Workshop on Risks of Unconventional Shale Gas Development

National Research Council

Discussant Presentation

May 30, 2013

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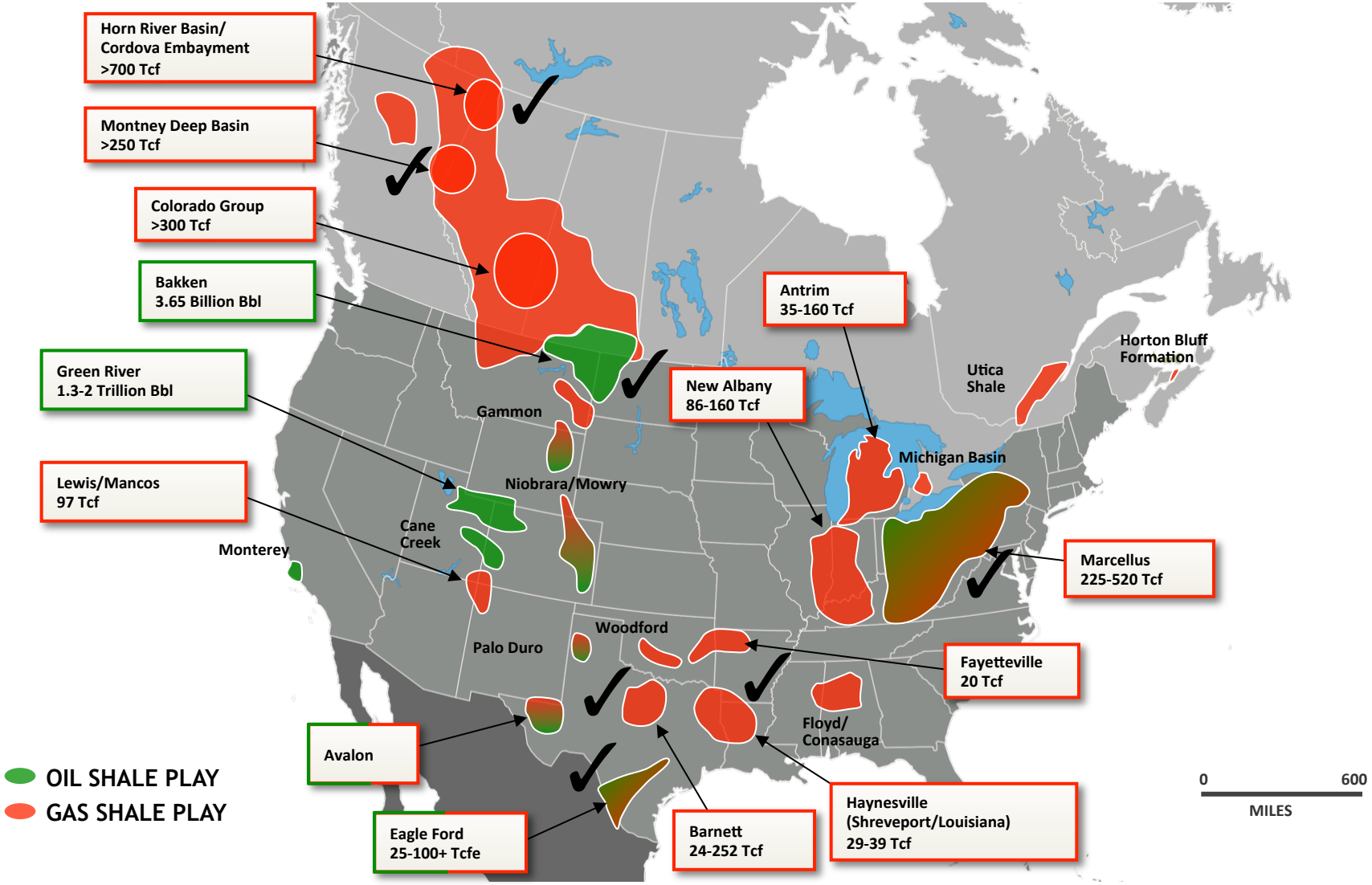
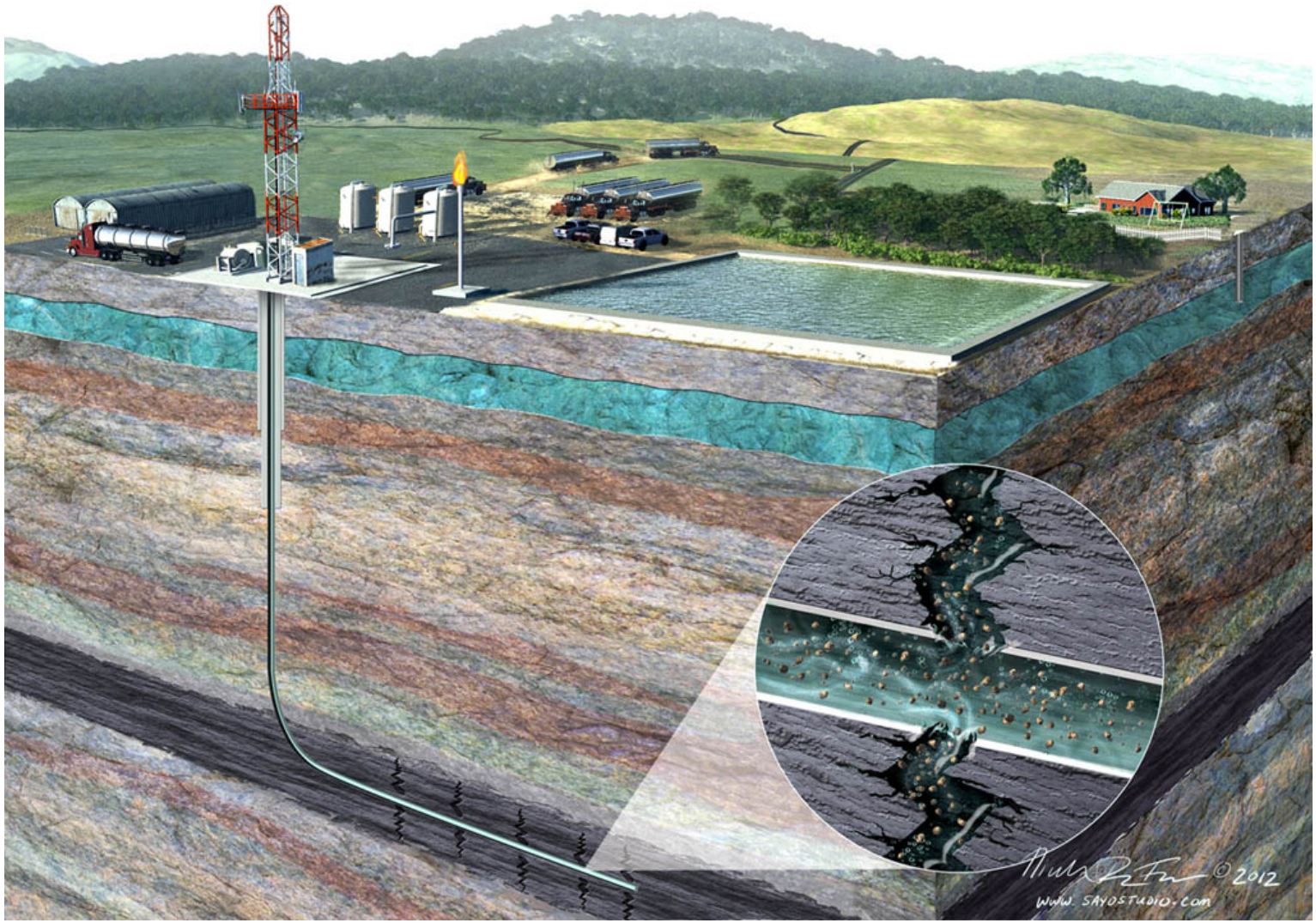
Professor of Geophysics

STANFORD UNIVERSITY

Shale Gas Research Projects



Minimizing the Environmental Impact of Shale Gas Development



Topics

- A Brief Update on SEAB Recommendations
- Managing Induced and Triggered Seismicity
- A Few Words About Methane Leakage

Secretary of Energy Advisory Board

Shale Gas Production Subcommittee 90-Day Report

August 18, 2011

U.S. DEPARTMENT OF ENERGY

Secretary of Energy Advisory Board

Shale Gas Production Subcommittee Second Ninety Day Report

November 18, 2011

U.S. DEPARTMENT OF ENERGY

DOE Shale Gas Subcommittee

- John Deutch – MIT
- Stephen Holditch – Texas A&M
- Fred Krupp – Environmental Defense Fund
- Katie McGinty – Pennsylvania DEP
- Sue Tierney – Massachusetts Energy
- Dan Yergin – Cambridge Energy Research
- Mark Zoback - Stanford

Report Summary

Shale gas can be developed in an environmentally responsible manner

but…..

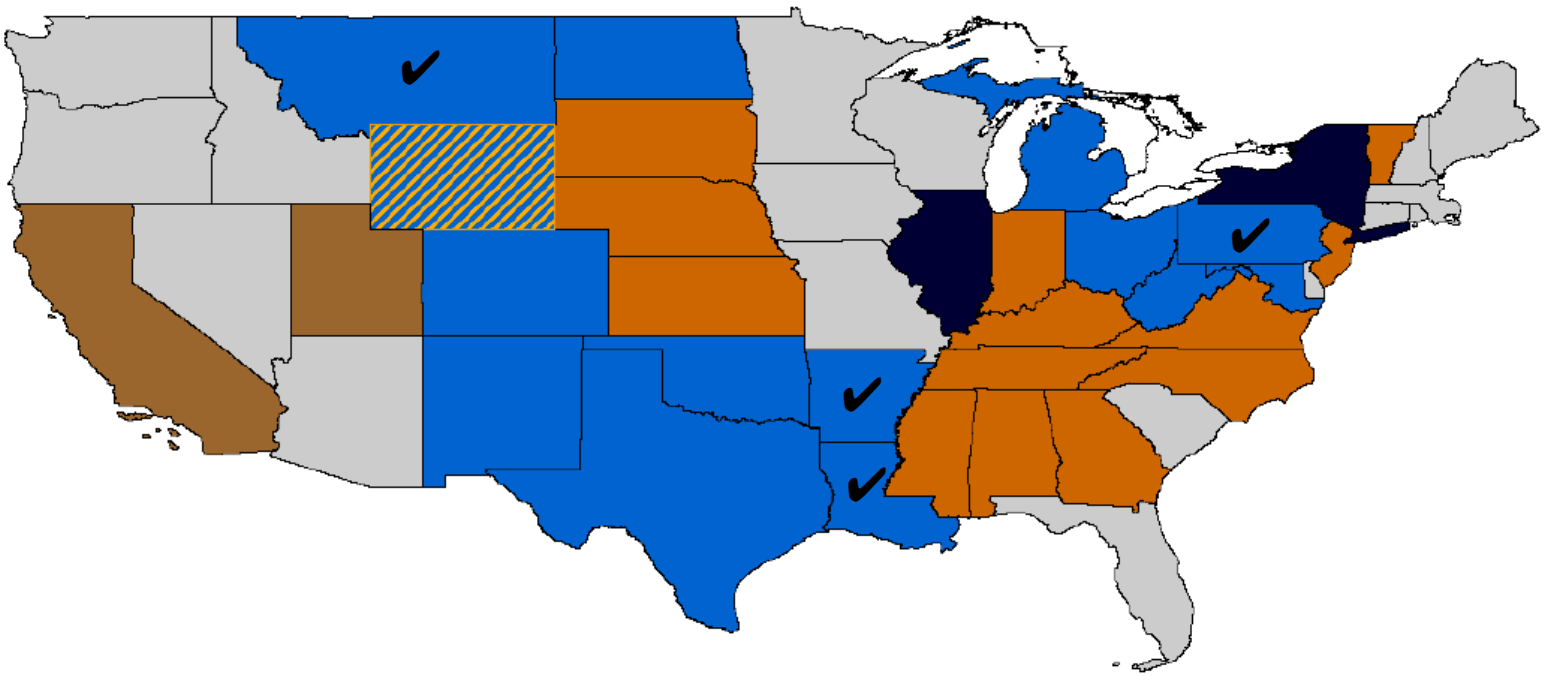
The SEAB Subcommittee Made 20 Recommendations About How to Develop Shale Gas Resources in a More Environmentally Responsible Manner

Four SEAB Recommendations

- Full Disclosure of the Composition of Drilling/Hydraulic Fracturing/Flow Back Fluids
- Full Manifesting of Drilling Fluids/Frac Fluids
- Creation of Regional Centers to Address Issues Such as Finding Optimal Ways to Minimize the Cumulative Impacts of Shale Gas Development
- Sustained Research Support for Continual Improvement of Resource Recovery and Environmental Protection

Full Disclosure of Frac Fluids?

Last updated July 9, 2012



* Require volume disclosure: MD, MI, NM, OH, OK. Concentration disclosure: WY. Volume and concentration: AR, LA, MT, PA

Resources for the Future, Managing the Risks of Shale Gas: Identifying a Pathway Toward Responsible Development A Review of Shale Gas Regulations by State (2012)

Four SEAB Recommendations

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- Formerly Institute for Gas Drilling Excellence
- Achieved agreement on proactive action from operators, NGOs
- ~15 high-level performance-based standards for Pennsylvania (& Marcellus)
- Company-level certification
- Establishment of regional centers

Four SEAB Recommendations

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?

Topics

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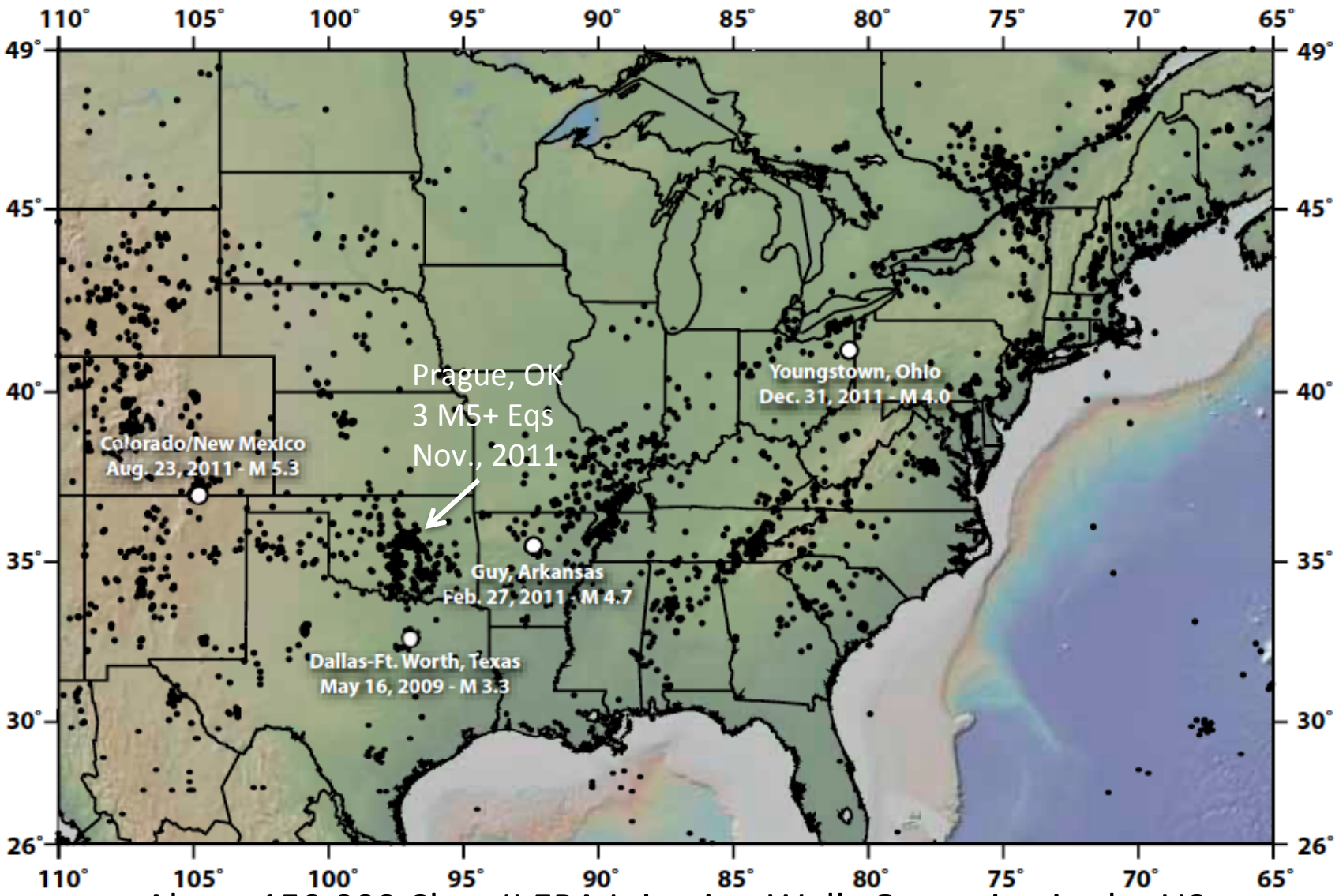
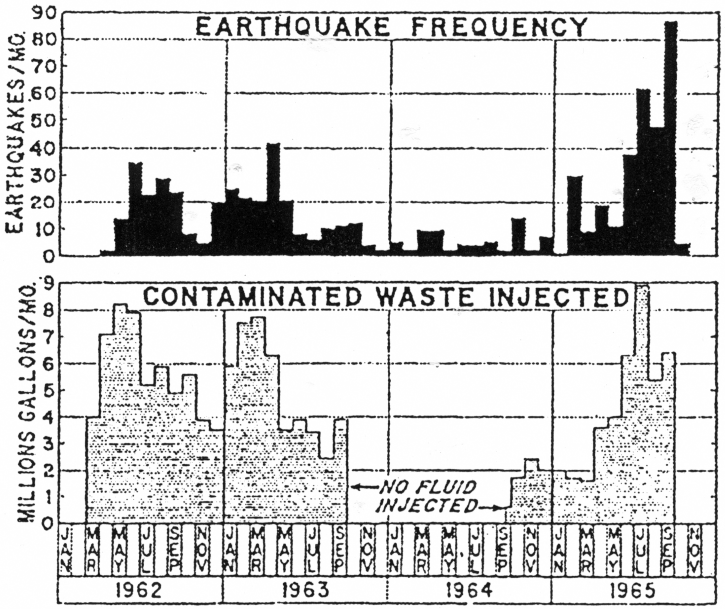
A Context for Triggered Seismicity



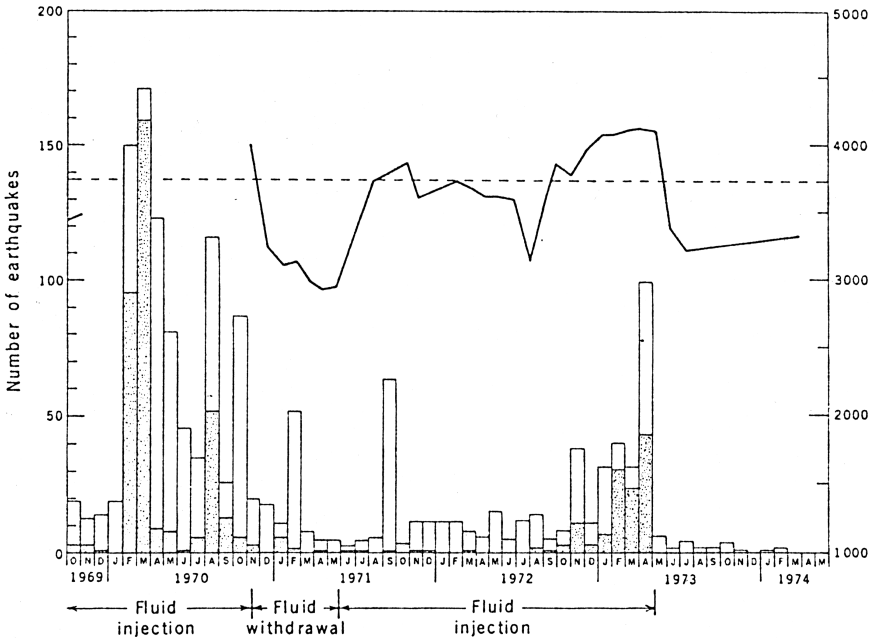
About 150,000 Class II EPA Injection Wells Operating in the US

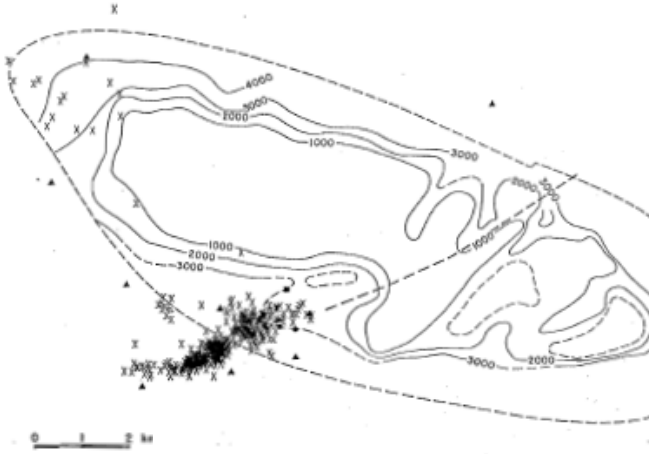
Why the Increase in Seismicity?

Waste Injection
Denver Arsenal

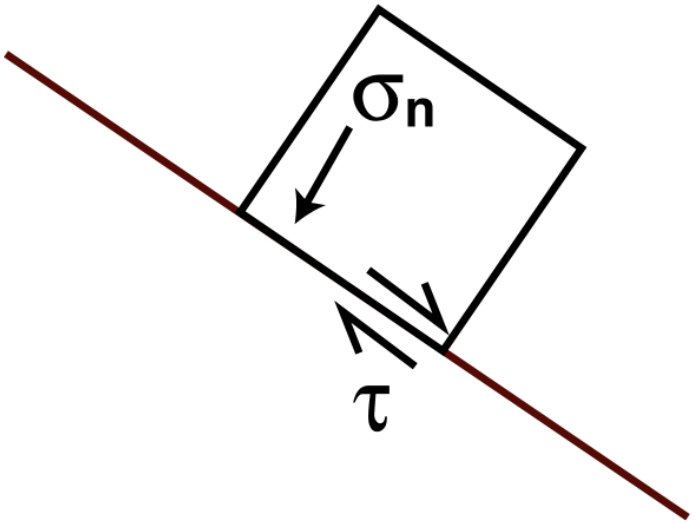


Fluid Injection
Rangely Oil Field





How Fluid Pressure Affects Frictional Sliding



Sliding occurs when
Amonton's Law is satisfied:

$$\frac{\tau}{\sigma_n} = \mu$$

Coefficient of Friction
(sliding friction)

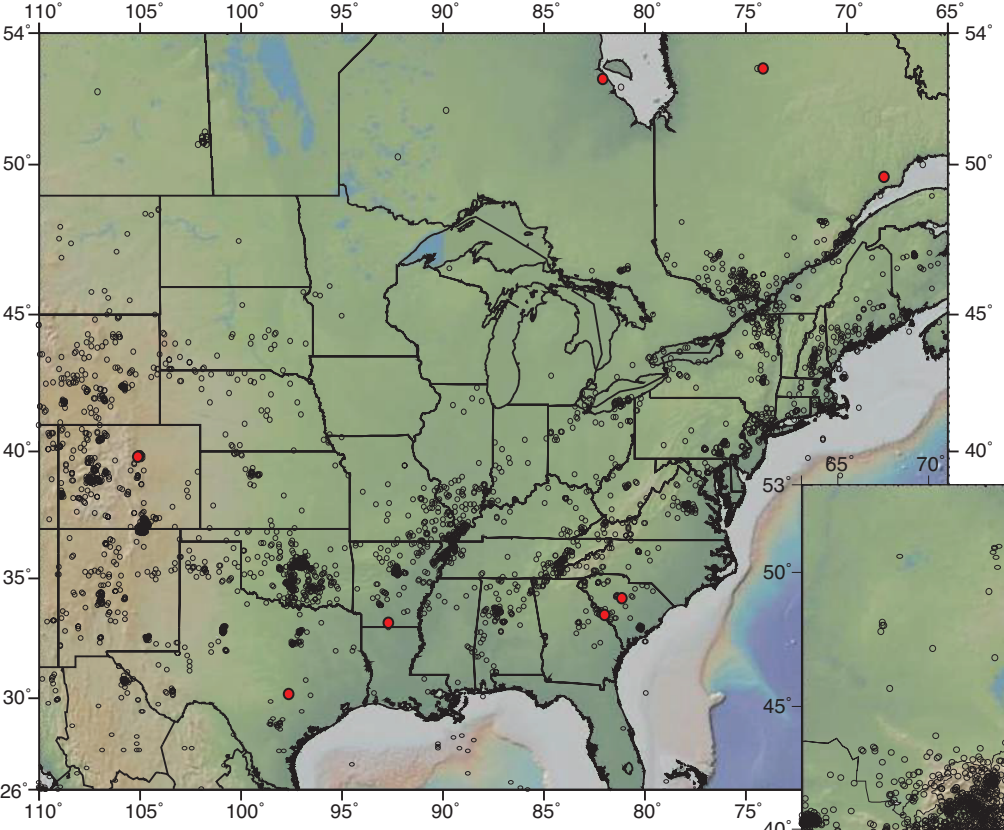
Effective Normal Stress:

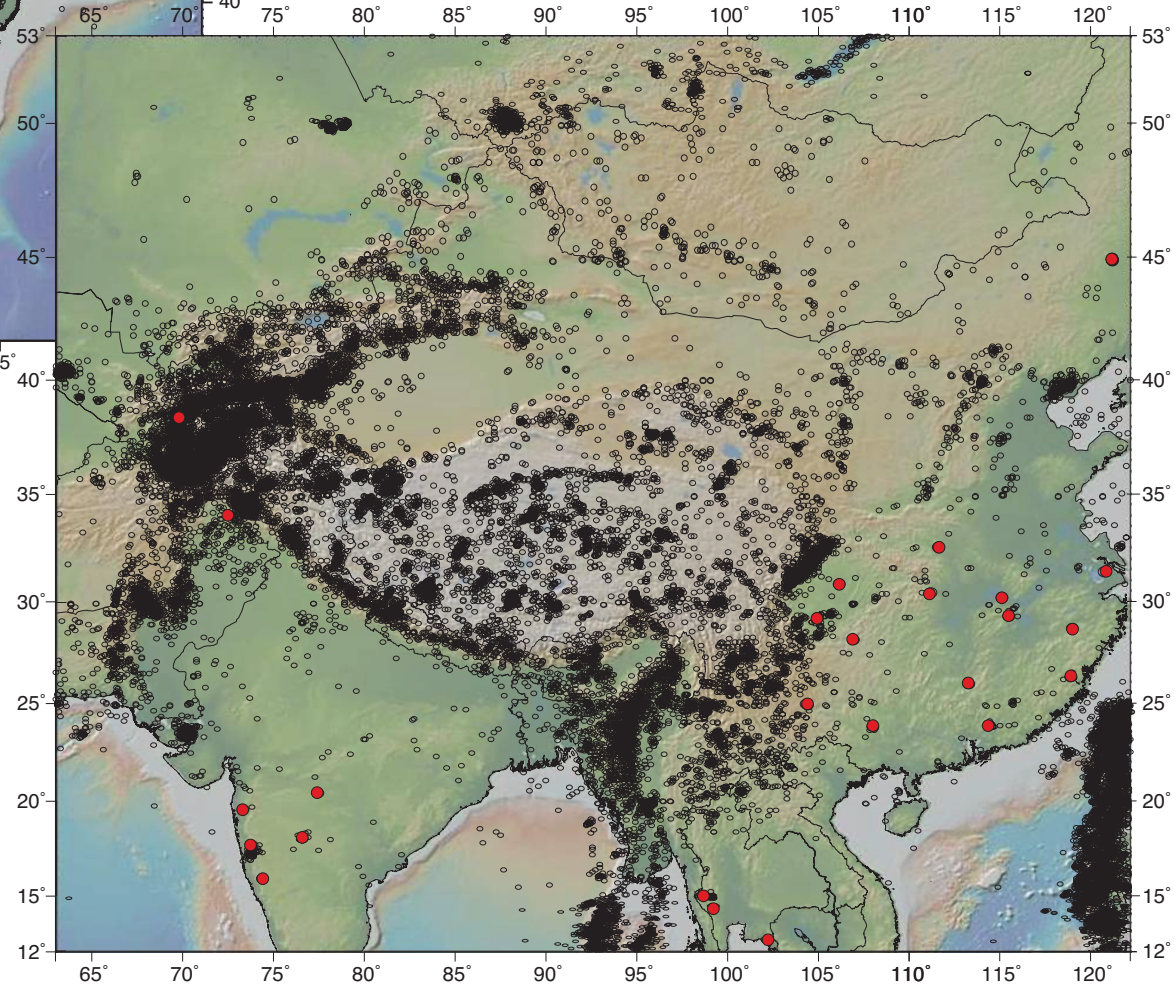
$$\sigma_n = S_n - P_p$$

Is Fault Movement In Response to Pressurization Important to be Concerned About?

Yes

A Critically-Stressed Crust



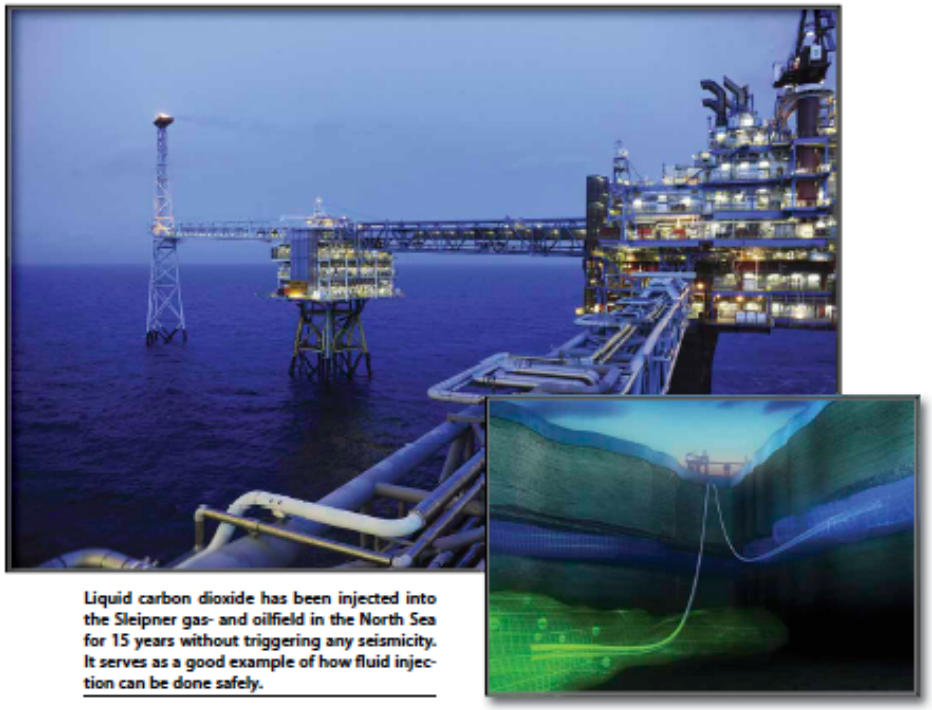


- Earthquakes Occur Nearly Everywhere in Intraplate Areas

- Small Perturbations Capable of Triggering Seismicity, Even in “Stable Areas”

- Rate of Earthquakes Reflect Intraplate Strain Rate, Not Stress State

Managing Triggered Seismicity



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.

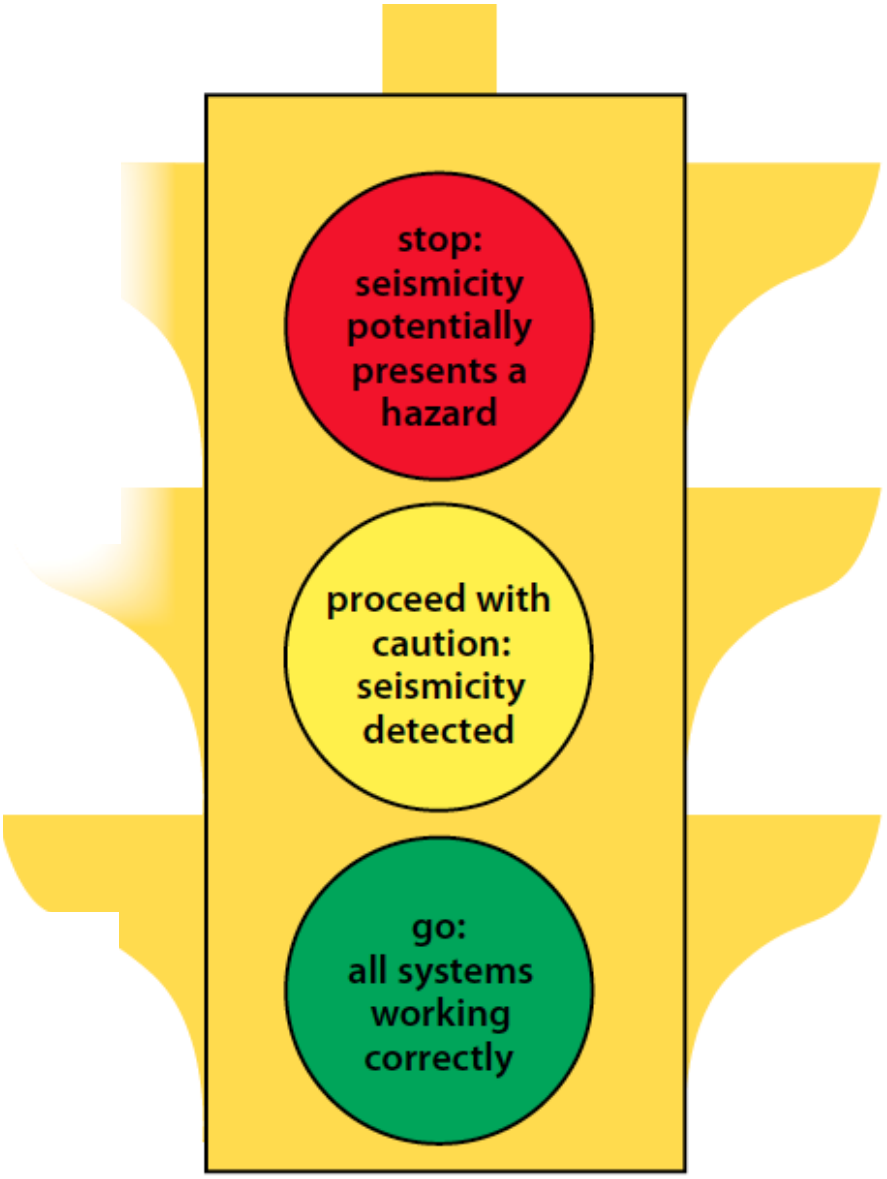
Managing the Seismic Risk Posed by Wastewater Disposal

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.

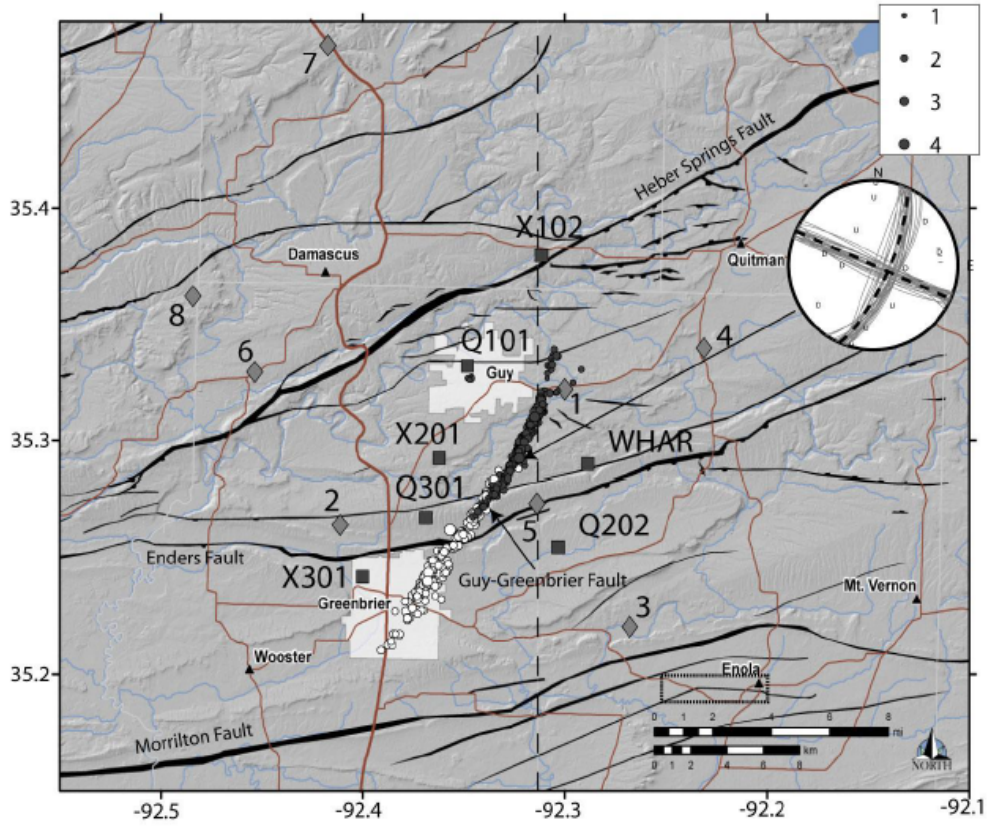
However, a number of the small-to-moderate earthquakes that occurred in the U.S. interior in 2011 appear to be associated with the disposal of wastewater, at least in part related to natural gas production. Several small earthquakes were apparently caused by injection of wastewater associated with shale 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 Stanoll



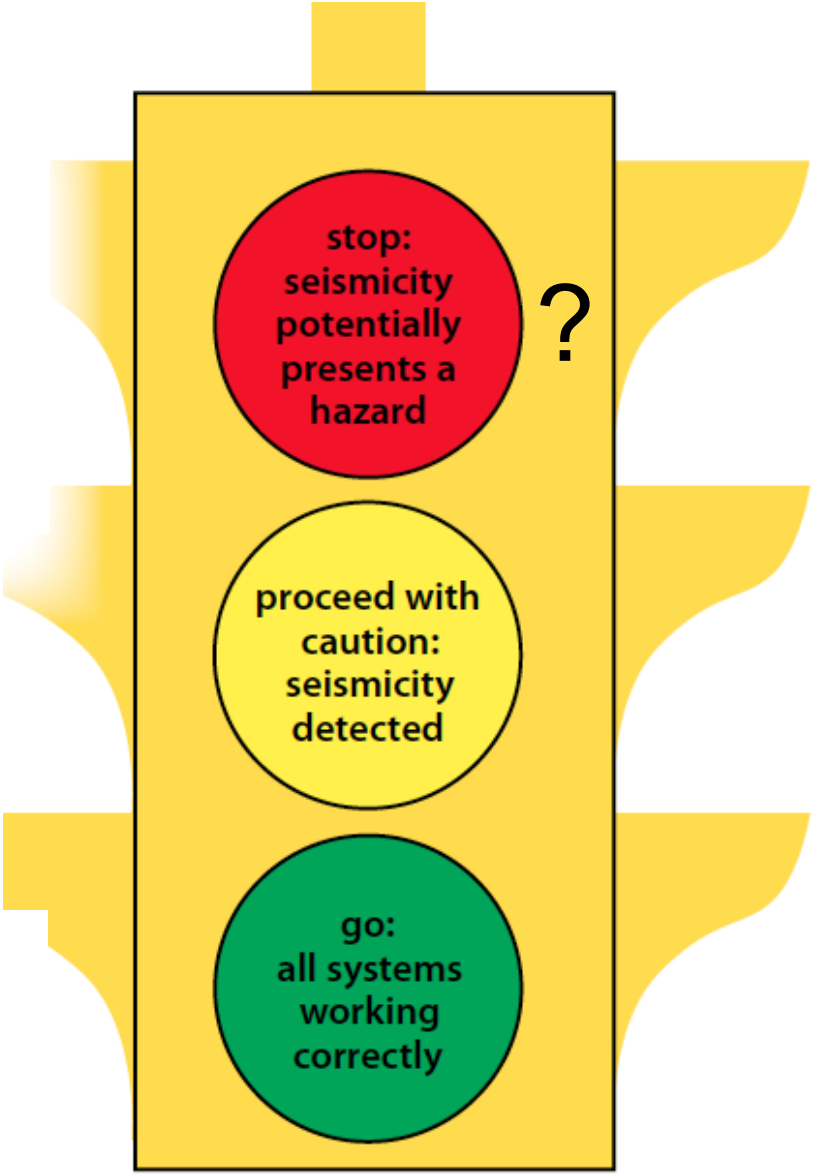
EARTH April, 2012

Seismicity Triggered by Injection

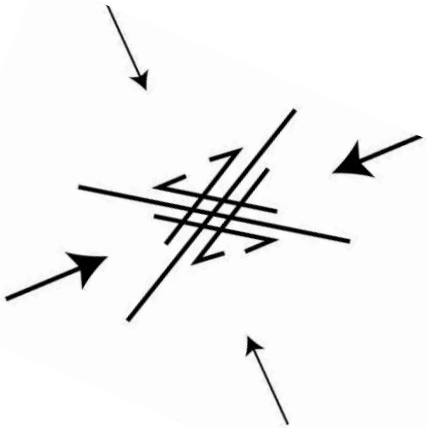


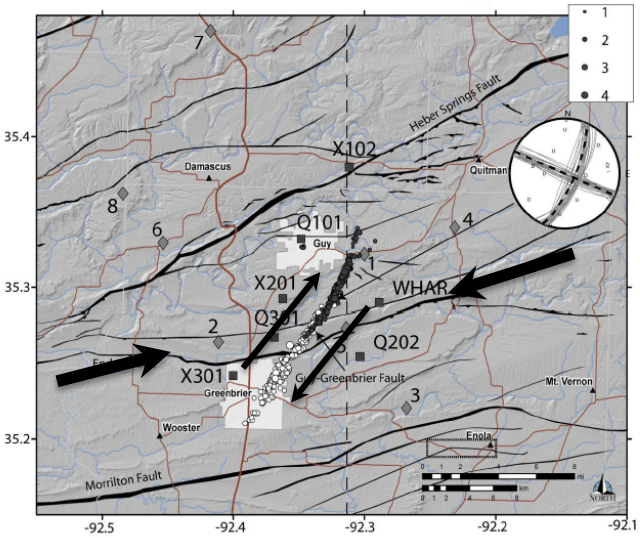
Horton (2012)

Guy Arkansas
Earthquake Swarm

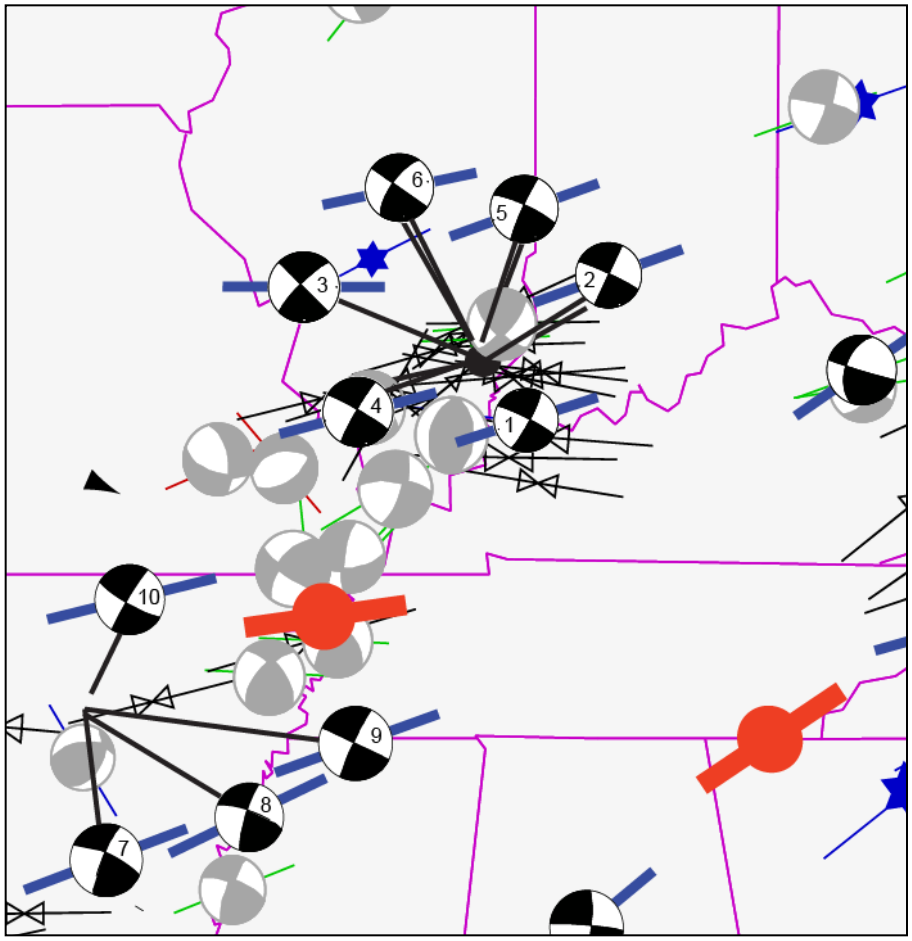


Earthquakes Spreading Out Along an Active Fault



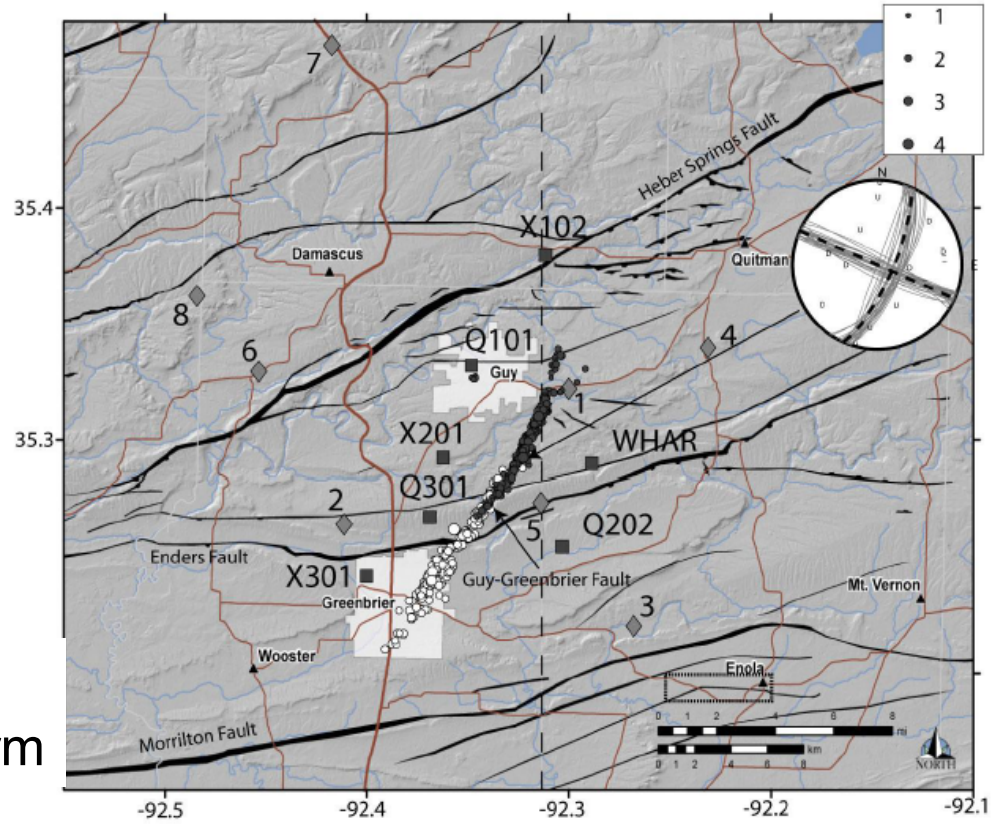


Horton (2012)



Hurd and Zoback (2012)

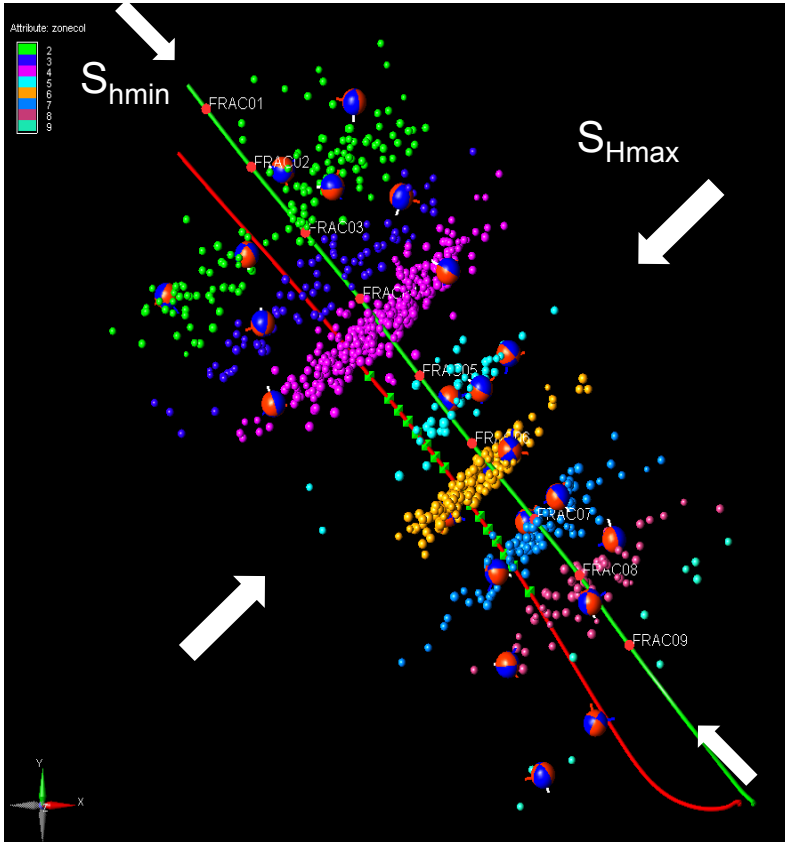
Seismicity Triggered by Injection



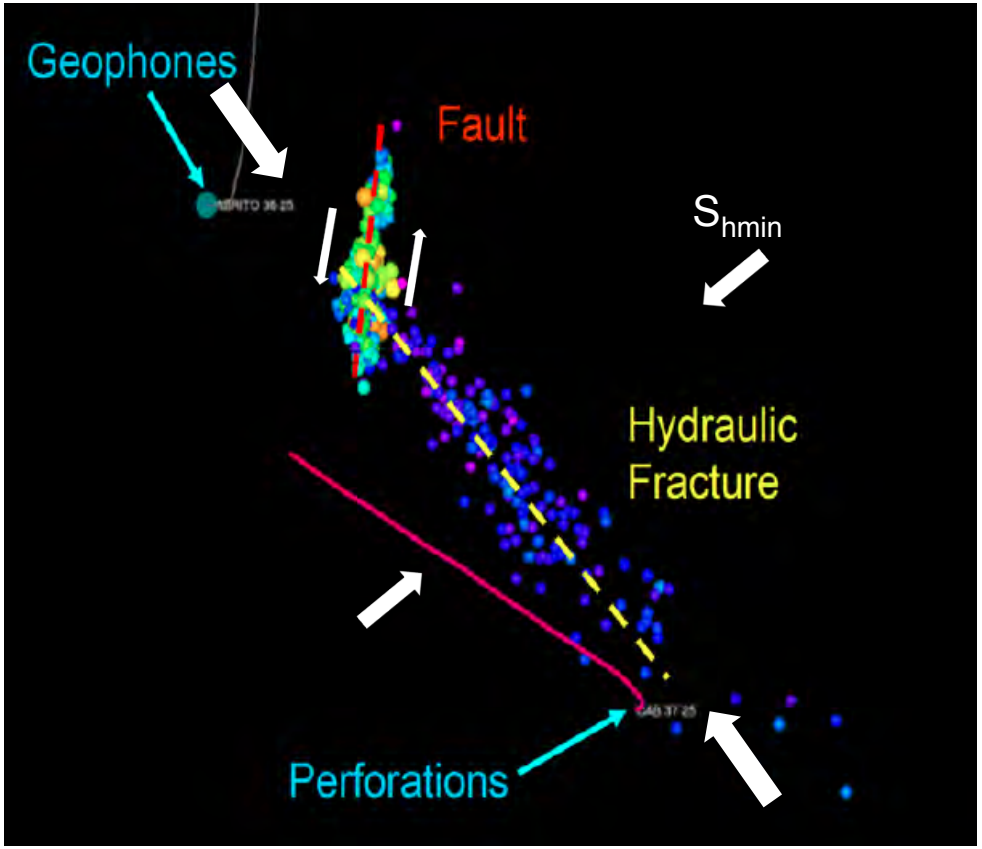
Guy Arkansas Earthquake Swarm

- Avoid Injection into Potentially Active Faults
- Limit Injection Rates (Pressure) Increases
- Monitor Seismicity (As Appropriate)
- Assess Risk
- Be Prepared to Abandon Some Injection Wells

Seismicity Triggered During HF



Moos, D. et al. SPE 145849 (2011)



Maxwell, S.C., J. Shemeta, E. Campbell and D. Quirk, SPE 116596 (2008).

Induced Seismicity Potential in Energy Technologies

NATIONAL RESEARCH COUNCIL
OF THE NATIONAL ACADEMIES

THE NATIONAL ACADEMIES PRESS
Washington, D.C.
www.nap.edu

Risk Associated with Injection and Triggered Seismicity

Microseismic Events Associated with Hydraulic Fracturing

- Very Low Risk to Public
  - Limited rock volume, limited pumping volume/time
  - Very few events > M 2 in ~1 million frac stages

Seismic Events Associated with Wastewater Injection

- Low Risk to Public
  - Much Larger Pumping Volumes
  - Can be Effectively Managed by Effective Site Characterization, Monitoring and Proactive Planning
  - Minimize Injection by Water Recycling

Potential of Triggered Seismicity with Large Scale CCS

- Injection of extremely large volumes pose considerable risk of triggering “larger” earthquakes

Shale gas extraction in the UK: a review of hydraulic fracturing

June 2012

THE ROYAL SOCIETY

ROYAL ACADEMY OF ENGINEERING

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JISEA Joint Institute for Strategic Energy Analysis

Natural Gas and the Transformation of the U.S. Energy Sector: Electricity

Jeffrey Logan, Garvin Heath, Jordan Macknick

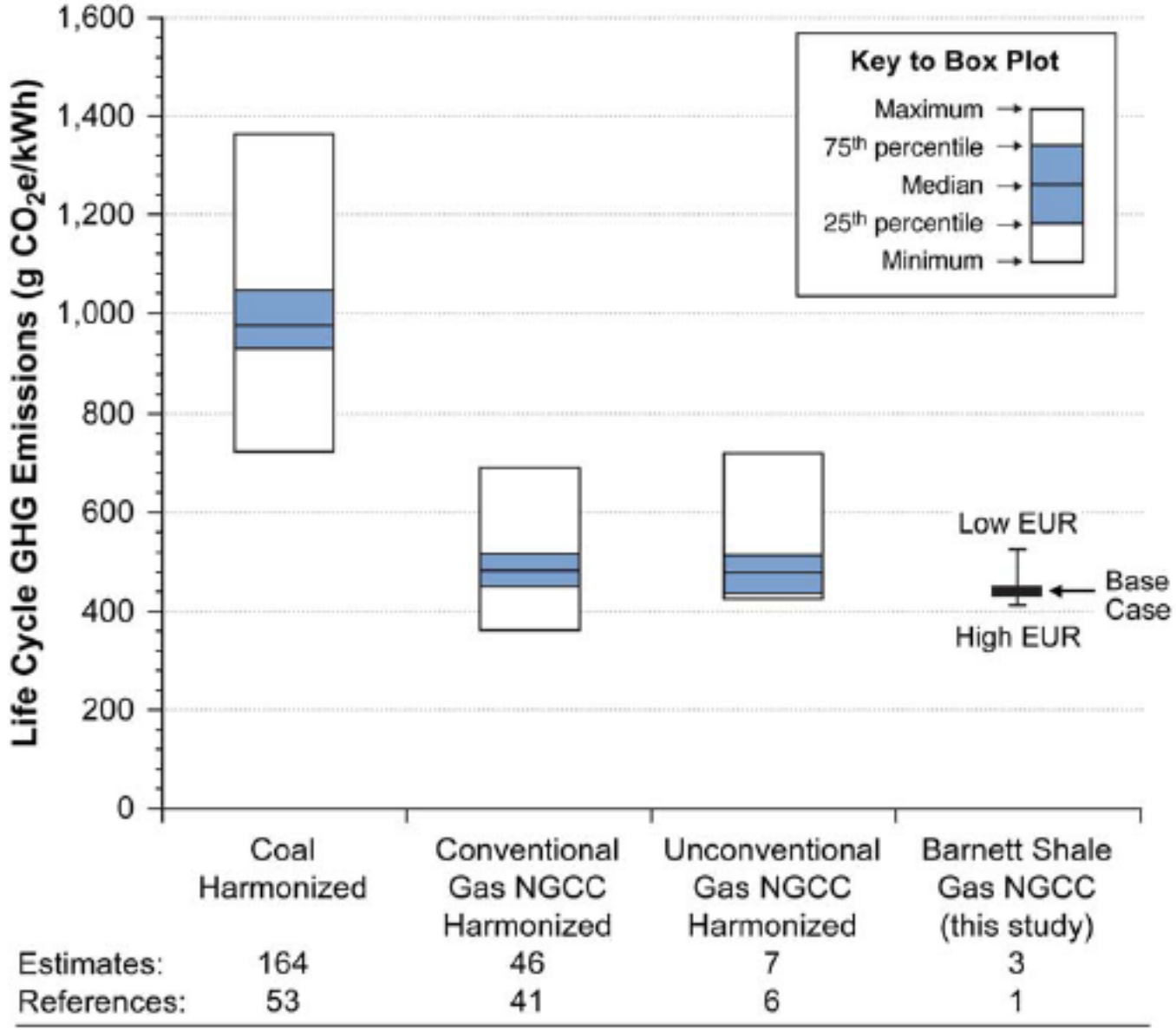
National Renewable Energy Laboratory

Elizabeth Paranhos, William Boyd

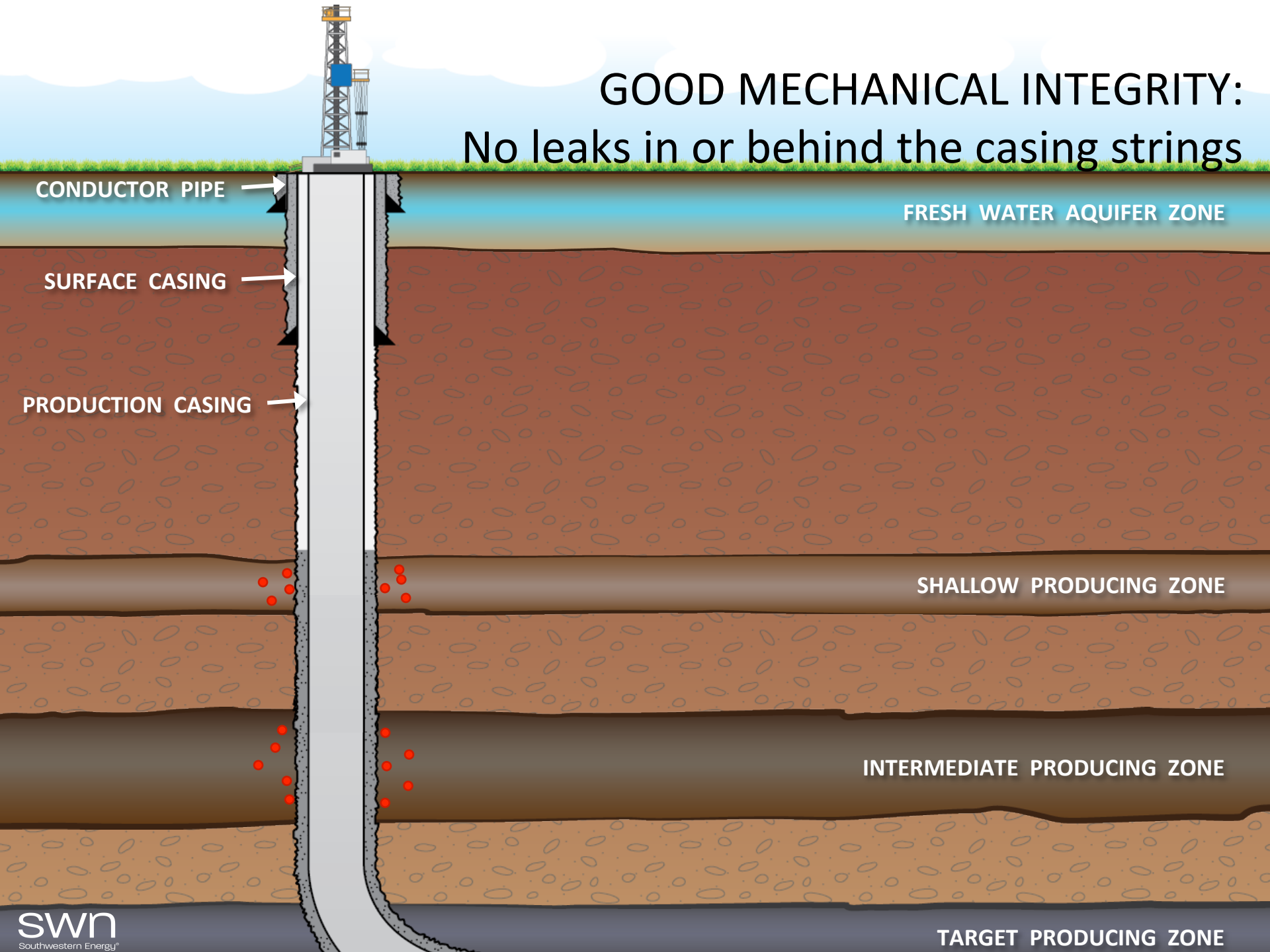
University of Colorado Law School

Ken Carlson

Colorado State University

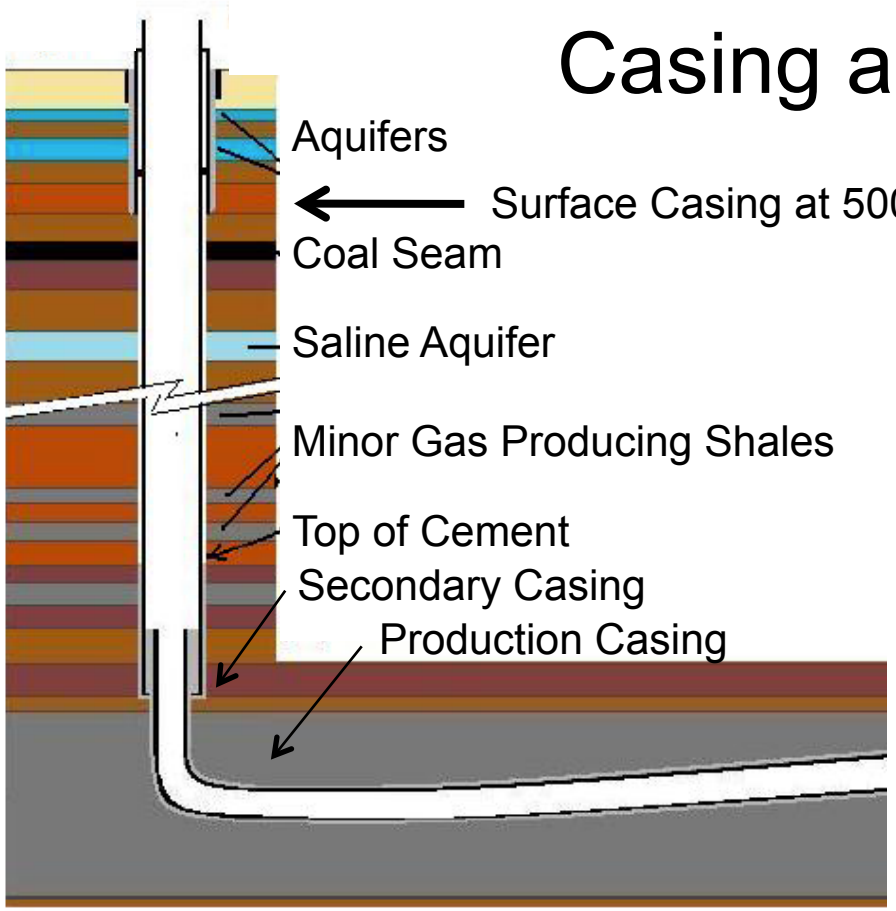

Life Cycle GHG Emissions (g CO_2e/kWh)
1,600
1,400
1,200
1,000
800
600
400
200
0
Key to Box Plot
Maximum
75th percentile
Median
25th percentile
Minimum
Low EUR
Base Case
High EUR
Coal Harmonized
Conventional Gas NGCC Harmonized
Unconventional Gas NGCC Harmonized
Barnett Shale Gas NGCC (this study)
Estimates: 164 46 7 3
References: 53 41 6 1

GOOD MECHANICAL INTEGRITY:
No leaks in or behind the casing strings



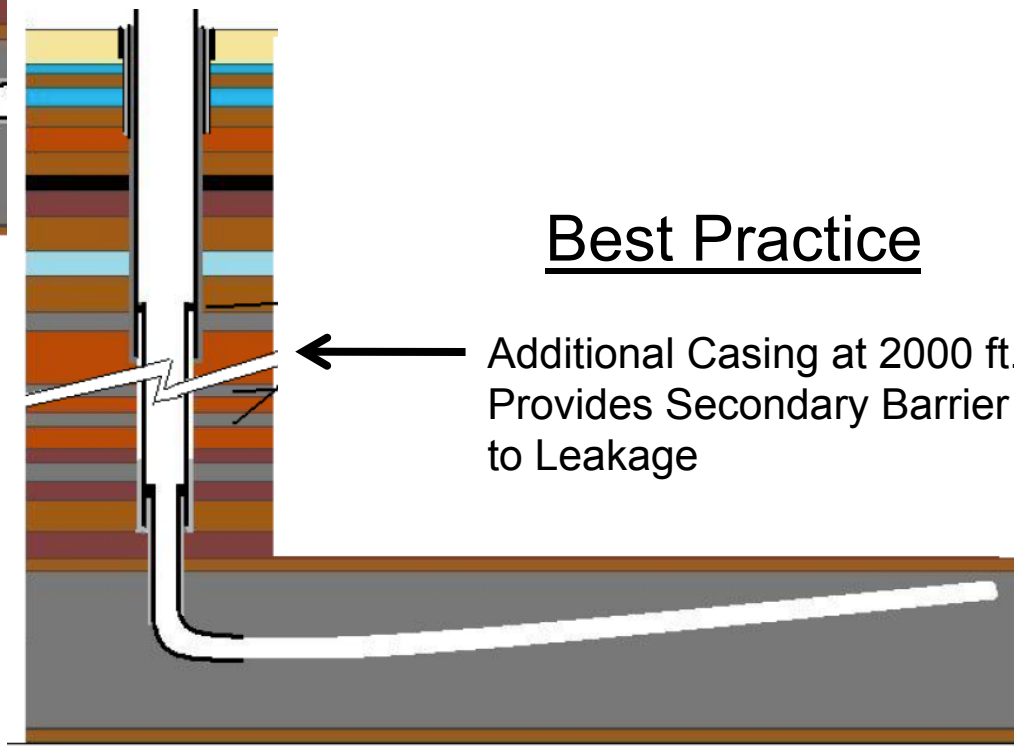
swn
Southwestern Energy®

Casing and Cementing Critical



API Recommended Practice

Best Practice



George King, SPE 152596 (2012)

Range Resources
Washington County, Pennsylvania

A Personal Perspective

- Shale Gas/Tight Oil Can be Developed in an Environmentally Responsible Manner
- There are Important Environmental Issues That Need to be Addressed, But There Are Solutions
- Hydraulic Fracturing Does Not Contaminate Aquifers But Poorly Constructed Shale Gas Wells Could, or Leak Methane to the Atmosphere
- Shale Gas Can be Blue Bridge to a Green Future … but It Has to be Developed in an Environmentally Responsible Manner and There Have to be Non-Carbon Energy Sources on the Other Side