Opportunities and Challenges of Shale Gas Development

Mark D. Zoback
Professor of Geophysics

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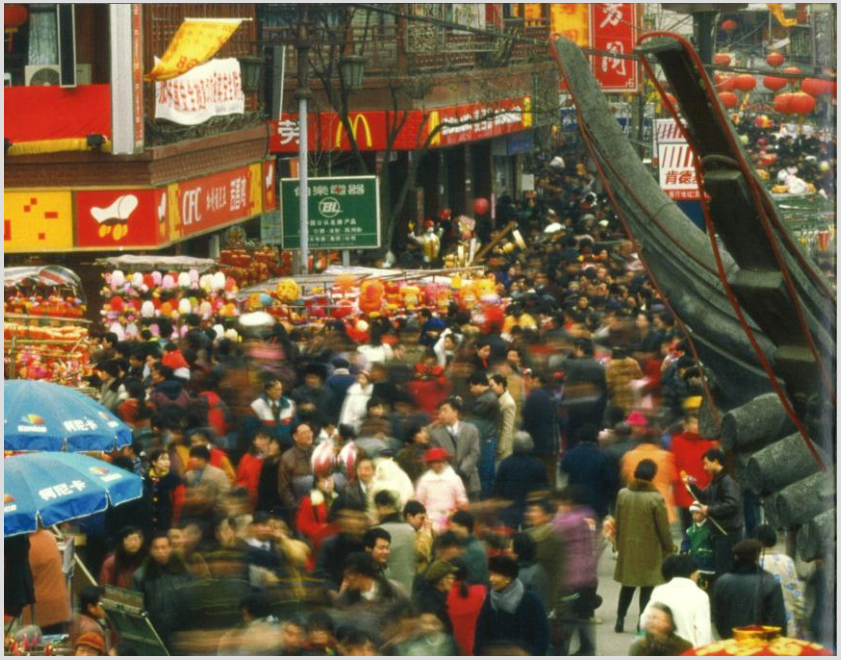
Director

Stanford | NATURAL GAS INITIATIVE
School of Earth, Energy & Environmental Sciences
and Precourt Institute for Energy

Global Energy and Environment Challenge

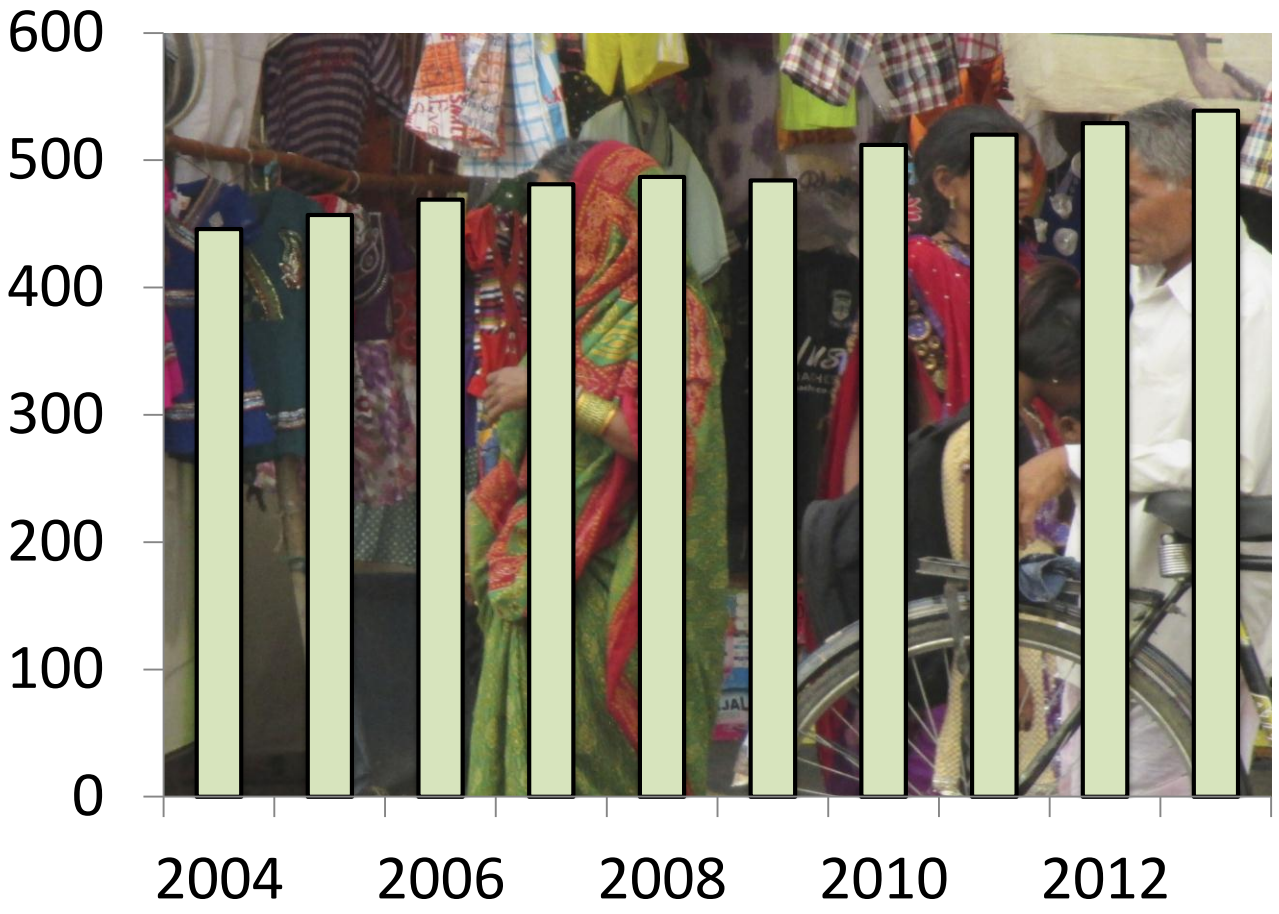
The World in 2050



~ 9 Billion People

How Do We Provide Twice As Much Accessible, Affordable, and Secure Energy While Protecting the Planet?

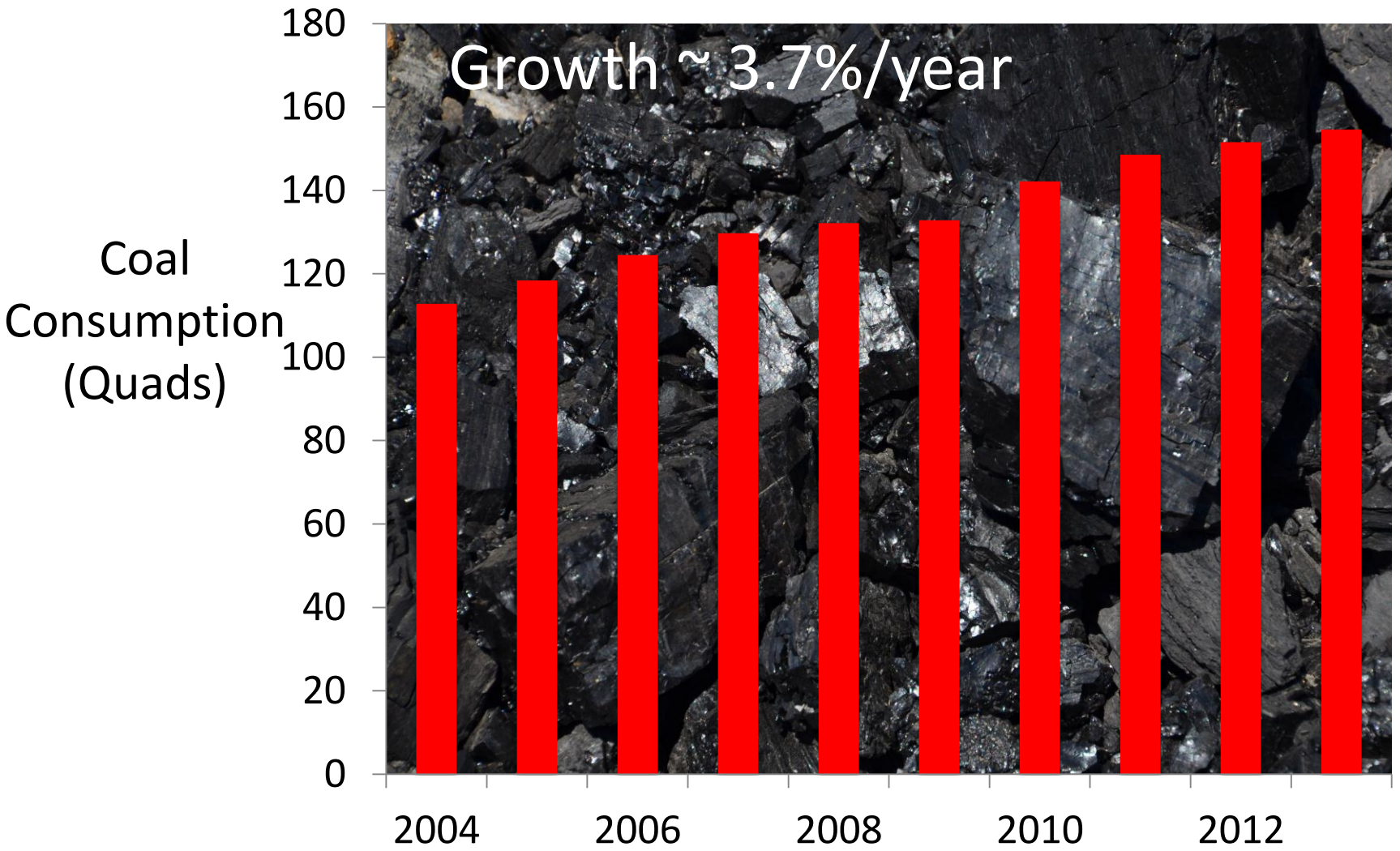
Growing Demand for Energy Services



- **Increasing at 2.1% per year**

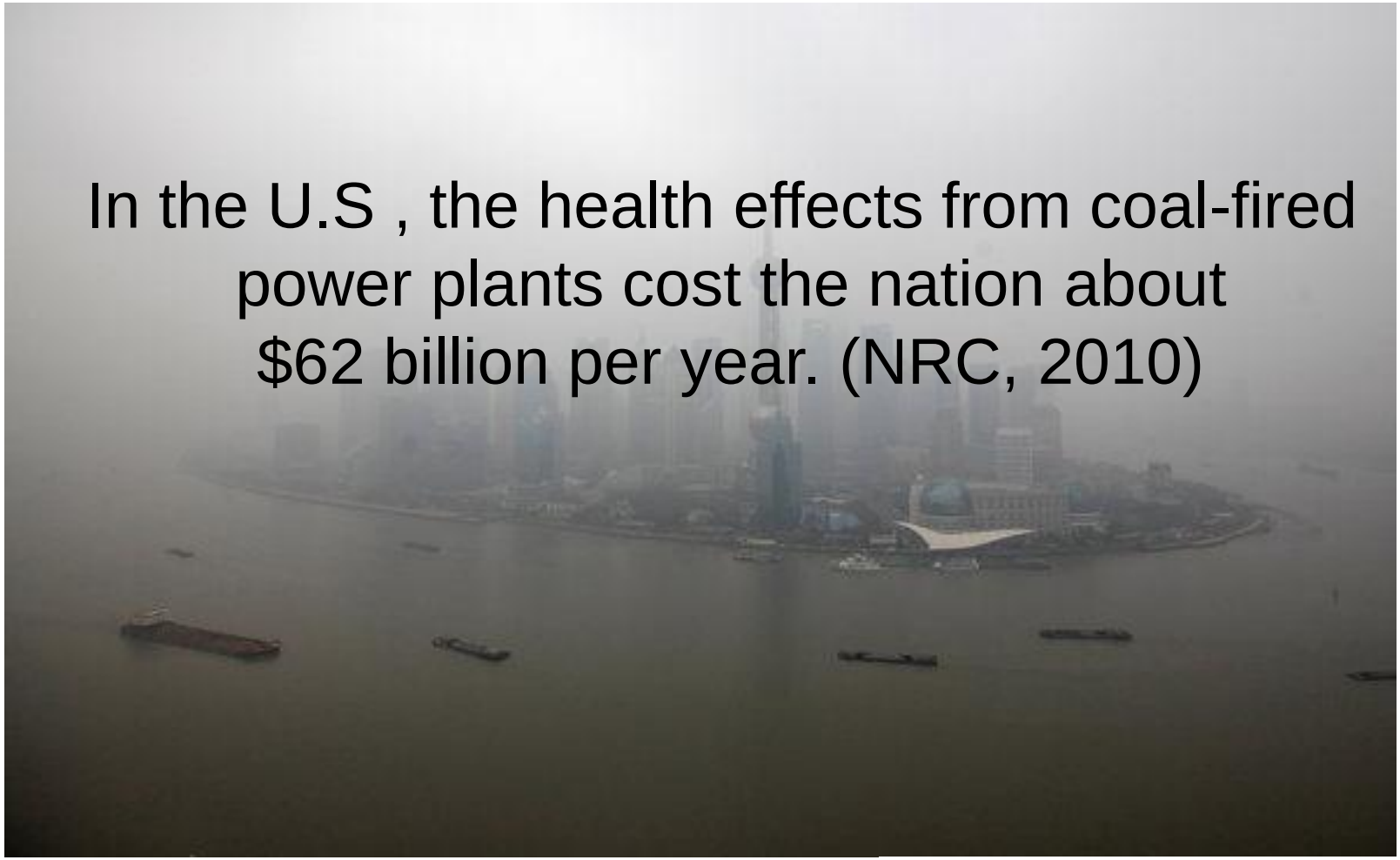
Source: Enerdata, 2014.

Coal Use Continues to Grow



Source: EIA International Energy Statistics 2014.

Air Pollution Linked to 1.2 Million Premature Deaths in China Each Year

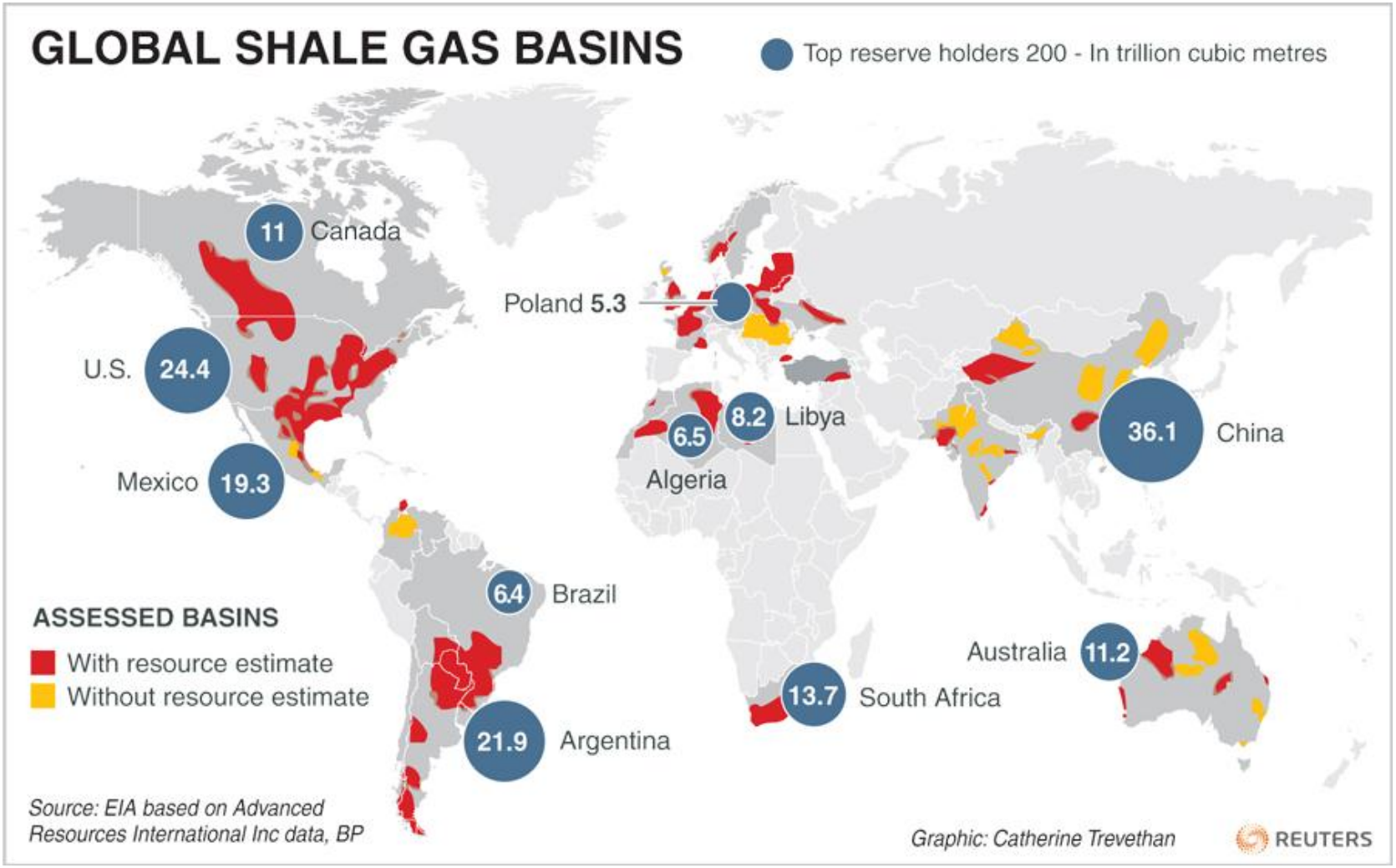


Shanghai, January

The New York Times

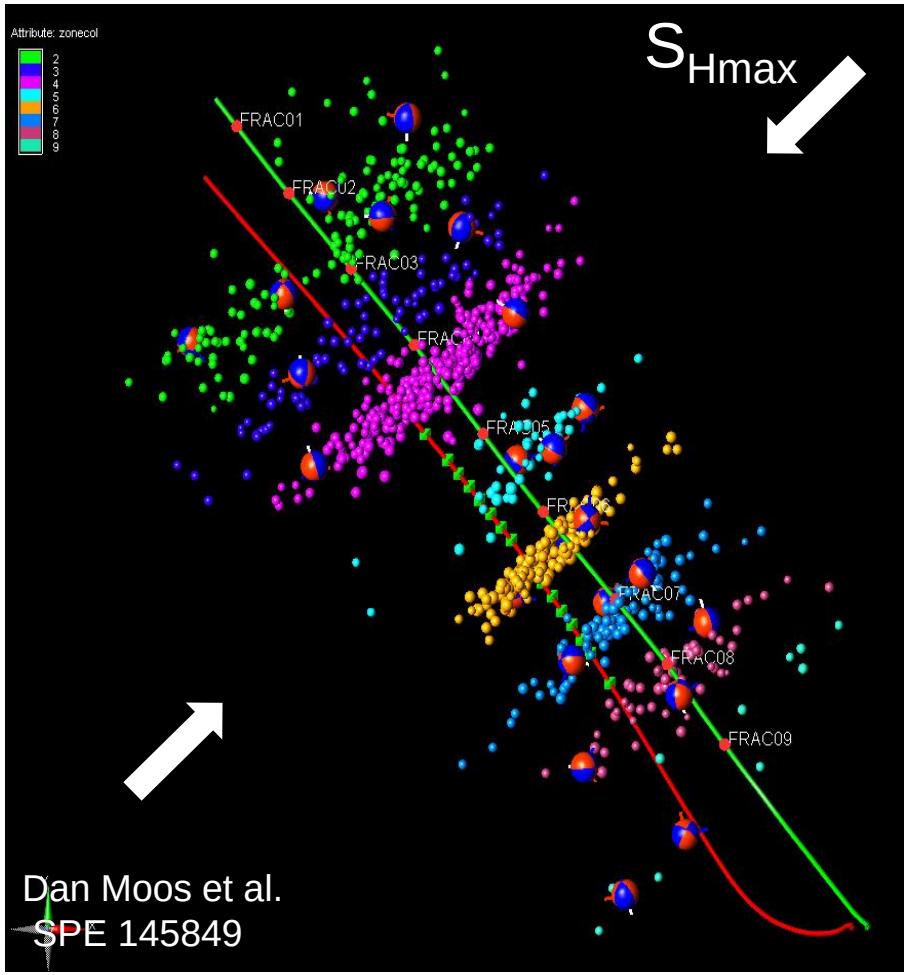
April 2013

Global Shale Gas ~ 200 Years of Supply



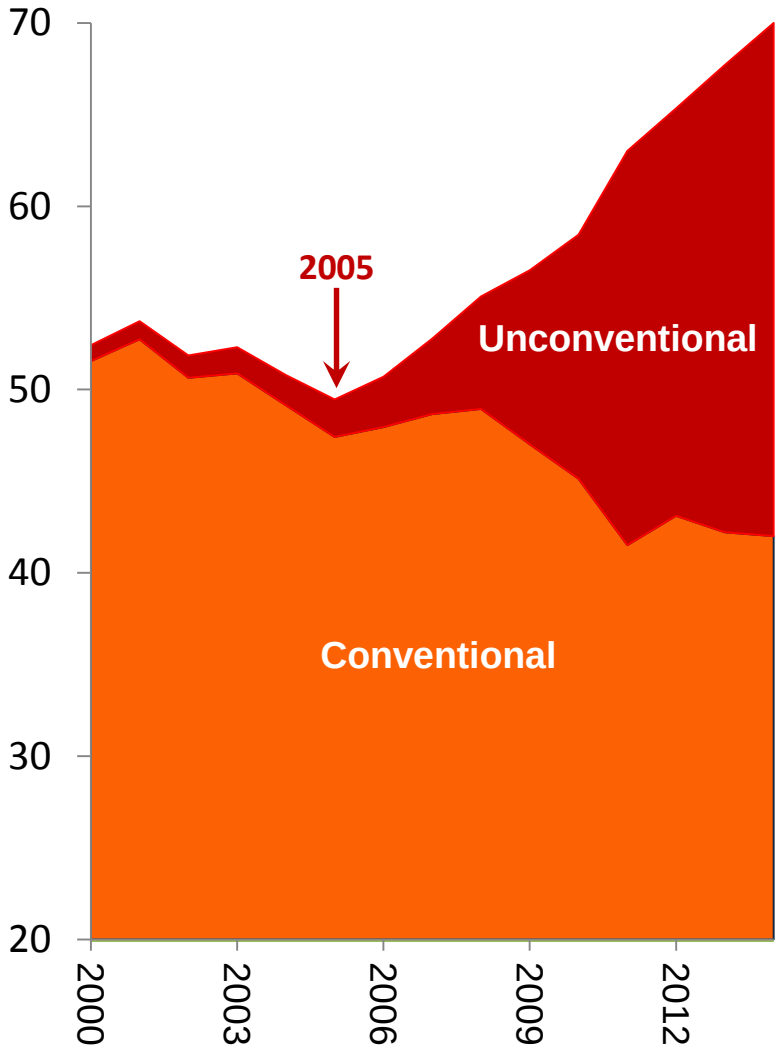
source | EIA based on Advanced Resources International Inc. data, BP
graphic | Catherine Trevethan, Reuters

Multi-Stage Hydraulic Fracturing



Horizontal Drilling and Multi-Stage
Slick-Water Hydraulic Fracturing
Induces Microearthquakes (M ~ -1 to M~ -3)
To Create a Permeable Fracture Network

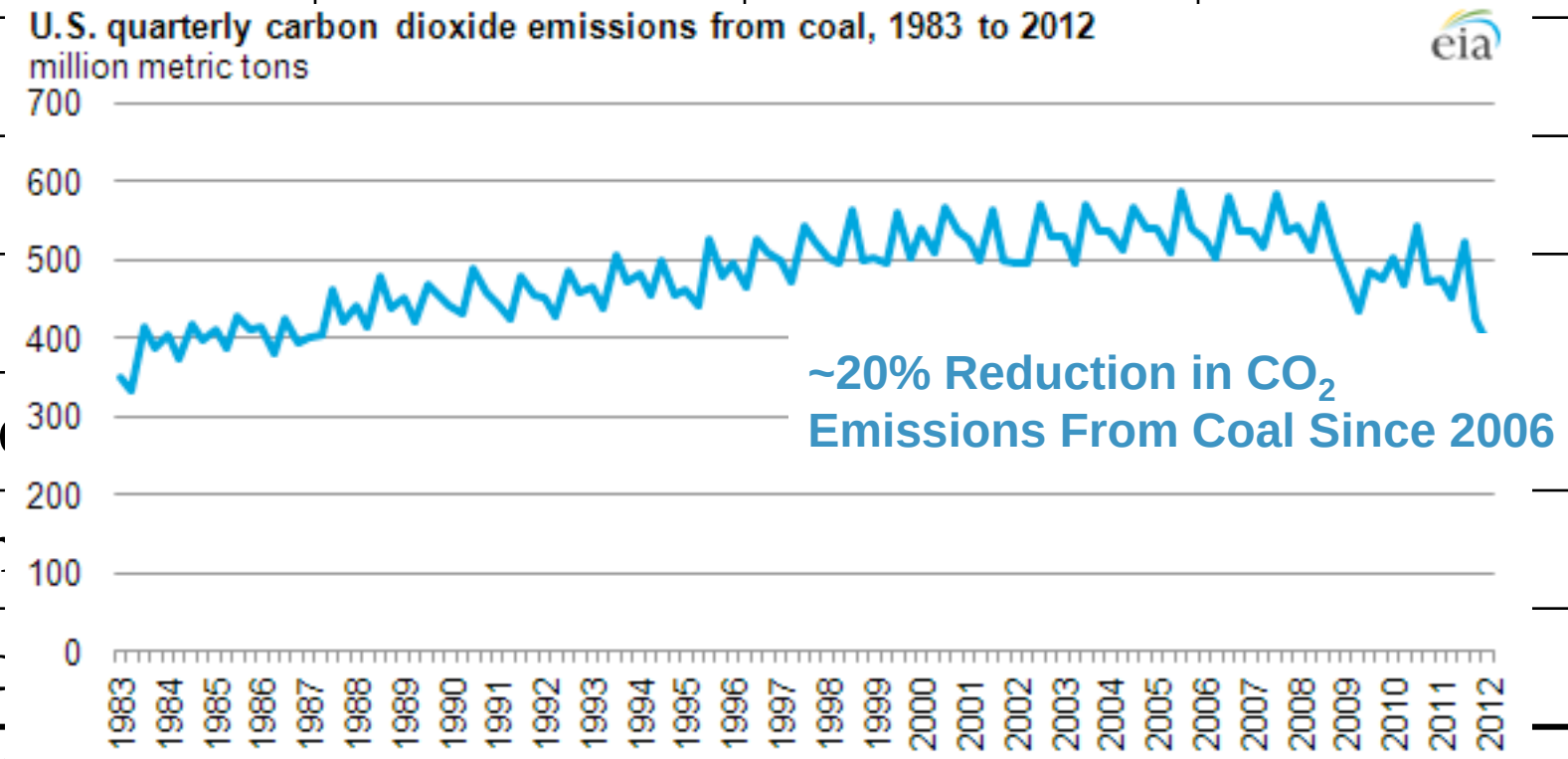
U.S. Natural Gas Production (billions of cubic feet per day)



Source: U.S. Department of Energy, Energy Information Administration (EIA)

Air Pollution and Energy Source*

	CH_4	Oil	Coal
CO_2	117,000	164,000	208,000
CO			
NO_x			
SO_2			
Parti			
Form			
Merc			



Source: U.S. Energy Information Administration, Monthly Energy Review.
CO2 emissions from coal were down 18% to 387 million metric tons in the January-March 2012 period.

Horizontal Drilling and Multi-Stage Frac'ing Are Large-Scale Industrial Processes

Opportunities and Challenges of Shale Gas Production

The development of shale gas resources in an environmentally responsible manner presents a critical opportunity to move toward decarbonizing the global energy system.

Shale Gas Development

Opportunities and Challenges

Mark D. Zoback

Douglas J. Arent

Mark D. Zoback and
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The use of horizontal drilling and multistage hydraulic fracturing technologies has enabled the production of immense quantities of natural gas, to date principally in North America but increasingly in other countries around the world. The global availability of this resource creates both opportunities and challenges that need to be addressed in a timely and effective manner.

There seems little question that rapid shale gas development, coupled with fuel switching from coal to natural gas for power generation, can have beneficial effects on air pollution, greenhouse gas emissions, and energy security in many countries. In this context, shale gas resources represent a critically important transition fuel on the path to a decarbonized energy future. For these benefits to be realized, however, it is imperative that shale gas resources be developed with effective environmental safeguards to reduce their impact on land use, water resources, air quality, and nearby communities.

Background

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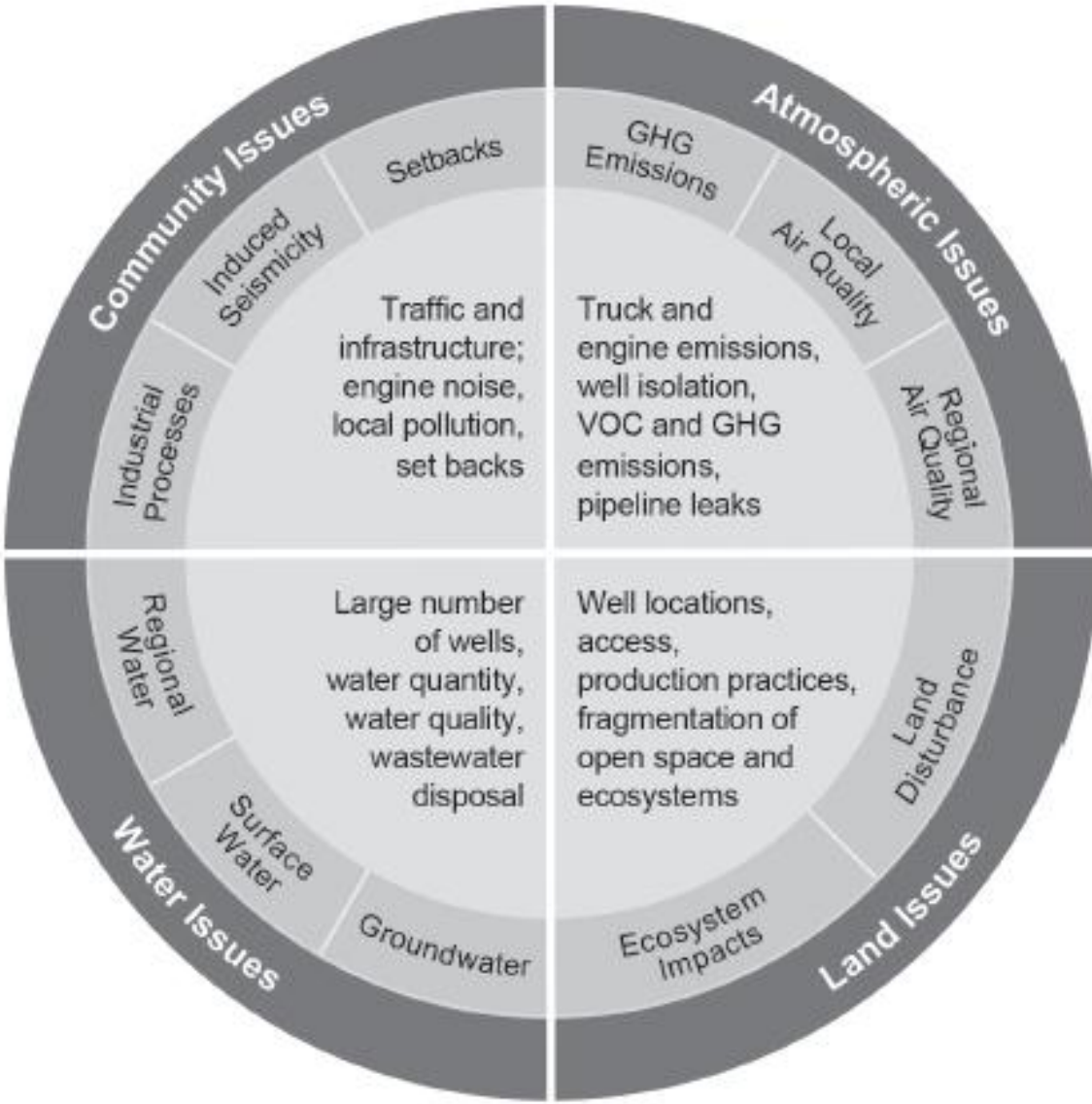

The Bridge (U.S. National Academy of Engineering), 2014

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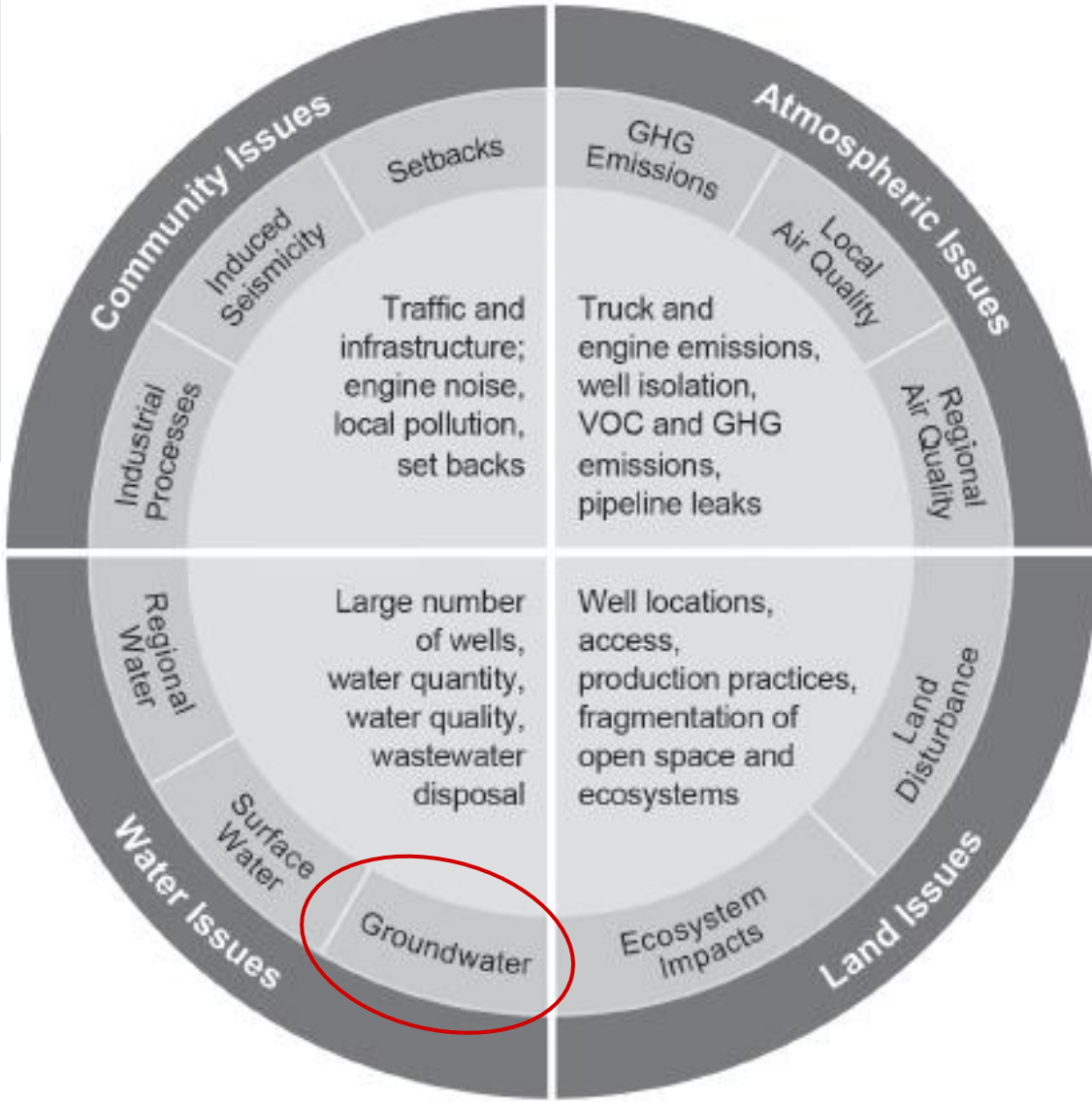
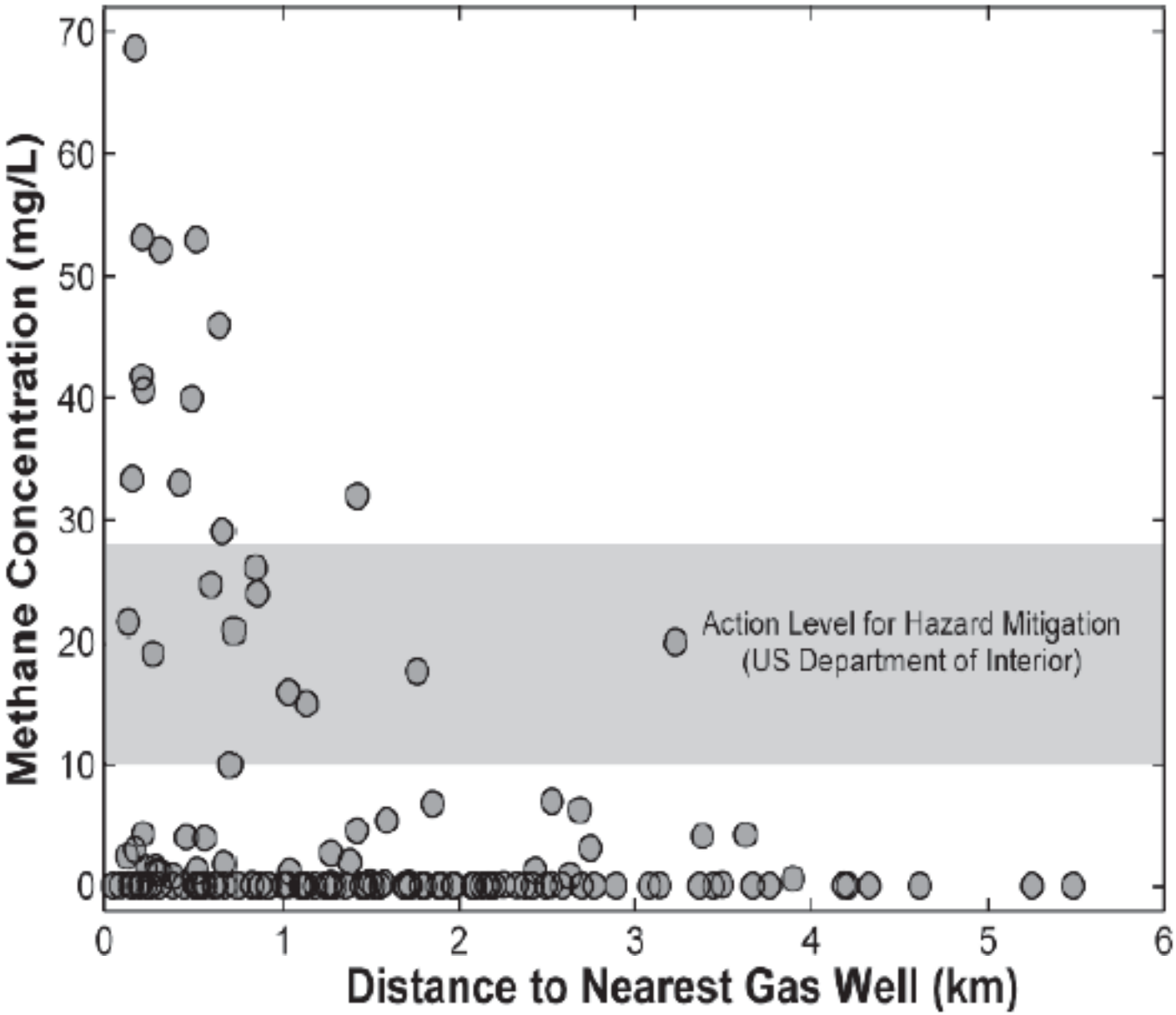


The Bridge (U.S. National Academy of Engineering), 2014

Does Vertical Hydrofrac Growth Affect Water Supplies?

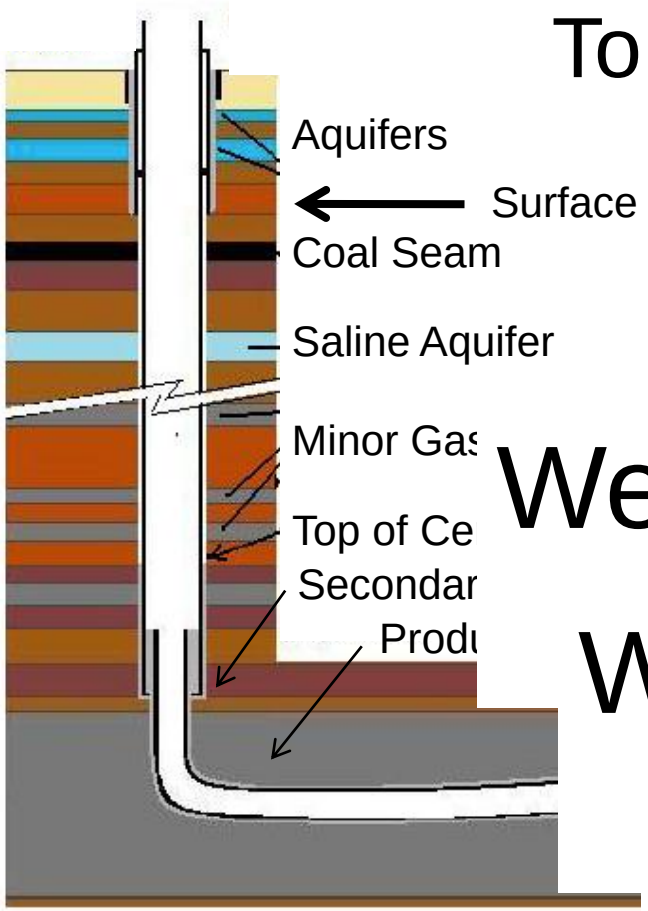
NO!
(No Evidence of HF Causing Contamination After ~2M HF's)

Evidence for Stray Gases in a Minority of Houses <1km away



Jackson et al. 2013 PNAS

To Prevent Leakage, Casing and Cementing are Critical



API Recommended Practice

Well Construction

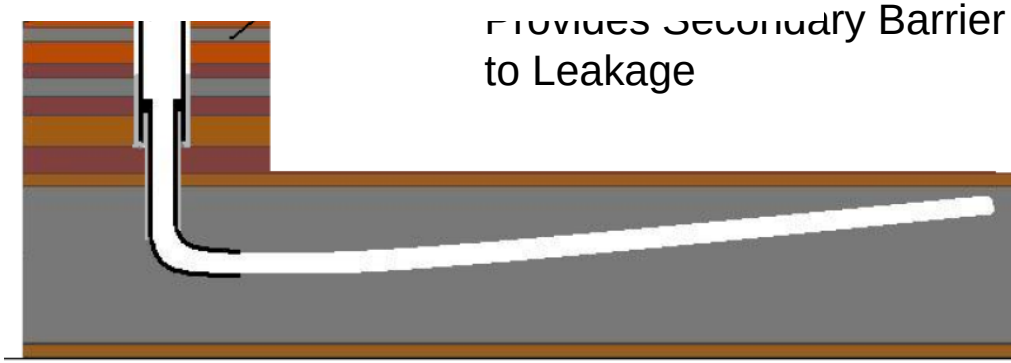
Well Construction

Well Construction

tice

at 2000 ft.

Provides Secondary Barrier to Leakage



Courtesy George King, Apache Corp.

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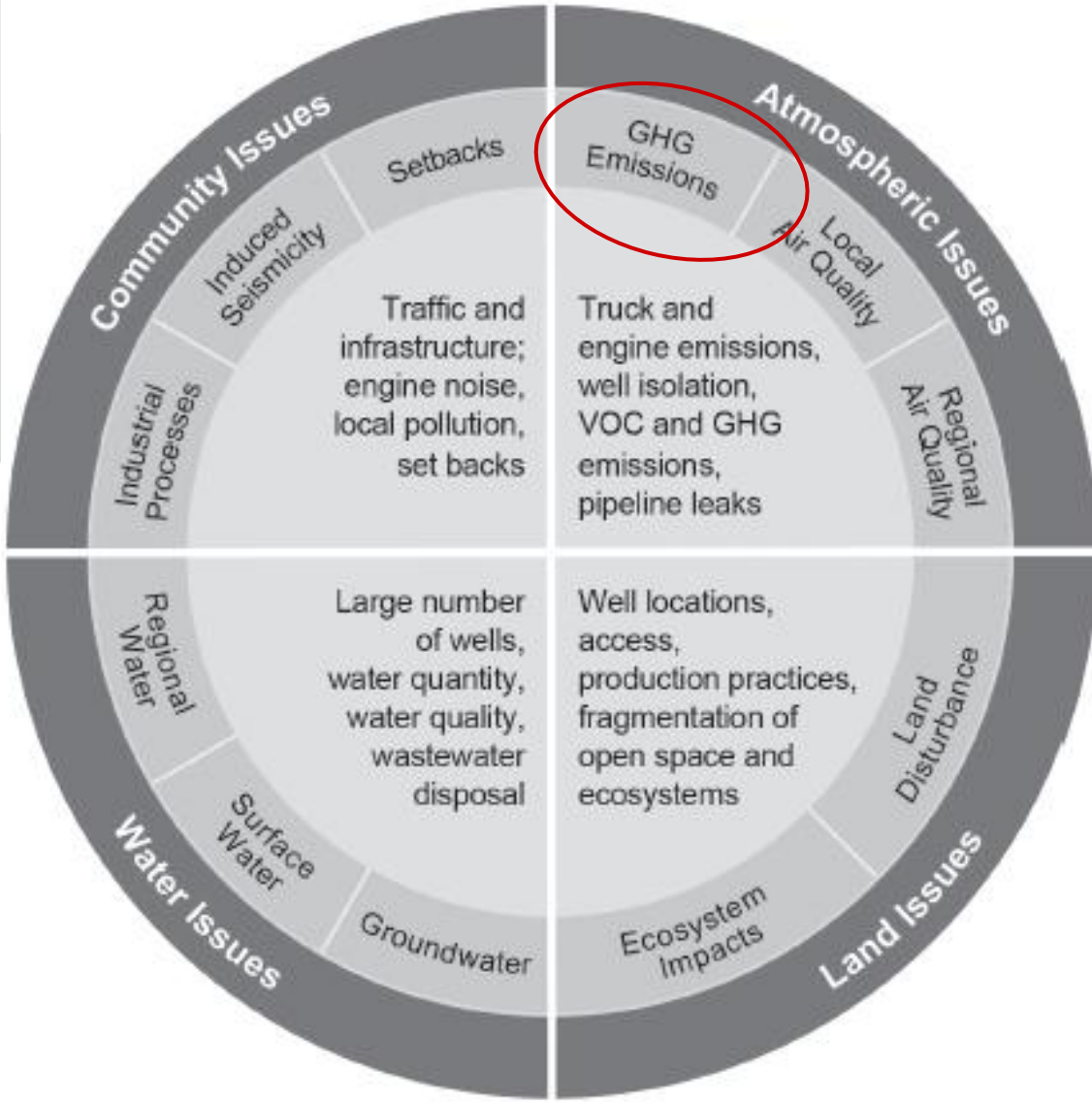
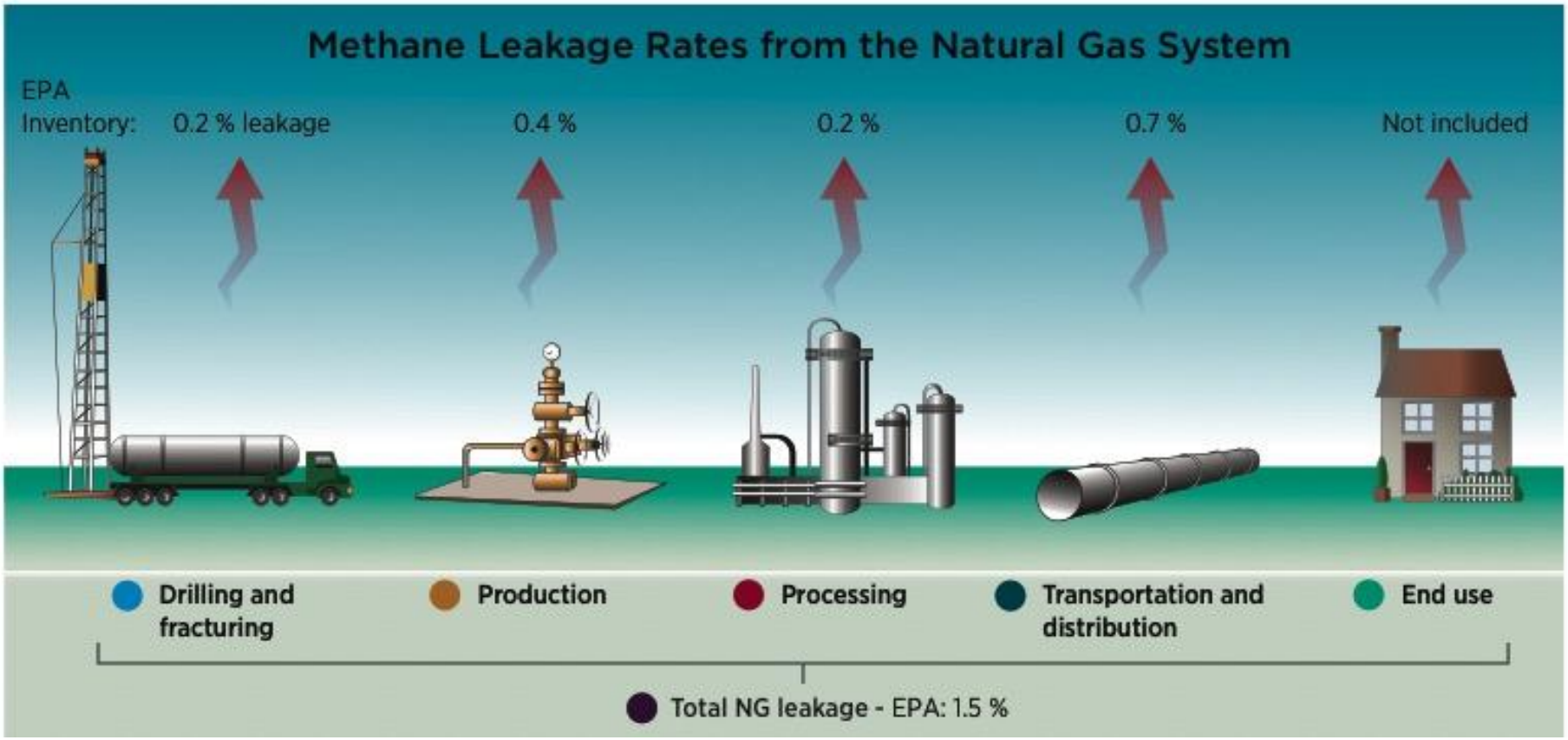


The Bridge (U.S. National Academy of Engineering), 2014

EPA Natural Gas Inventory

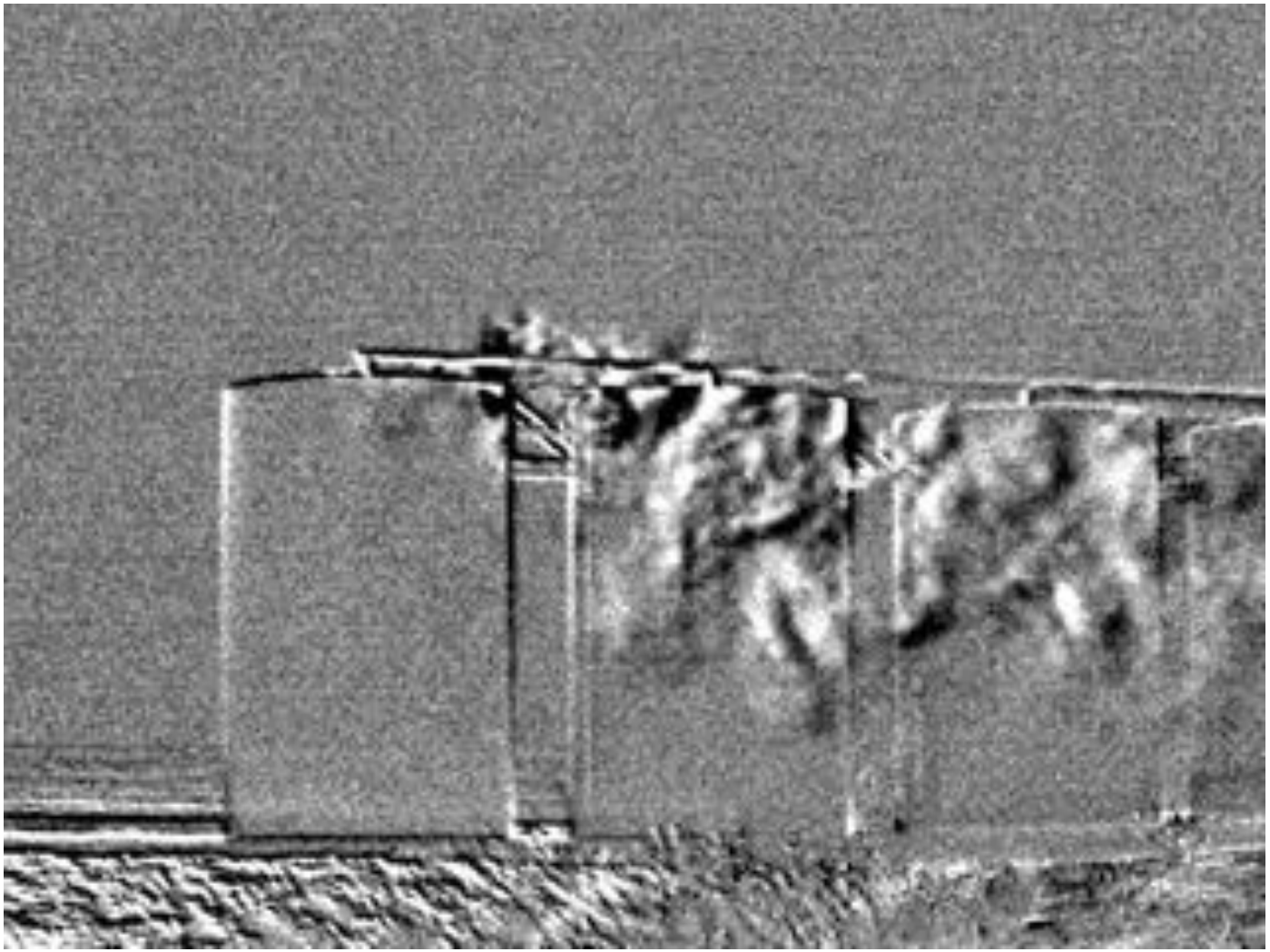


Total leakage fraction = ~1.5% (2013 inventory)

The Impact of “Super-Emitters”

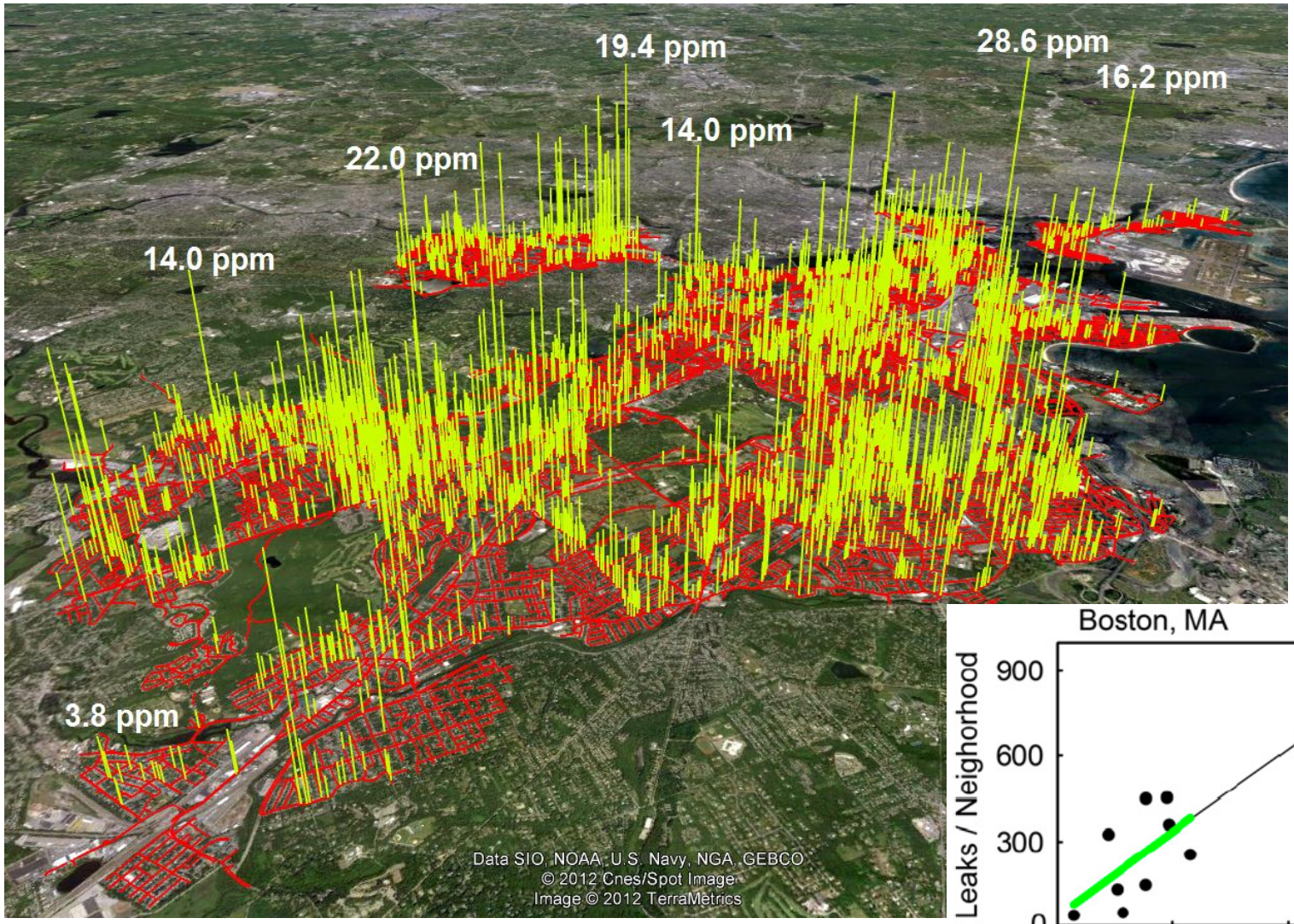
- Bottom-up studies suggest that unintentional leakage rates vary greatly between devices
  - Most devices do not leak
  - A small fraction of components or devices leak excess gas (1 - 4%)
  - A **very** small fraction (<1%) leak a large amount. These super-emitters often contribute a large fraction of the total leakage

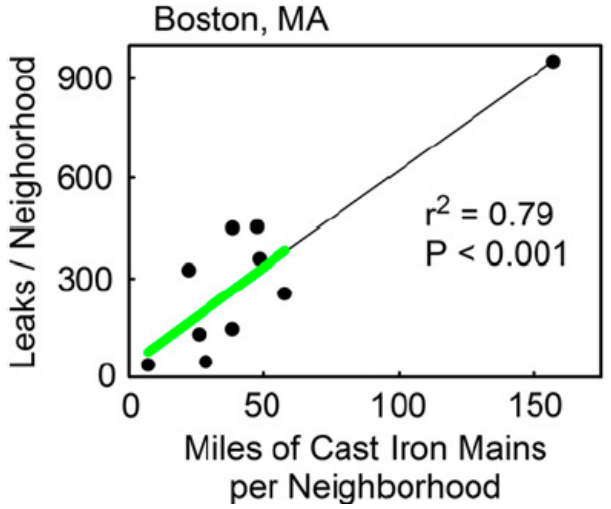
Example Hydrocarbon Leak



Source: Englander, Wang, Brandt, Jackson (2015)

Boston (~3,400 leaks; 800 road miles)
#1 predictor – miles cast iron pipes; P<0.001





Red = roads driven; Yellow = leaks

Phillips et al. 2013 Env Pollution

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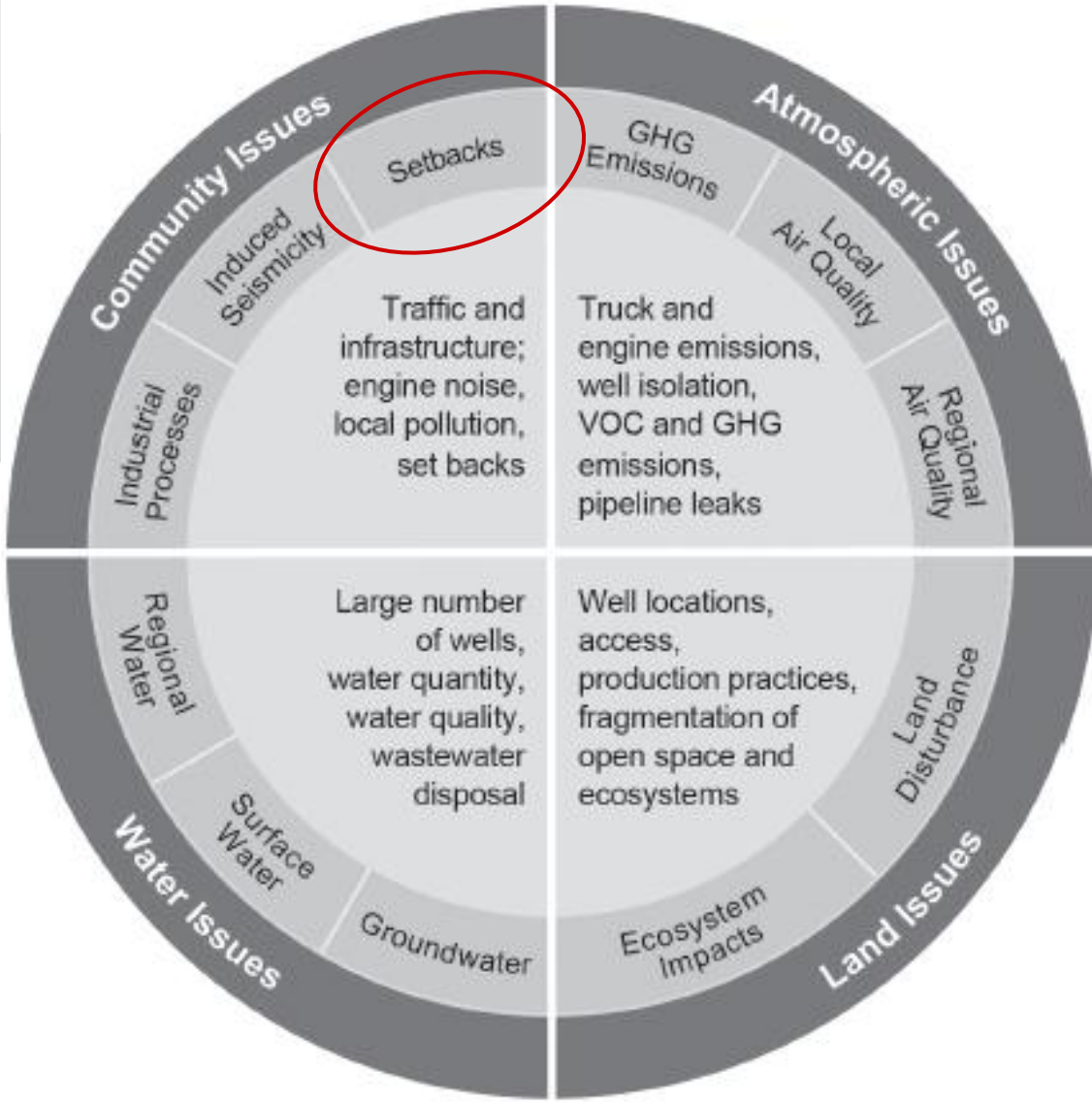

The Bridge (U.S. National Academy of Engineering), 2014

Shale Development Operations In Pennsylvania

February, 2012

Governor Corbett signs Marcellus Shale bill into law

Images

A A A A

Print Story

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Published: 2/13 7:18 pm

Updated: 2/13 7:20 pm

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Governor Tom Corbett Monday signed House Bill 1950, the Marcellus Shale bill, into law. The bill enhances protection of our natural resources through stronger environmental standards, authorizes counties to adopt an impact fee, and builds upon efforts to help move Pennsylvania toward energy independence.

Some of its changes:

1) Restrict drilling within 1000 ft of a public water supply.
2) Double the distance from 250 feet to 500 feet to separate a gas well from a private water well,
3) Extend a well operator's presumptive liability for pollution or water loss from 1,000 feet to 2,500 feet.

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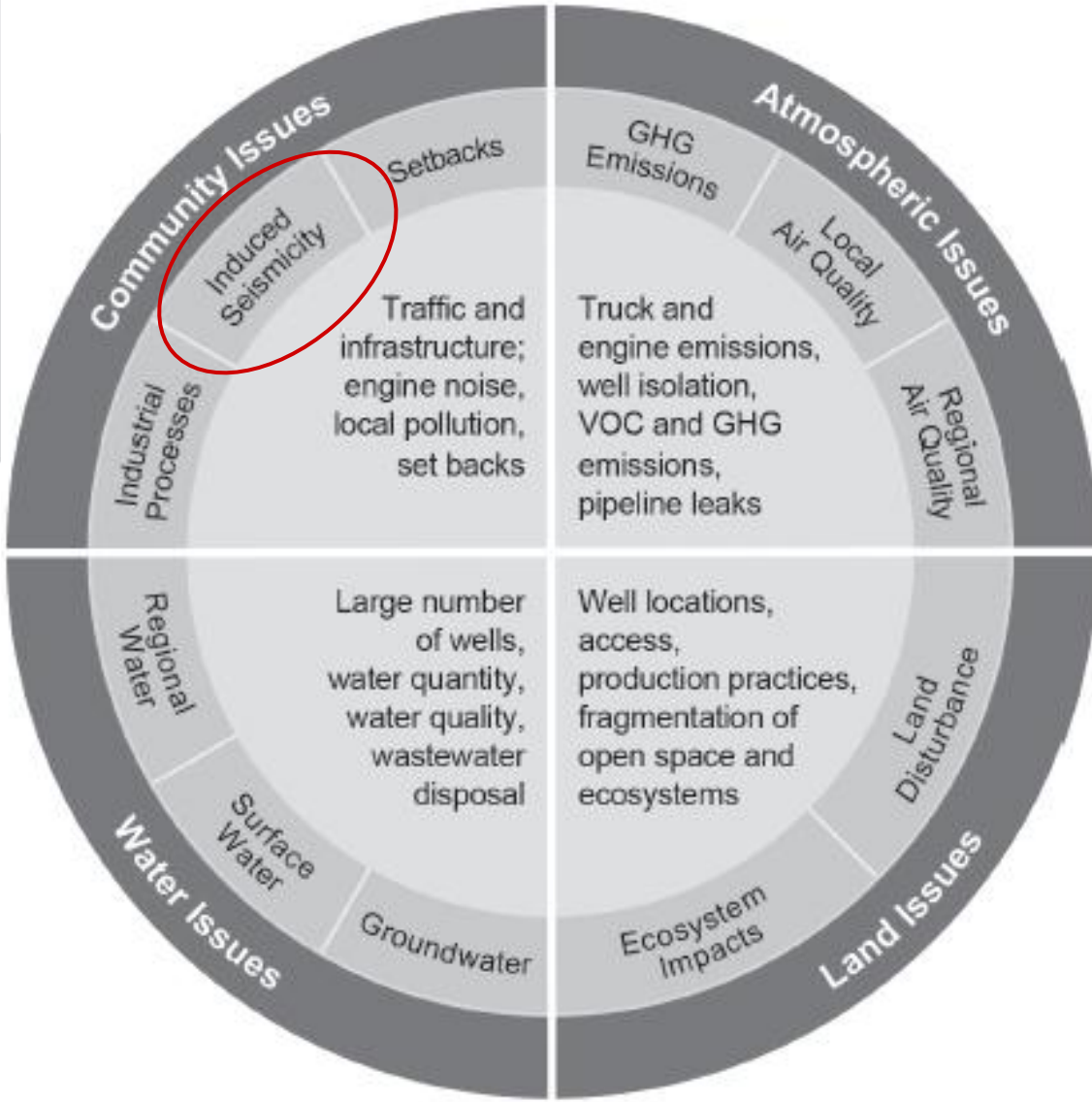
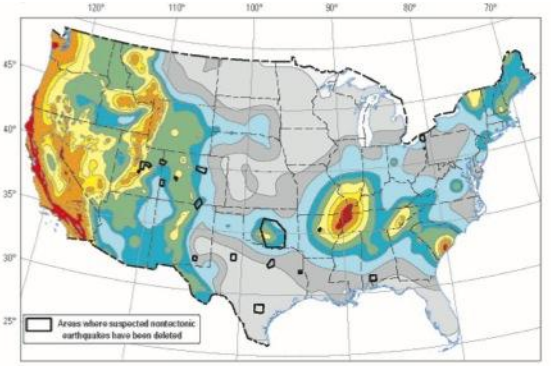
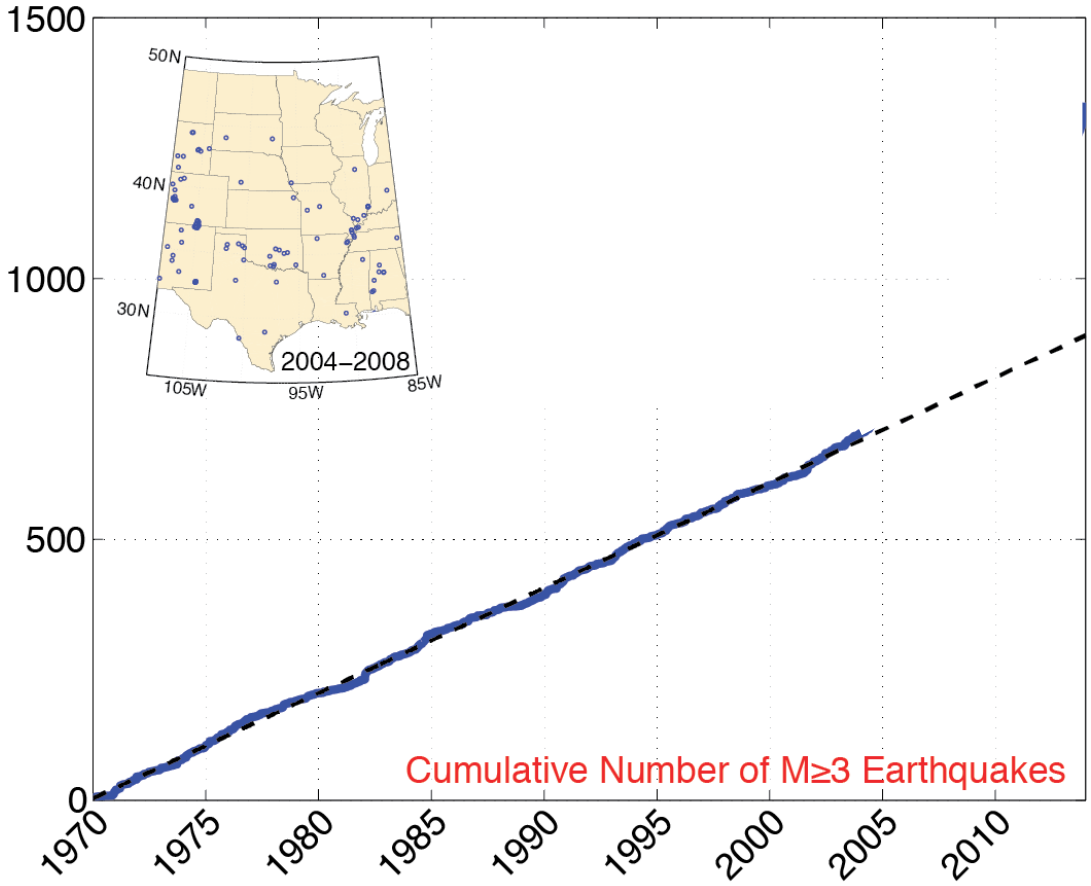


The Bridge (U.S. National Academy of Engineering), 2014

Earthquakes in the Mid-Continent





Ellsworth (2013)

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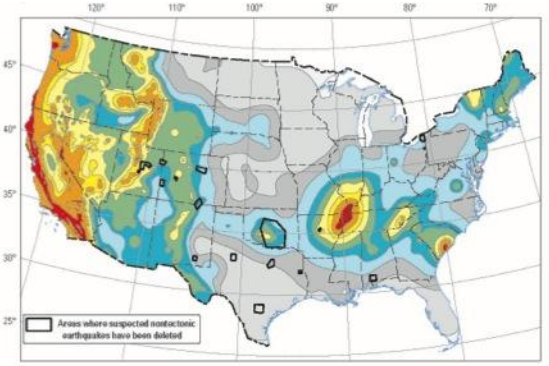
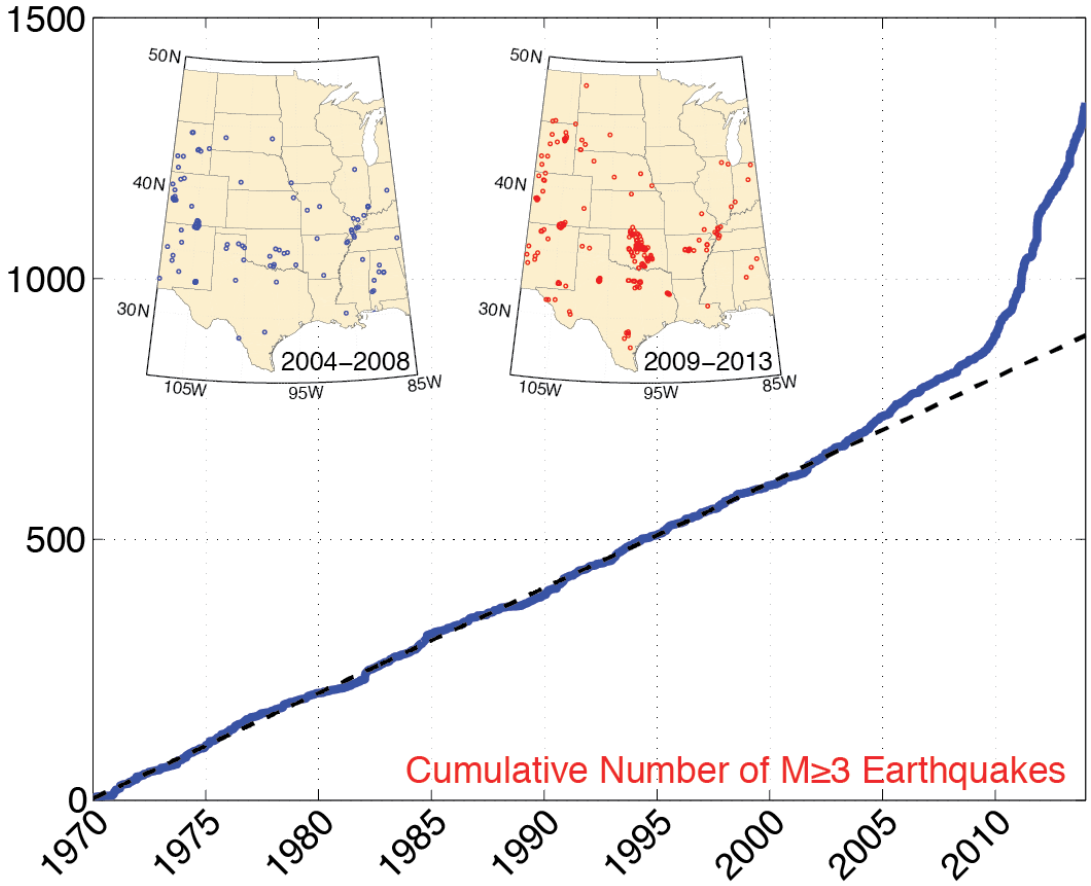
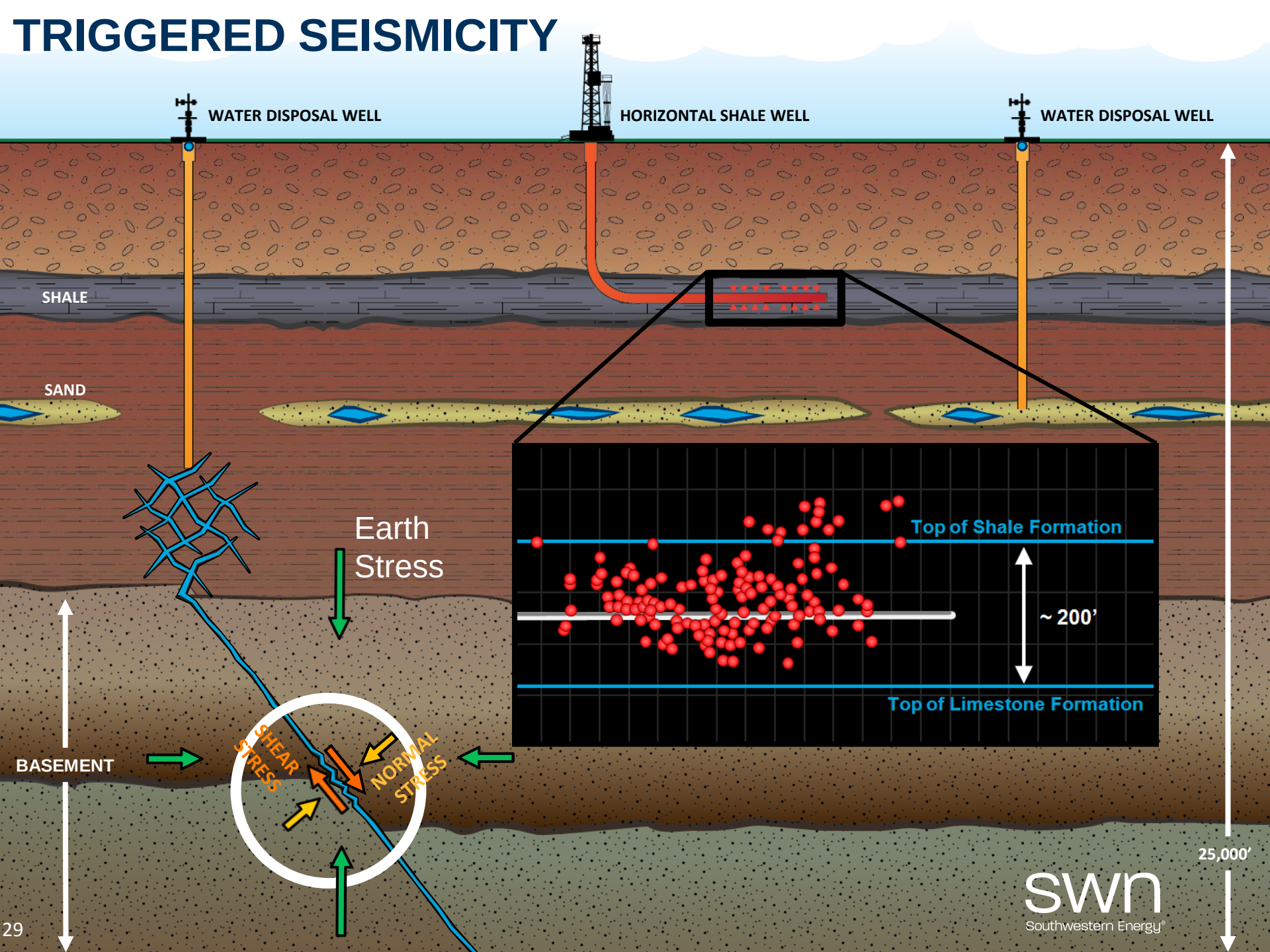




Ellsworth (2013)

TRIGGERED SEISMICITY



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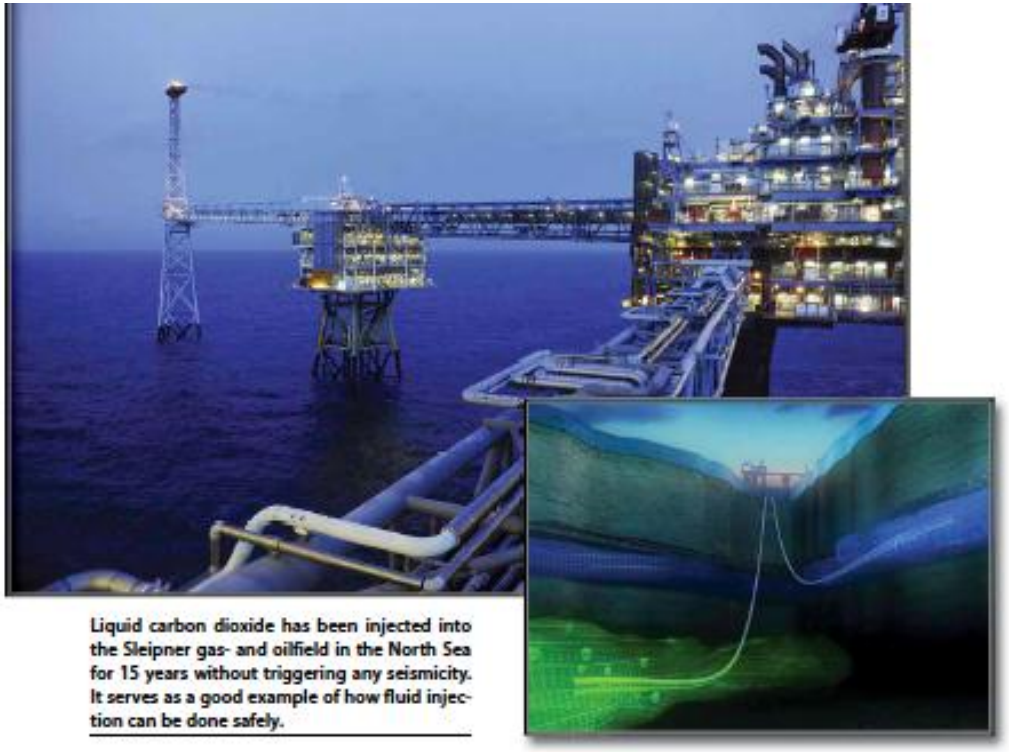


Liquid carbon dioxide has been injected into the Sleipner gas- and oilfield in the North Sea for 15 years without triggering any seismicity. It serves as a good example of how fluid injection can be done safely.

Managing the Seismic Risk Posed by Wastewater Disposal

Mark D. Zoback

From an earthquake perspective, 2011 was a remarkable year. While the devastation accompanying the magnitude-9.0 Tohoku earthquake that occurred off the coast of Japan on March 11 still captures attention worldwide, the relatively stable interior of the U.S. was struck by a somewhat surprising number of small-to-moderate earthquakes that were widely felt. Most of these were natural events, the types of earthquakes that occur from time to time in all intraplate regions. For example, the magnitude 5.8 that occurred in central Virginia on Aug. 23 was felt throughout the northeast, damaged the Washington Monument, and caused the temporary shutdown of a nuclear power plant. This earthquake occurred in the Central Virginia Seismic Zone, an area known to produce relatively frequent small earthquakes.

However, a number of the small-to-moderate earthquakes that occurred in the U.S. interior in 2011 appear to be associated with the disposal of wastewater, at least in part related to natural gas production. Several small earthquakes were apparently caused by injection of wastewater associated with shale gas production near Guy, Ark.; the largest earthquake was a magnitude-4.7 event on Feb. 27. In the Trinidad/Raton area near the border of Colorado and New Mexico, injection of wastewater associated with coalbed methane production seems to be associated with a magnitude-5.3 event that occurred on Aug. 22, and small earthquakes that appear to have been triggered by

Ruth Shahal

EARTH April, 2012

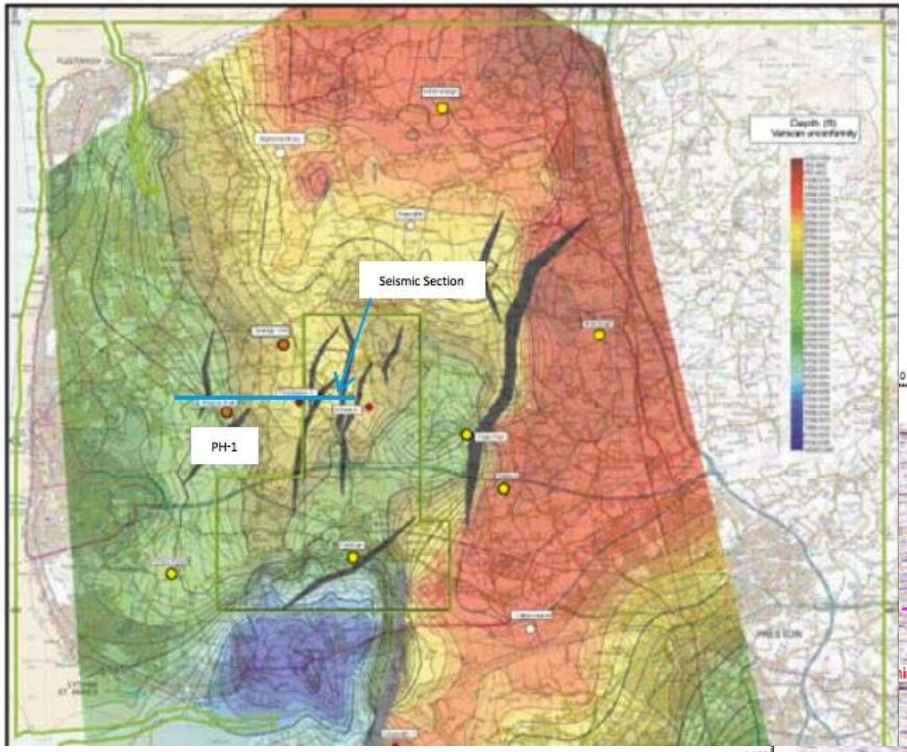
I. Be Proactive

Characterizing and Responding to Seismic Risk Associated with Earthquakes Potentially Triggered by Fluid Disposal and Hydraulic Fracturing

by Randi Jean Walters, Mark D. Zoback, Jack W. Baker, and Gregory C. Beroza

Seismological Research Letters, 2015

II. Avoid Injection Near Potentially Active Faults



M 2.3 Earthquake During HF in Bowland Basin

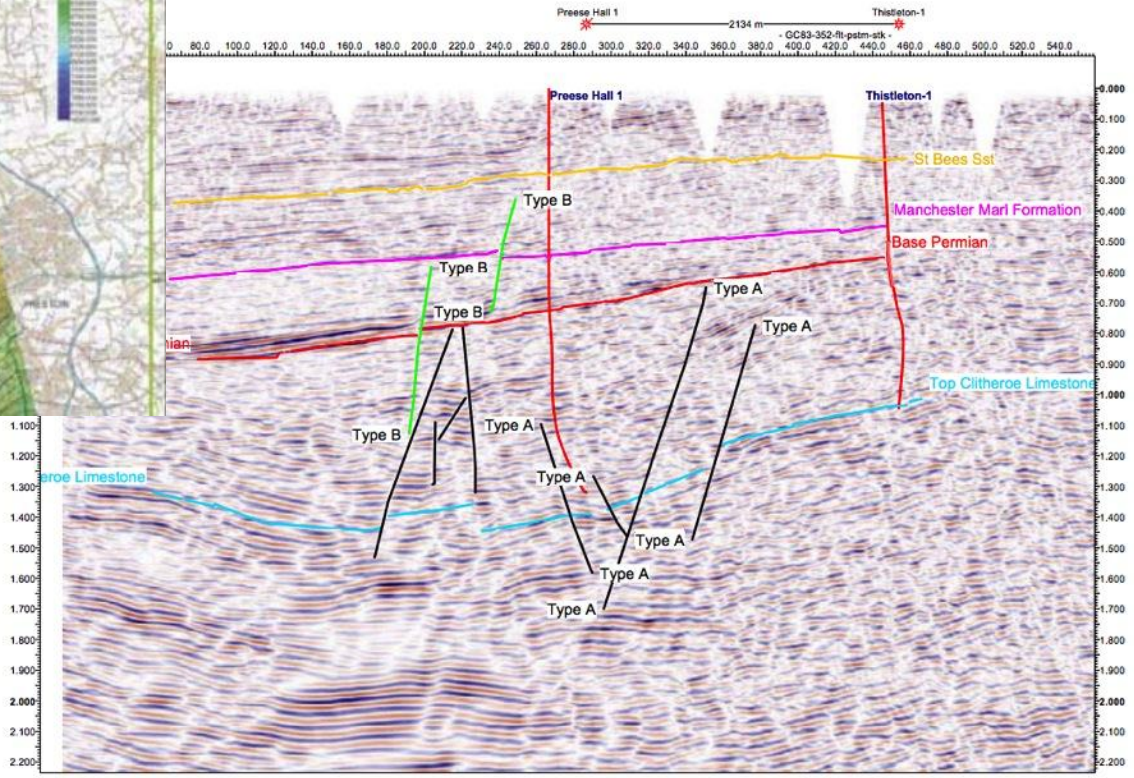
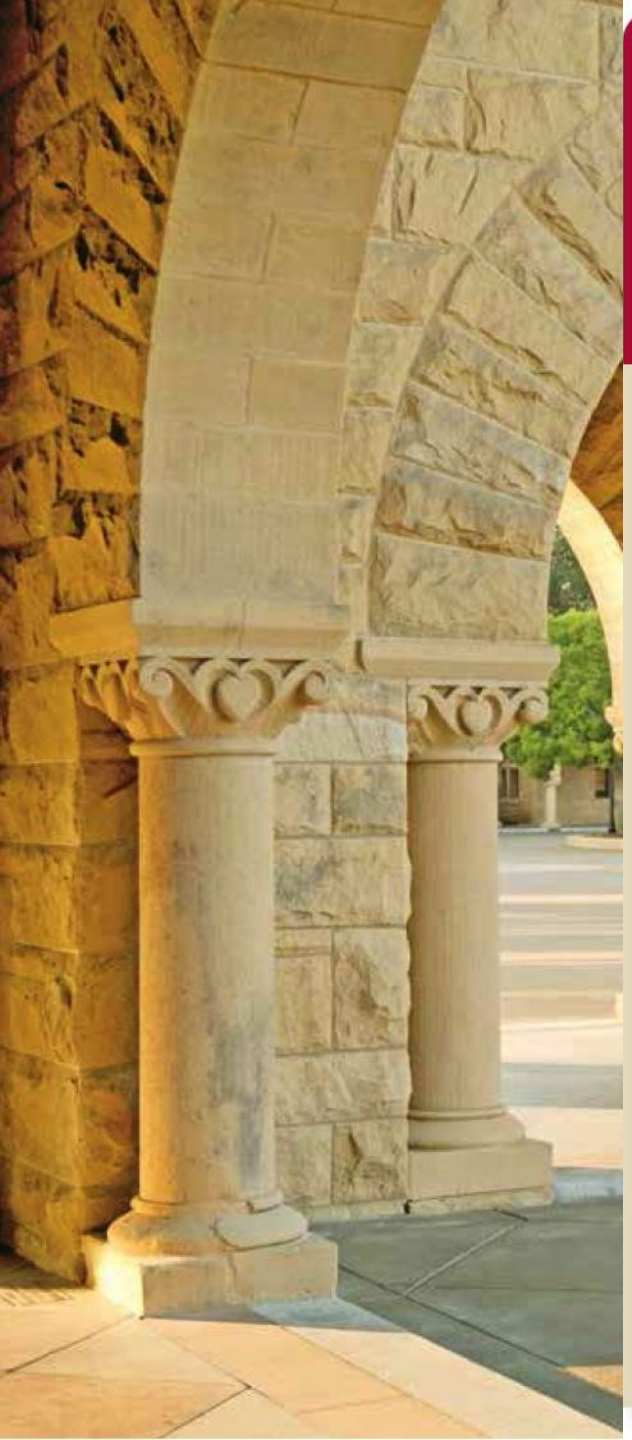


Figure 8: Reprocessed seismic section showing the two fault types, A and B in the proximity of Preese Hall-1 and Thistleton-1. The seismicity was caused by a type A fault that is contained in the Carboniferous.

III. Consider Water Recycling As in Pennsylvania



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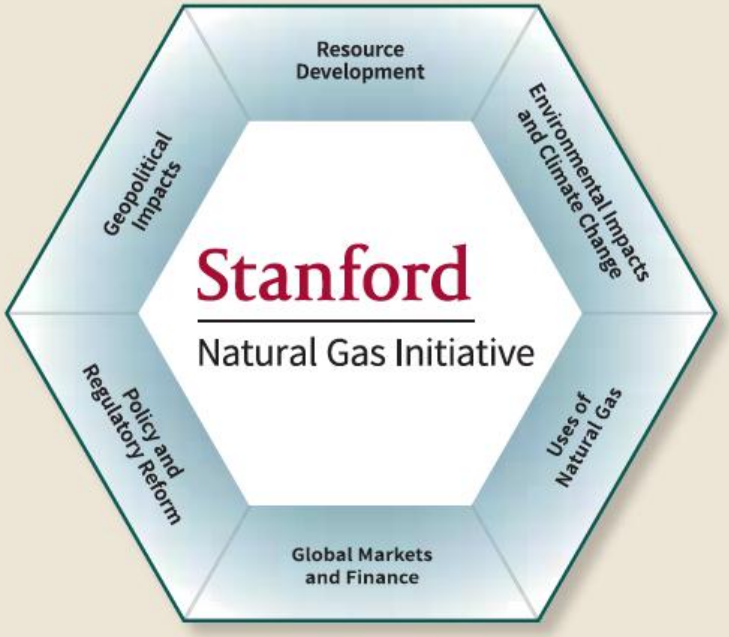

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Thank you