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Hydrofracing 101 (Part 2)

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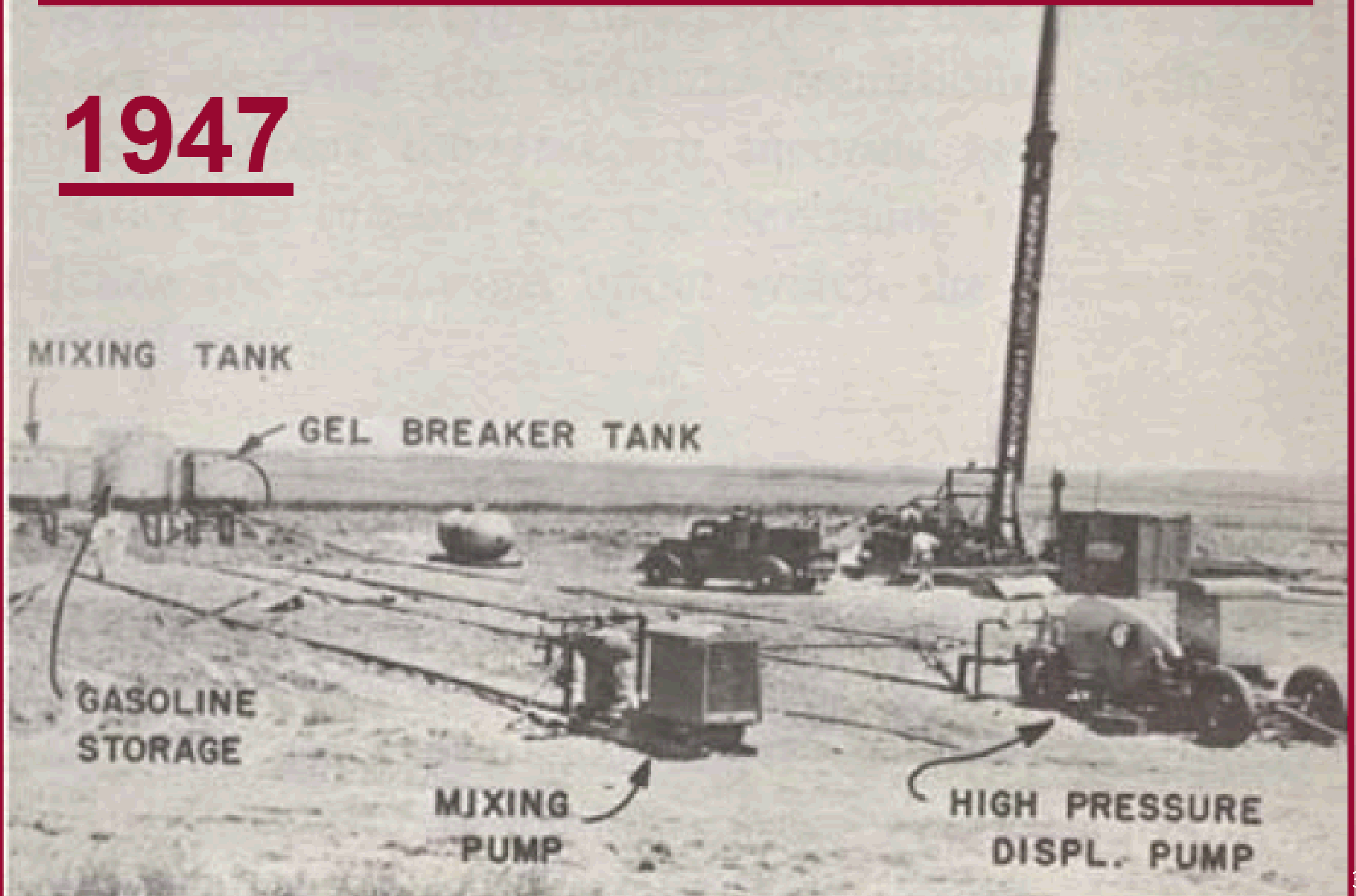
Outline

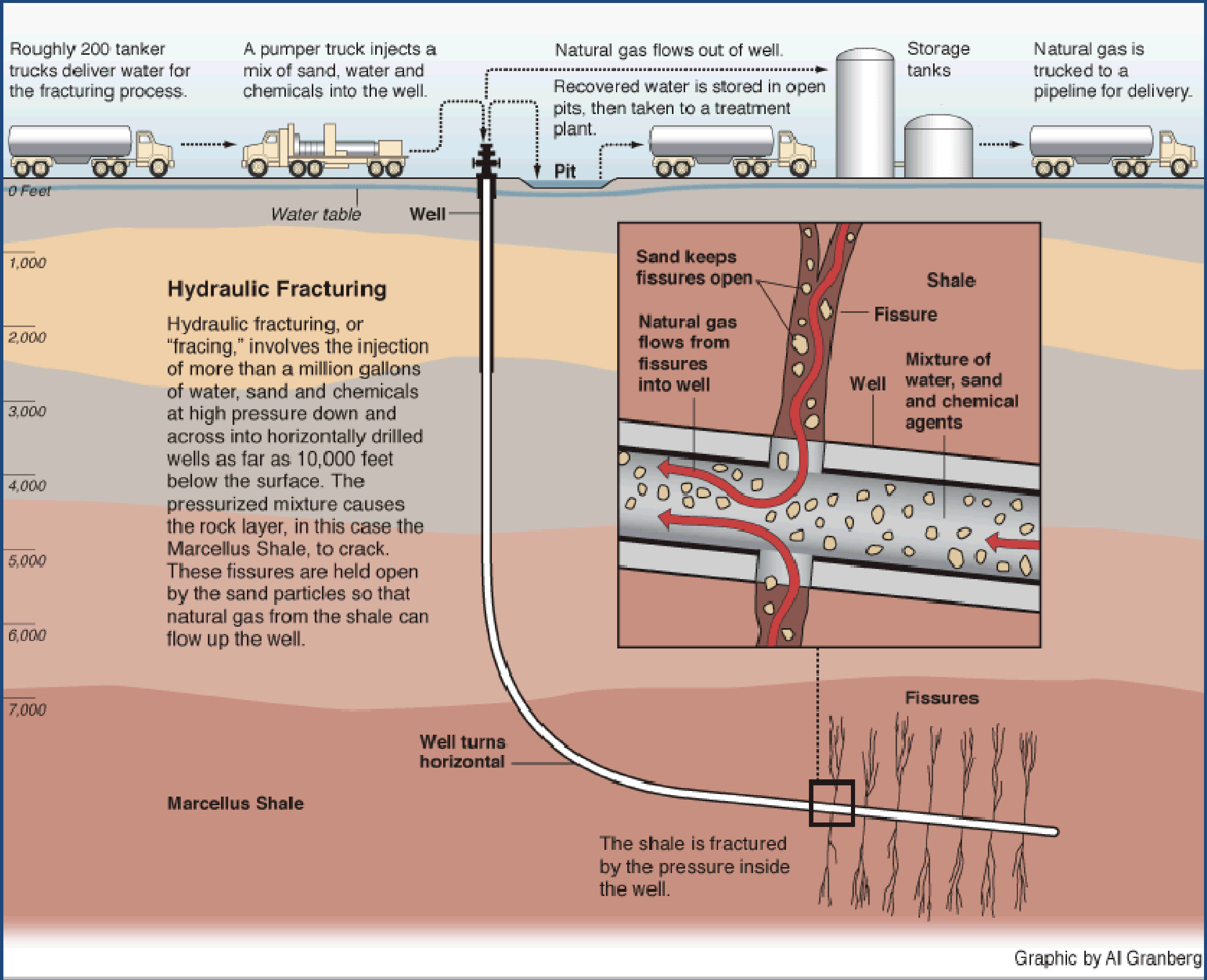
- A typical hydrofrac operation
- Some technical aspects
- Water issues
- Induced seismicity

Klepper Gas Unit No. 1, Hugoton field, Kans. The first well to be hydraulically fractured to increase well productivity. (SPE Monograph Vol. 2)



How does hydraulic fracturing work?

- Three steps:
  - Pump the fracturing fluid into the wellbore at a rate sufficient to increase the pressure downhole to a value in excess of the fracture gradient of the formation rock.
  - The pressure causes the formation to crack, allowing the fracturing fluid to enter and extend the crack farther into the formation.
  - To keep this fracture open after the injection stops, a solid proppant, commonly a sieved round sand, is added to the fracture fluid. The propped hydraulic fracture then becomes a high permeability conduit through which the formation fluids can flow to the well.



from EPA/600/D-11/001/February 2011/www.epa.gov/research

A well head at a fracking operation near Carrizo Springs, TX

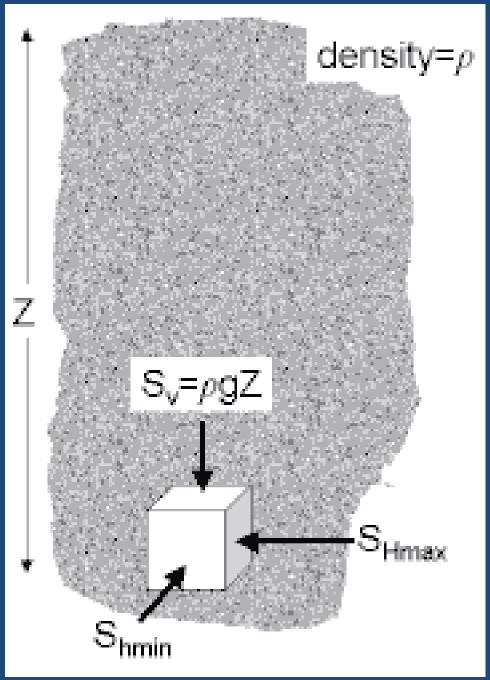
Source: SA Express News

Typical Drilling Pad

See http://www.glossary.oilfield.slb.com/

Earth Stresses and Hydrofractures

Add slide on fracture propagation



Hydrofrac.com (Dr. Moo Lee, Sandia)

Perforations and (Small) Hydraulic Fractures

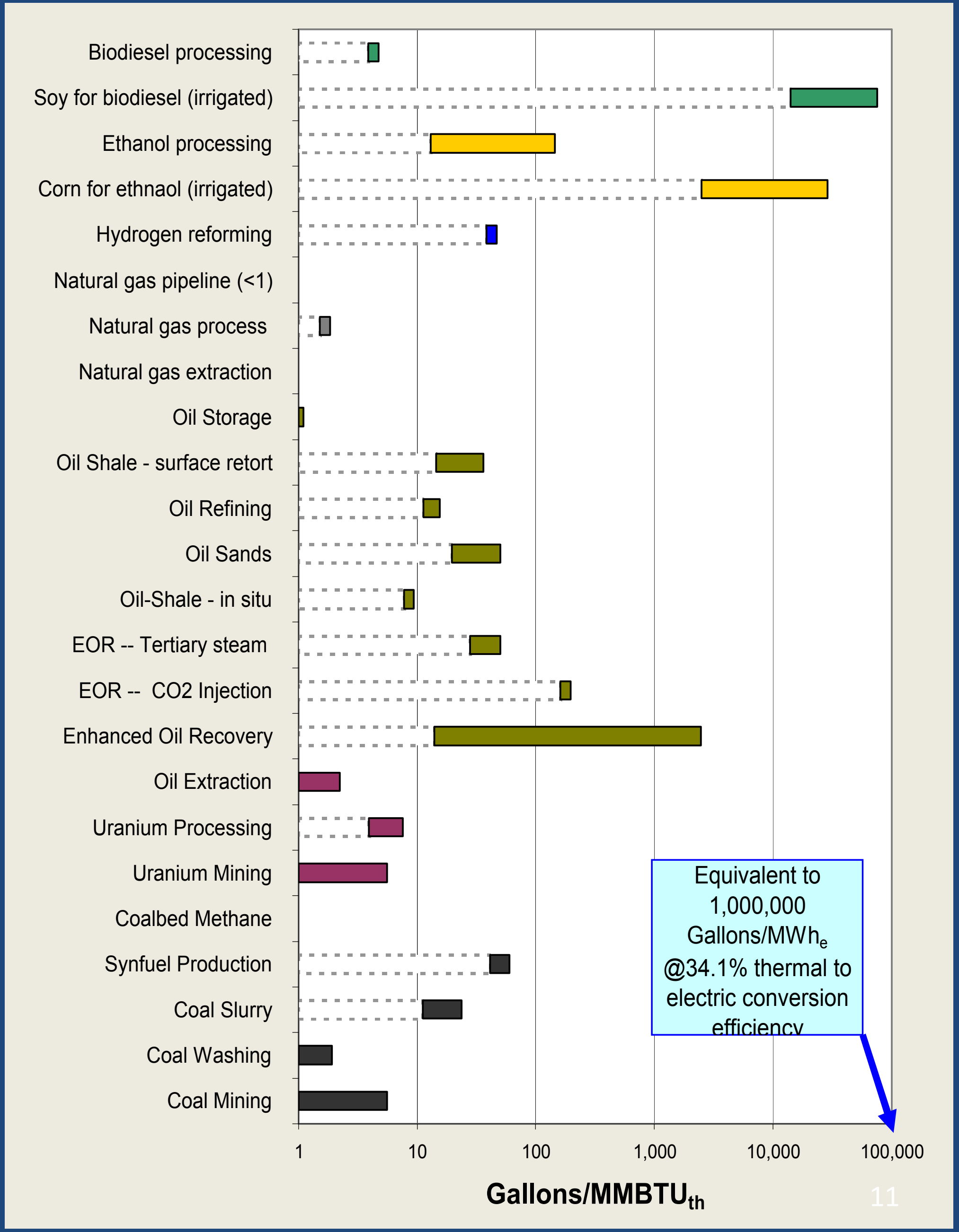
Water Issues

Energy development adds to demands on water

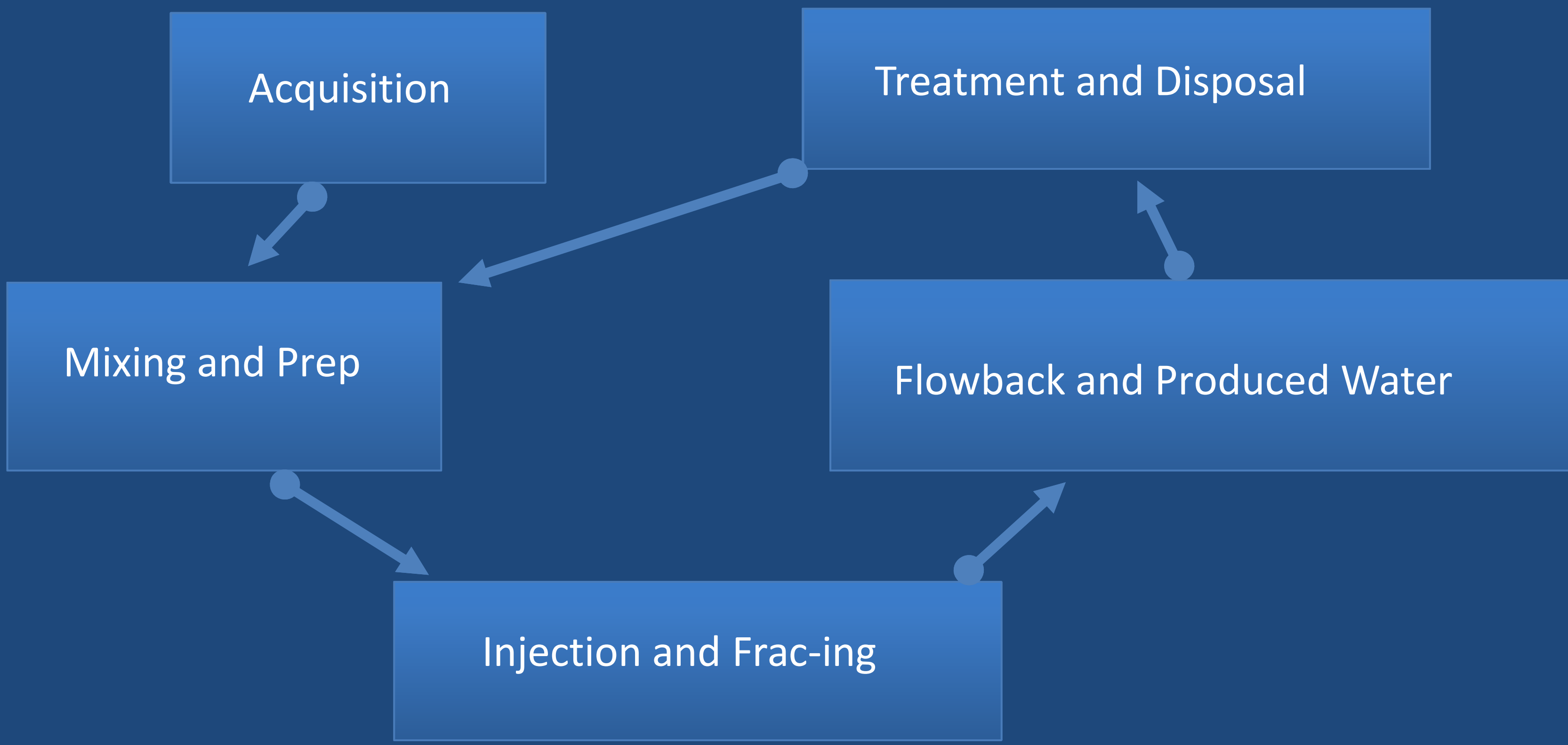
- Much has been made of shale gas production as being water intensive, and indeed the water requirements can be huge

- However many newer technologies will be more water intensive

- Biofuels and hydrogen economy would require significantly more water than fossil transportation fuels



Water Handling in Typical Hydrofracture Operation



How much water needed?

- A multi-stage fracturing of a single horizontal shale gas well can use several million gallons of water.
  - Compare with: 70 gallons per capita per day in US
  - San Antonio has a population of 1.5 million, consumes 38,325 million gallon per year
  - According to DOE by All Consulting, Marcellus shale production consumes 20,150 million gallon per year

- Most water used in hydraulic fracturing comes from surface water sources such as lakes, rivers and municipal supplies. This is much more constrained in the Western US.

How Much Water For Each Well?

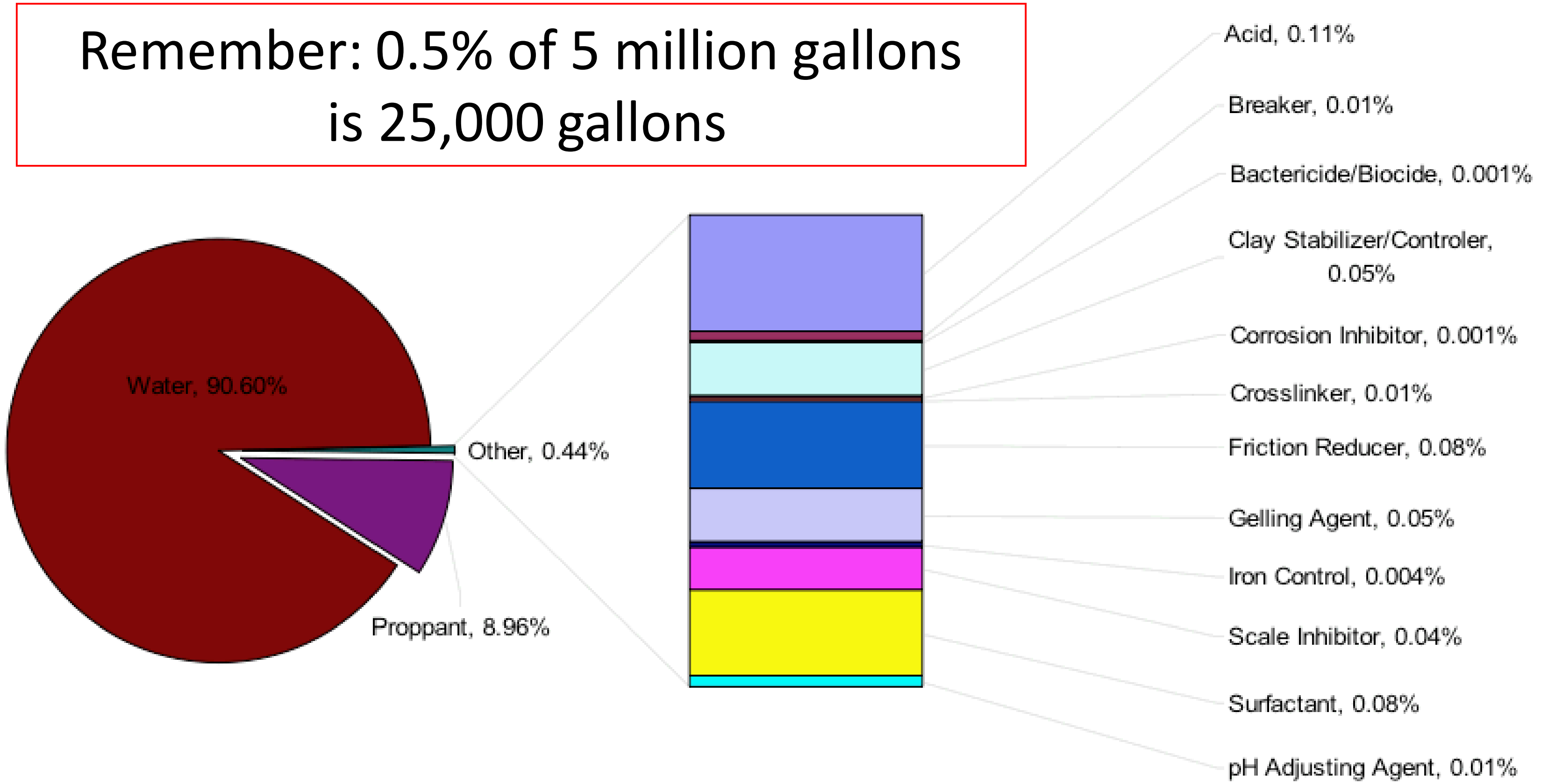
- Depends on number and size of hydraulic fractures in that well
- Typically, much more than 1 million gallons
- There's about 10 gallons per cubic foot, so…
- That's at least 100,000 cubic feet, and..
- That's at least 1,000 seconds, 15 minutes, of flow in a stream which flows at 100 CFS.
- Need large river flow rates, or lake supply to meet this demand

Chesapeake is averaging 5.5 million gallons/well in PA Marcellus play.

http://hydraulicfracturing.aitrk.com/Pages/information.aspx

Breakdown of Additives to Fracturing Fluid

Remember: 0.5% of 5 million gallons is 25,000 gallons



From NYS DEC's SGEIS, 2009

What Else Goes Down The Well With All That Water?

Proppant: Particles, like sand, transported into the fractures to keep them open after fracturing pressure release.

Gelling Agents: Increase fluid viscosity to help proppant transport.

Biocides: Kill bacteria that harm the gelling agents.

Breakers: Decrease viscosity of the fracturing fluid, after the fracturing process, to improve flowback.

Fluid-Loss Additives: Decrease leakoff of fracturing fluid into the rock.

Anti-Corrosives: Protect metallic elements in the well.

Friction Reducers: Allow high pressures and flow rates.

http://www.epa.gov/OGWDW/uic/pdfs/cbmstudy_attach_uic_ch04_hyd_frac_fluids.pdf

http://www.earthworksaction.org/hydfracking.cfm

What's in the Frac fluid?

Fracturing Fluid Additives, Main Compounds, and Common Uses.

Additive Type	Main Compound(s)	Purpose	Common Use of Main Compound
Diluted Acid (15%)	Hydrochloric acid or muriatic acid	Help dissolve minerals and initiate cracks in the rock	Swimming pool chemical and cleaner
Biocide	Glutaraldehyde	Eliminates bacteria in the water that produce corrosive byproducts	Disinfectant; sterilize medical and dental equipment
Breaker	Ammonium persulfate	Allows a delayed break down of the gel polymer chains	Bleaching agent in detergent and hair cosmetics, manufacture of household plastics
Corrosion Inhibitor	N,n-dimethyl formamide	Prevents the corrosion of the pipe	Used in pharmaceuticals, acrylic fibers, plastics
Crosslinker	Borate salts	Maintains fluid viscosity as temperature increases	Laundry detergents, hand soaps, and cosmetics
Friction Reducer	Polyacrylamide	Minimizes friction between the fluid and the pipe	Water treatment, soil conditioner
	Mineral oil		Make-up remover, laxatives, and candy
Gel	Guar gum or hydroxyethyl cellulose	Thickens the water in order to suspend the sand	Cosmetics, toothpaste, sauces, baked goods, ice cream
Iron Control	Citric acid	Prevents precipitation of metal oxides	Food additive, flavoring in food and beverages; Lemon Juice ~7% Citric Acid
KCl	Potassium chloride	Creates a brine carrier fluid	Low sodium table salt substitute
Oxygen Scavenger	Ammonium bisulfite	Removes oxygen from the water to protect the pipe from corrosion	Cosmetics, food and beverage processing, water treatment
pH Adjusting Agent	Sodium or potassium carbonate	Maintains the effectiveness of other components, such as crosslinkers	Washing soda, detergents, soap, water softener, glass and ceramics
Proppant	Silica, quartz sand	Allows the fractures to remain open so the gas can escape	Drinking water filtration, play sand, concrete, brick mortar
Scale Inhibitor	Ethylene glycol	Prevents scale deposits in the pipe	Automotive antifreeze, household cleansers, and de-icing agent
Surfactant	Isopropanol	Used to increase the viscosity of the fracture fluid	Glass cleaner, antiperspirant, and hair color

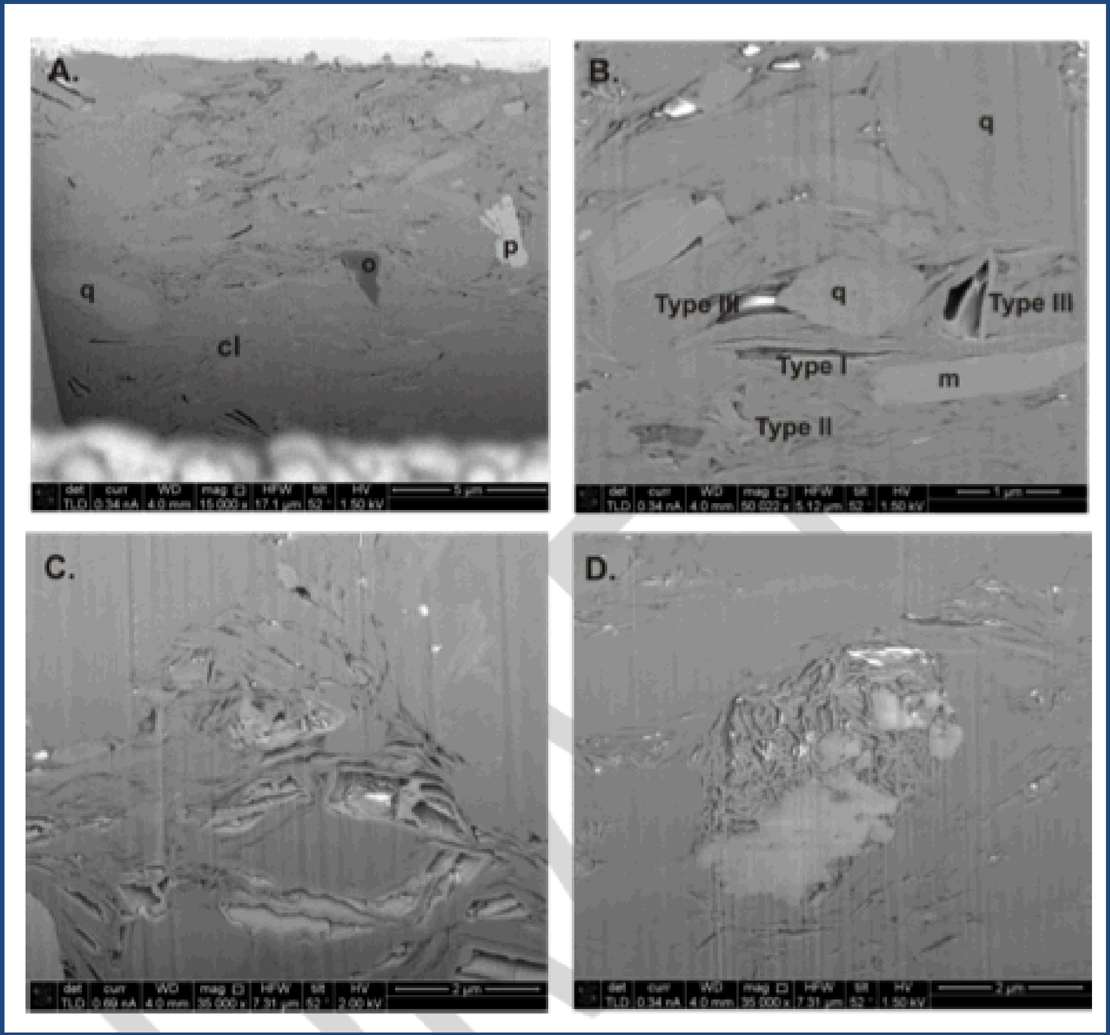
Note: The specific compounds used in a given fracturing operation will vary depending on company preference, source water quality and site-specific characteristics of the target formation. The compounds shown above are representative of the major compounds used in hydraulic fracturing of gas shales.

from www.netl.doe.gov/technologies/oil-gas/.../shale_gas_primer_2009.pdf

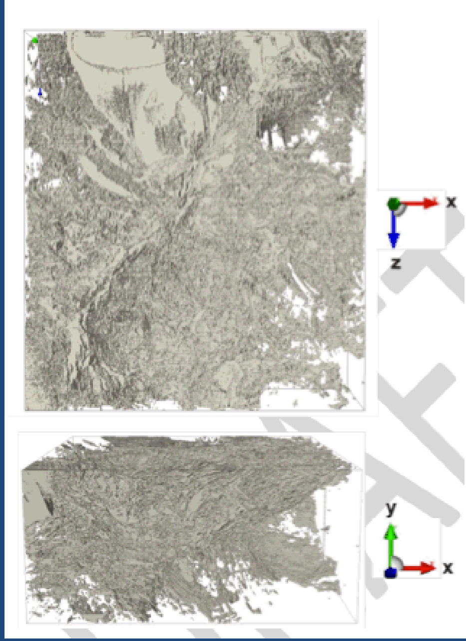
An employee of Cheapeake Energy pours a chemical mixture called cross linked gel that is mixed with sand and used in the hydraulic fracturing process

Source: SA Express News

Mudstone Pores and Pore Waters



Water-wetting pore types (Dewers et al., 2011)



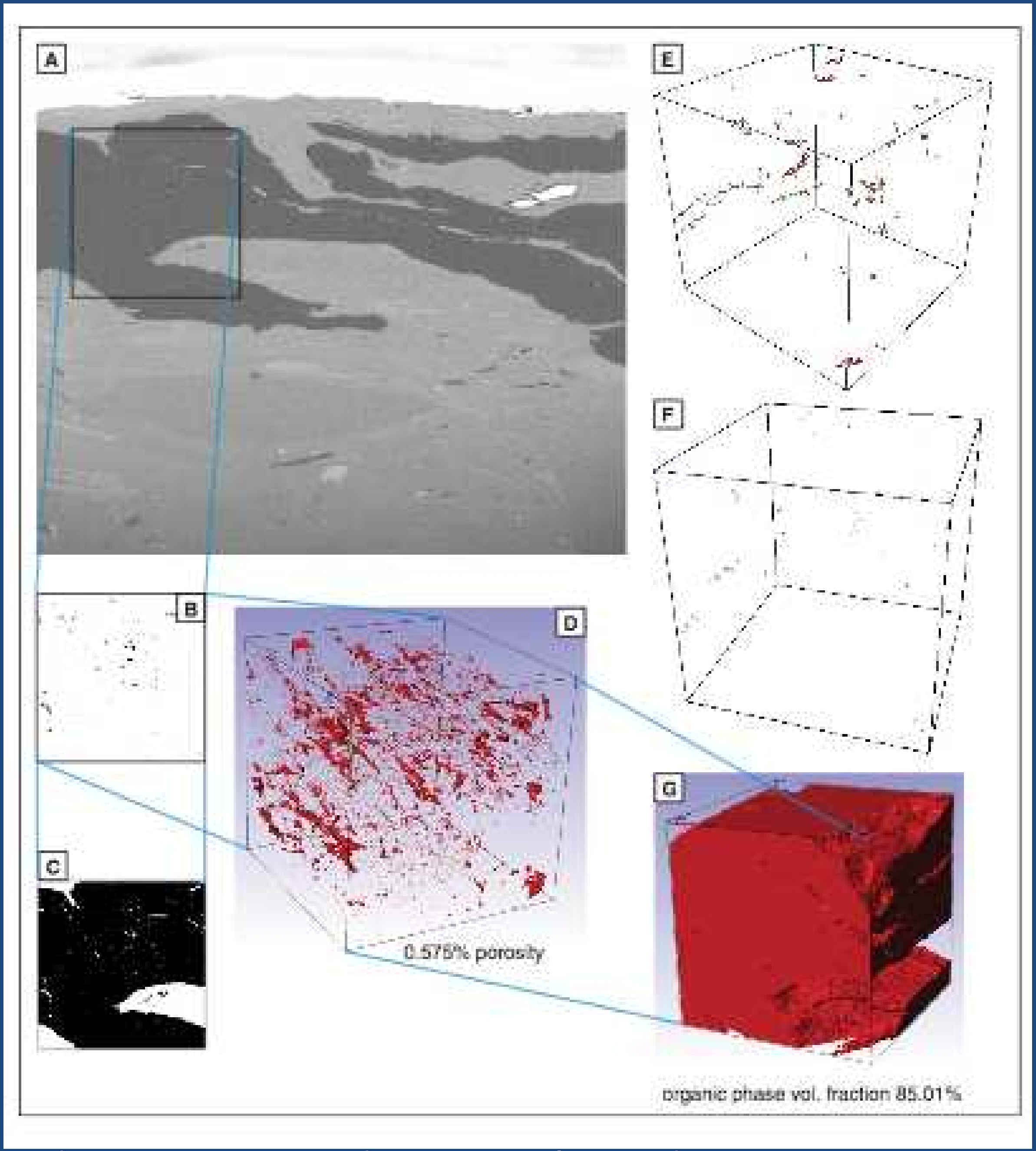
3D Pore Networks

Pore Water Compositions

<u>Salts</u> – NaCl, $CaCl_2$, ...
<u>Trace elements</u> – Mercury, Lead, Arsenic, heavy metals
<u>NORM</u> – Radium, Thorium, Uranium, Radon
<u>Organics</u> – Acids, PAHs, etc.
<u>Gas</u> – H_2S, CO_2, Methane

Pores in organic phases – reservoirs for gas?

- •Nanopore “tubules” likely created by gas generation form kerogen
- •Nano-darcy permeability
- •Gas production is likely from similar pore networks intersected by hydro-fractures



Oil-wetting pores in kerogen in four-cubic micron portion of Marine Tuscaloosa mudstone)Heath et al., 20110

What Comes Back Up?
FLOWBACK Fluid and Produced Water

- When the fracturing process is completed, the pressure is released, and much of the fracturing fluid backflows to the wellhead*.

- The backflow can:

➢ be highly saline;

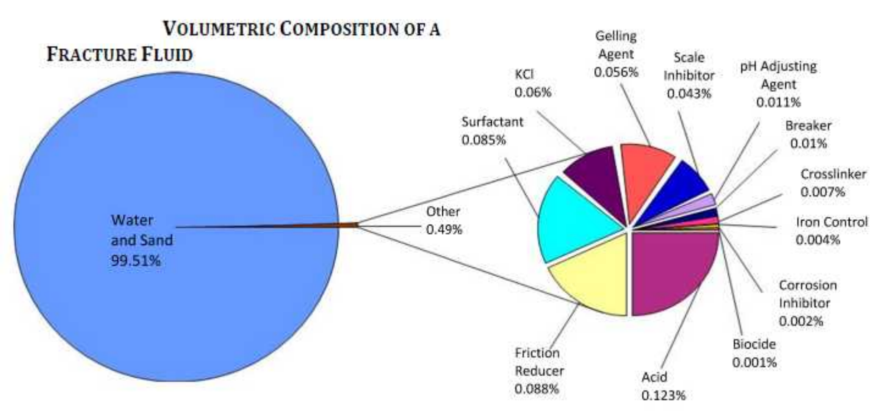
➢ contain some heavy metals;

➢ contain fluid additives;

➢ contain a level of NORM.

*Industry spokespeople say 10-50% of injected fluid flows back

What's in the frac fluid



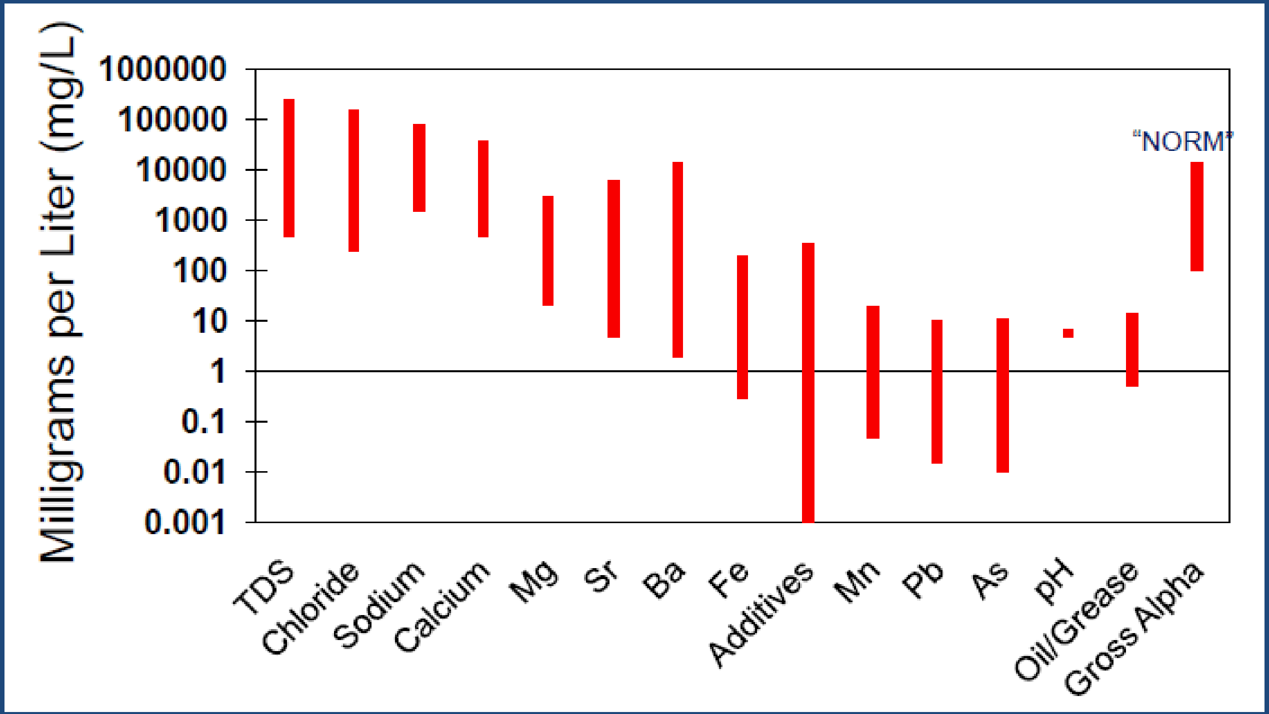
+

+ What's in the Shale Water

Salts – NaCl, $CaCl_2$, ...
Trace elements – Mercury, Lead, Arsenic
NORM – Radium, Thorium, Uranium, Radon
Organics – Acids, PAHs, etc.
Gas – H_2S, CO_2, Methane

= What's in the Flowback

=



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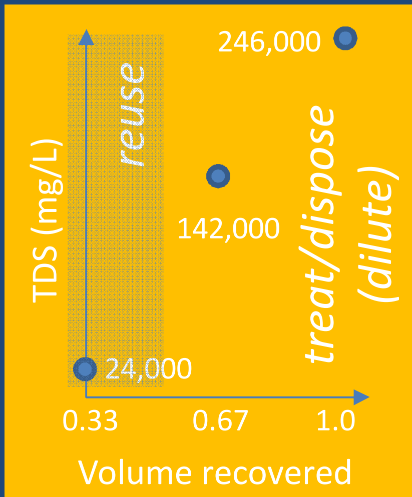
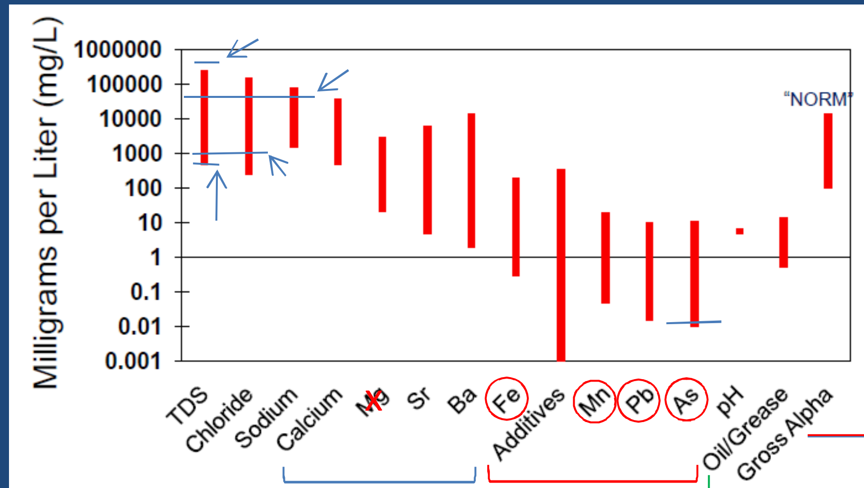
from Swistock, B. Treatment/disposal options for wastewaters from shale gas drilling, 2009, Penn State University, http://downloads. cas.psu.edu/naturalgas/pdf/updated%20wastewater%20webinar% 20oct%202009.pdf.

How to Treat the Flowback?





"NORM" = radium + thorium + uranium + radon

sulfate scale

Fe co-precipitate

(e.g. ProChemTech) → form sulfate and carbonate scales, (ion exchange)

co-precipitate with Fe oxidation

→ flocculation, biodegradation, oxidation

NaCl is the big treat/dispose/dilute obstacle

- Not removed by wastewater treatment plants
- Is often bad for wastewater treatment plants
- High levels in flowback often prevent full dilution

Desalination?

(if no UIC class II wells)

Shale Gas Basin	Water Management Technology	Availability	Comments
Barnett Shale	Class II injection wells[303]	Commercial and non-commercial	Disposal into the Barnett and underlying Ellenberger Group[304]
	Recycling[305]	On-site treatment and recycling	For reuse in subsequent fracturing jobs [306]
Fayetteville Shale	Class II injection wells[307]	Non-commercial	Water is transported to two injection wells owned and operated by a single producing company [308]
	Recycling	On-site recycling	For reuse in subsequent fracturing jobs[309]
Haynesville Shale	Class II injection wells	Commercial and non-commercial	
Marcellus Shale	Class II injection wells	Commercial and non-commercial	Limited use of Class II injection wells[310,311]
	Treatment and discharge	Municipal waste water treatment facilities, commercial facilities reportedly contemplated[312]	Primarily in Pennsylvania
	Recycling	On-site recycling	For reuse in subsequent fracturing jobs[313]
Woodford Shale	Class II injection wells	Commercial	Disposal into multiple confining formations[314]
	Land Application		Permit required through the Oklahoma Corporation Commission[315]
	Recycling	Non-commercial	Water recycling and storage facilities at a central location[316]
Antrim Shale	Class II injection wells	Commercial and non-commercial	
New Albany Shale	Class II injection wells	Commercial and non-commercial	

from www.netl.doe.gov/technologies/oil-gas/.../shale_gas_primer_2009.pdf

Underlying figures above from: Swistock, B. Treatment/disposal options for wastewaters from shale gas drilling, 2009, Penn State University, http://downloads. cas.psu.edu/naturalgas/pdf/updated%20wastewater%20webinar% 20oct%202009.pdf.

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The Industry Is Still in the R&D Stage of Recycling Technologies

"With fortunes, water quality and cheap energy hanging in the balance, exploration companies, scientists and entrepreneurs are scrambling for an economical way to recycle the wastewater.

"Everybody and his brother is trying to come up with the 11 herbs and spices," said Nicholas DeMarco, executive director of the ***West Virginia Oil and Natural Gas Association.*** **"** AP Sunday, February 7, 2010

From Halliburton:

"...The industry is also trying to find ways to recycle the water used in fracturing in order to reduce the effect on local water supplies.

"We're still in the infancy of trying to figure out how to recycle the water," said Ron Hyden, the manager for Halliburton's production enhancement business. "We're trying to be good corporate citizens on that front.""

HOUSTON CHRONICLE, Fri 12/11/2009

Produced Water Treatment ?

Cost avoidance

- Cost to dispose of produced water: $24 - $120 / 1000 gal
- Cost to desalinate produced water: ~$5 / 1000 gal
- (these numbers vary by gas play)

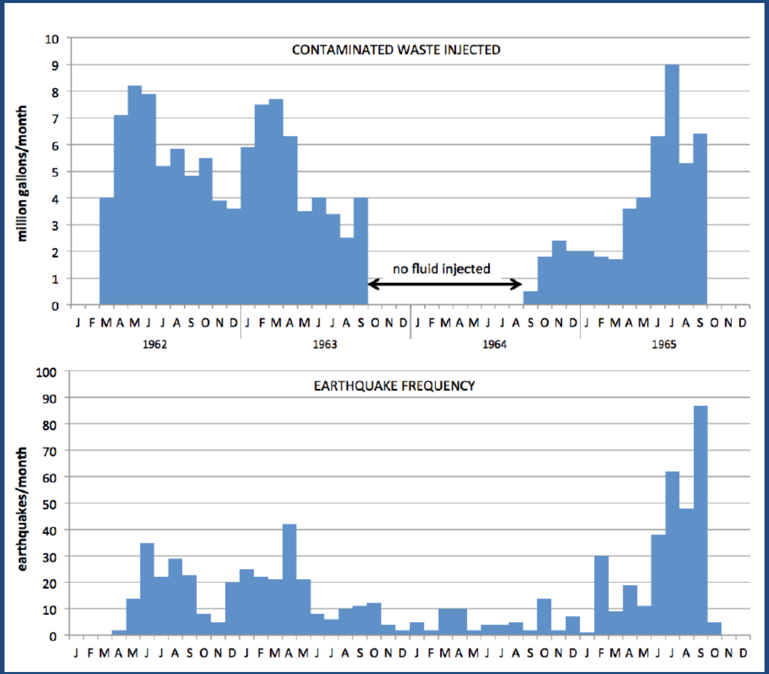
Potential beneficial uses of treated produced water

- Rangeland/riparian rehabilitation
- Recycle for fracing applications
- Industrial process use (cooling water, biofuels)
- Aquifer or surface reservoir storage

Cheapest option is to re-inject wastewater into subsurface saline formations (maybe 80-90% cheaper??)

Triggered (Induced) Seismicity

- Fluid injection (e.g. Rocky Flats)
- Hydrofracturing (“fracking”; e.g. Eola Field, OK)
- Mining (e.g. South African Gold Mines)
- Enhanced Geothermal (e.g. Soultz-sous-Forets)
- Reservoirs (e.g. Aswan Dam)



Injection-induced seismicity at Rocky Flats, CO

From: National Research Council, 2012

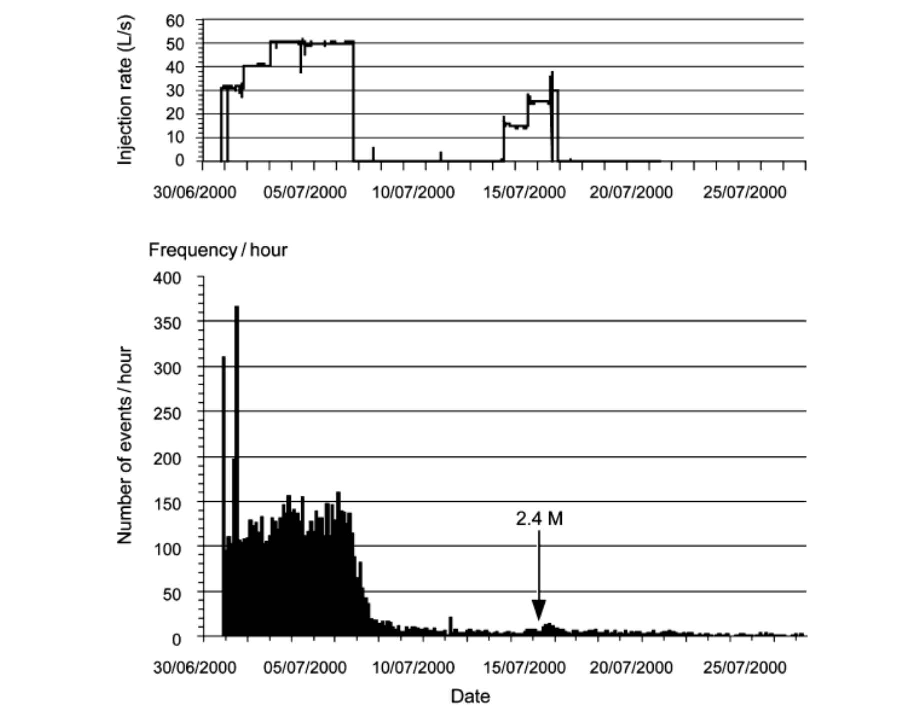


Fig. 17. Injection rates and microseismic data for the hydraulic stimulation of borehole GPK2 at Soultz-sous-Forêts. Arrow shows when the magnitude 2.4 event occurred. *M*: Local magnitude (Baria et al., 2005).

Why worry about induced seismicity?

National Research Council, 2012

"Three major findings emerged from the study:

(1) the process of hydraulic fracturing a well as presently implemented for shale gas recovery does not pose a high risk for inducing felt seismic events;

(2) injection for disposal of waste water derived from energy technologies into the subsurface does pose some risk for induced seismicity, but very few events have been documented over the past several decades relative to the large number of disposal wells in operation; and

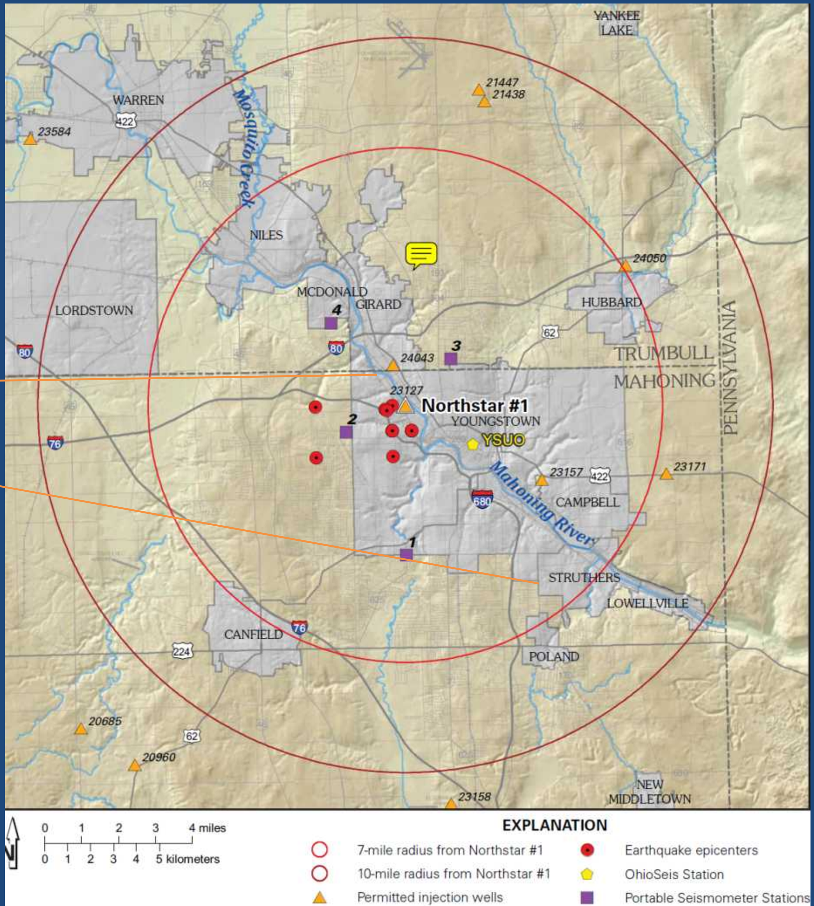
(3) CCS, due to the large net volumes of injected fluids, may have potential for inducing larger seismic events."

Seismicity examples associated with hydrofracing

Earthquake cluster associated with waste water injection well, Youngstown, Ohio

- Good Seismic Network
- Relatively good knowledge of subsurface
- Seismicity associated with Precambrian basement fault??

Northstar #1 Injection well, Youngstown, OH



Large induced Events in the US

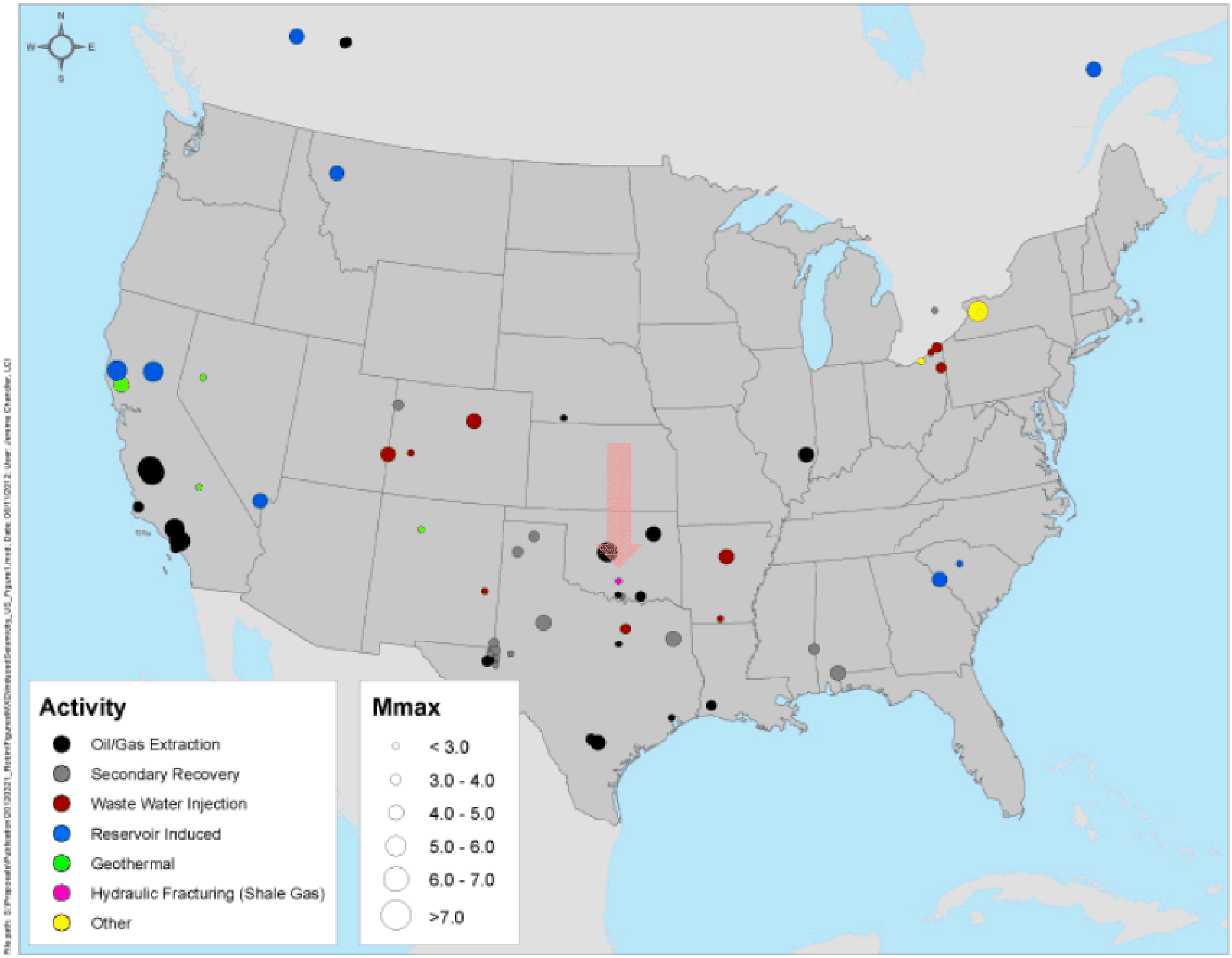
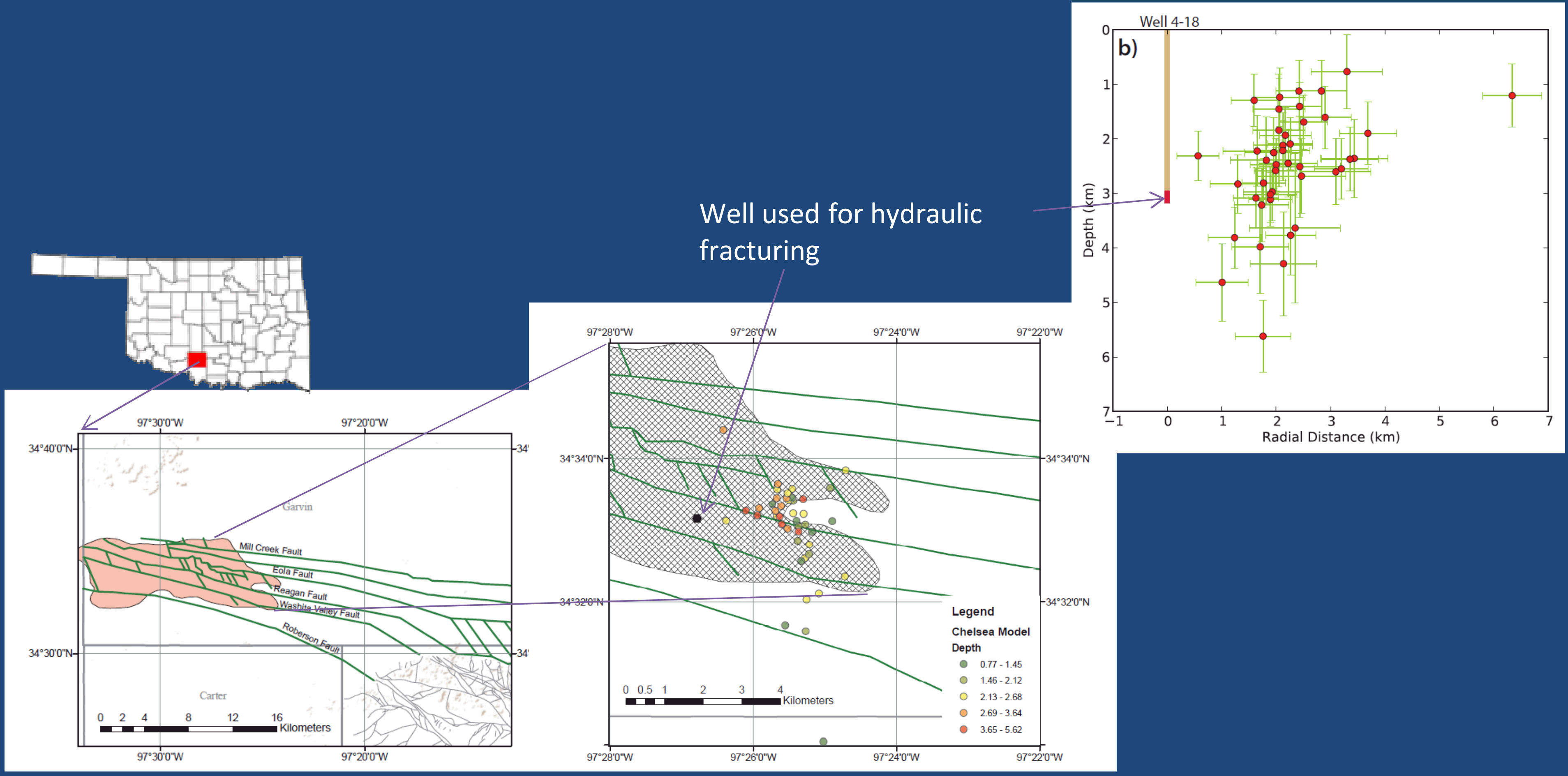


Figure Locations of seismic events caused by or likely related to human activities within the coterminous United States and portions of Canada as documented in the technical literature.

From: National Research Council, 2012

Can hydrofrac activity induce damaging earthquakes??

Example of induced Seismicity from hydraulic fracturing, Eola Field, Garvin Co. Oklahoma (Holland, 2011)



Summary

•Big unknowns about fracture geometry, proppant placement, and predicting efficiencies, production decline

•Water handling procedures are still “immature”

•Biggest obstacle to treatment and reuse of shale gas produced/flowback water is dissolved salts (not norm or gas per se).

•Are hydrofracing operations responsible for “Gasland”-type methane in tapwater? Is poor wellbore design responsible?

•Induced (triggered) seismicity: biggest risk associated with shale gas operations involves fluid injection. Very little risk so far seen from hydrofracturing itself.