Hydraulic Fracturing & Water Use

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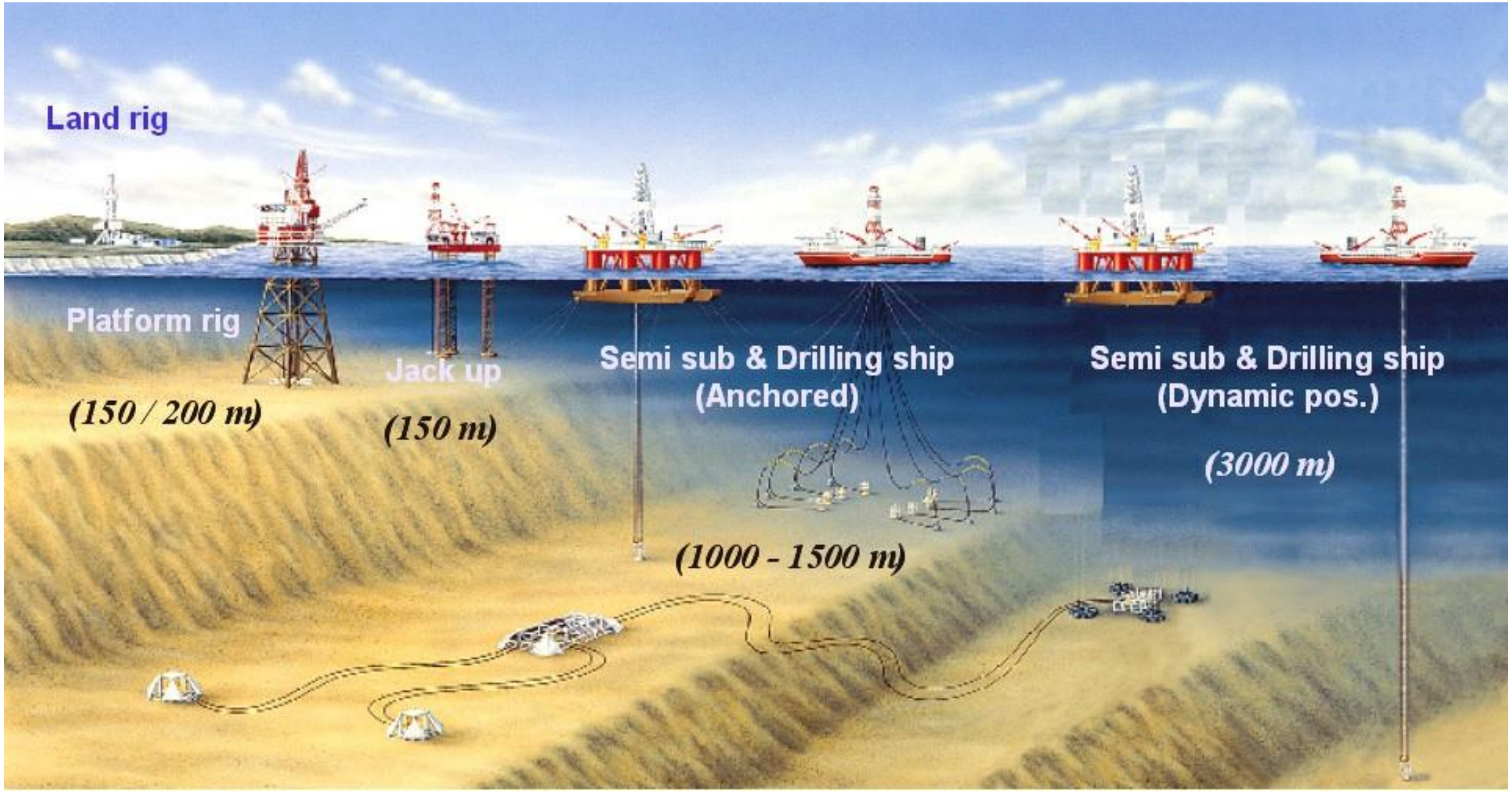
July 30, 2018

Onshore Wells

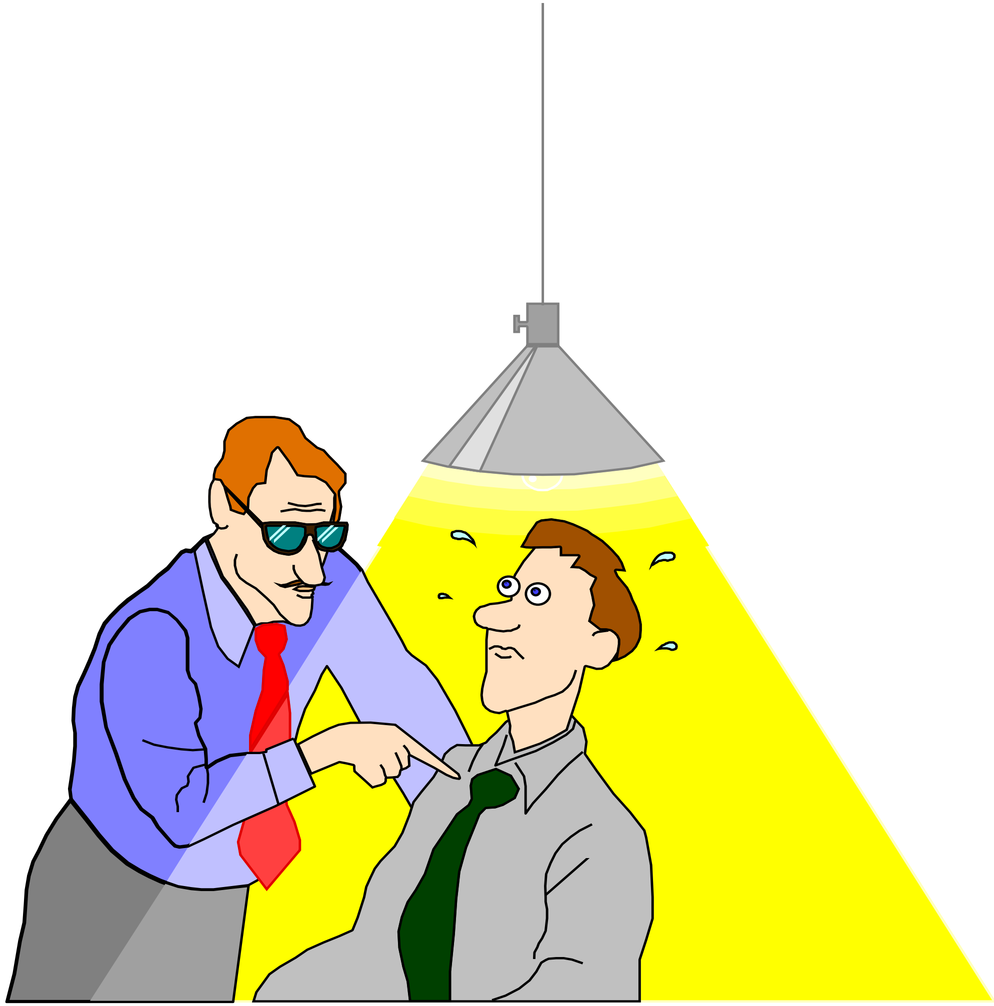
BP's biggest onshore UK oil well at Wytch Farm, Poole Harbour. Photo: BNPS

Offshore Wells



Courtesy: Magnific.biz

What Is Hydraulic Fracturing?



Is a well stimulation technique through which the rock is fractured by injecting a pressurized fluid to optimize oil and gas production.

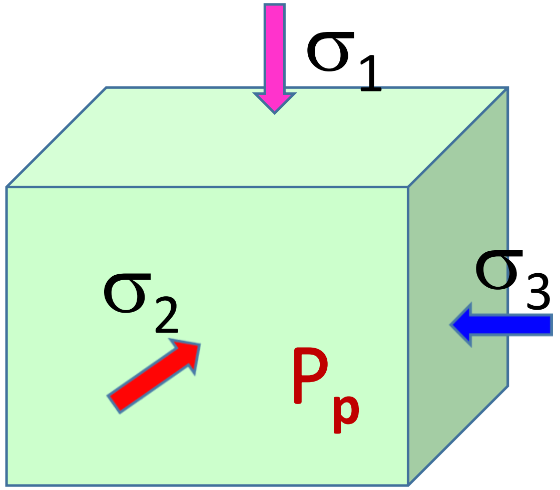
https://www.youtube.com/watch?v=_jBtP1C3C-0

Fracturing History

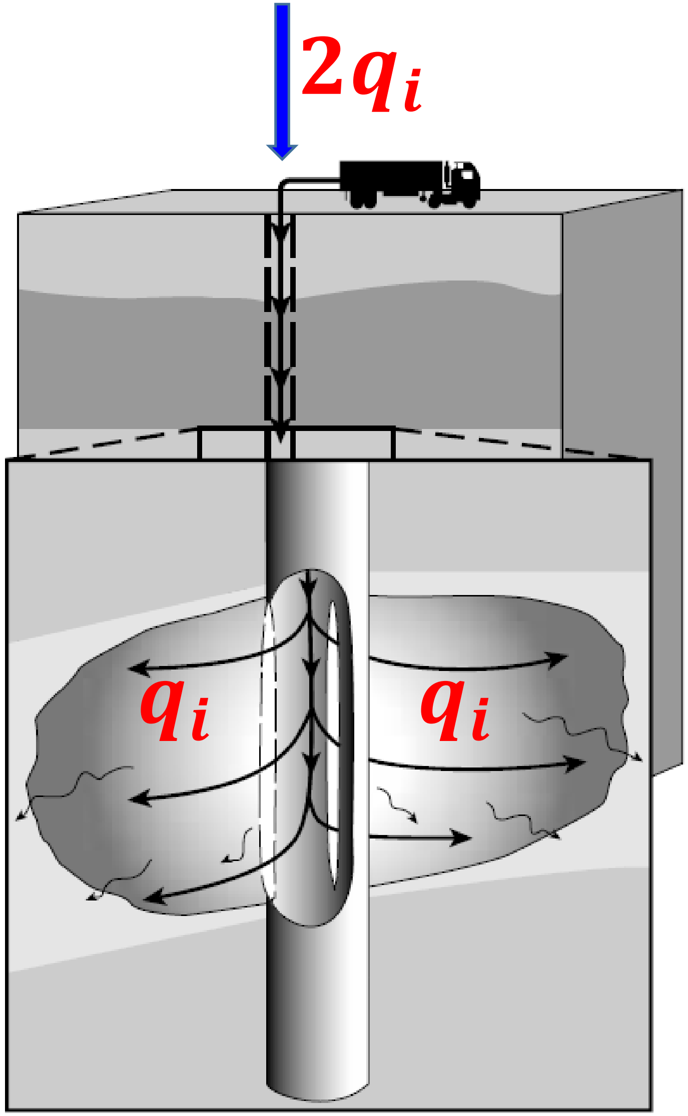
SPE Monograph Vol. 2

- **1947** - Klepper Gas Unit No. 1, Hugoton Field, Kansas. The first well fractured to increase production
- **1949** – First & Second Commercial Fracturing Treatments, Stephens County, OK – and, Archer County, TX

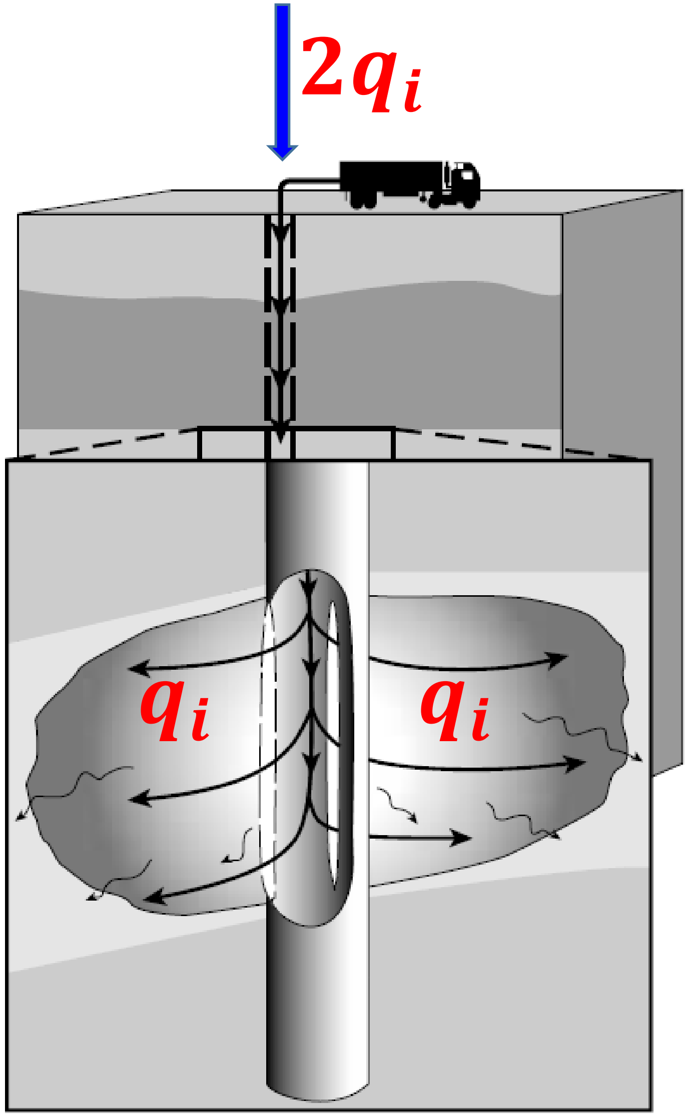
Hydraulic Fracturing Process

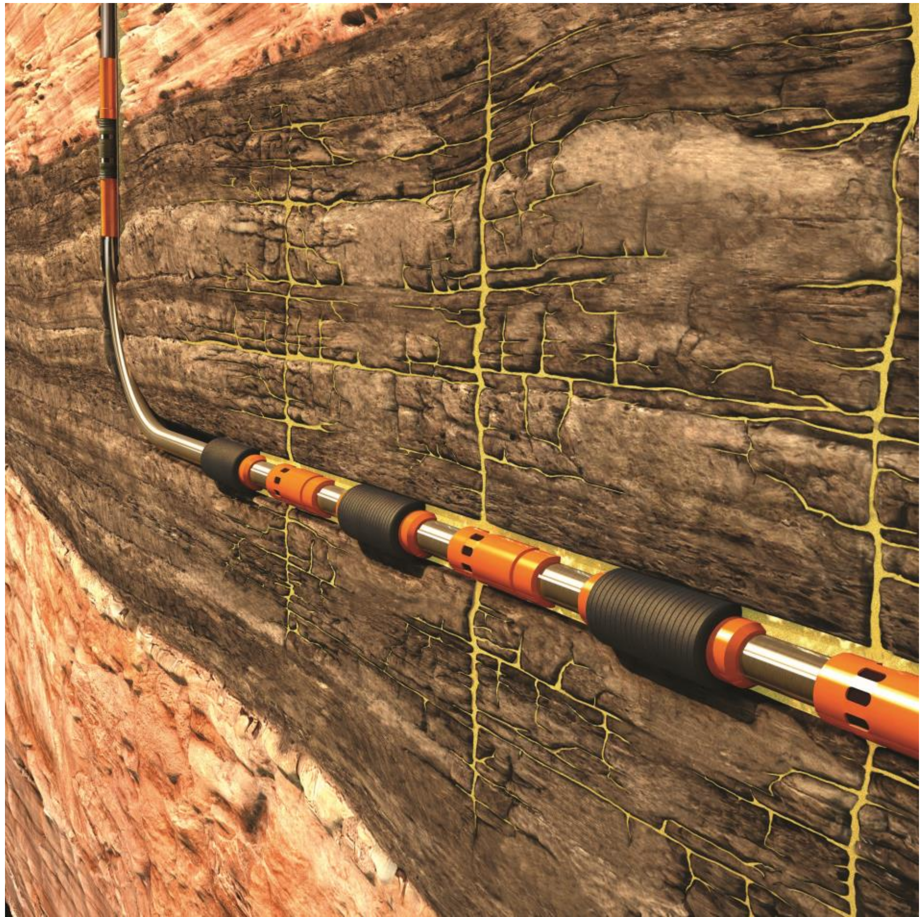


- *Fluid injection* through a wellbore into the formation at a pressure higher than the formation parting pressure (minimum stress also known as the closure stress)
- The *fluid must be pumped well faster* than it can escape (*leak off*) into the formation



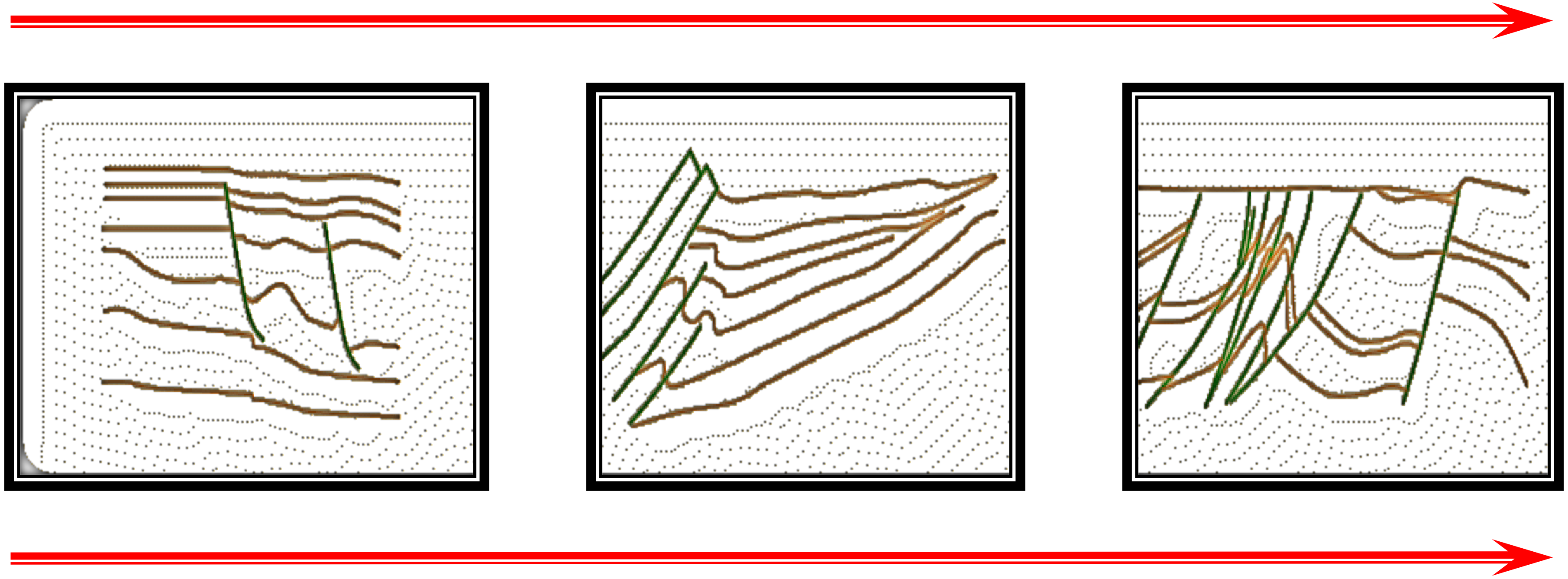
Well & Fracture Orientation





Fracture Complexity - Tectonic Regime/Well Productivity

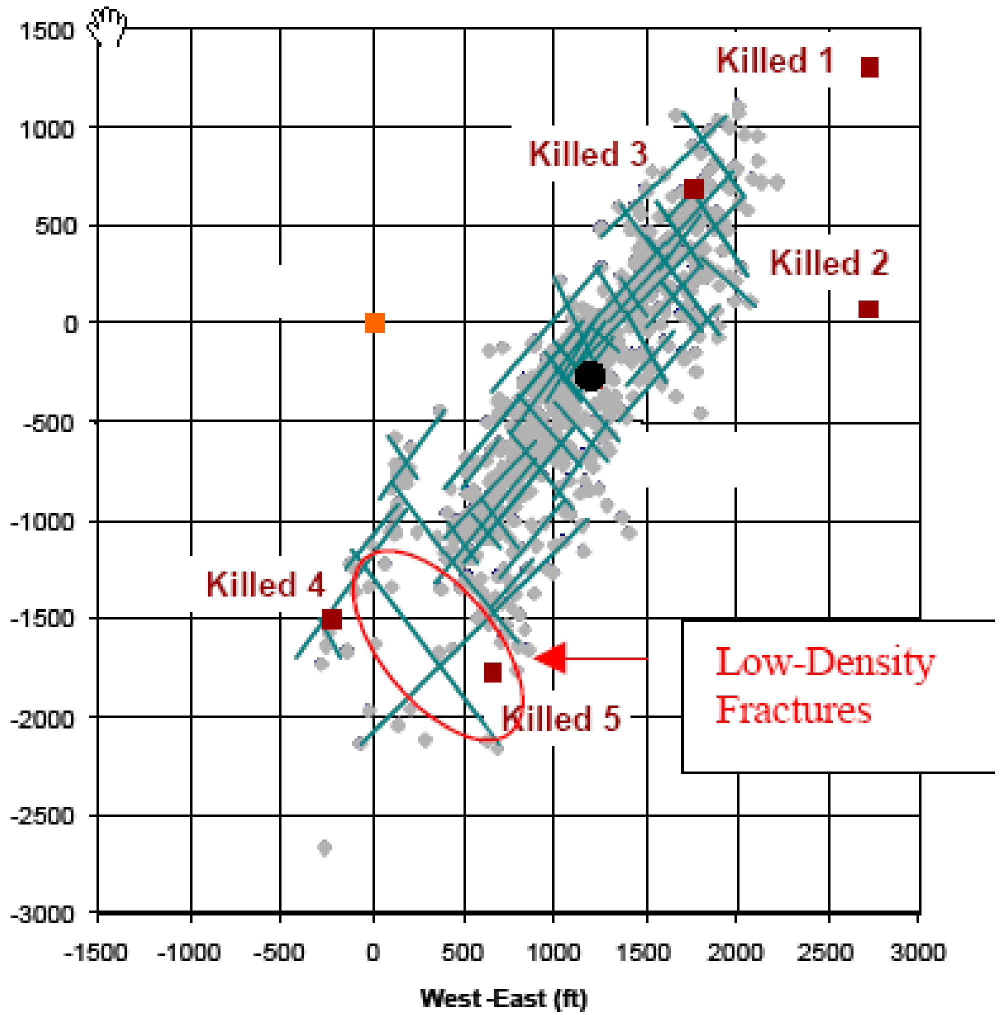
Complexity increase due to tectonic activity (in-situ stress regimes)



Productivity decrease

After Potocki, 2012, SPE 162814

Fracture Mapping [SPE 77441]



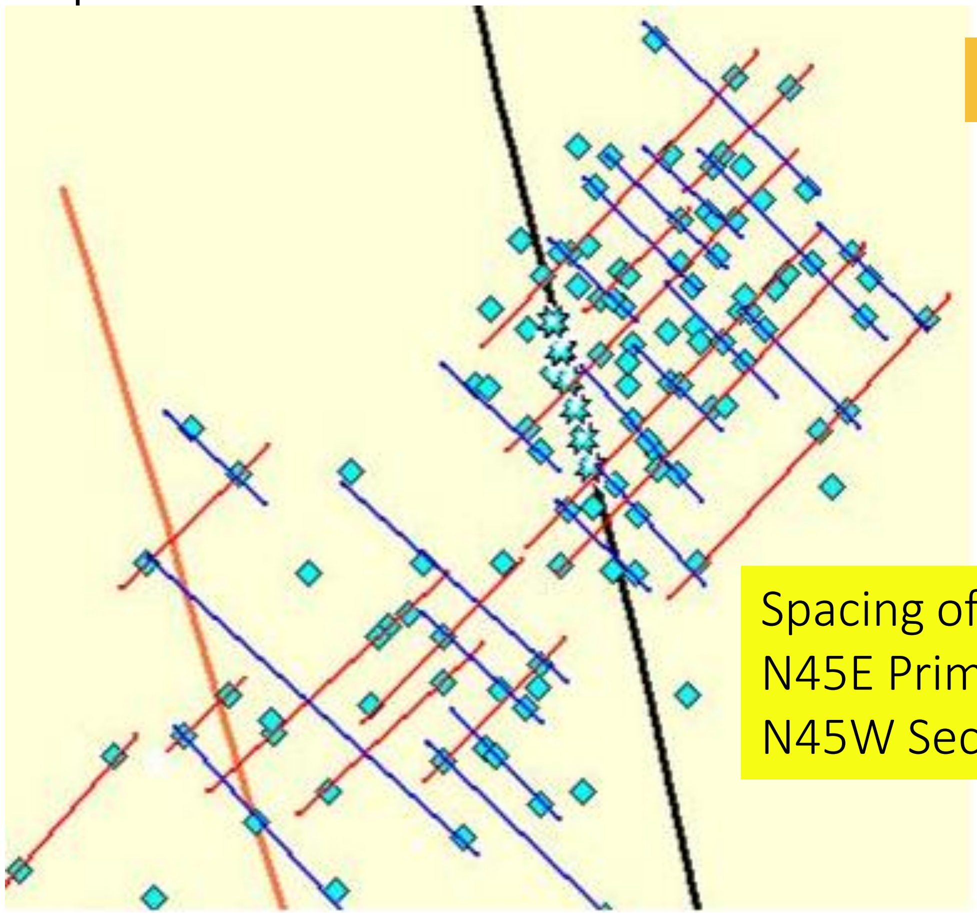
- Geology: Mississippian age
- Extremely low permeability (7e-5 – 5e-3 md) Barnett shale (North Texas)
- Formation height ~ 200-300ft (500 ft in the core area)
- Understanding the fracture geometry critical to the stimulation effectiveness and infill drilling program
- New method of Micro-seismic (MS) evaluation combined with surface and downhole tilt mapping
- Abnormally pressure formation

Fracture Mapping [SPE 119896]

Primary frac direction (red) roughly N45°E, secondary (blue) is N 45°W plane.

Up to 3 frac directions have been recorded.

Contact Area > 10 million ft^2.

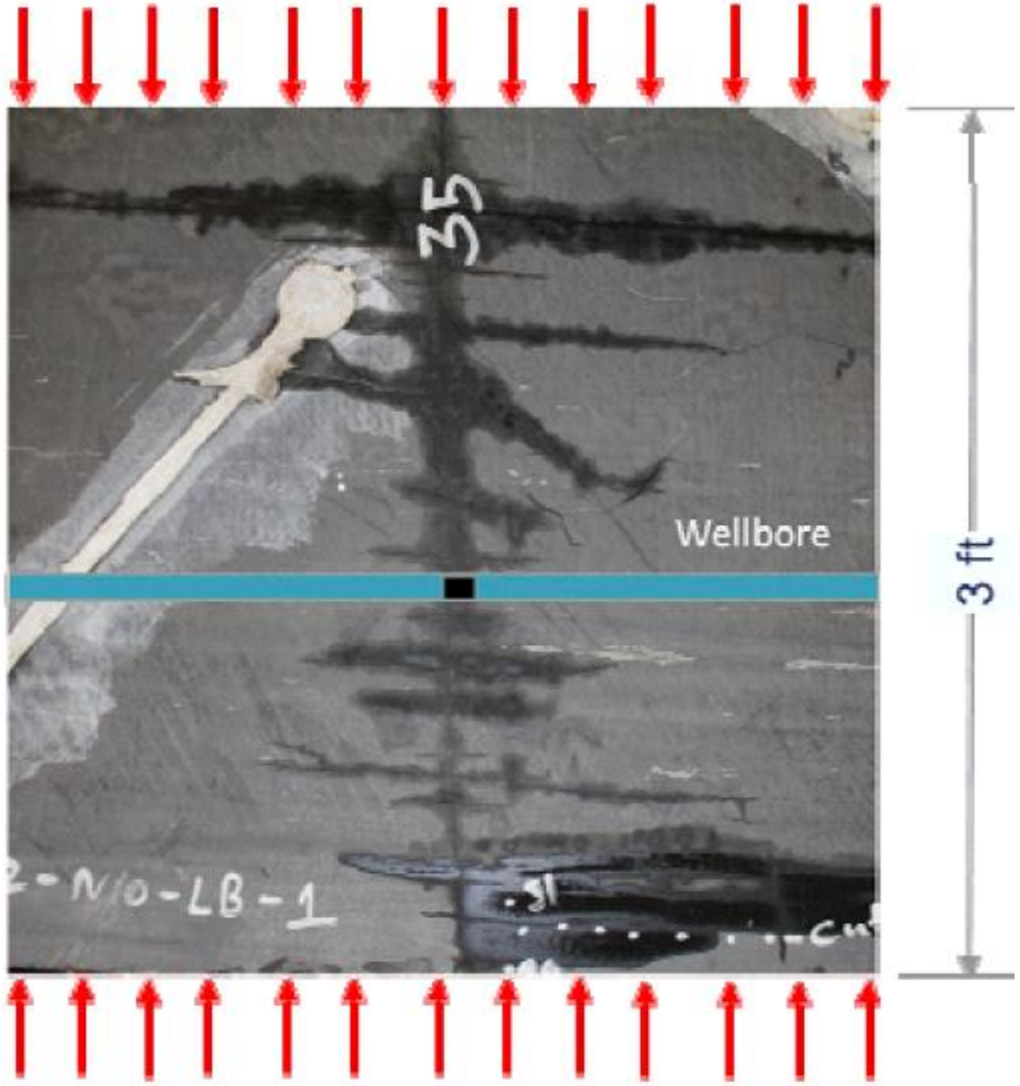


Barnett Shale

Spacing of fractures:
N45E Primary: 60 - 70 ft
N45W Secondary: 70 - 80 ft

King, G., et al SPE 119896, Shale Gas Prodn. Conf, Fort Worth, TX, 16-18 Nov 2008

Acoustic Emissions (AE) & Fracture Geometry



Roberto Rivera Suarez et al., IPTC, Beijing 2013

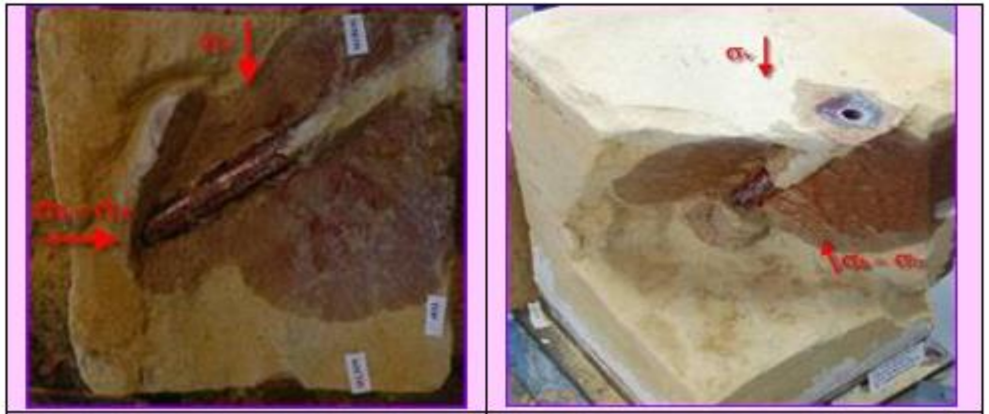
SPE 159262

Experimental Results

Effect of Wellbore Inclination with Isotropic Horizontal Stress

$\sigma_v = 1,200$ psi; $\sigma_H = 780$ psi; $\sigma_h = 780$ psi

$\alpha = 30°, 45°, 60°$; $\beta = 0°$



a) Deviation $\alpha = 60°$ | b) Deviation $\alpha = 30°$

In a stress state with equal horizontal stresses:

- the fracture initiates and propagates along the wellbore axis
- It is possible to produce bi-wing fractures

SPE 159262
Modelling Results

- **Example 4**

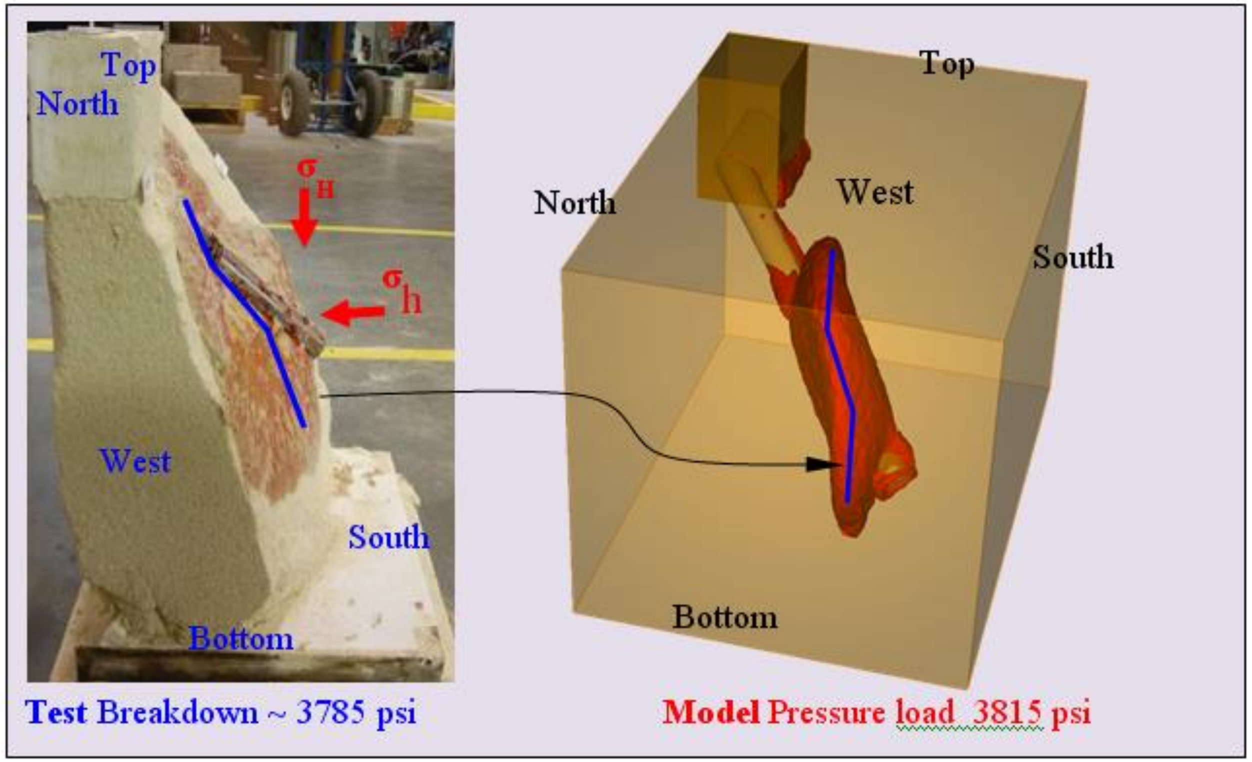
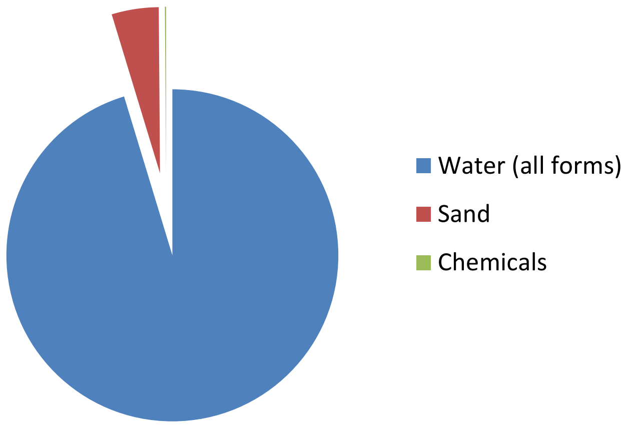


Figure 17 - Small Block Test ($\alpha = 60°$ $\beta = 45°$, σ_x [NS] = 260 psi, σ_y [EW] = 1,200 psi, σ_z [TB] = 780 psi)

Frac System Components

- Frac Fluid – Most fracs fluids are water based.
- Proppant – natural sand and a man made



Water = 95.1%
Sand = 4.8%
Chemicals = 0.13%

Total chemicals on location is usually 1300 gallons, much of it water based.

Fracturing Fluids Systems

WATER

Gelling agents

Cellulose

- Hydroxy Ethyl
- Carboxy Methyl

Guar

- Natural
- Modified
- Improved
- …

Cross linking agents

- Titanium
- Zirconium
- Aluminum
- Chromium
- Antimony
- Boron
- …

Additives

- Antifoaming
- Defoamers
- Buffers
- Breakers
- Bacteria control
- Clay stabilizing
- Demulsifiers
- Fluid loss
- Friction reducing
- Scale inhibitors
- pH Control
- Surfactants
- Temperature stabilizers
- …

Most Common Additives

Additives	Composition	Alternate Use
Friction reducer	Polyacrylamide	Adsorbent in baby diapers Flocculent in drinking water preparation
Biocide	Glutaraldehyde	Medical disinfectant
Alternate Biocide	Ozone Dioxide UV Chlorine	Disinfectant in municipal water supplies
Gellants	Cellulose Guar	Thickening ice cream and soups
Surfactants	Various	Cleaners, dish soaps
Scale Inhibitor	Polymers Phosphonate	Some cleaners and medical treatment for bone issues

Post those fracs in www.fracfocus.com

Fracturing Fluids Characteristics

- Capable to transport the propping agent in the fracture
- Compatibility with the formation rock and fluid
- Capable to generate sufficient pressure drop along the fracture to create fracture width
- Minimize friction pressure losses during injection
- Use approved chemical additives to comply with environmental regulations
- Capable to control-breakdown to a low-viscosity fluid for cleanup (backflow) post treatment
- Cost-effective

Cross-Linked Fluids

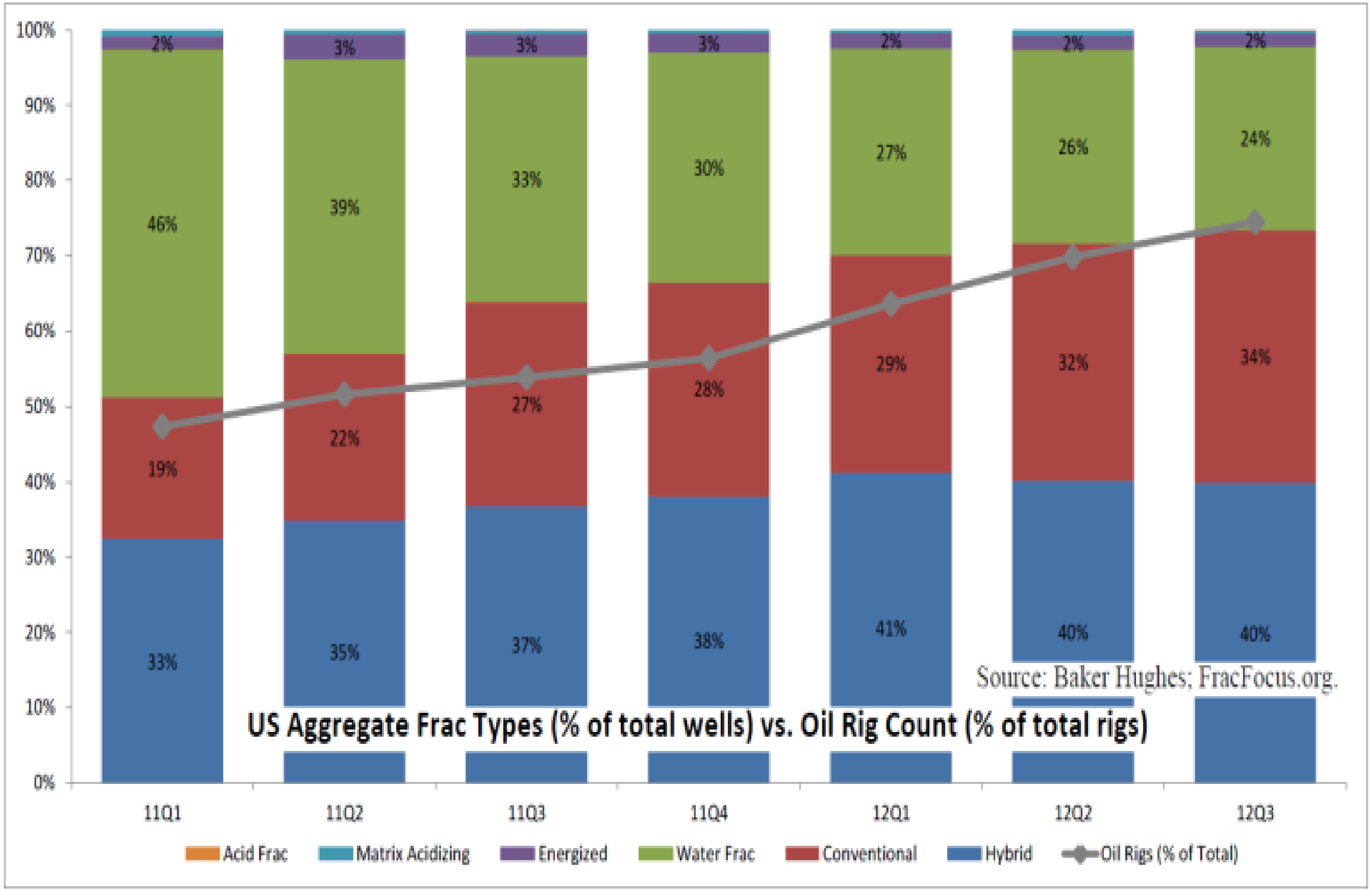
J. R. Cameron - 1990

Frac Types – Fluid System Trends

Frac Type	Definition
Conventional	Treatment type that uses a gelling agent and one or more crosslinkers in order to transport proppant into a hydraulic fracture.
Water Frac	Treatment type that uses a friction reducer, a gelling agent or a viscoelastic surfactant in order to transport proppant into a hydraulic fracture.
Hybrid	Treatment type that uses a combination of a friction reducer, gelling agent, acid gelling agent, or one or more crosslinkers in order to transport proppant into a hydraulic fracture.
Energized	Treatment type that incorporates an energizer, normally nitrogen or carbon dioxide, into the base fluid in order to generate foam that transports proppant into a hydraulic fracture.
Other/Unknown	Treatment type category that includes the following less common treatment types: Acid Frac, Gas Frac, Matrix Acidizing. This category also includes records for which a classification was unknown or unavailable, generally due to incomplete data

SPE 163875 - 2014

Fluid System Trends

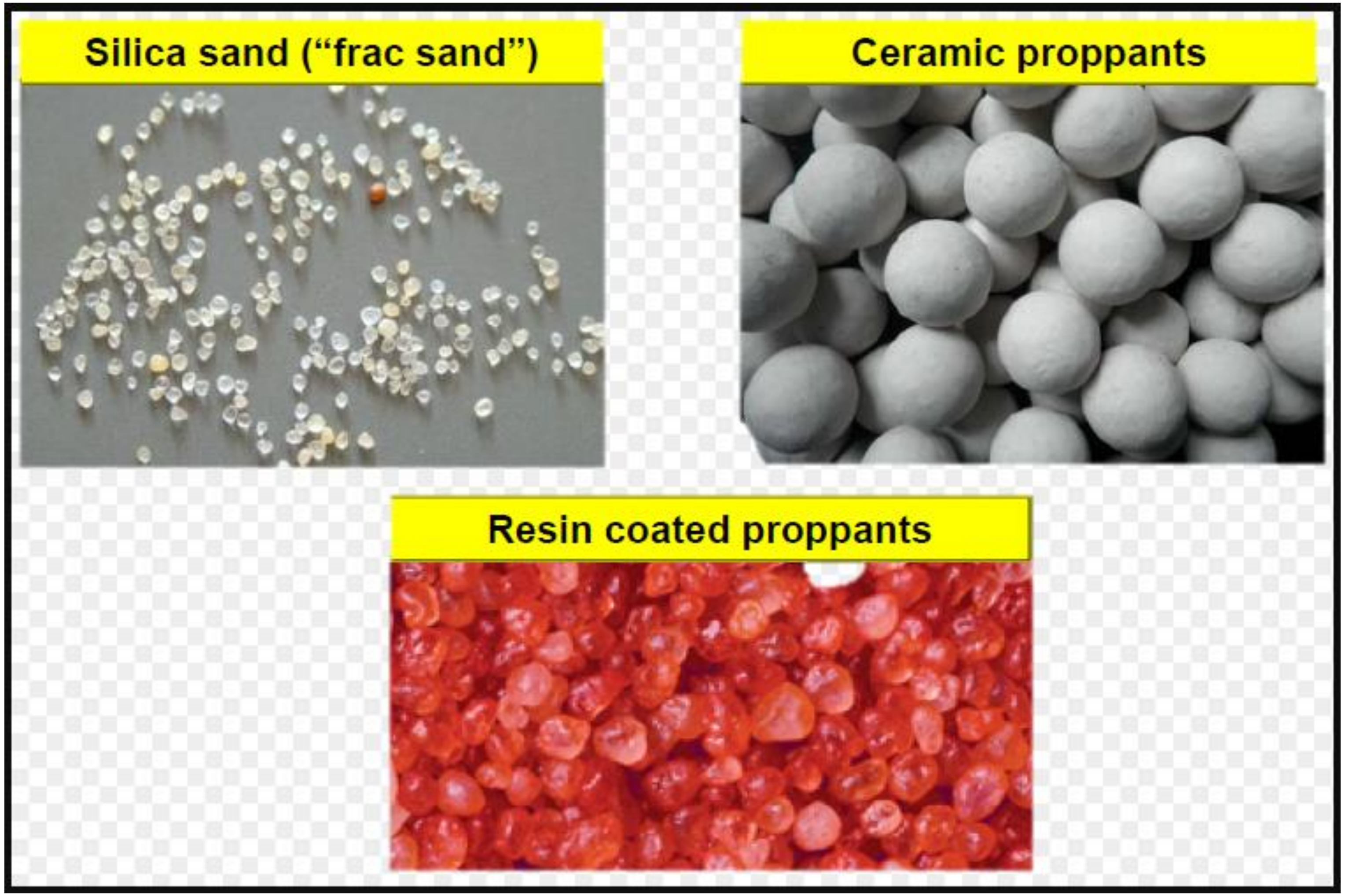


SPE 163875 - 2014

Hydraulic Fracturing Proppant (Sand)

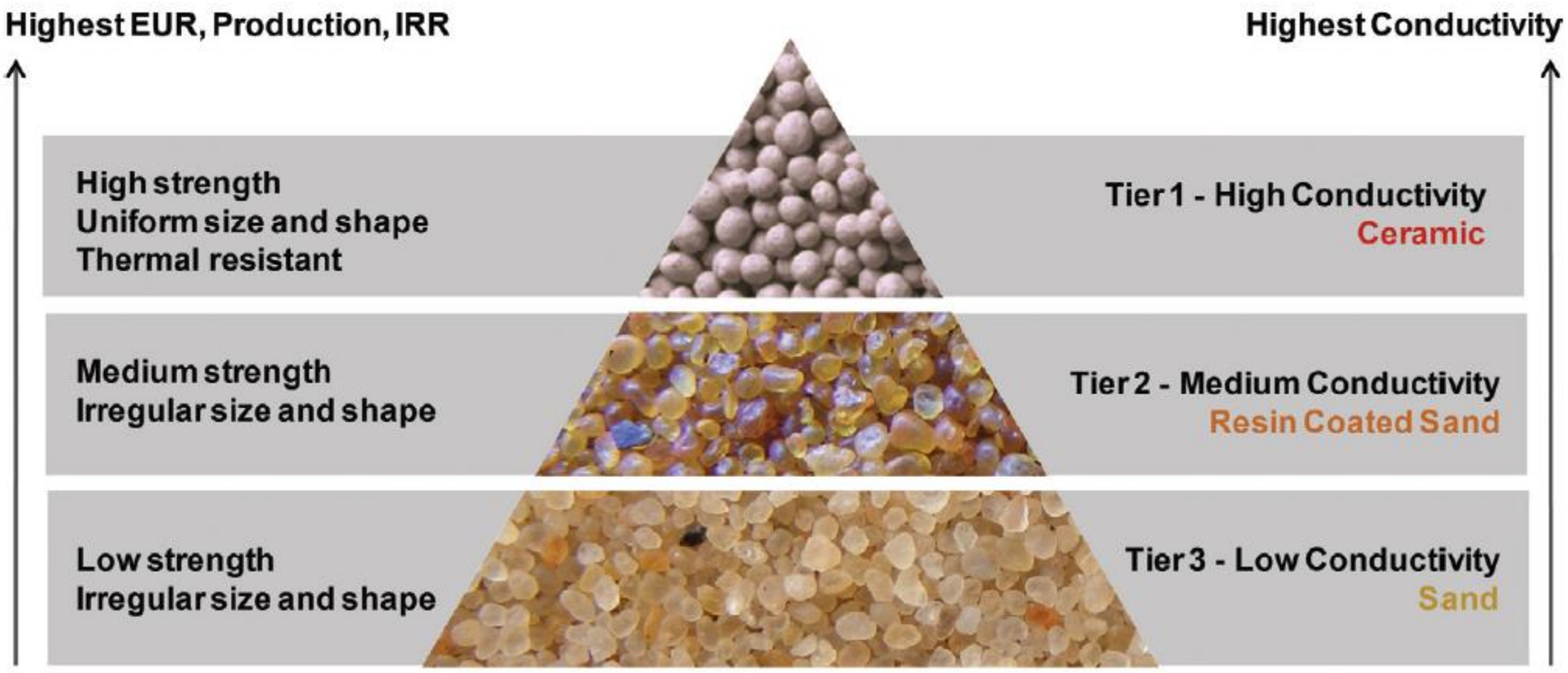
Source: Shutterstock.com

Fracturing Proppant



Barry Stephens, 2014

Fracturing Proppant

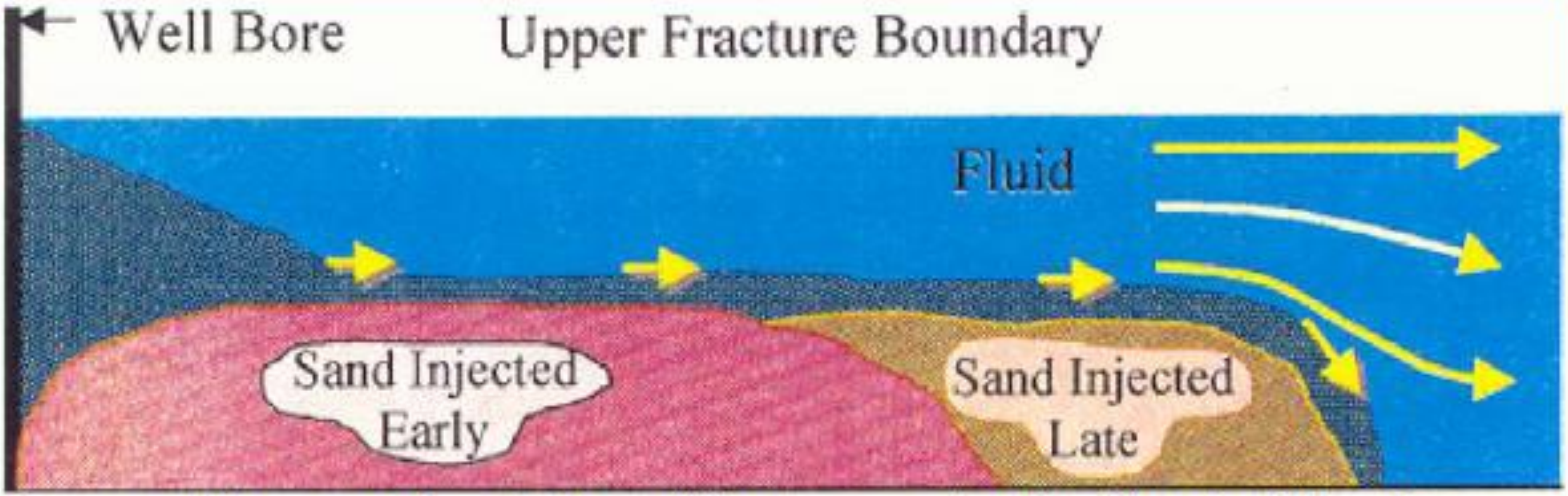


David G. Gallagher, JPT 2011

Typical Proppant Size

- 20-40 mesh (840 µm -420 µm)
- 30-50 mesh (590 µm – 300 µm)
- 40-70 mesh (420 µm - 210 µm)
- 70-140 mesh (210 µm - 105 µm)
- 100 mesh (149 µm)

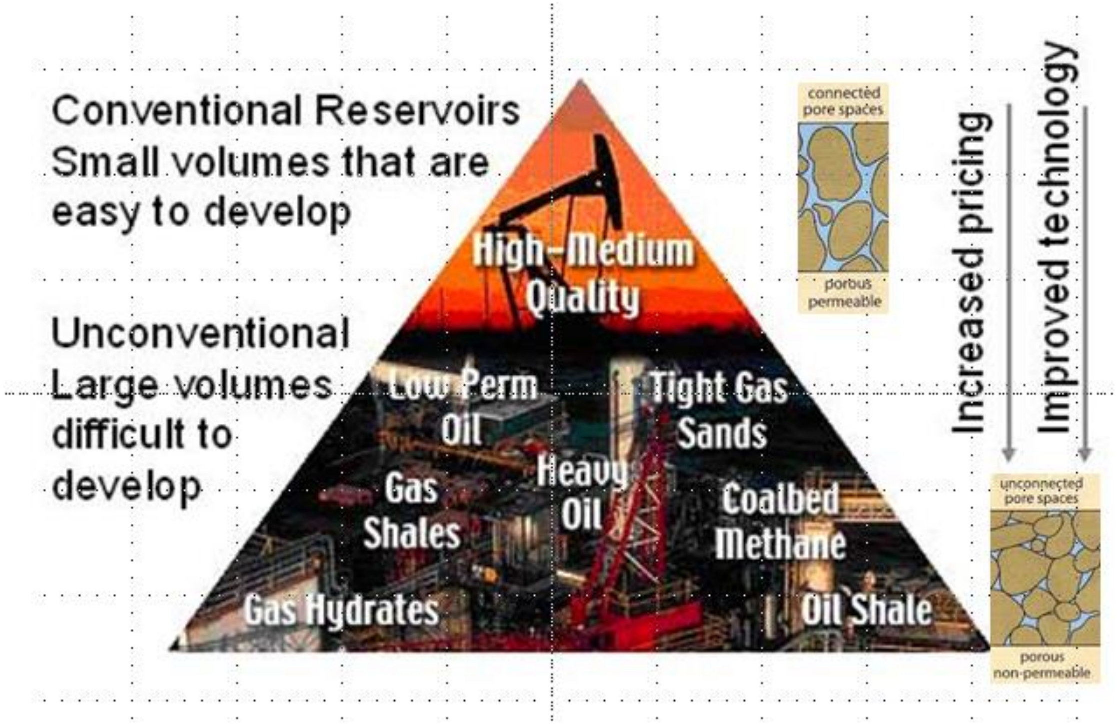
Proppant Transport

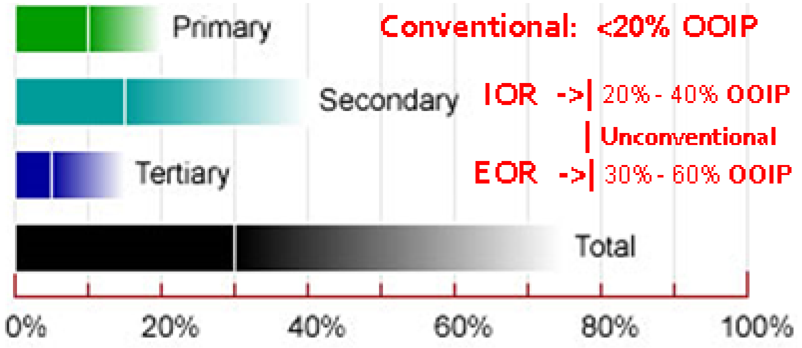


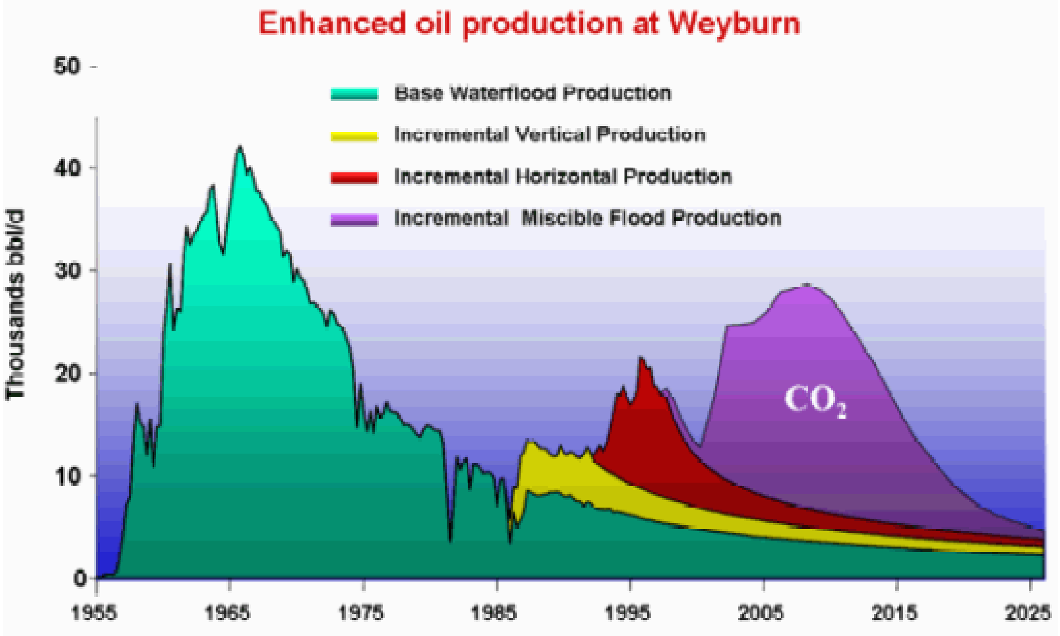
Proppant transport and deposition conceptualization by Patankar

Patankar, 2002, reported by Palisch, 2008, SPE 115766

Fracturing Conventional vs Unconventional







Barry Stephens, 2014

Fracture Monitoring

- Downhole gauges
  - Pressure/Rate
- Fiber optics
  - Flow rate/Temperature (every foot along the well) – even when the well is being frac'd
- Radioactive tracers are selected to have
  - the readily detectable radiation
  - appropriate chemical properties
  - and a half life and toxicity level that will minimize initial and residual contamination
  - radioactive isotopes chemically bonded to glass (sand) and/or resin beads may also be injected to track fractures
- Microseismic monitoring
  - Estimate fracture size and orientation (geophones placed in monitoring well) – mapping of seismic events locations – approximate fracture geometry
- Tiltmeteres (arrays placed on the surface or downhole)
  - Monitoring formation strain during fracturing

Other Use of Hydraulic Fracturing

- To stimulate groundwater wells
- To dispose waste by injection deep into rock
- To measure stress in the Earth
- To increase injection rates for geologic sequestration of CO_2

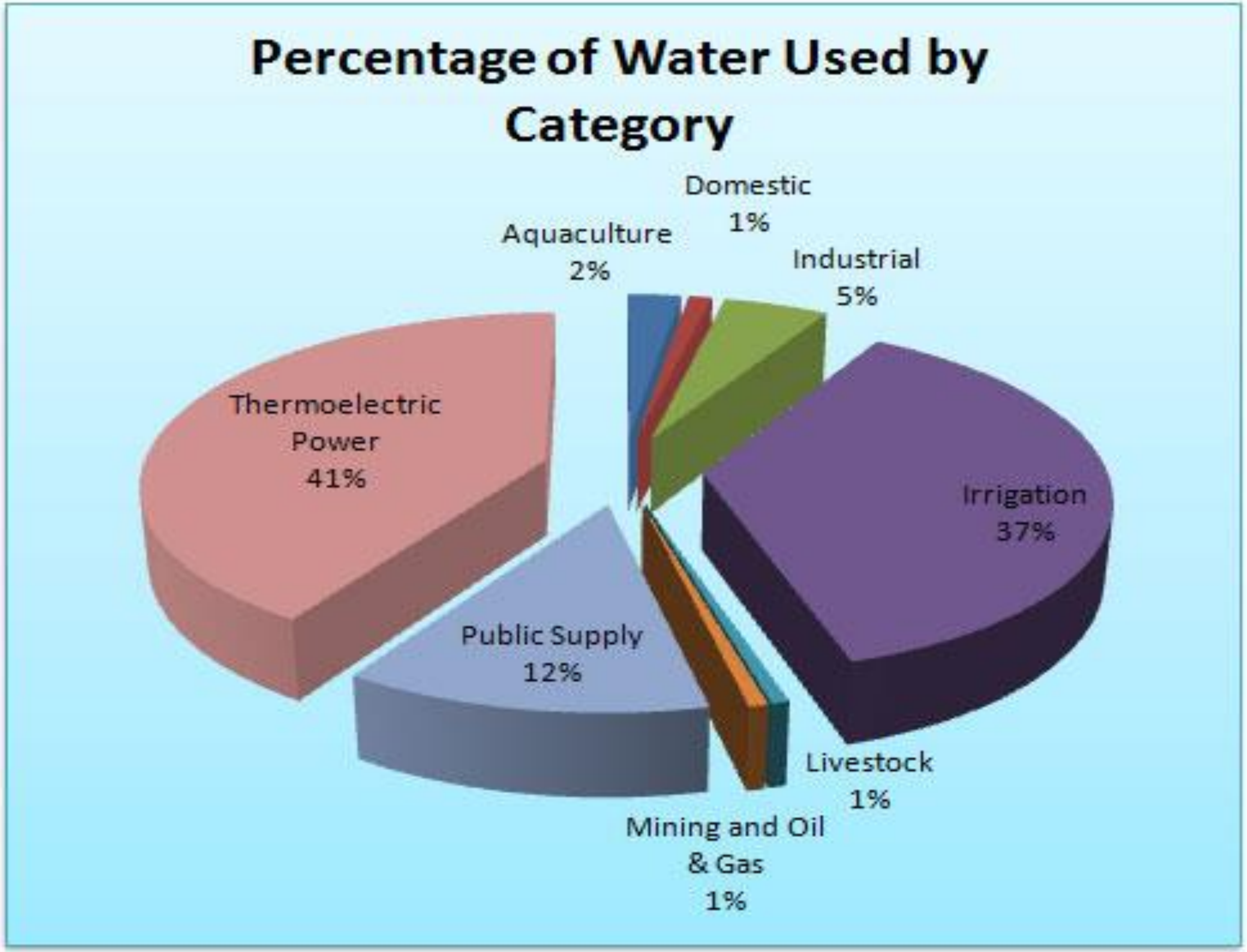
Challenges and Opportunities

- Surface handling of water & solids
- Slurry additives (food grades)
- HF treatment monitoring
- Cementing QC/QA
- Induced seismicity
- New technologies
  - Energized fractures
  - Reduced stimulation rate
  - Thermal treatments
- Reduction of treatment volume:
  - Increase fracturing efficiency
  - Flowback and forecasting improvement

Categories of Water Use

Source: https://water.usgs.gov/watuse/

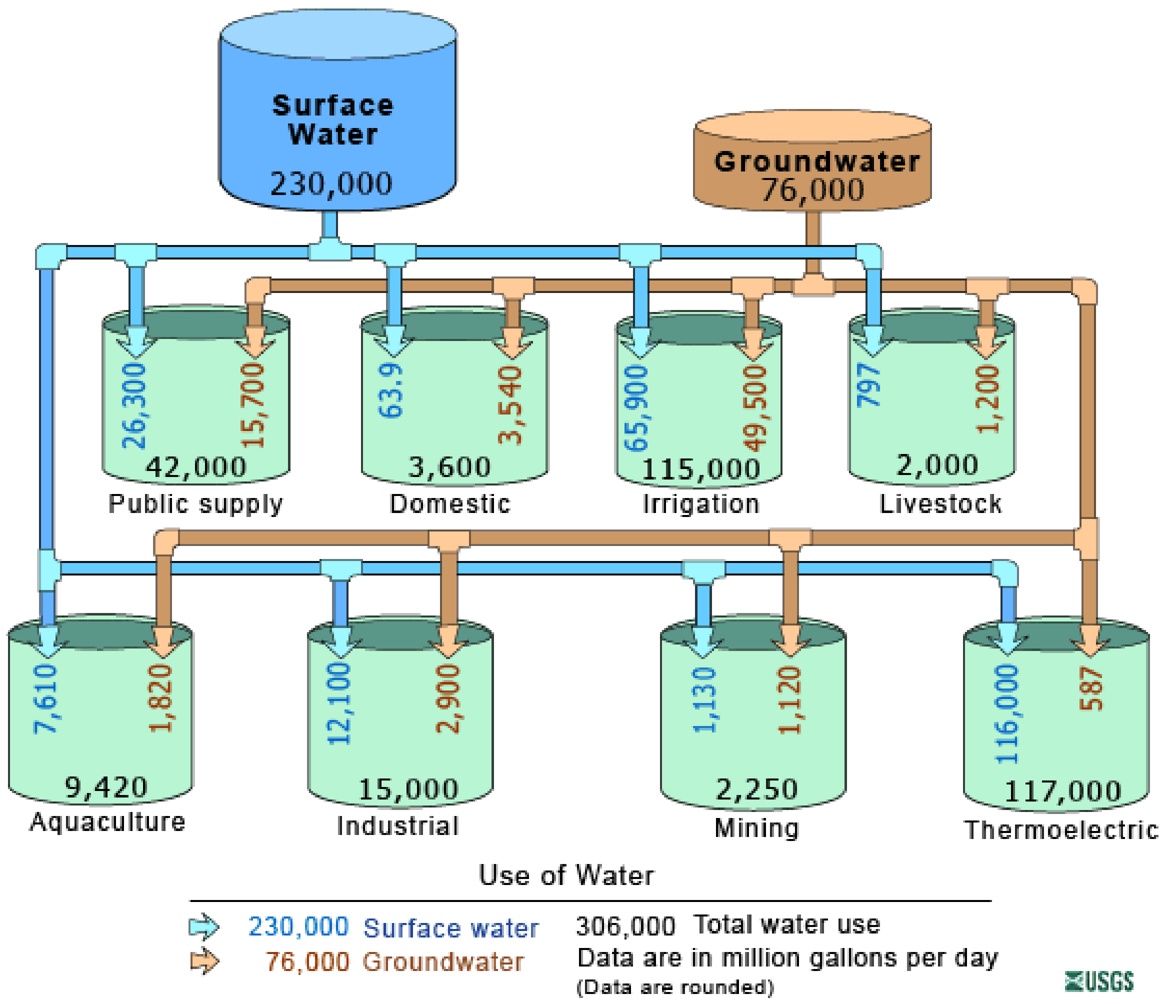
Water Use



Source: https://water.usgs.gov/watuse/

Water Use

Source and use of freshwater in the United States, 2010



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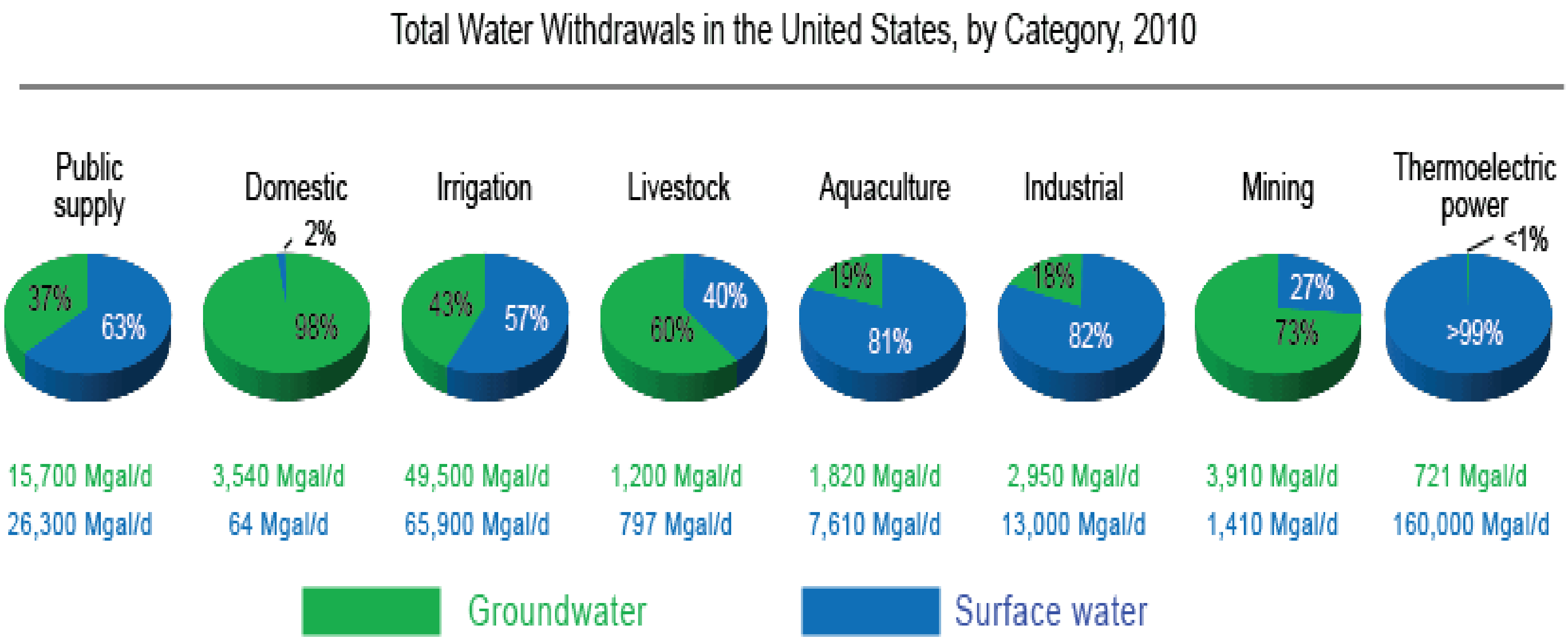
Water Use



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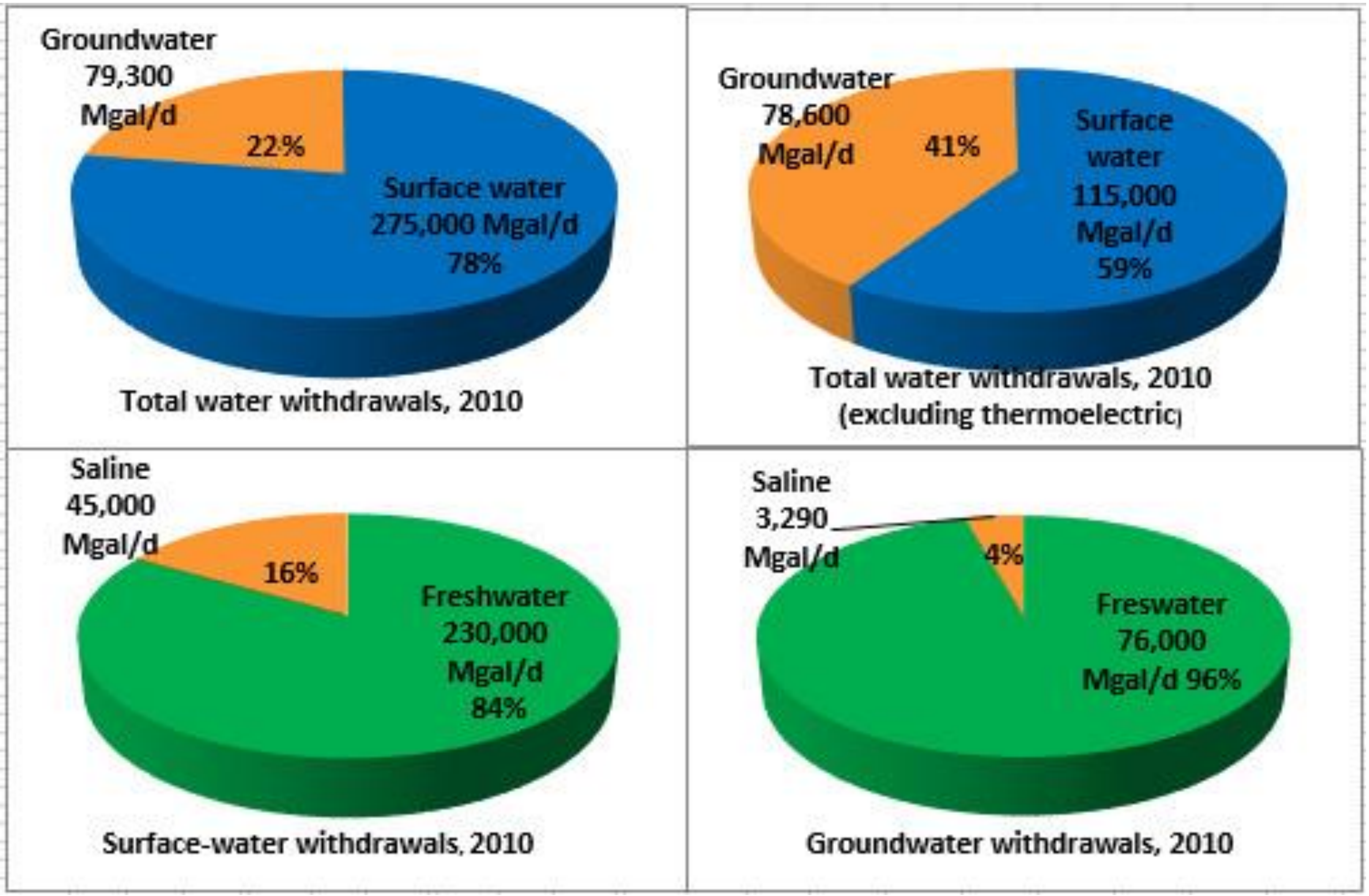
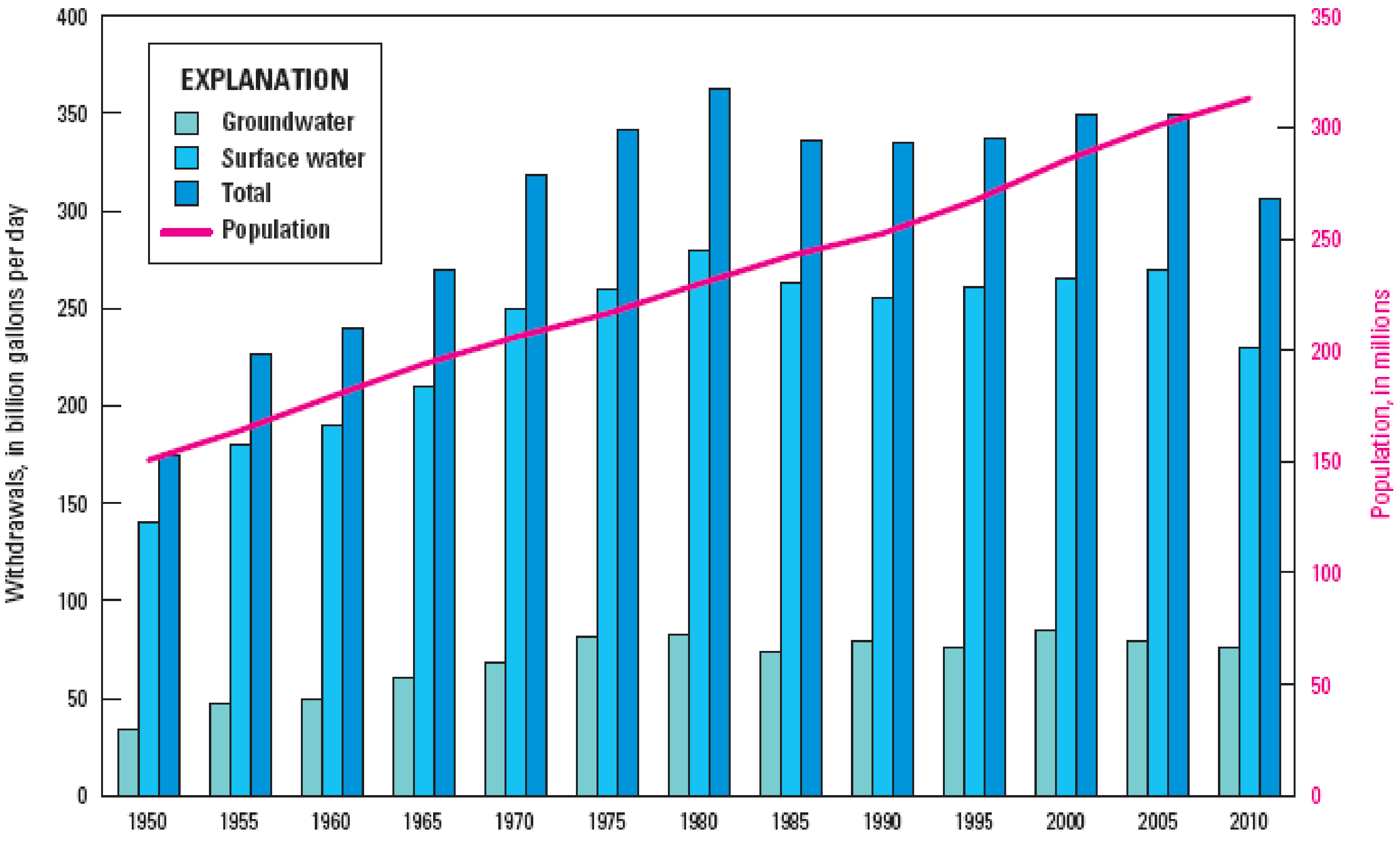
Water Use



Source: https://water.usgs.gov/watuse/

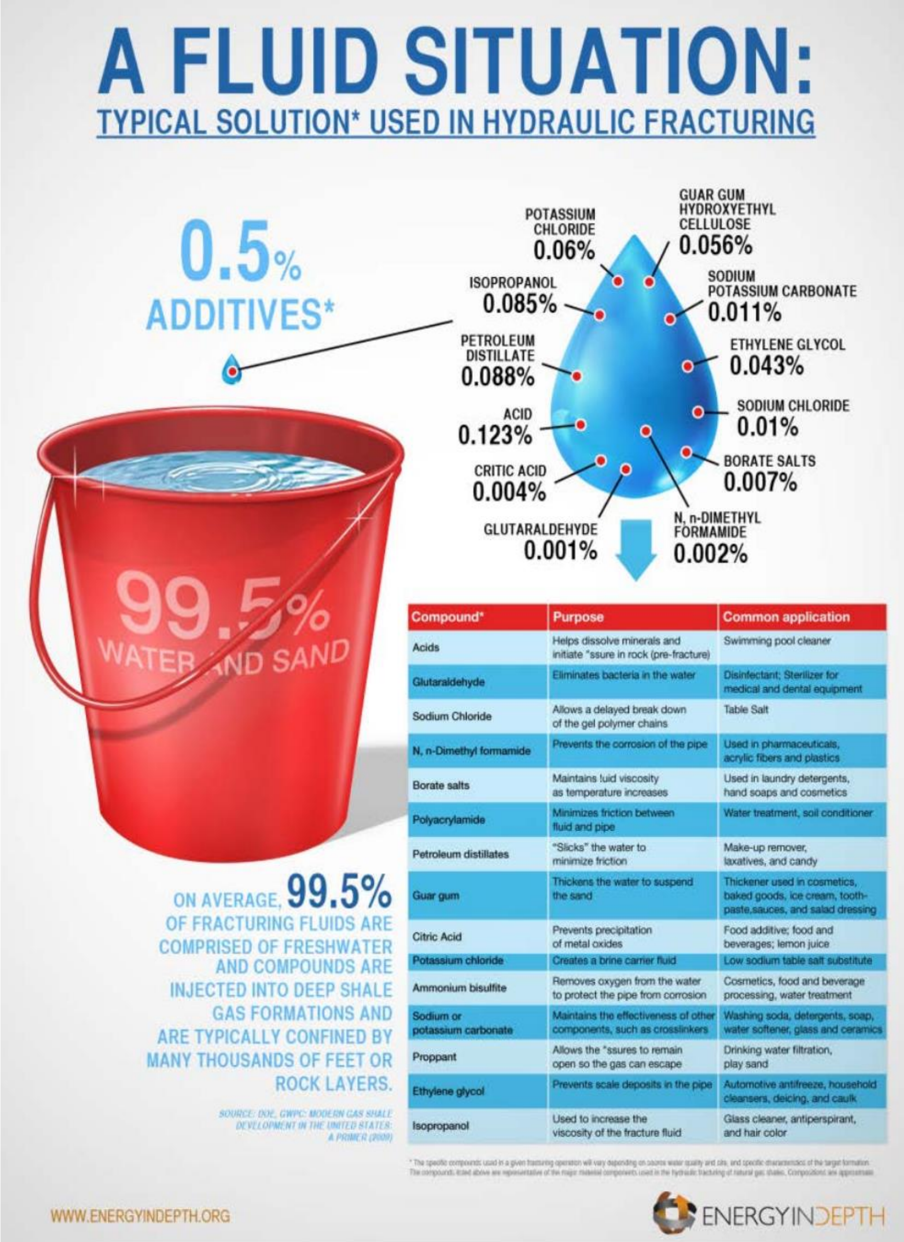
Water Use Trends



Trends in population and freshwater withdrawals by source, 1950–2010.

Source: https://water.usgs.gov/watuse/

Typical Hydraulic Fracturing Fluid System



Compound*	Purpose	Common application
Acids	Helps dissolve minerals and initiate "ssure in rock (pre-fracture)	Swimming pool cleaner
Glutaraldehyde	Eliminates bacteria in the water	Disinfectant; Sterilizer for medical and dental equipment
Sodium Chloride	Allows a delayed break down of the gel polymer chains	Table Salt
N, n-Dimethyl formamide	Prevents the corrosion of the pipe	Used in pharmaceuticals, acrylic fibers and plastics
Borate salts	Maintains !uid viscosity as temperature increases	Used in laundry detergents, hand soaps and cosmetics
Polyacrylamide	Minimizes friction between fluid and pipe	Water treatment, soil conditioner
Petroleum distillates	"Slicks" the water to minimize friction	Make-up remover, laxatives, and candy
Guar gum	Thickens the water to suspend the sand	Thickener used in cosmetics, baked goods, ice cream, tooth-paste,sauces, and salad dressing
Citric Acid	Prevents precipitation of metal oxides	Food additive; food and beverages; lemon juice
Potassium chloride	Creates a brine carrier fluid	Low sodium table salt substitute
Ammonium bisulfite	Removes oxygen from the water to protect the pipe from corrosion	Cosmetics, food and beverage processing, water treatment
Sodium or potassium carbonate	Maintains the effectiveness of other components, such as crosslinkers	Washing soda, detergents, soap, water softener, glass and ceramics
Proppant	Allows the "ssures to remain open so the gas can escape	Drinking water filtration, play sand
Ethylene glycol	Prevents scale deposits in the pipe	Automotive antifreeze, household cleansers, deicing, and caulk
Isopropanol	Used to increase the viscosity of the fracture fluid	Glass cleaner, antiperspirant, and hair color

Source: https://water.usgs.gov/watuse/

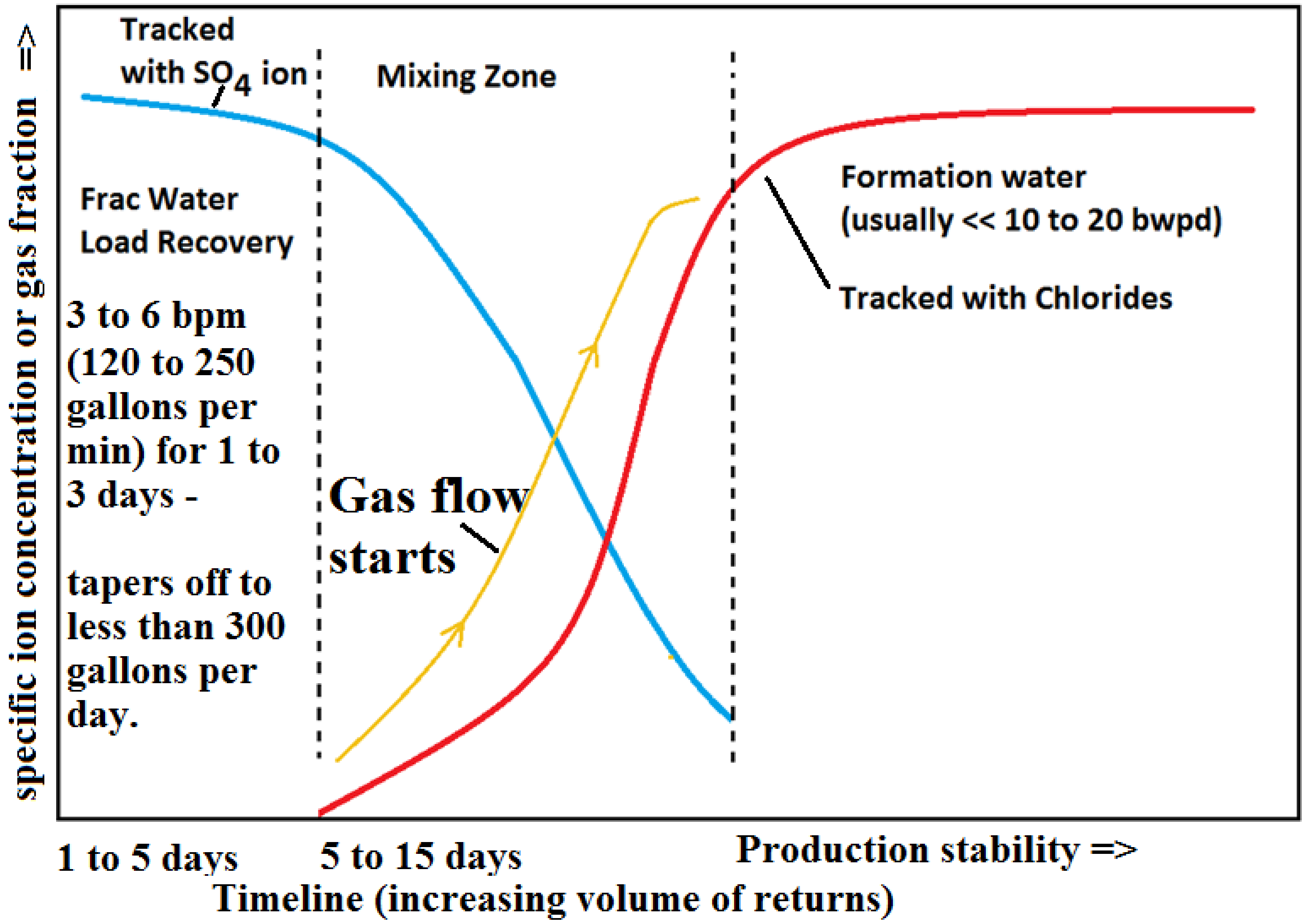
How Much Water Does US Fracturing Really Use?

Study finds that **Water used in fracking makes up less than one percent of total industrial water use nationwide**

Energy companies *used nearly 250 billion gallons of water to extract shale gas and oil from hydraulically fractured wells in the US between 2005 and 2014*, a new study finds. During the same period, *the fracked wells generated about 210 billion gallons of wastewater*. As large as those numbers seem, the study calculates that the water used in fracking makes up less than one percent of total industrial water use nationwide

Source: Duke University Study – Sept. 15, 2015

Tracking Flow Back



George King Training 2017

Produced & Brine Water Sources

Water Type	Total Dissolved Solids (TDS)
	PPM
Fresh	< 1000
Brackish (can be used)	1000 – 3000
Brackish High	5000 – 15000
Saline	15000 - 30000
Sea water	30000 - 50000
Brine	40000 – 300000 +

Modified from George King SPE – GCS Oct. 27, 2011

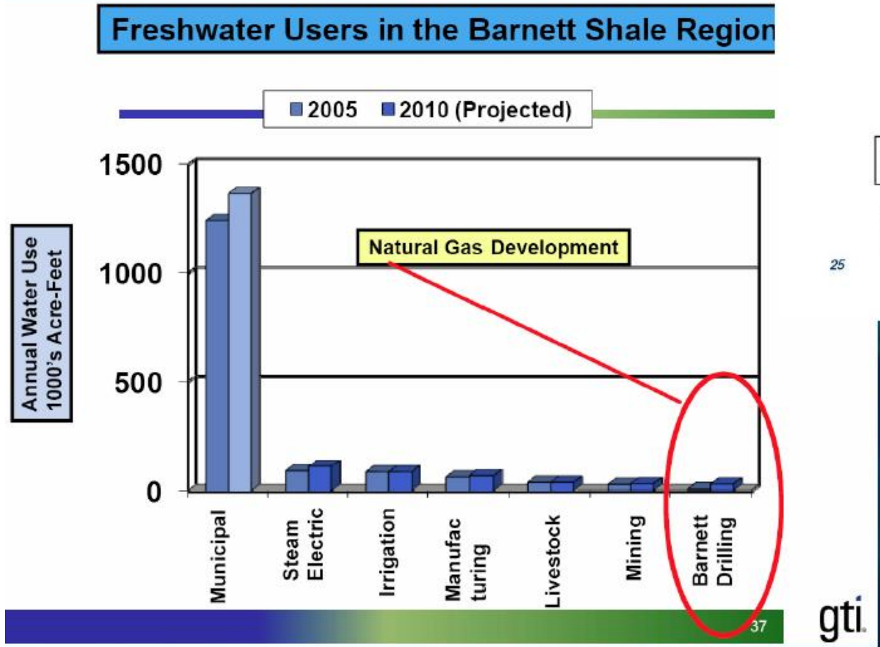
Water Management:
Quantities Flowed Back in Shale Reservoirs (Ranges)

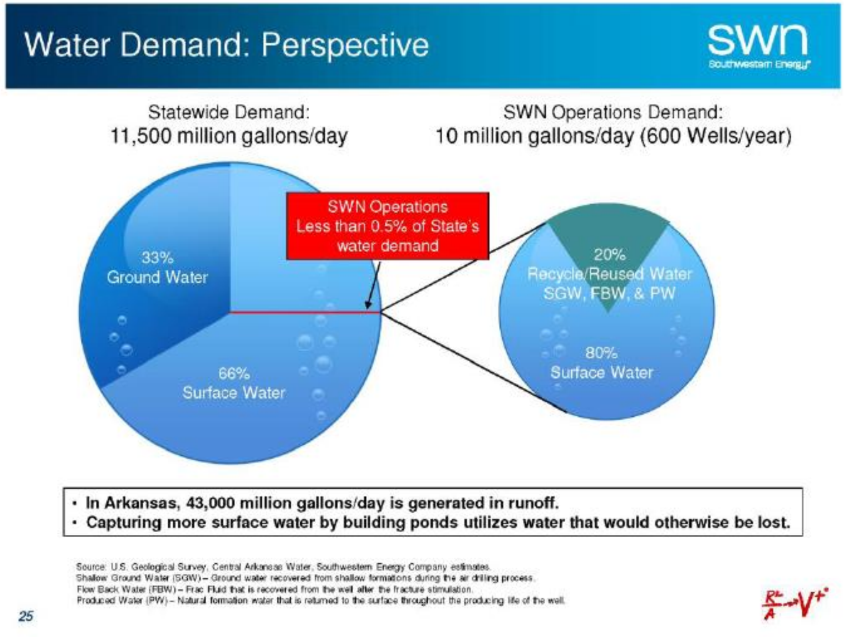
Basin or Area	% Frac Water Recovered	Typical Frac Volume Used (Gal.)	Typical Chemical % in Frac	Chemical % in Flowback (Gross Est.)
Barnett	30 to 50%	4 to 5 mm	0.2%	<0.05%
Devonian	40 to 50%	4 to 5 mm	0.2%	<0.1%
Eagle Ford	5 to 10%	4 to 5 mm	0.3 to 0.4% (Hybrid Frac)	<0.2% (polymer dominated)
Fayetteville	30 to 60%	3 to 4 mm	0.2%	<0.05%
Haynesville	5 to 15%	4 to 6mm	0.3% (Hybrid Frac)	<0.1% (polymer dominated)
Horn River	30 to 50%	10 to 12mm (95% from salt water supply wells)	<0.1% (Apache)	<0.05%
Woodford	30 to 50%	4 to 5 mm	0.2%	<0.05%

Sources: SPE 133456, SPE 152596, George E. King's communication with operators in these basins. Also SPE papers on produced water treating.

Water Use and Management

- Water requirements for fracture stimulation low relative to other users.

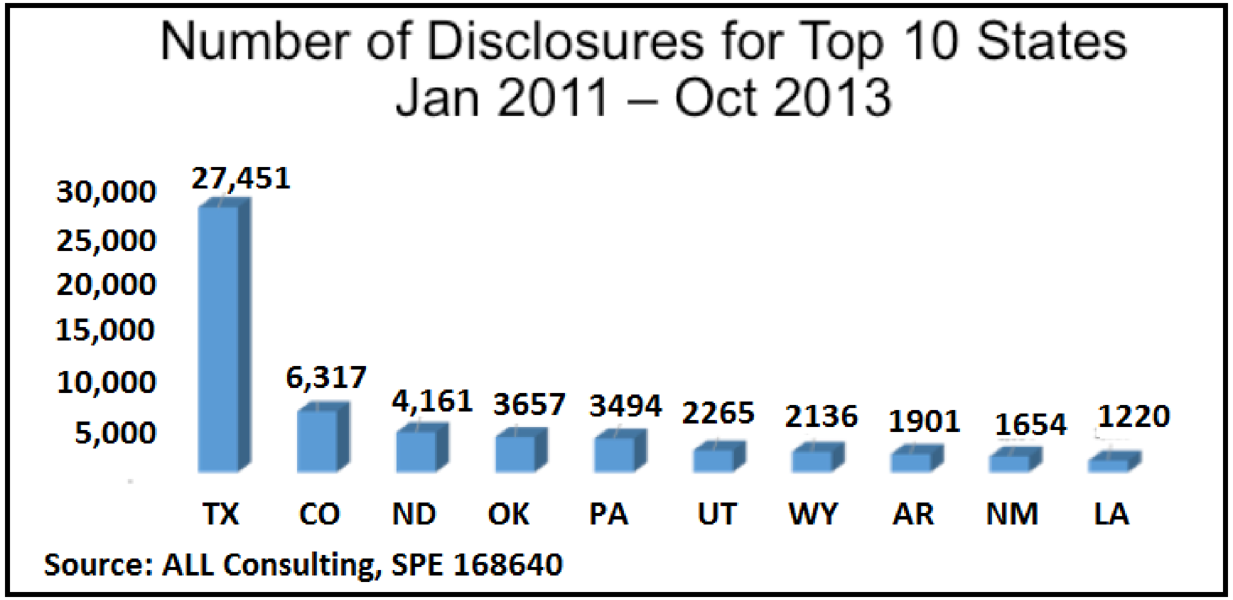


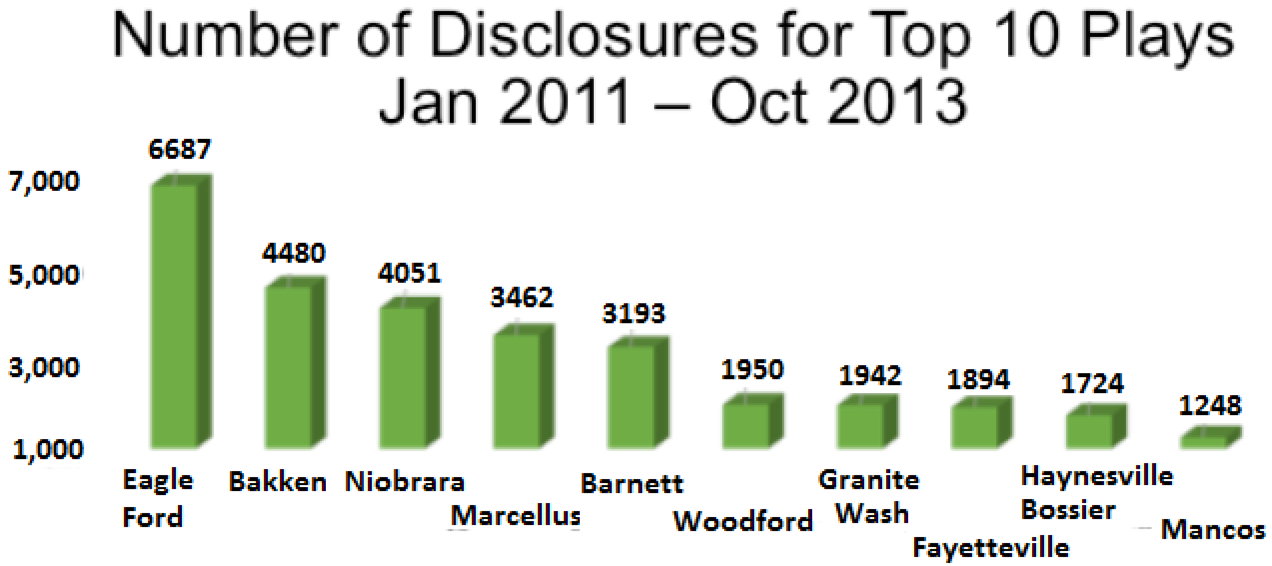


- Recover < 50% of injected fluids during flow-back.
- Disposal is the big issue.

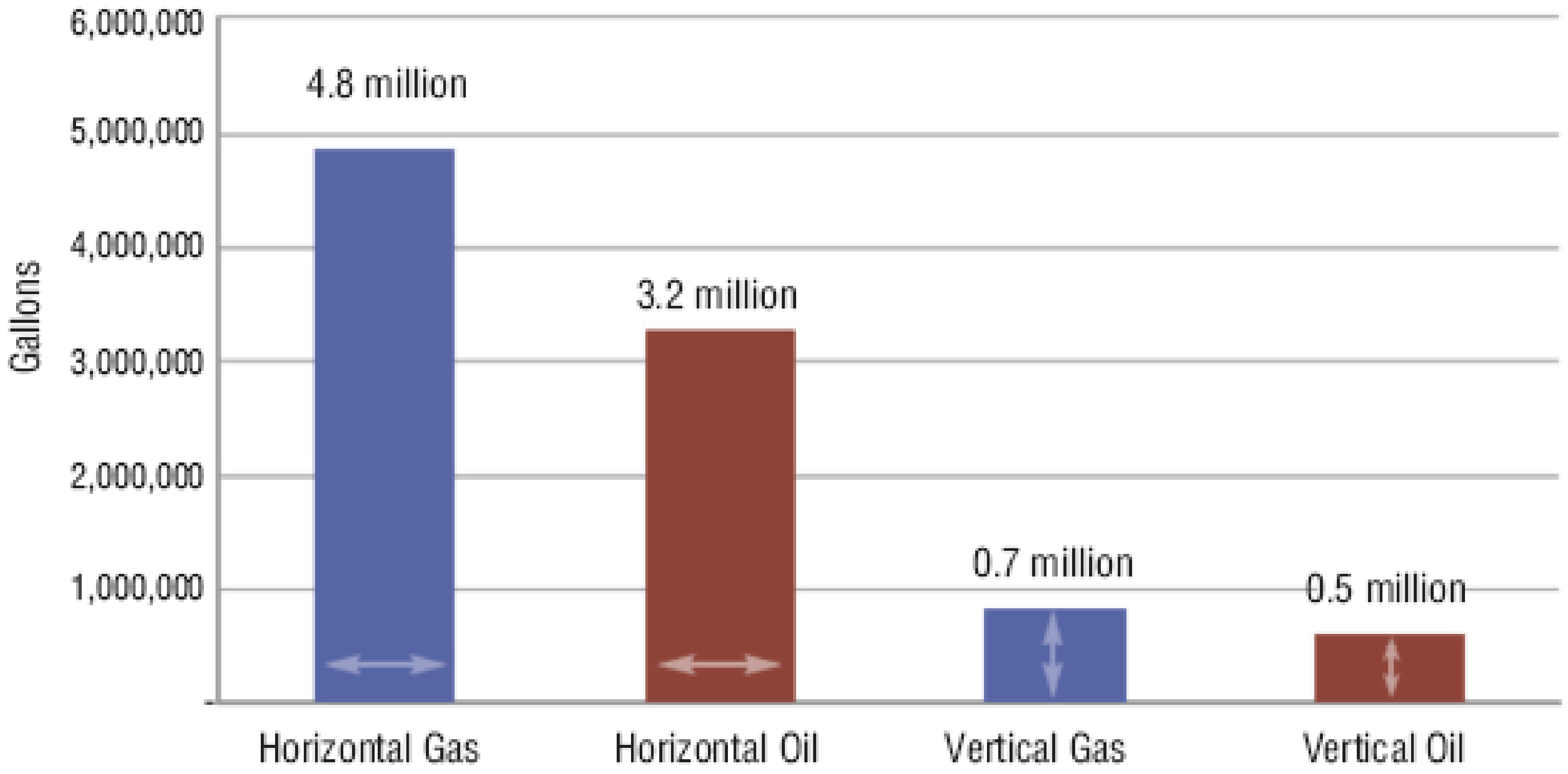
Source: Water Demand chart from Southwestern Energy website. Freshwater users chart Natural Gas:The Path to Clean Energy Forum Hydraulic Fracturing a Historical and Impact Perspective, Kent_Perry GTI 2010

Where Are We Fracturing?





Water Usage (Processed) – Permian Basin

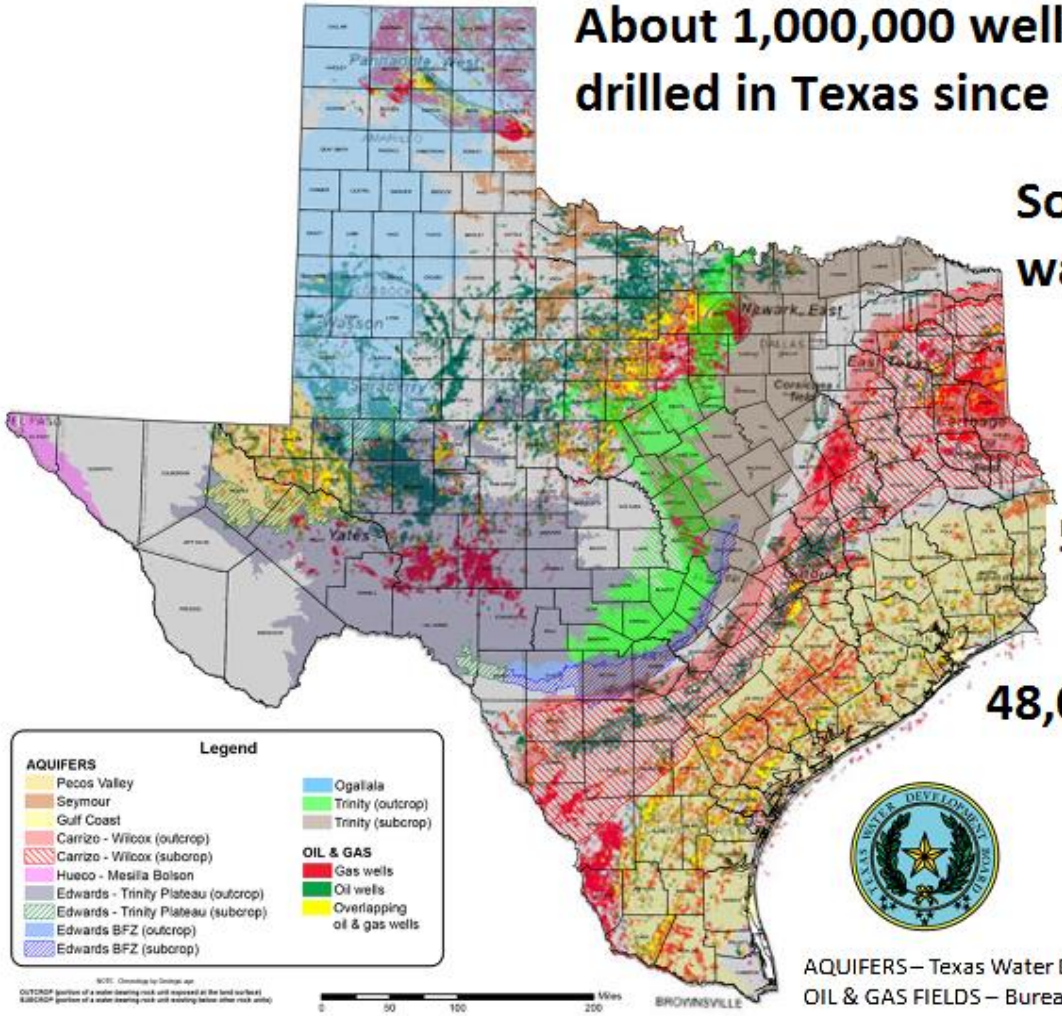


JPT December 2015

Typical Water and Fracture Tops From > 4000 fracs

Fracture Height-Growth Limits in Four Major U.S. Shale Plays (*Fisher, 2011*)					
Shale	Number of fracs with micro-seismic data	Primary Pay Zone Depth Range	Typical Water Depth and (Deepest)	Typical Distance Between Top of Fracture and Deepest Water	Closest Approach of Top of Frac in Shallowest Pay to Deepest Water
Barnett (TX)	3000+	4700’ to 8000’	500’ (1200’)	4800’	2800’
Eagle Ford (TX)	300+	8000’ – 13,000’	200’ (400’)	7000’	6000’
Marcellus (PA)	300+	5000’ to 8500’	600 (1000)	3800’	3800’
Woodford (OK)	200+	4400’ – 10,000’	200 (600)	7500’	4000’

Drilling, Fracturing and Injection



About 1,000,000 wells drilled in Texas since 1866

Some of longest standing fresh water protection regulations in US.

250,000 producing wells

500,000 fracturing jobs since 1950

48,000 injection & disposal wells

AQUIFERS – Texas Water Development Board
OIL & GAS FIELDS – Bureau of Economic Geology, UT Austin

Treating the Water

Treating the produced water consists on the removal of:

- Suspended solids,
- Gas and liquid hydrocarbons,
- Treating H_2S and CO_2 in a few areas
- Bacteria

Water Recycling

Recycled Water - Quality Standards

TABLE 2—QUALITY STANDARDS FOR RECYCLE WATER	
Parameter	**Range**
TDS at 180°C, mg/l	9,000–16,000
Turbidity, NTU	0–5
pH	6.5–8
Iron, mg/l	1–10
Chloride, mg/l	5,000–10,000
Potassium, mg/l	100–500
Calcium, mg/l	50–250
Magnesium, mg/l	10–100
Sodium, mg/l	2,000–5,000
Boron, mg/l	0–20

Oil & Gas Facilities - 2012

Water Processing

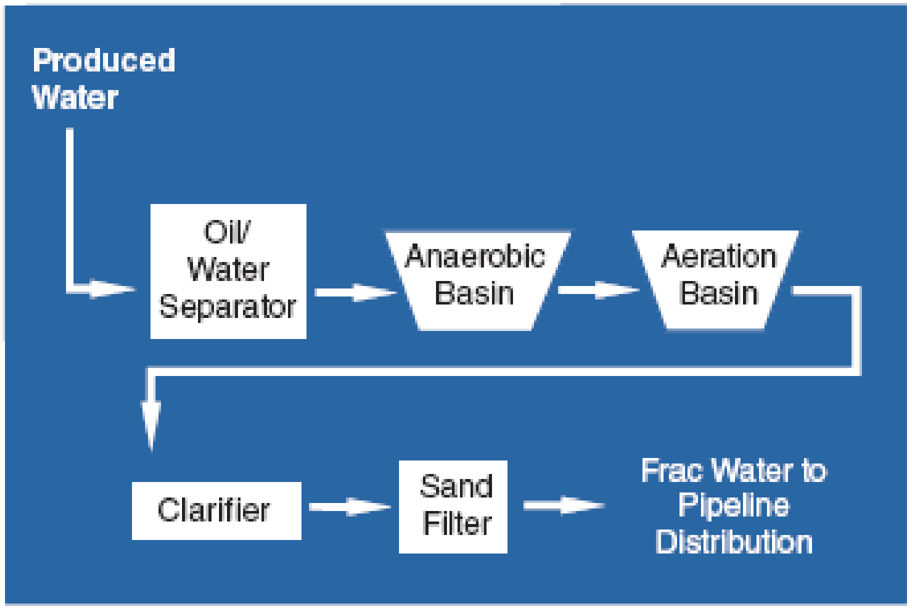


Fig. 1—Simplified fracture water process used in the

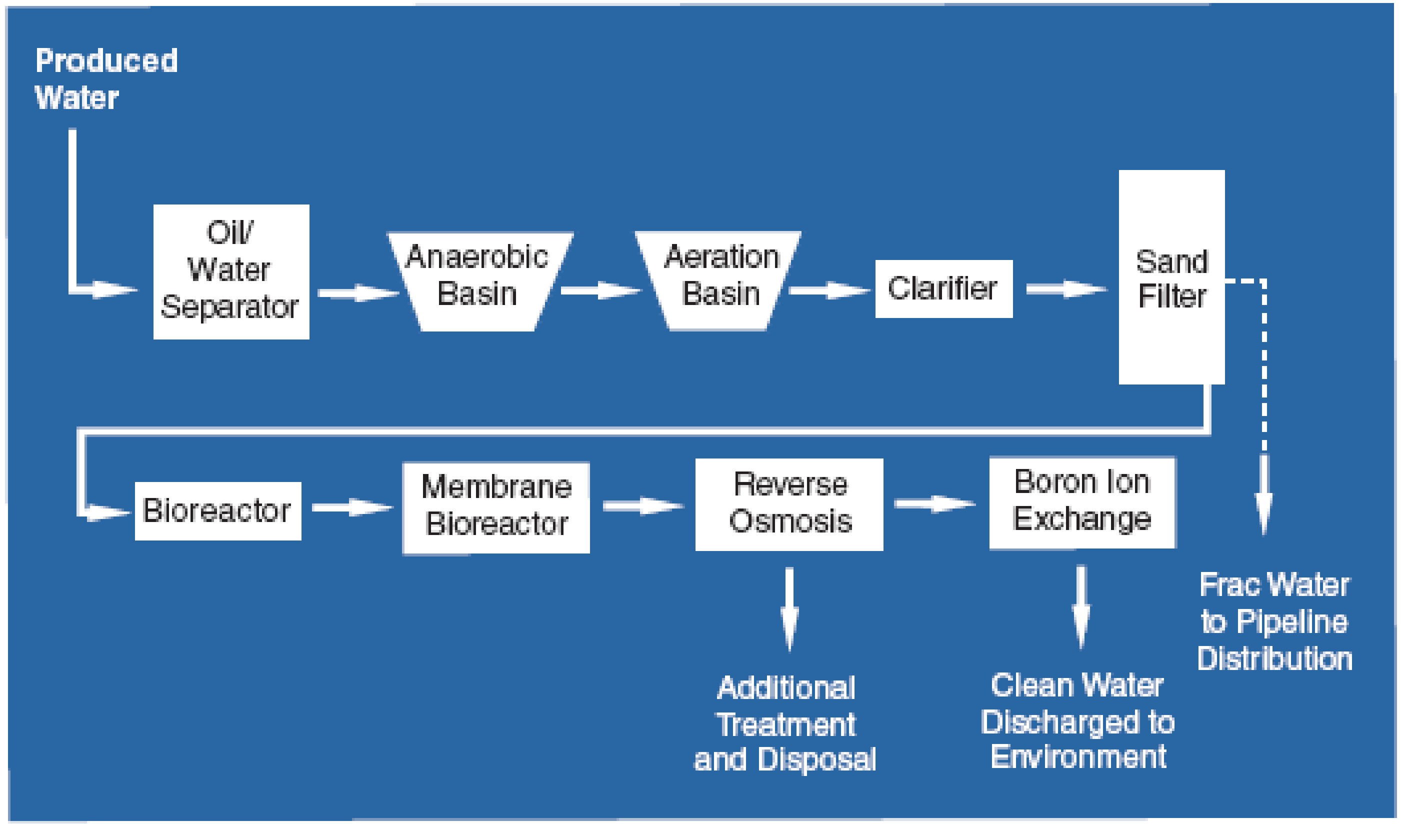
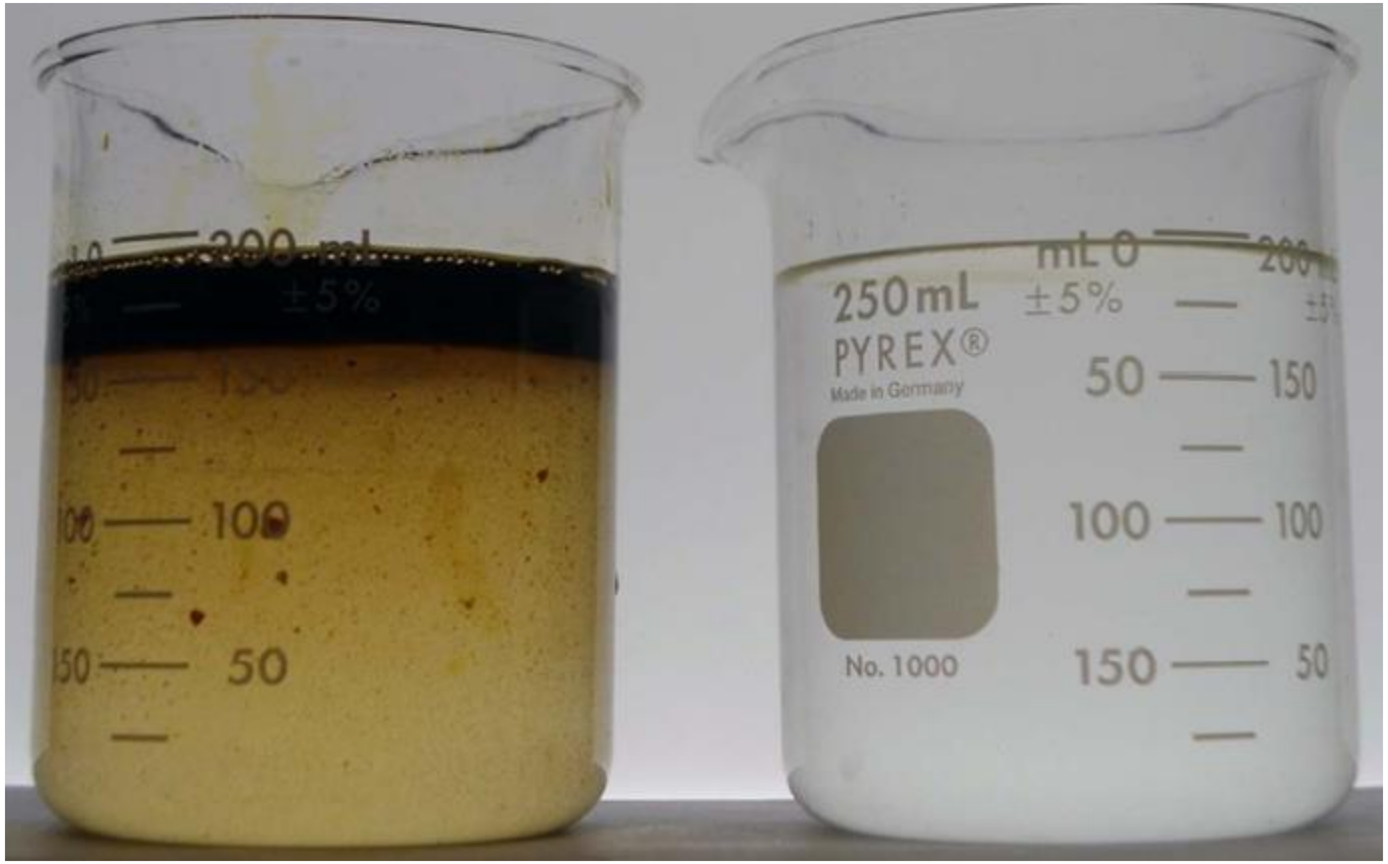


Fig. 2—Discharge water process used in the Pinedale Anticline field.

Oil & Gas Facilities - 2012

Water Processing/Treatment – Electro Coagulation (EC)



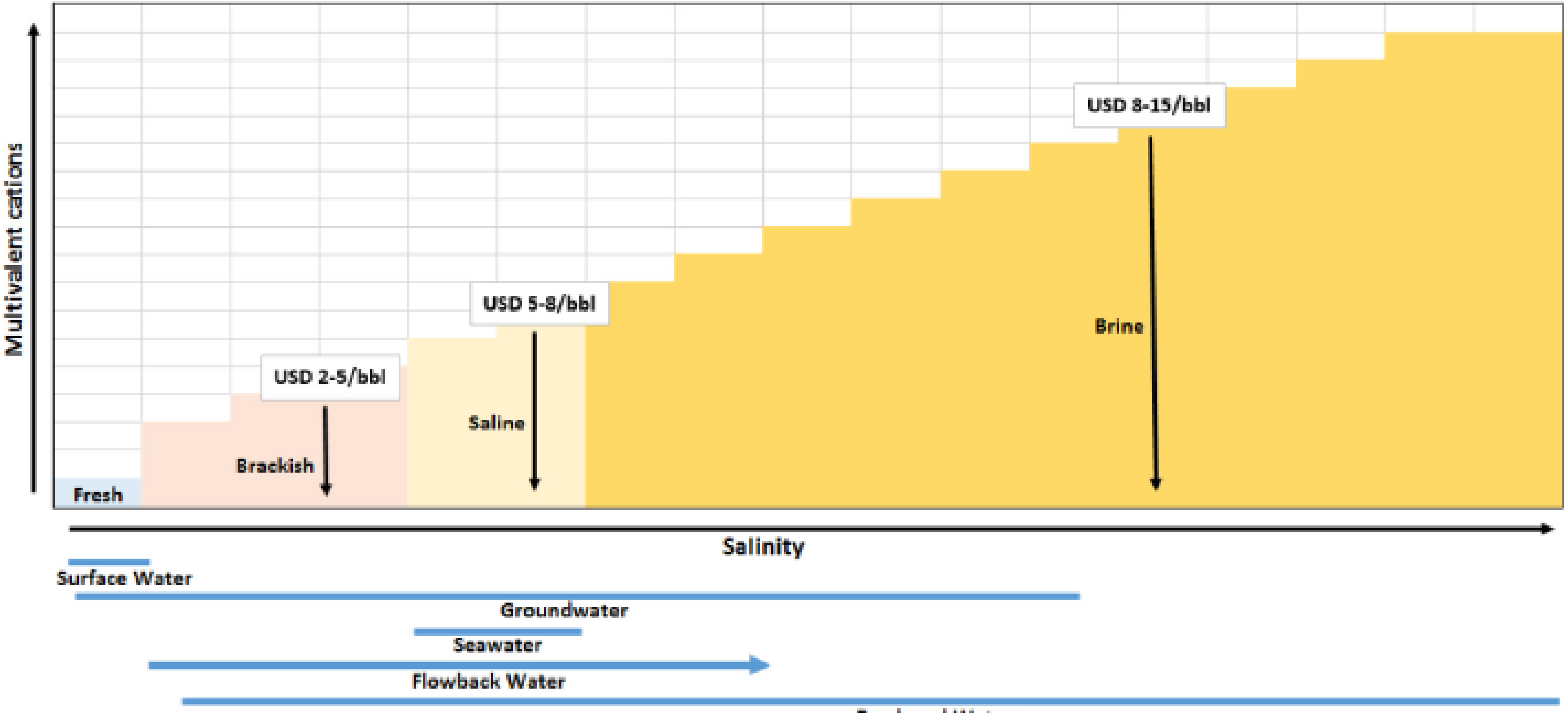
SPE 163824

Water Handling Costs

TABLE 1—BAKKEN FIELD WATER-HANDLING COSTS	
Acquisition Costs	**Cost, USD/bbl**
Raw Water	0.25–1.75
Transportation	0.63–5.00
Disposal Costs	
Transportation	0.63–9.00
Deep-well Injection	0.50–1.75

Oil & Gas Facilities - 2012

Water Treatment Costs



SPE 178699 MS/URteC - 2173887

Salt Water (Oilfield Brine) Disposal Wells

- Even recycling, which involves some type of evaporation or distillation, can’t give 100% return so disposal of salt water and solids needs to be injected in the disposal wells
- Underground injection in porous rock sealed above and below by unfractured impermeable layers
- Regulated by the Texas Railroad Commission which implements certain rules to protect groundwater
- Construction of multiple layers (3: surface casing, production casing, injection tubing) of casing and cement
- Injection at depths over 1 mi (2mi in the Barnett shale)
- ~ 50000 SWD’s in Teaxas
- No ground water contamination recorded in Barnett, the state’s largest natural shale gas producing formation (since 1997)

JPT January - 2018

Permian Basin Water Demand & Salt Water Disposal Wells

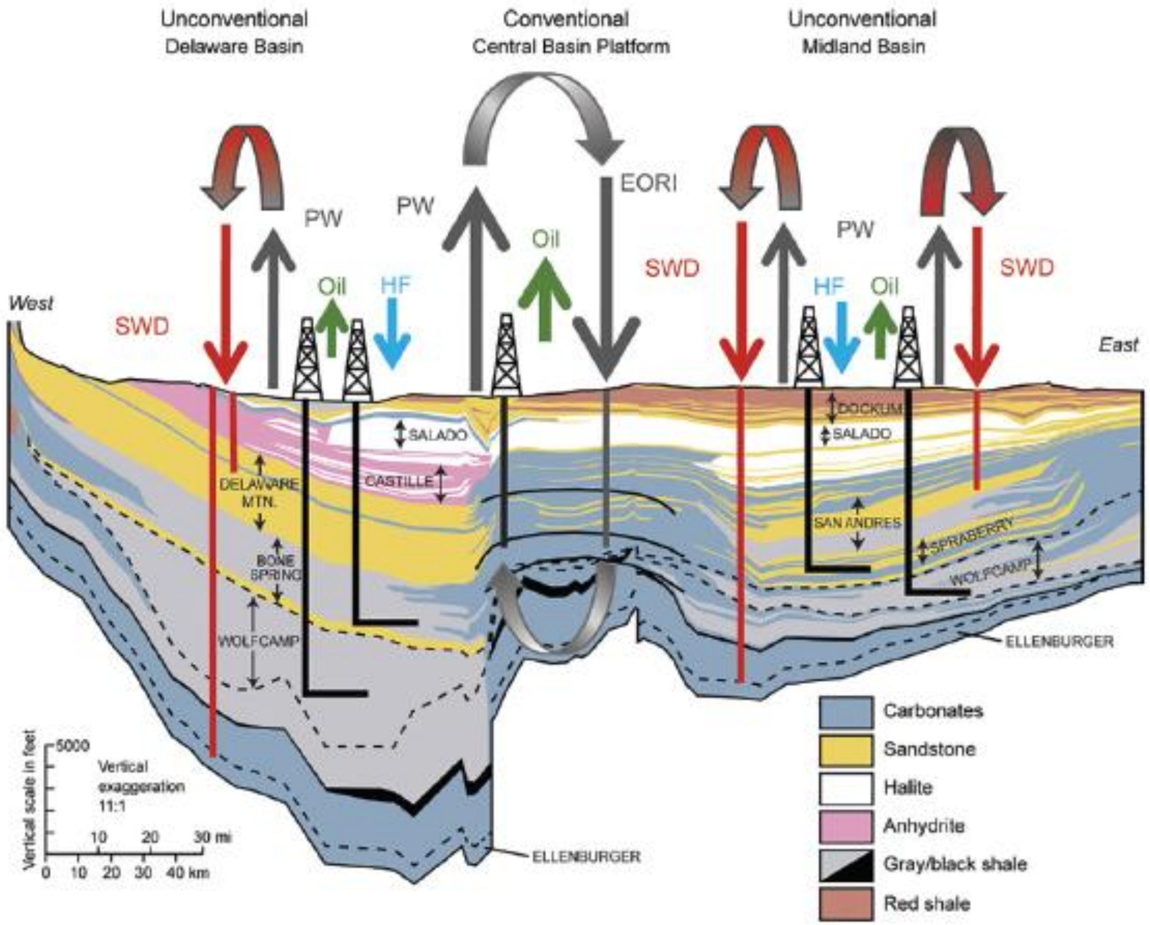


Fig. 1—An east-west cross section along the southern margin of the Permian Basin shows thicker reservoirs in the Delaware than in the Midland. Operators in the Midland may seek to drill deeper SWD wells into the Ellenburger unit, requiring further capital investment. PW=produced water, HF=hydraulic fracturing, EORI=enhanced oil recovery injection, SWD=saltwater disposal.
Source: Scanlon and Reedy et al. (2017).

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