
Recycling and Re-Using Produced Water: Cutting Edge Technology Adapted for New Water Resources

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The Environmentally Friendly Drilling Program



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Burnett Frequently Asked Questions

What is shale and what is HF?

What are some environmental problems that have been associated with HF?

Earthquakes (**yes**), H₂S in groundwater (**possible**) CH₄ in groundwater (**maybe, but often no**)

HF injection fluids in groundwater (no? but flowback, yes or no?)

Is Produced Water Dangerous? (**About like Seawater**)

Two to Three times saltier

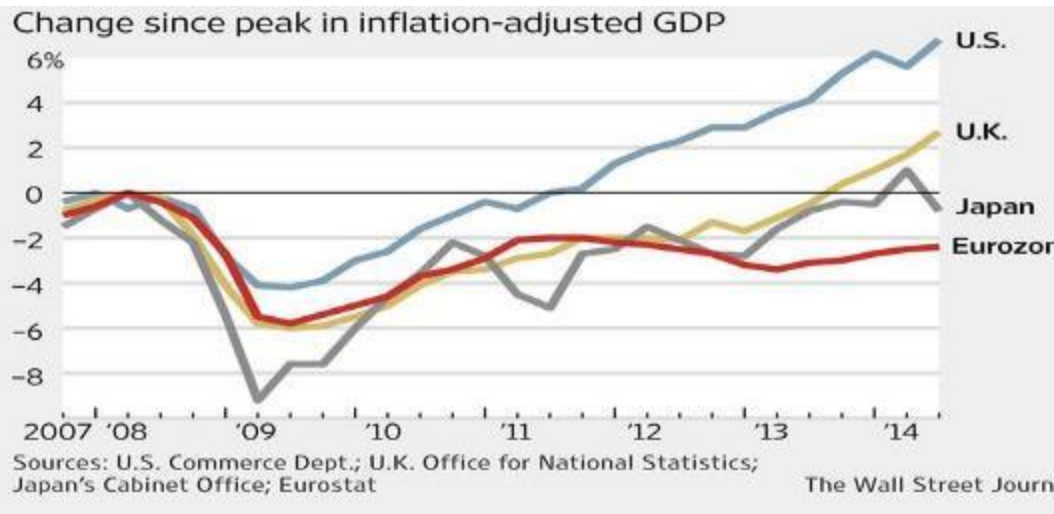
May contain hydrocarbon oils

Harmful to plants

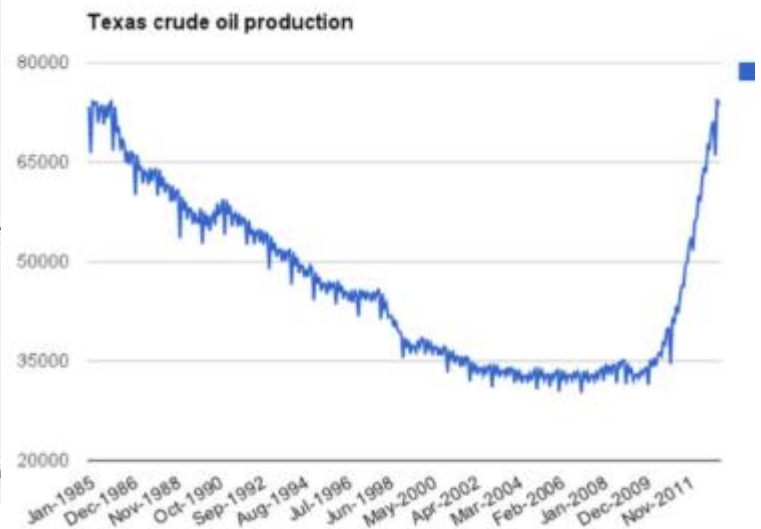
Best argument *for* HF? Best argument *against* HF?

Unconventional Shale Gas Saved America

The EU Left Behind



USA World Leader



An Argument *for* HF!

For more Info see:

<http://www.washingtontimes.com/news/2014/oct/18/moore-oil-the-real-economic-stimulus/#!#ixzz3Gh561bVA>

Arguments Against

Concerns about Water Resource Uses

Concerns about Ground Water Contamination

Concerns about Land Use (Access)

Concerns about Emissions

Other

Lack of Infrastructure

Public/policy Demands (environmental & perception** Issues)**

2. Water Use; Eagle Ford Shale Well & a City of 4,000 Population

Water Usage	Well Operations	City Operations(1)	Comments
Water Usage	10 million gal	18 million gal (3 mo.)	5-6 mm gal frac. 1-2 mm gal well ops.
Power Use	7,500 HP	6 MW (8,000 Hp)	Avg. SCR rig
Solid Waste	100,000 lbs. (wbm, 10,000 ft well)	1,600,000 lbs (3 months)	3 mo. Ops. MSW highly variable
Unit Budget	\$2 to \$5 MM	~\$1.7 MM	3 mo. Ops.

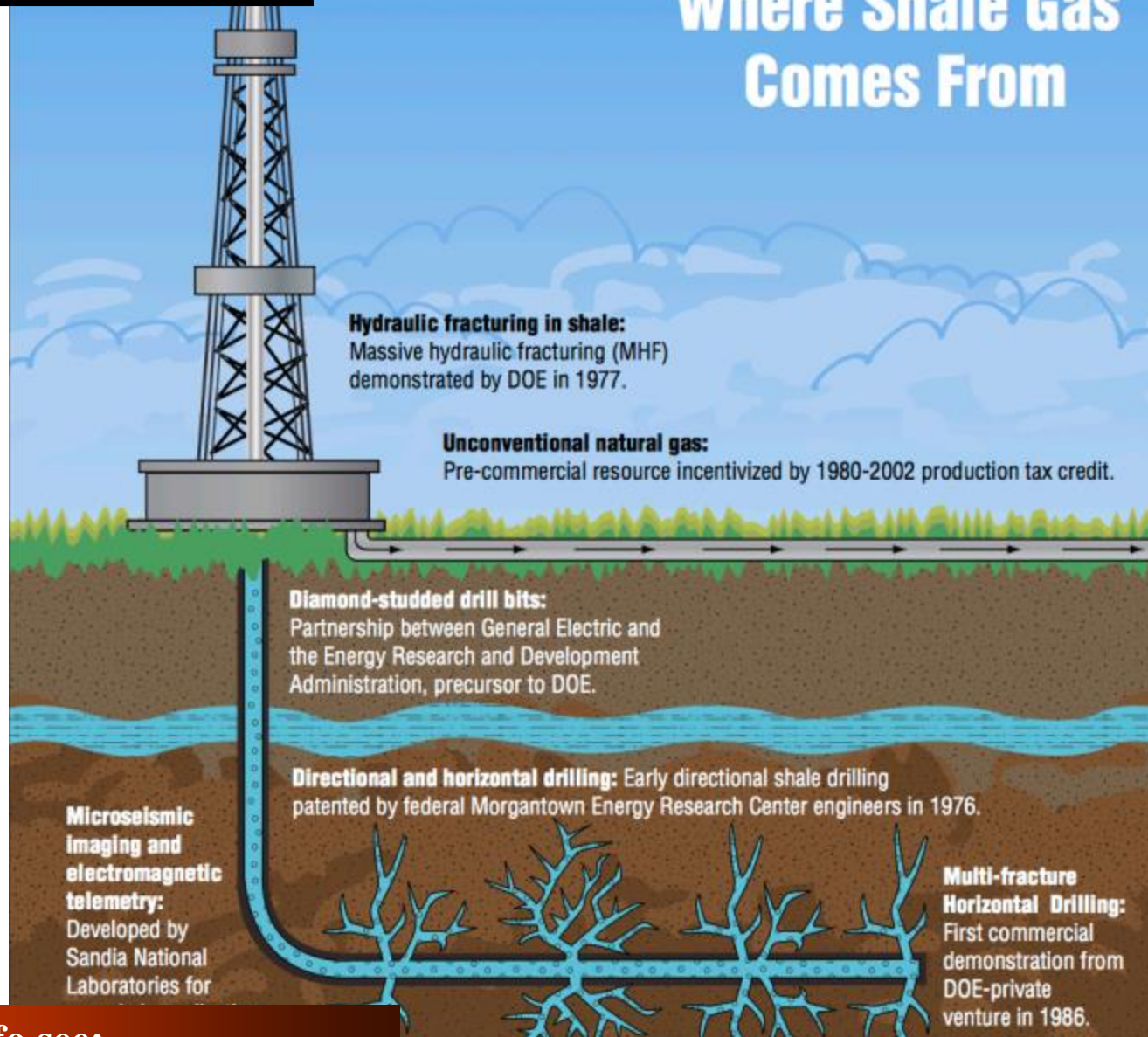
(1) Based on comparison to Andrews TX city budget (pop.9,600) 2008 FY

(2) 2003 4.5 lbs per person per day R. T. Wright "Environmental Science 10 ed. 2008 Pearson Prentice Hall

18,000 lbs day * 90 days= 1,600,000 lbs

New Technology

Where Shale Gas Comes From



For more Info see:

http://thebreakthrough.org/archive/shale_gas_fracturing_history

Aquifer Protection / Well Construction

- Cemented to Surface
- Conductor Casing
- Cemented to Surface
- Surface Casing
- Cement
- Intermediate Casing
- Cement
- Production Casing

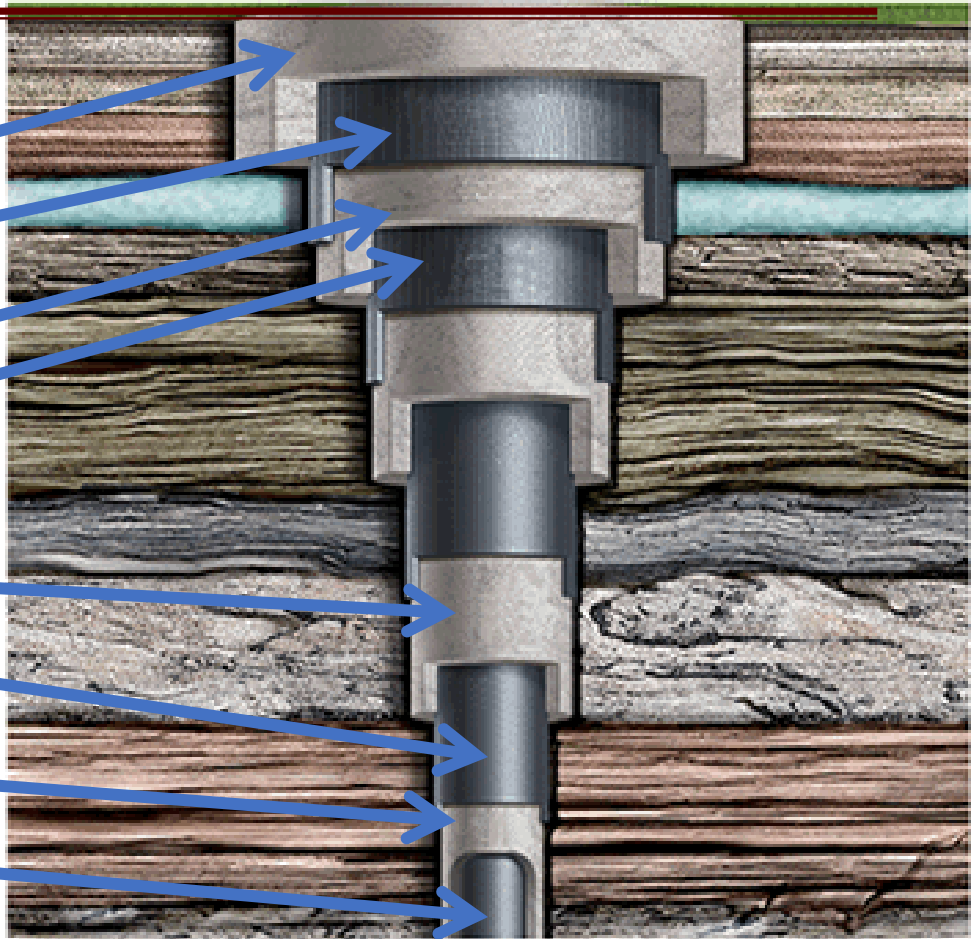
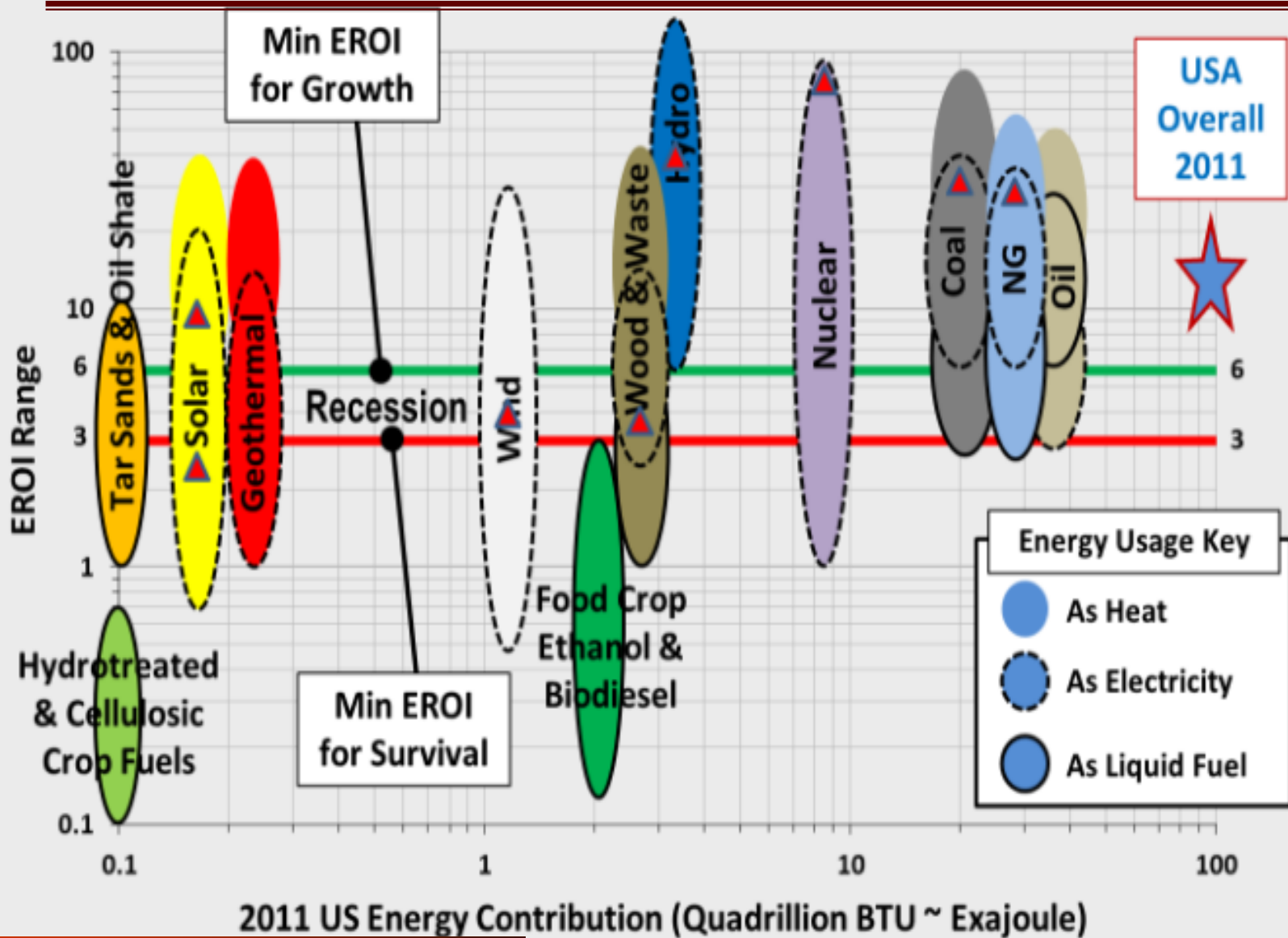


Image Source: FracFocus

Energy Return on Investment (EROI) of US Energy Sources



For more Info see:

<http://www.ourenergypolicy.org/metrics-for-comparing-alternative-liquid-fuels/>

Texas A&M University GPRI Team's Successes:

- 1997 –First University Program Addressing Barnett Shale Productivity
- 2001 First Major University Research Program on Treatment of Produced Water
- 2005 First Functional Membrane Technology for Produced and Frac Flowback Brine
- 2005 First University Program Addressing Environmental Issues in Oil & Gas Drilling
- 2007 First EFD “Scorecard” Proposed
- 2008 “Disappearing Roads” Program
- 2009 University/National Labs Alliance
- 2009 Eagle Ford Shale EFD Study
- 2010 EFD A&M Marcellus Shale Pre-Treatment Field Demos
- 2010 EFD EU Program Started
- 2011 Frac Flowback Brine Analytical Technology Partnership
- 2012 Pennsylvania Field Trials – Pre-Treatment
- 2012 EFD Technology Program Funded



New Technology: GPRI Process Trains



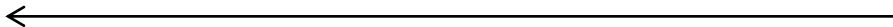
Raw Water Source



pH, Temp.,
Conductivity,
turbidity,



/Wire Screen + 25 U Cartridge



Oil & Grease removal



Media Filtration

BETEX Removal



Micro Filter *

TSS removal



Turbidity, BETEX,
Conductivity



Nano Filter

Hardness Removal



pH, Conductivity



Reverse Osmosis

Desalination



pH, conductivity,

Technology Carryover: GPRI's Produced Water Treatment Research

Advanced Filtration Technology

Cost Effective BW Desalination

Second Source of Fresh Water

Advanced Analytical Monitoring Technology

On site real time monitoring

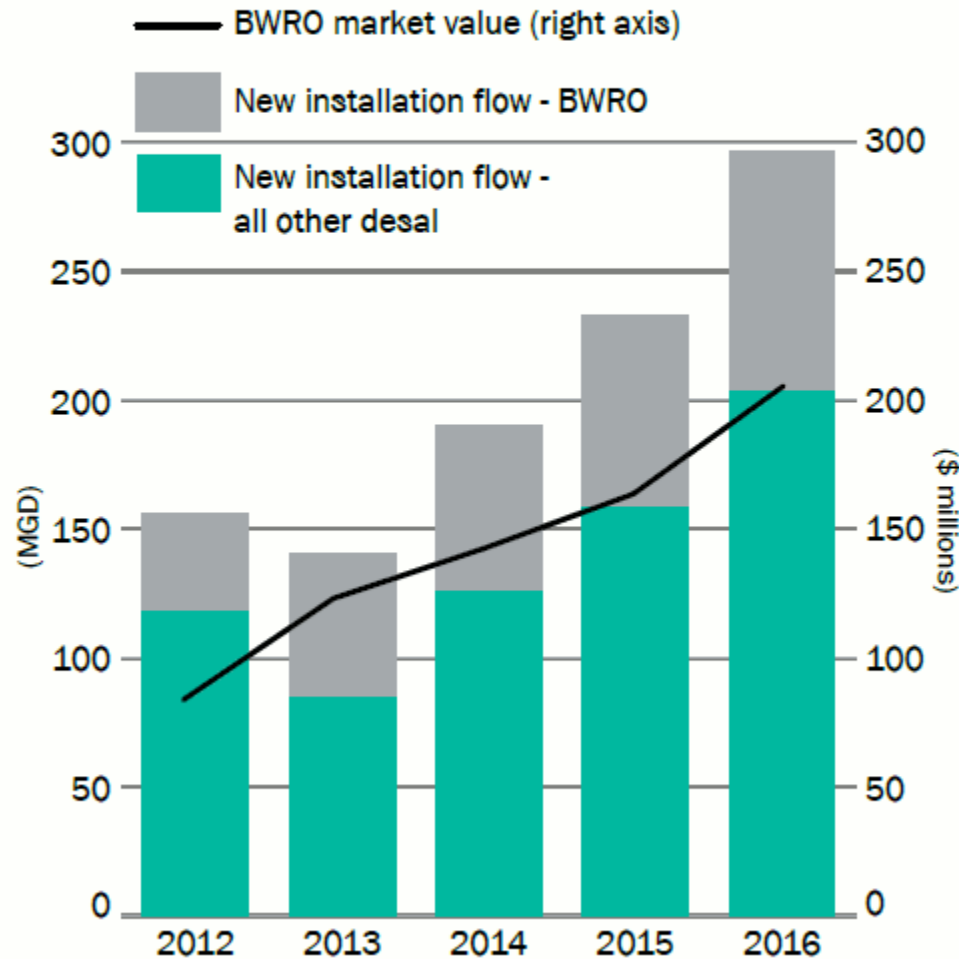
Early detection of potential contamination

Better Community Engagement Practices

Citizen Engagement in environmental health

Pocket Guidelines/Test Kits for Analytes

U.S. BRACKISH WATER MARKET FORECAST BY CONTRACTED CAPACITY AND CAPEX VALUE, 2012-2016



Source: AWI/GWI

<http://www.americanwaterintel.com/archive/3/6/market-analysis/data-show-bearish-forecast-brackish-water-market.html>



Texas A&M Brine Re-Use-Ector Co. TX Proves Recycling and Re-Use is Cost Effective, Environmentally Safe

Deliverables

- Identify optimal treatment techniques for ultra-high brine concentrations
- Provide information to community leaders

Status

- ***Current field trials in Eagle Ford and Permian Basin***
- ***A&M Separation Sciences pilot testing new technology***¹³
- ***Creation of new Analytical Services Roundtable***

Unconventional Oil & Gas Development GPRI's Field Operation Technology Integration

Team Lead: David Burnett

Engineers: C. Vavra, F. Platt, A. Robertson



**GLOBAL PETROLEUM
RESEARCH INSTITUTE**
TEXAS A&M ENGINEERING EXPERIMENT STATION

Harold Vance Department of
PETROLEUM ENGINEERING
TEXAS A&M UNIVERSITY

OBJECTIVES

To provide a “window” into oil field operations so that technological advances can be assimilated faster and more reliably.

Address environmental and societal aspects of oil and gas drilling through the Environmentally Friendly Drilling Program (TIP) partnership with the Houston Advanced Research Center.

To identify advanced water treatment processes for produced water recycling and re-use.

APPROACH

Offer “third party” testing services for new technology.

Use GPRI's knowledge of the industry sector to optimize testing services

Provide field qualified equipment and engineers to run field tests of new technology



ACHIEVEMENTS

- 1997 – First University Program Addressing Barnett Shale Productivity
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- 2005 – First University Program Addressing Environmental Issues in Oil & Gas Drilling
- 2007 – First Environmentally Friendly Drilling “Scorecard” Proposed
- 2009 – University/National Labs Alliance Created for EFD
- 2009 – Eagle Ford Shale EFD Study
- 2010 – EFD A&M Marcellus Shale Pre-Treatment Field Demos
- 2010 – EFD EU Program Started
- 2011 – Frac Flowback Brine Technology Integration Program (RPSEA)
- 2013 – Analytical Technology Partnership Created (RPSEA)

SIGNIFICANCE

New research for upstream O&G operations can be tested under actual field conditions with minimal interruption of drilling or production operations.

Gas shale operators can be provided with reliable “third party” reports on technology demonstrations.

The public is provided with “sound science” information about energy development in their community.

FUTURE WORK

Further Field Trials – Water Treatment
On-site monitoring of biological activity
Emissions monitoring and evaluation of new mitigation technology

REFERENCES

1. Burnett, D. B., Vavra, C. J., Platt, F. C., “Achieving Water Quality Required for Fracturing Gas Shale: Cost Effective Analysis and Treatment” Technologic paper SPE 131217 presented at the Oil Field Chemistry Symposium The Woodlands, 2015.
2. Burnett D. B., Vavra C.A., Platt F.M., McLenny L.A., Woods R.W., Texas A&M University, New York Field Trial of Ultra-High Salinity Brine Pre-Treatment: Texas A&M Environmentally Friendly Technology for the Marcellus Shale
3. <http://www.effsystems.org>
4. <http://www.gpri.org>
5. Theodor, G.L., Lutz, M., Willis, P.G., Burnett, D.B. “Energy Research and Social Science, Energy Research & Social Science 2 (2014) 60-74”
6. Thomas E. Williams, Rich Hunt, HARC, David Burnett, Texas A&M GPRI, Greg Anderson, Moody International, Gene Theodor, Sam Houston State, Creating A Company’s
7. Shover, S., Burnett, D. B., Hunt, R., “Reducing Water Needs in Energy Production and Lowering Environmental Footprint of Oil and Gas Development.” Report to City of San Antonio, Texas, April, 2011
8. Burnett, David “Lowering the Environmental Footprint of O&G Operations by the Land, Seawater, and Air”, Technical Report to Canadian Society for Unconventional Gas, Calgary, Alberta Canada (CSUG), April, 2011

EFD Field Trials – Sites





Texas A&M Marcellus Shale Brine Re-Use

Deliverables

- Identify optimal treatment techniques for ultra-high brine concentrations
- Provide information to community leaders

Status

- ***Current field trials in New York***
- ***A&M Separation Sciences pilot testing new technology***
- ***Creation of new Analytical Services Roundtable***

New York Field Trial of Ultra-High Salinity Brine Pre-treatment: Texas A&M Environmentally Friendly Drilling Technology for the Marcellus Shale –SPE 158396

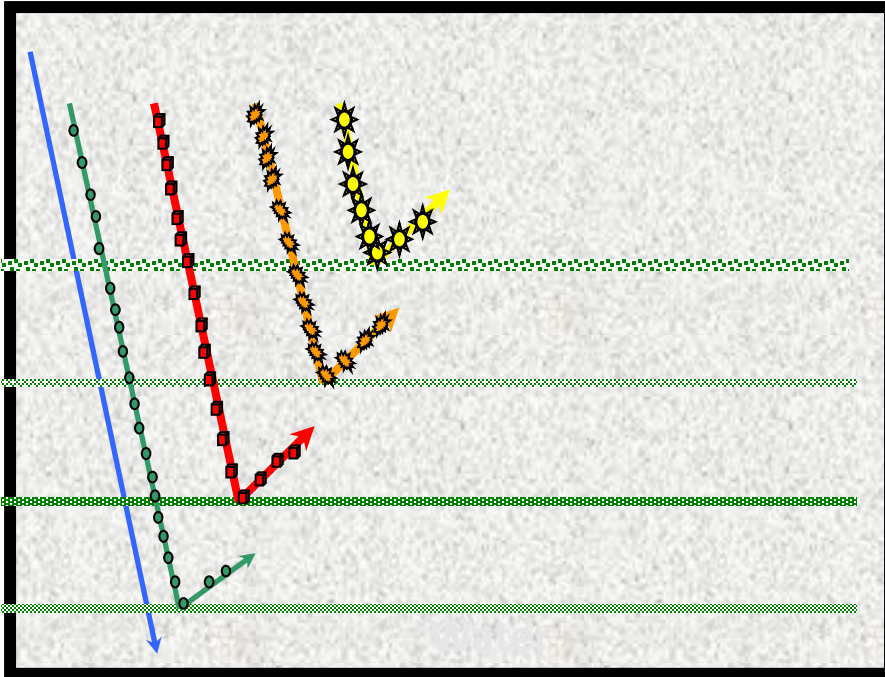
Produced Water Transport; Eagle Ford



Produced Water Storage in the Eagle Ford



Identifying Key Filter/ Membranes



Micro Filtration (MF) ($10-0.1\mu\text{m}$)
Bacteria, suspended particles



Ultrafiltration (UF) ($0.05-0.005\mu\text{m}$)
Colloids, macromolecules



Nanofiltration (NF) ($5e^{-3}-5.e^{-4}\mu\text{m}$)
Sugars, dyes, divalent salt ppts.

Reverse Osmosis (RO) ($1.e^{-4}-1e^{-5}\mu\text{m}$)
Monovalent salts, ionic metals



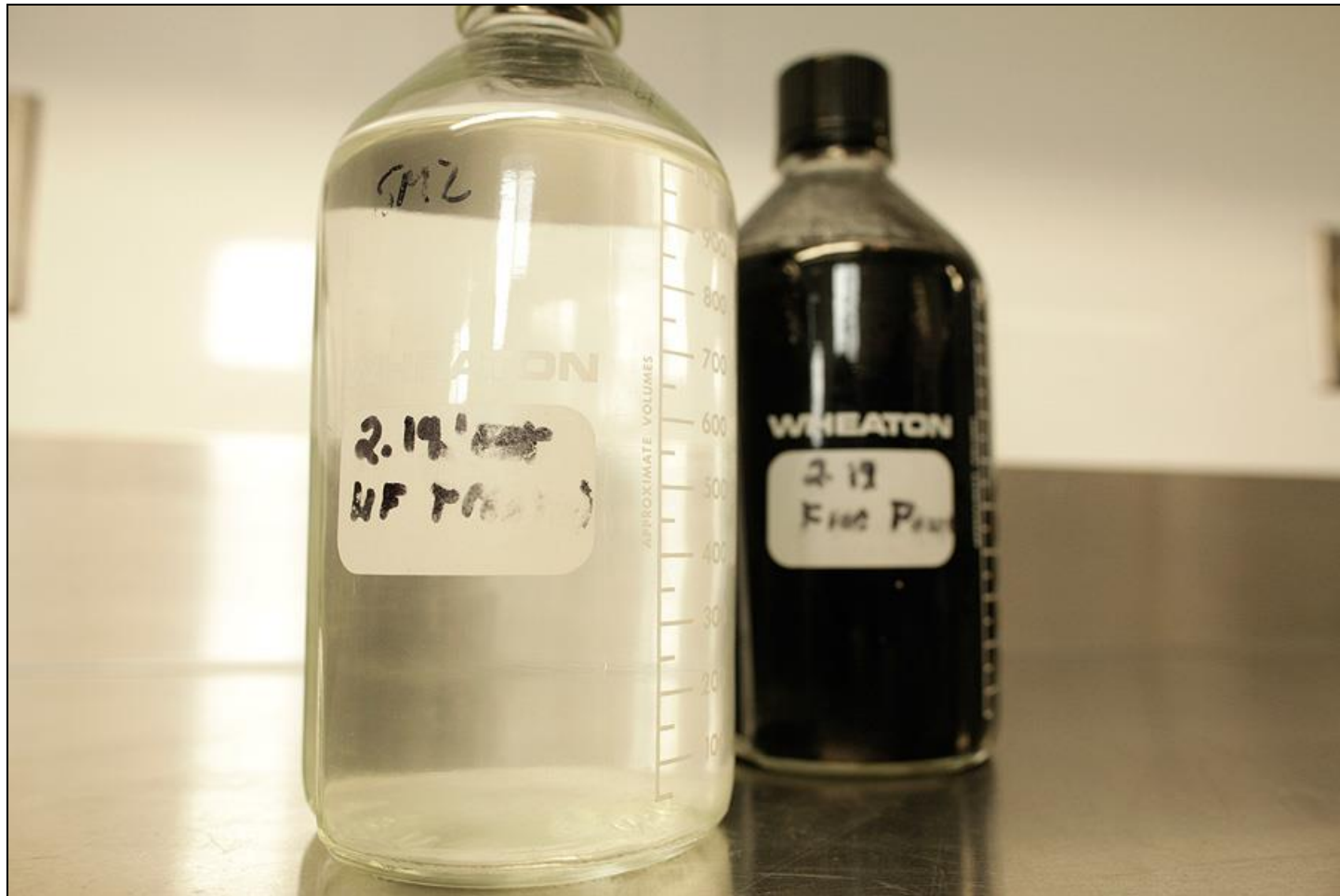
Microfiltration Summary of Performance

Table Summary						
Date	10.26.2012					
Filter	microfilter					
Delta Psi	27					
	Time	gpm	total Q	Q Perm	Vol	NTU B/A
	11:53	25.7	2259	0.6	77	339/0.4
	12:40	25	3450	0.44	102	303/.3
	1:15	25	4500	0.5	117	339/1.1
	2:45	24	6300	0.45	150	511/0.2
	3:15	24	6975	0.45	160	536/0.3
	4:00	24	7950	0.45	175	498/0.4

Field Frac Brine after Three Weeks

Treated

Un-Treated



Advanced Analytical Technology

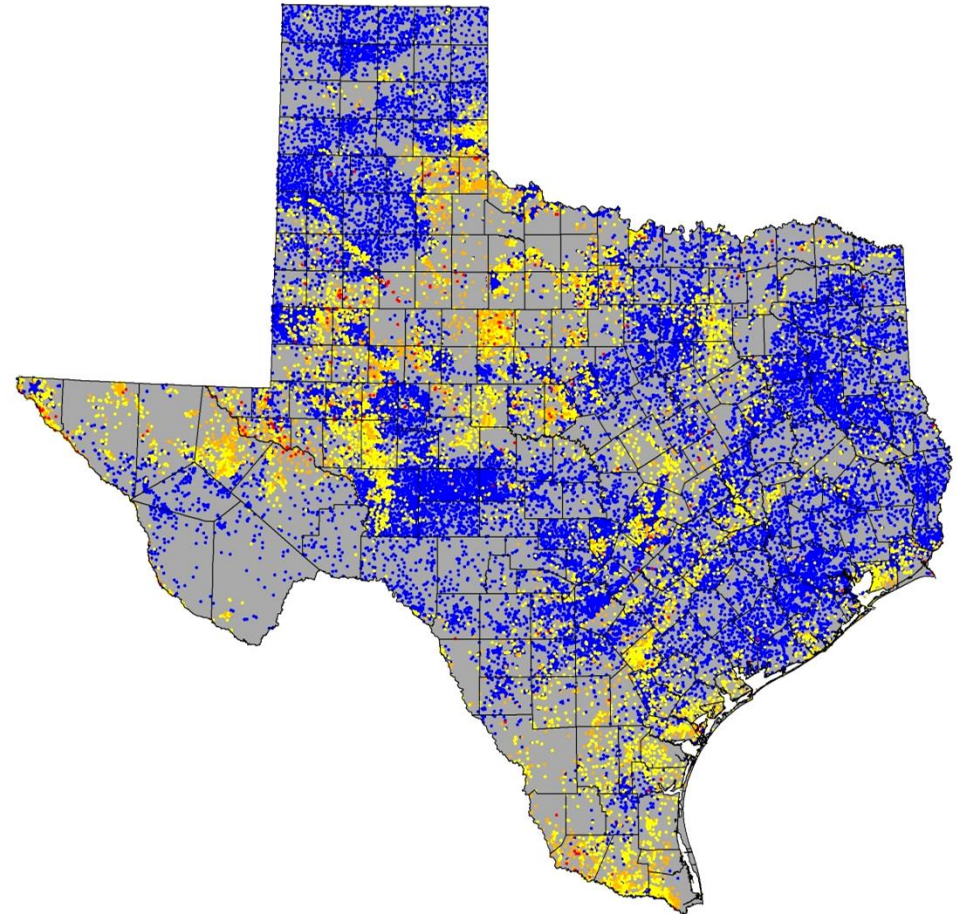


Hach Frac Brine Analysis Kit



Other Water Resources: TWDB Study

Texas Water Development Board identified the saline ground water aquifers in Texas. The study found more than 780 million acre feet of brackish aquifers that would be amenable to desalination.



For more Info see:

<http://www.TWDB.state.TX.us>

Hydraulic Fracturing and Brackish Groundwater Desalination

How They Can Mutually Benefit From Each Other

CONCEPT

Drilling and production of natural gas has been expanding rapidly on a global scale. Worldwide natural gas production has doubled over the last 30 years from 53 trillion cubic feet of production in 1980 to 112 trillion cubic feet in 2010.[1] With such rapid expansion into unconventional gas resources, oil and gas companies are constantly searching for more efficient, more profitable, and more environmentally friendly ways to boost hydrocarbon production. One of the most effective and rapidly-expanding techniques to stimulate unconventional oil and gas wells is hydraulic fracturing.

Aquifer Characterization System (BRACS) program (TWDB)

In 2011, the estimated volume of groundwater with a total dissolved solids level between 1,000 and 10,000 mg/L at almost 2.7 billion acre-feet (3,330 billion m³).

1 Ac ft =~ 7,400 bbls

GPRI Designs Mobile Lab in McAllen Texas



Mobile Laboratory Allows Multiple Water Treatment Tests

Hydrocarbon removal
Suspended solids removal
Bacteria removal
Brine softening



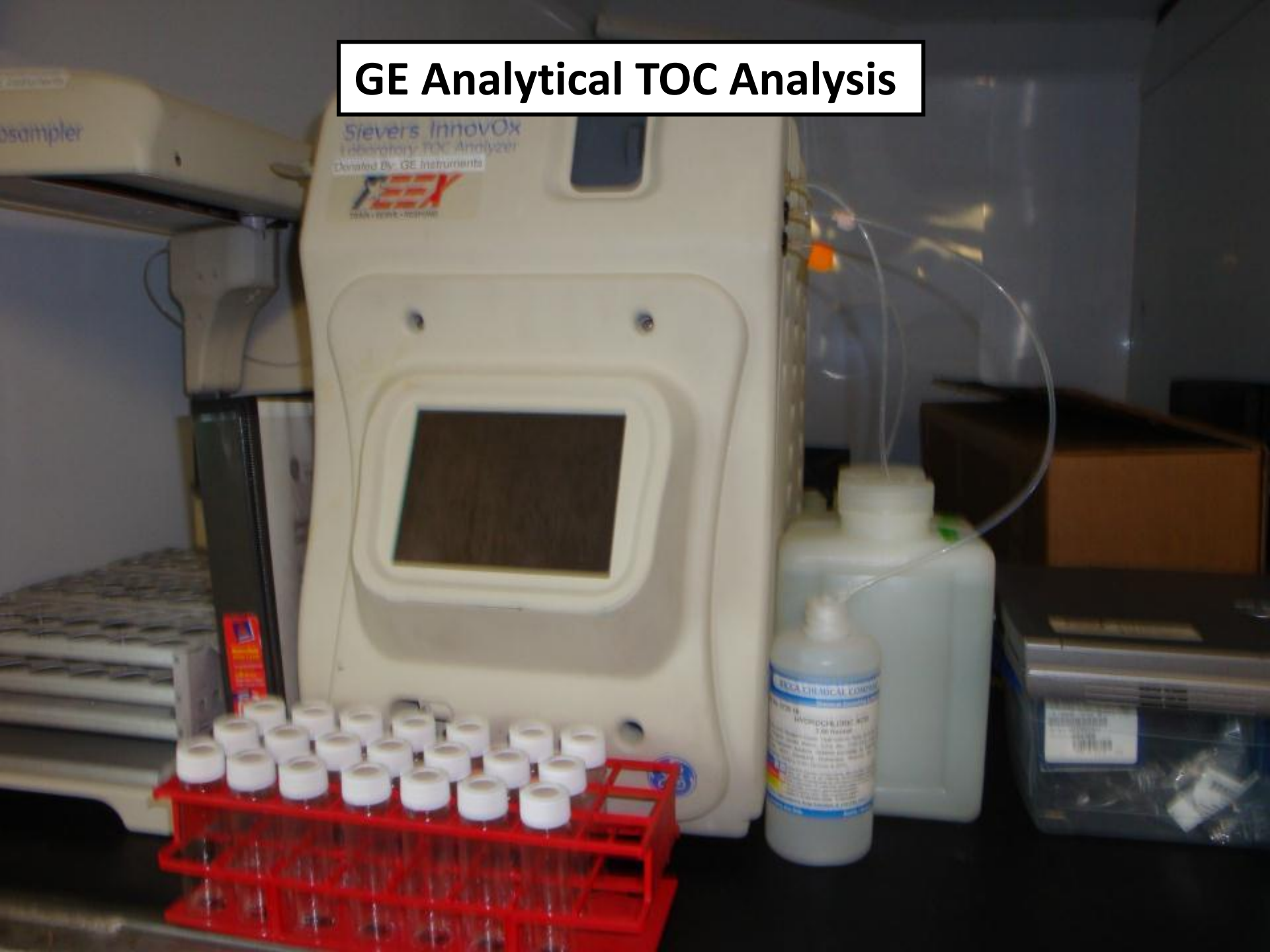
Process piping and membrane setup inside the GPRI Mobile Lab



Analytical Testing in McAllen



GE Analytical TOC Analysis



Pocket Guides for Frac Water Quality; Testing Kits



- Onsite testing of water to be used for Hydraulic Fracturing mixtures
- Will be used as a way to screen good water from bad water
- It's cheap and quick
- Will be a catalyst to new innovations in oil field water usage

Rapid Chemistry Kit for Compatibility Testing

	Suggested Levels		Suggested Levels
Boron	5 mg/L	pH	4-9
Barium	40 mg/L	Iron	70 mg/L
Bacteria	2500 ATP	Sulfate	400 mg/L
Calcium	500 mg/L	Total Suspended Solids	5000 mg/L
Chloride	30,000 mg/L	Acidity	500 mg/L

Chemical

- < 8 = Good
- 4-8 = Some filtration/mixing needed
- > 4 = Extensive filtration needed

Chemical



Photo from LaMotte Corp.

Major MIC Groups Monitored in Field Applications

- (SRB) Sulfate-reducing
- (TRB) Thiosulfate-reducing
- (NRB) Nitrate-reducing
- (SuRB) Sulfite-producing
- (IOB) Iron-oxidizing

- (APB) Acid-producing
- (IRB) Iron-reducing
- Methanogens
- (SPB) Slime-producing

Note: (SPB) also classified as (EPS) Extra polymeric substance producing

Sherman, S., Brownlee, D., kakadjian, SPE.S., Luft, B., Trican Well Service Ltd. 2014. Microbial Influenced Corrosion of Coil Tubing Milling Strings in the Eagle Ford Shale. No. IPTC-18032-MS. International Petroleum Technology Conference, Kuala Lumpur, Malaysia (2014).

On Site Testing; Microbial Influenced Corrosion (MIC)



- Current rapid test mobile technologies quantify total bacterial numbers
- QuickChek SRB is the only rapid test mobile technology that measures a specific group of bacteria

Current Mobile Monitoring Options

Molecular Technology	Ease of Use	Testing Time (min)	Portability	Accuracy	Microbial Activity Tested	Cost per Test
ATP LuminUltra	Easy	5	Very Good	Good	All (viable & nonviable)	\$7
Bactiquant	Moderate	11	Very Good	Good	All (viable only)	\$20
QuickChek SRB	Moderate	10	Very Good	OK	SRB (viable & nonviable)	\$14
Rapid-B Flow Cytometer	Easy	3	Benchtop Based	Very Good	All (viable only)	\$20
Bug Bottles	Easy	5-7 days	Benchtop Based	OK	Specific to Media (viable only)	\$0.60

http://www.hach.com/quick_search-quick_search.jsa?keywords=ATP+LuminUltra <http://www.modernwater.com/monitoring/by-industry/oil-and-gas>

(Victor Pena Sales Account Manager)

<http://www.mycometer.com/> <http://www.biotechnologysolutions.com/> <http://www.pcbdservices.com/technology/oil-and-gas.php>

Hydraulic Fracturing Regulations

Texas Railroad Regulations on HF

Commission regulates well construction requirements and surface gauges to monitor casings at the surface

Content of HF Fluids –

<http://www.rrc.state.tx.us/about-us/resource-center/faqs/oil-gas-faqs/faq-hydraulic-fracturing/>

Protection of Ground water-

Commission's Groundwater Advisory Unit performs an essential function in determining specific groundwater protection depths for each new well

HF Fluid Disposal

Rules prohibit disposal of flow back fluids or produced formation fluids, in any manner that is not explicitly and specifically permitted

For more Info see:

<http://www.rrc.state.tx.us/about-us/resource-center/faqs/oil-gas-faqs/faq-hydraulic-fracturing/>

Challenge: Solving Societal Problems

- New development should be technically, economically, and environmentally feasible – but also **SOCIALLY ACCEPTABLE**

- It is better to practice **Conflict Avoidance** up front than attempt costly **Conflict Resolution** later on



As we get closer to having on-site development of geothermal energy in Texas and the Gulf Coast, the time is now

– TODAY –

begin building community relationships.



3. GPRI and Key Environmental Programs

The **Global Petroleum Research Institute** within the Department of Petroleum Engineering at Texas A&M University has collaboration programs both within the University and with External Research Centers.

For more Info see:

www.efdsystems.org

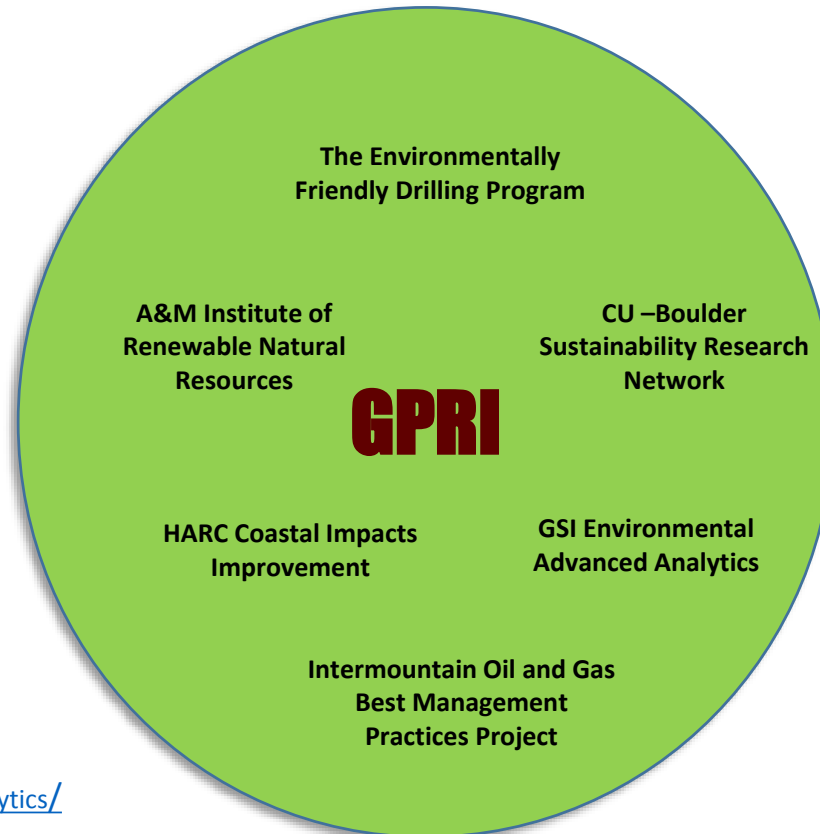
<http://irn.r.tamu.edu/about/>

<http://www.colorado.edu/news/releases>

<https://sites.google.com/site/amadvancedanalytics/>

<http://efdsystems.org/index.php/coastal-impacts-technology-program-citp>

<http://outreach.colorado.edu/programs/details/id/359>





The EFD Team

Co-funded by RPSEA, U.S. Fish & Wildlife, Industry, Environmental Organizations

SPONSORS

- RPSEA: Research Partnership to Secure Energy for America
- NETL
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- Hess
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- devon
- Chevron
- HALLIBURTON
- Tenaris
- bp
- Gulf Coast Green Energy
- BASIN
- MI SWACO
- Shell
- CSI Technologies: A SUPERIOR ENERGY SERVICES COMPANY
- Newpark Resources
- Huisman
- Katch Kan
- NYSERDA: New York State Energy Research and Development Authority
- WyoComposites, LLC

MANAGEMENT TEAM

- HARC
- ATM: Texas A&M University
- SH

ENVIRONMENTAL ORGANIZATIONS

- The Nature Conservancy
- Fort Worth Nature Center Conservancy
- NRDC: NATURAL RESOURCES DEFENSE COUNCIL THE EARTH'S BEST DEFENSE

COLLABORATORS

- HART: American Association of Petroleum Geologists An International Geological Organization
- GROUNDWATER PROTECTION COUNCIL
- PTIC: Petroleum Technology International
- CEA: Chemical Energy Association

ALLIANCE MEMBERS

- University of Arkansas
- NATURAL RESOURCES LAW CENTER: University of Colorado Law School
- MONTAN UNIVERSITY
- Argonne
- Los Alamos NATIONAL LABORATORY
- OAK RIDGE NATIONAL LABORATORY
- INL: Idaho National Laboratory
- UNIVERSITY OF KENTUCKY
- UNIVERSITY OF WEST VIRGINIA
- UK: University of Kentucky
- PennState
- CLEMSON
- The University of Vermont
- Gund Institute for Ecological Economics
- UNIVERSITY OF WISCONSIN
- USC: UNIVERSITY OF SOUTHERN CALIFORNIA
- Rensselaer
- Utah State University
- UAF: UNIVERSITY OF ALABAMA IN FAIRBANKS
- OU: Oklahoma University
- TCAT: Texas Center for Applied Technology

For more Info see:

<http://www.efdsystems.org>



Environmental Management: Aspects & Impacts... “think holistically”

Petroleum
Production
& Energy



Surface &
Subsurface

Air Quality &
Greenhouse
Gas



Water
Resources

Questions?

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