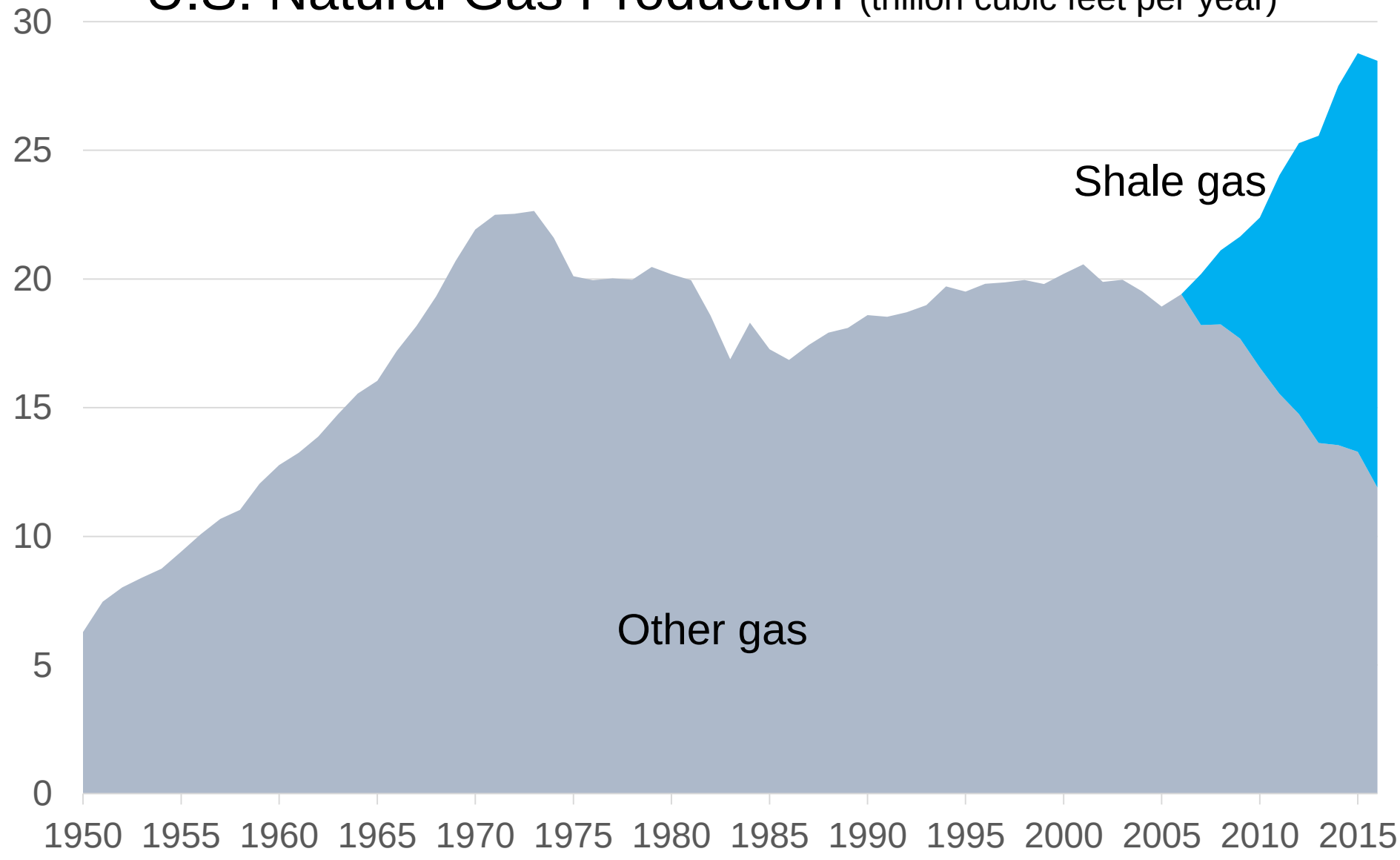
Scientists Working To Harness Energy Produced By Intense Fracking Debates

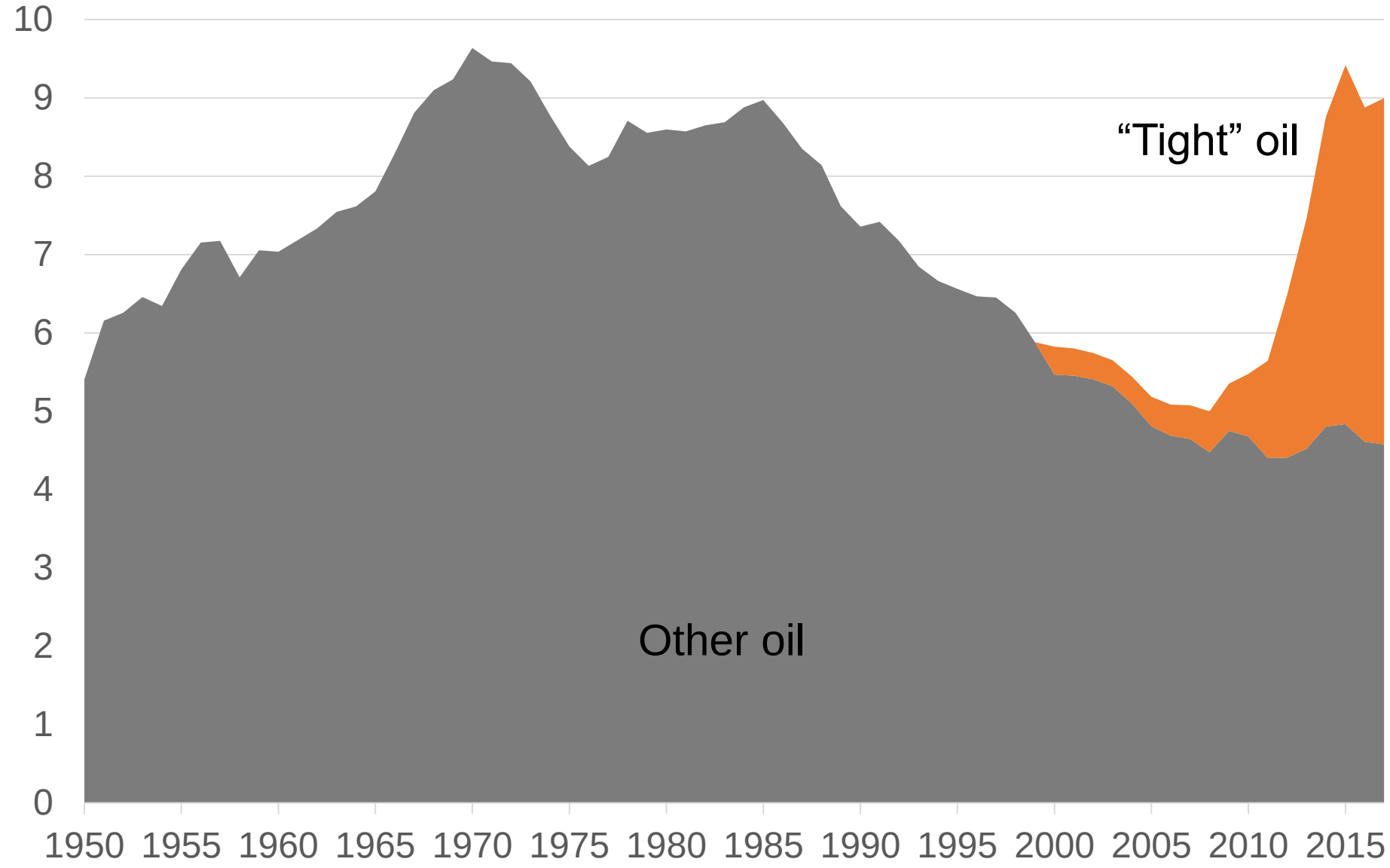


U.S. Natural Gas Production (trillion cubic feet per year)



Data source: U.S. EIA. Note: Shale production available only from 1/2007

U.S. Crude Oil Production (million barrels per day)



Data source: U.S. EIA. Note: Shale production available only from 1/2007

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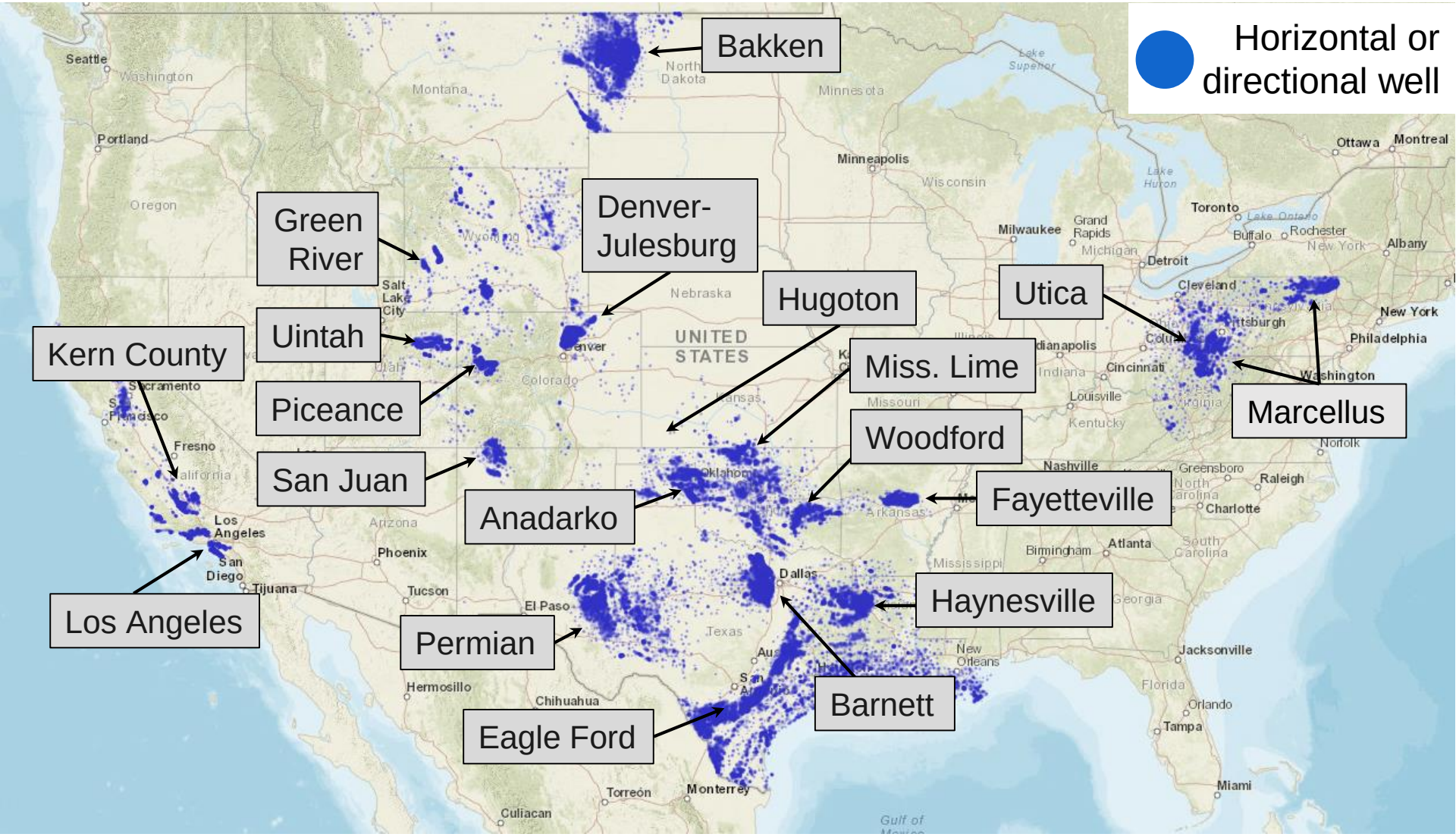


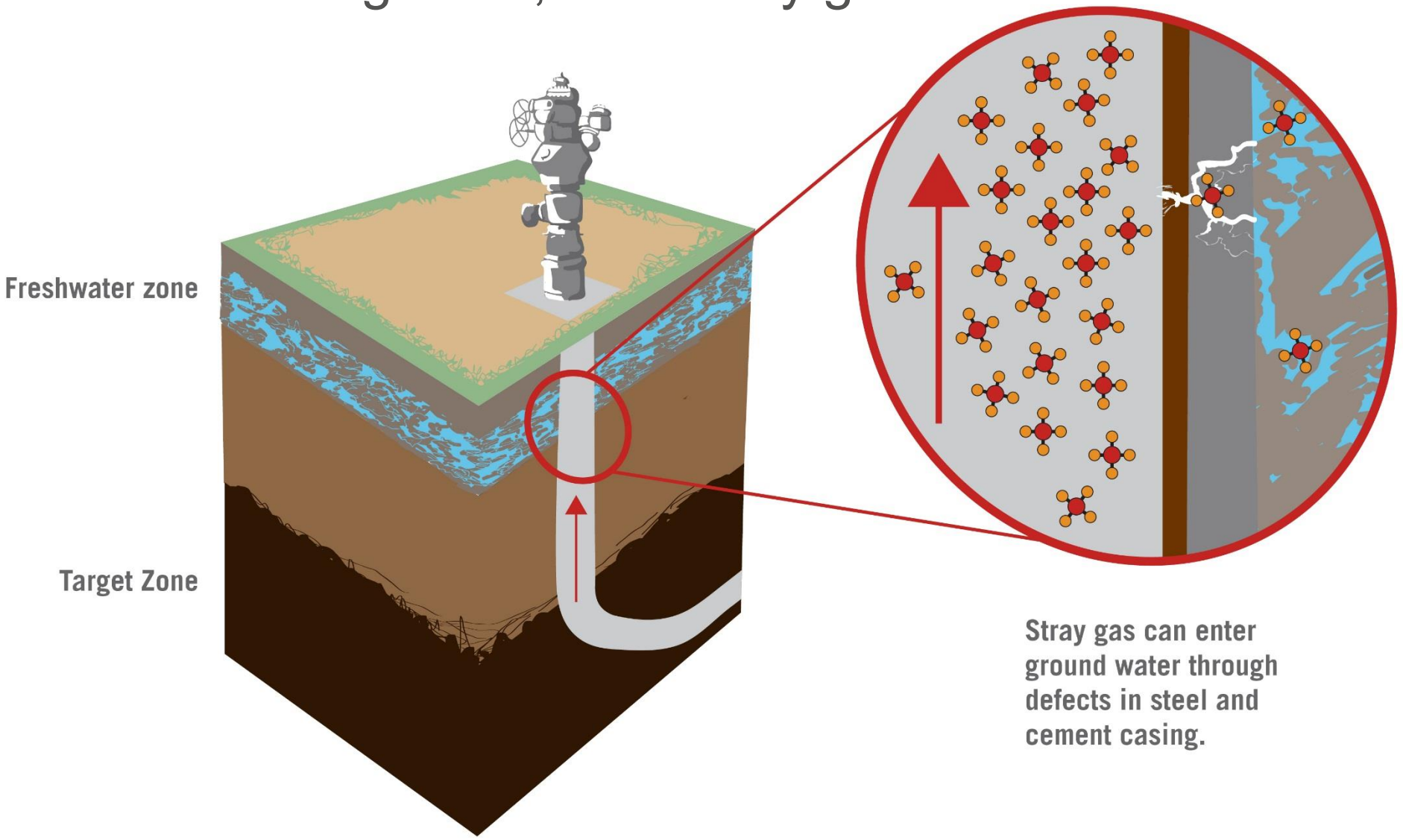
Map source: Drilling Info. Map shows all directionally and horizontally drilled wells. Data not available for Alaska.

Water supply risks

Impacts on water supplies are rare, but important

- There are very few cases where chemicals used during fracking have affected water supplies
- However, improper well construction can lead to methane migration, or “stray gas”
  - Methane is essentially the same thing as natural gas
  - There are hundreds of cases in Pennsylvania alone
  - In many cases, the impacts can be mitigated

Methane migration, aka “stray gas”



Impacts on water supplies are rare, but important

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  - Methane is essentially the same thing as natural gas
  - There are hundreds of cases in Pennsylvania alone
  - In many cases, the impacts can be mitigated
- Wastewater management is also a challenge
  - Spills from trucks
  - Spills from impoundments
  - Spills from pipelines
  - Earthquakes (more on that in a few minutes)

Economic impacts

In the near term, oil and gas development benefits local economies, with less clear long term impacts

- Leasing revenue for mineral owners
- Employment opportunities for local residents
  - Varies by region due to local workforce characteristics
- Increased economic activity for local businesses
- Magnitude of these effects vary regionally, and some studies overstate the benefits
- Research on the longer term economic impacts is mixed

Public health impacts

Implications for local and national public health

Effects diverge at different scales

Local scale

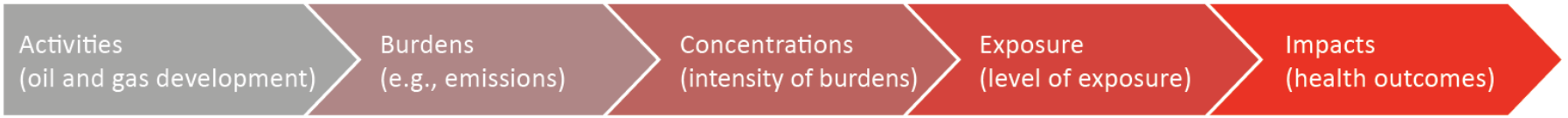
- Existing evidence is limited
- But there are known risks
  - Diesel and other air emissions
  - Vehicle traffic
  - Stress
- Impacts likely occur within close proximity to well sites
- More research is needed

National scale

- Natural gas has displaced coal
- This has reduced criteria pollutants
- Public health benefits are substantial, but diffuse

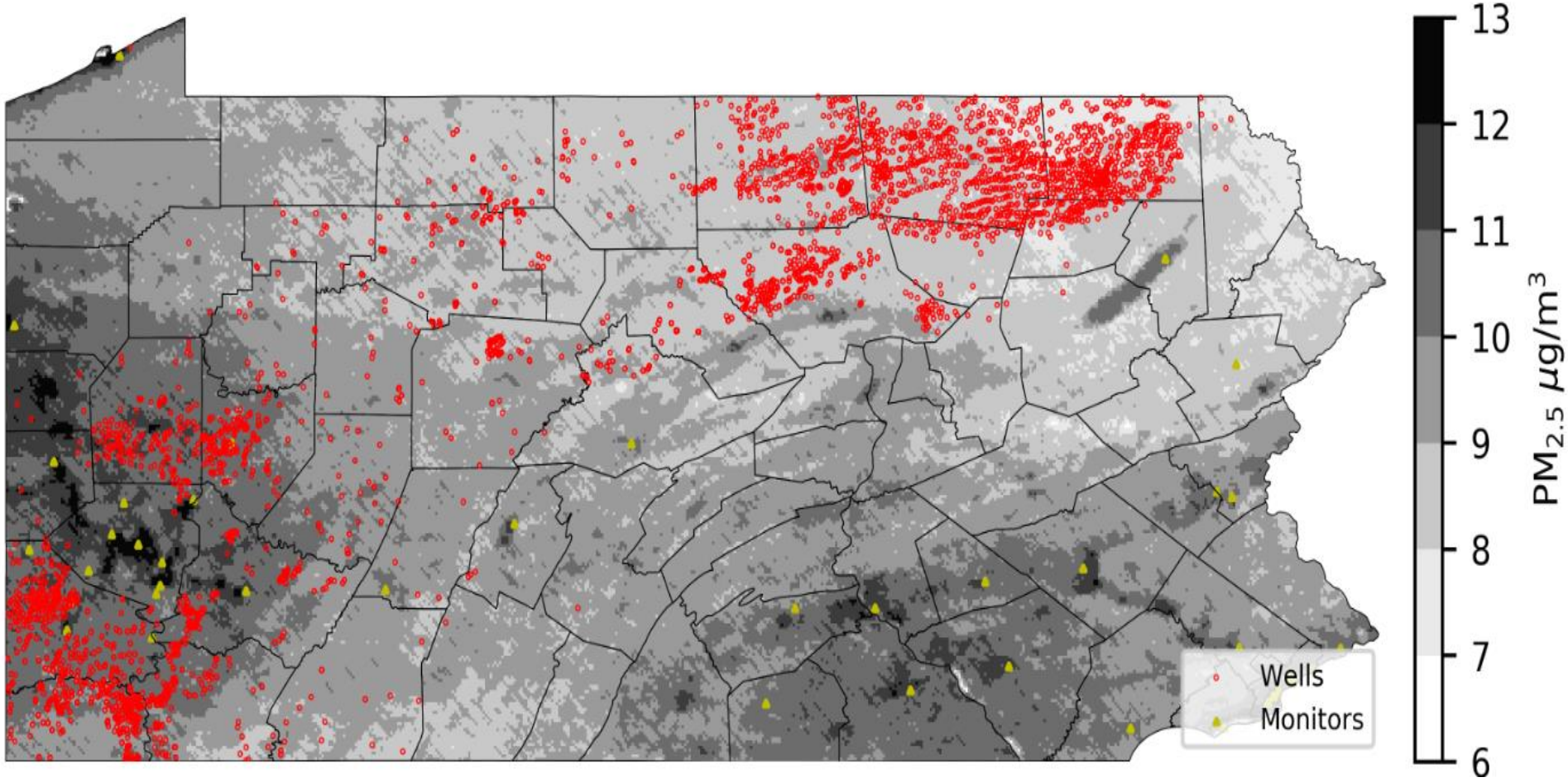
Health studies face methodological shortcomings due to data limitations

- When looking at the results for each impact (i.e., birthweight) across studies, the results are inconsistent
- This literature suffers from data limitations



- We believe the studies provide useful information but overall show the need for further research
- RFF.org/oilgashealth

New research is working to address these shortcomings



Local government impacts

Most local governments have experienced net fiscal benefits, but the effects are mixed

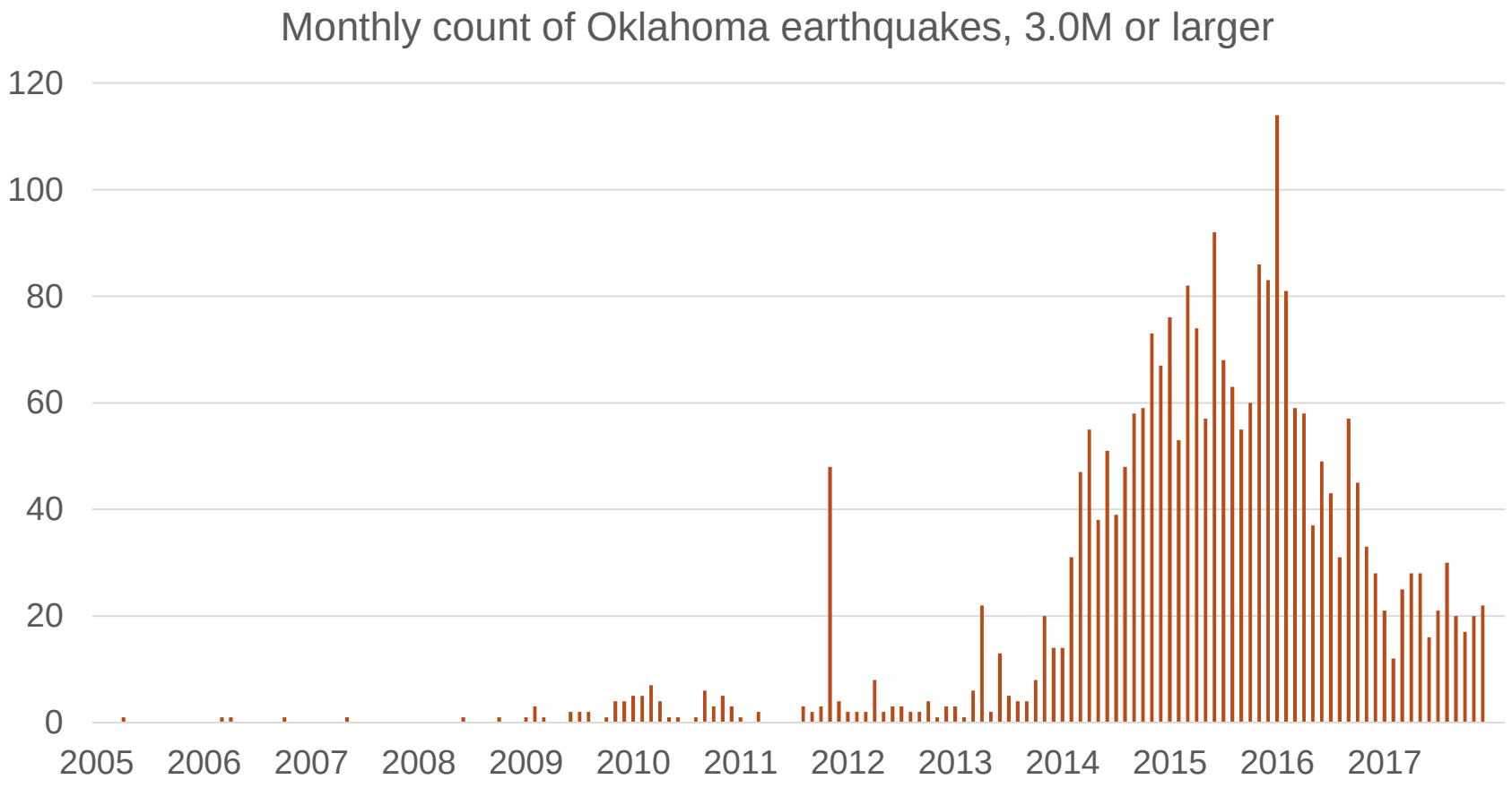
Key revenues	Key demands for services
Property taxes	Roads
Sales taxes	Water and wastewater systems
Allocation of state severance taxes	Public safety
Leasing revenue	Assorted staff costs
In-kind agreements	

Count of local governments reporting fiscal impacts						
Net negative			Roughly neutral	Net positive		
Lg.	Med.	Sm.	23	Sm.	Med.	Lg.
6	5	8		44	38	39
19 (12%)			**23 (14%)**	**121 (74%)**		

Data source: Raimi and Newell 2018

Induced Seismicity

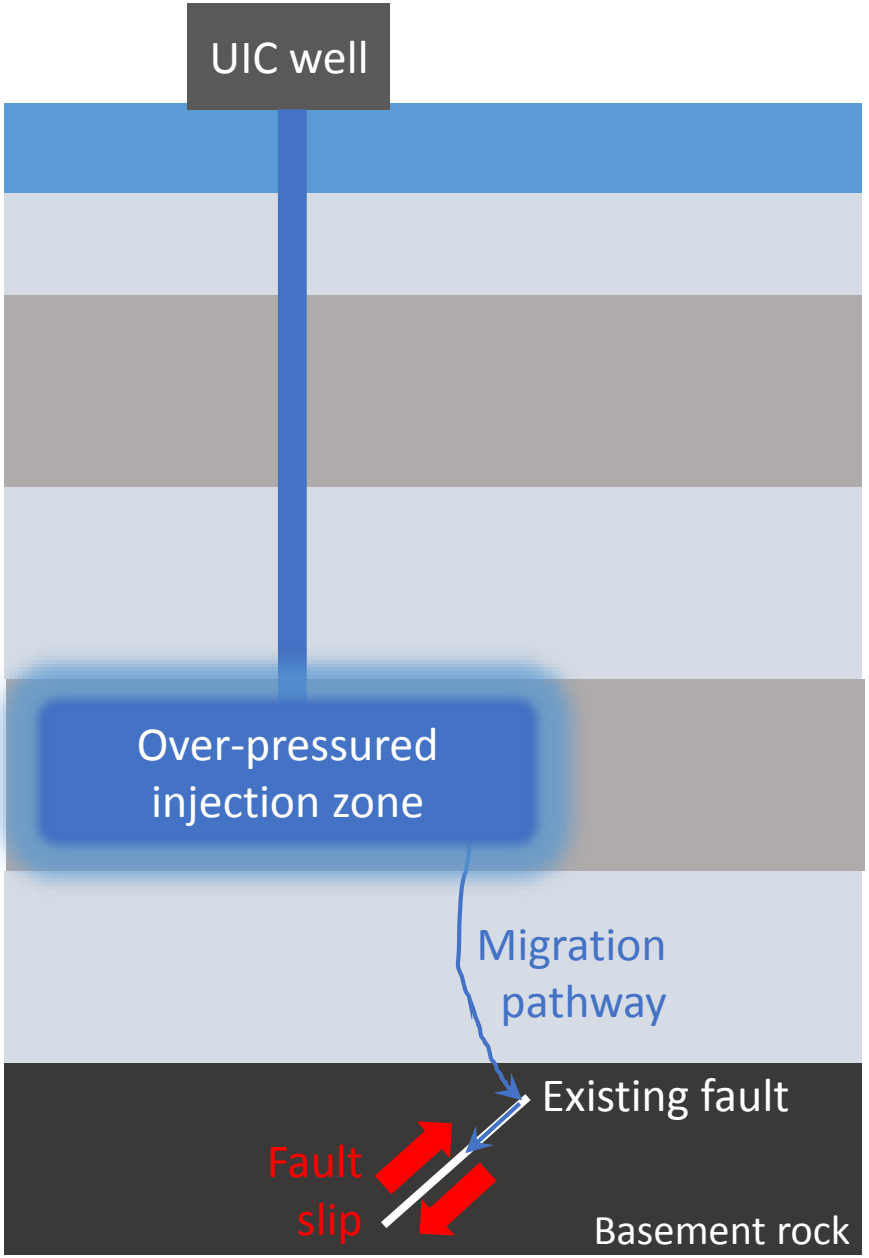
Earthquake activity has grown rapidly in the mid-continent



Data source: US Geological Survey

Wastewater disposal, not “fracking”, has been the primary cause

- All oil and gas wells produce wastewater
- Much of it is disposed of deep underground via underground injection control (UIC) wells
- More oil and gas production has led to more wastewater
- In some places, this new wastewater has caused quakes



Few Studies Look at Above-Ground Impacts

STUDY SPAN CHART: SEISMICITY STUDIES

	Study	Activities Specific activities or the presence of fracking in a community.	Burdens Initial consequences of shale development (e.g., earthquakes).	Exposure Evidence or amount of exposure (e.g.,	Impacts The effects felt by the community (e.g., stress or
Survey	McComas et al. (2016)				
Statistical	Liu et al. (2016)				
	Hough (2014)				
	Weingarten et al. (2015)				
	Llenos and Michael (2013)				
	Frohlich (2012)				
	Rubinstein et al. (2014)				
	Walsh and Zoback (2015)				
	Goebel et al. (2015)				
	Van der Elst et al. (2016)				
Historical	Frohlich et al. (2016)				
Geomechanic Modeling, Simulations	Keranen et al. (2014)				
	Gono (2015)				
	Hornbach et al. (2015)				
	Hornbach et al. (2016)				
	Rutqvist et al. (2013)				
	Zhang et al. (2013)				
	Dieterich et al. (2015)				
	McClure and Horne (2011)				
Probabilistic/ Predictive and for Hazard Assessment	Walsh and Zoback (2016)				
	Langenbruch and Zoback (2016)				
	Shirzaei et al. (2016)				
Geologic/ Seismologic	Justinic et al. (2013)				
	McNarmara et al. (2015)				
	Kim (2013)				
	Keranen et al. (2013)				
	Sumy et al. (2013)				
	Horton (2012)				
	Yeck et al. (2016)				
	Frohlich et al. (2011)				
	Frohlich and Brunt (2013)				
	Block et al. (2014)				
	Ake et al. (2005)				
	Skoumal et al. (2015)				
	Friberg et al. (2014)				
	Holland (2011)				
	Holland (2013)				
	Gan and Frohlich (2013)				
	Van der Elst et al. (2013)				

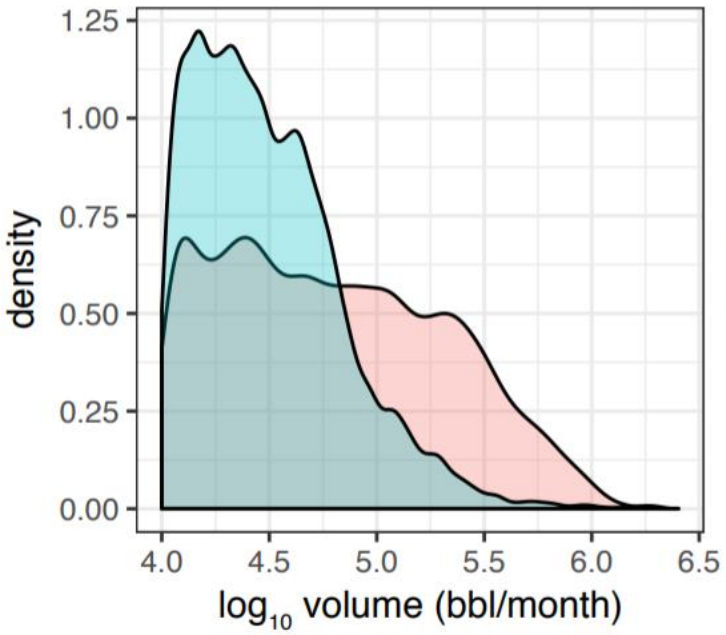
Source: Krupnick and Echarte (2017)

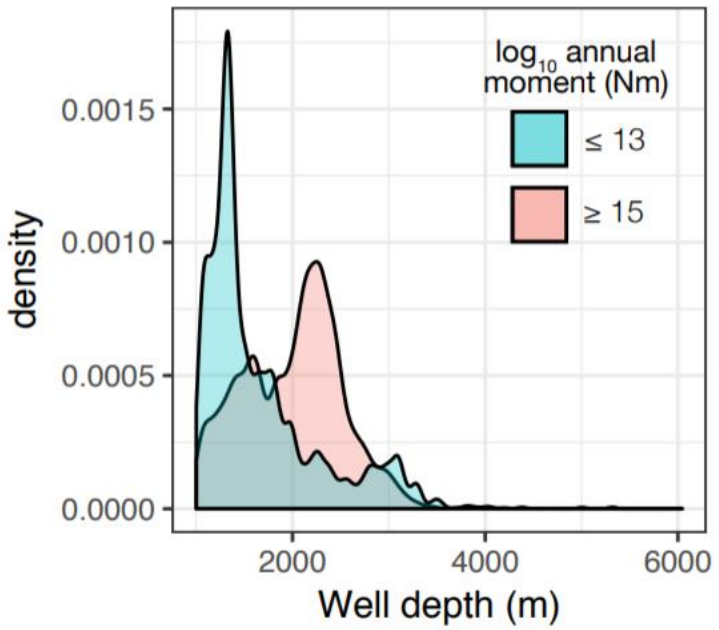
RFF.org/seismicityimpacts

Research Assessing Policies and Future Seismicity

Recent research includes:

- Walsh and Zoback (2016)
- Langenbruch and Zoback (2016)
- Hincks et al. (2018)

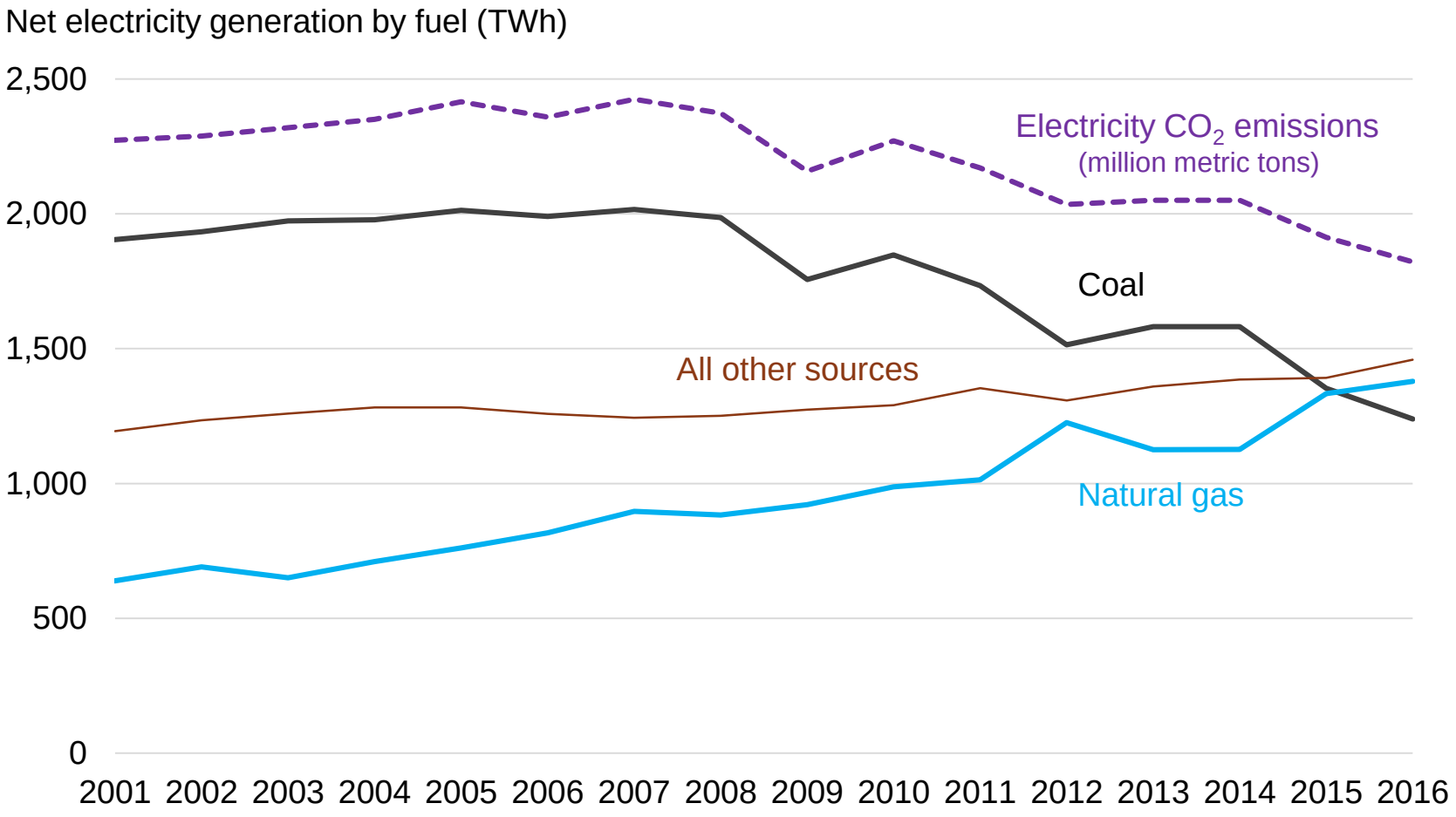




Source: Hincks et al. (2018)

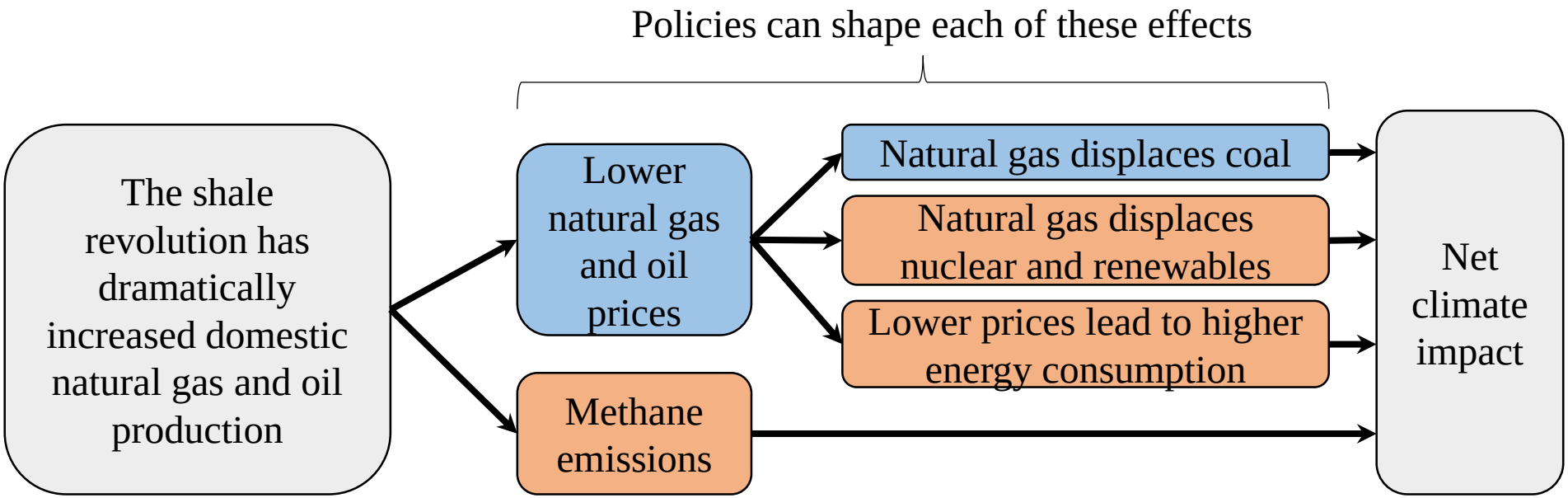
Implications for climate change

Decreased natural gas prices have displaced coal, substantially reducing US CO_2 emissions



Data source: U.S. EIA.

The effects of the shale revolution on climate change are complex and controversial



Several studies have sought to aggregate each of these effects

- Over the longer term, studies find limited decadal effects
  - Reduced CO_2 from coal is largely offset by increased energy consumption and competition with low-carbon sources
- But uncertainties remain over
  - Methane emissions
  - Aggregate energy consumption (elasticity of demand)
  - Policy
- Low cost natural gas provides a window of opportunity for climate policy
  - Whether those policies are implemented is another question

RFF's Shale Research Clearinghouse (SHARC)

- The Issue Briefs derived from the Raimi book and from our WHIMBY website are built on libraries of original studies.
- Our intention is to become a clearinghouse for studies of the positive and negative effects of unconventional oil and gas development
- This project has begun
  - Merging our libraries
  - Re-doing classifications of topics (and prioritizing which topics to take up first and to what depth)
  - Taking input from a stakeholder user survey
- Next will be to curate the high priority topic reviews
- Developing the web interface

Shale Research Clearinghouse

The Shale Research Clearinghouse (SHARC) is a publicly accessible, curated repository for information on the economic, health, and environmental impacts of oil and gas development.

Browse by topic

● = comprehensive coverage with issue brief and literature review
● = partial coverage

ISSUE BRIEF

Human Health Issue Brief (test)

Daniel Raimi

LITERATURE REVIEW

Human Health Literature Review (test)

Daniel Raimi

JOURNAL ARTICLE *Environmental Health* December 2018

Exploring the endocrine activity of air pollutants associated with unconventional oil and gas extraction

Ashley L. Bolden, Kim Schultz, Katherine E. Pelch, and Carol F. Kwiatkowski

Phases II and III

With secured funding, we can

- Expand on the literature review topics and update
  - Groundwater/Surface water
  - Air Quality
  - National Economy
  - Community-Industry interaction
- Build on two existing models to create a new tool to facilitate community-industry interactions:
  - Schlumberger's Shale Gas Development Impact Model
  - EPA's Benefit Mapping Model (BENMAP) that links pollution concentrations to health and other physical impacts and their economic value

Literature curation

	Higher quality: The majority of studies reviewed for an impact are of higher quality. Where there is one study of higher quality, it is marked as such.
	Medium quality: The majority of studies reviewed for an impact are of medium quality. Where there is one study of medium quality, it is marked as such.
	Lower quality: The majority of studies reviewed for an impact are of lower quality. Where there is one study of lower quality, it is marked as such.
	Not reviewed: Research on an impact was not reviewed.
↑	Increase: Studies show a positive, robust association with an impact (an increase in incidence or magnitude).
↓	Decrease: Studies show a negative, robust association with an impact (a decrease in incidence or magnitude).
↑↓	Heterogeneous: Across regions or areas, studies report robust results that differ.
∅	No association: Studies report results that showed no association.
~	Inconsistent: Studies report differing (contradictory) results.

Thank you

April 25, 2018

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For more, visit:

www.rff.org/thefrackingdebate

www.rff.org/whimby

RESOURCES FOR THE FUTURE