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Shale Gas Water Management - Experiences from North America

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Society of Petroleum Engineers
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Topics for Discussion

- Importance of shale oil and gas
- The shale gas development process
- Shale gas water needs
- Management of flowback and produced water

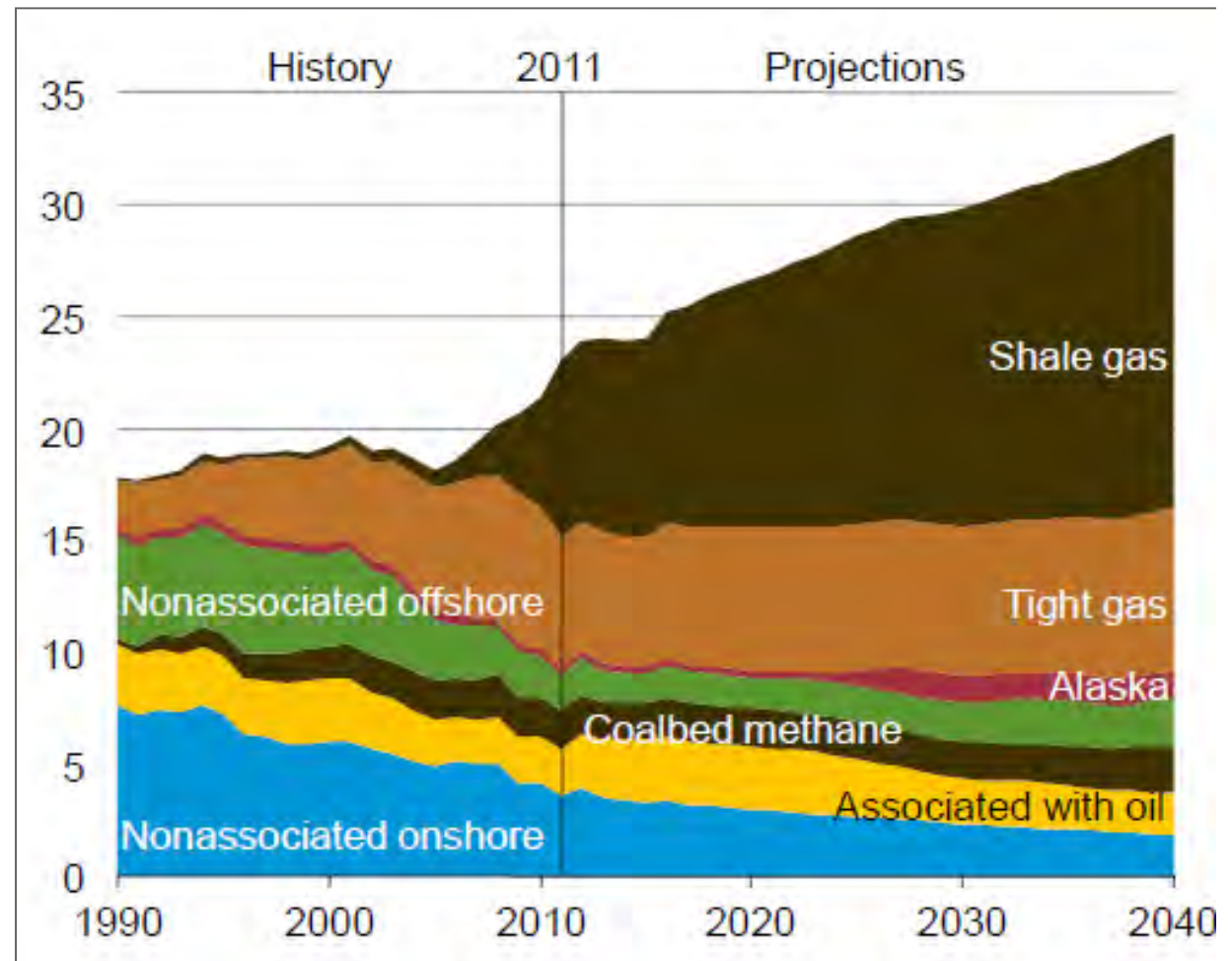




Shale Gas - Introduction

Importance of Shale Gas to the USA

- Natural gas is an important energy source for the United States. Shale formations represent a growing source of natural gas for the nation and are among the busiest oil and gas plays in the country.



Source: DOE/EIA Annual Energy Outlook 2013

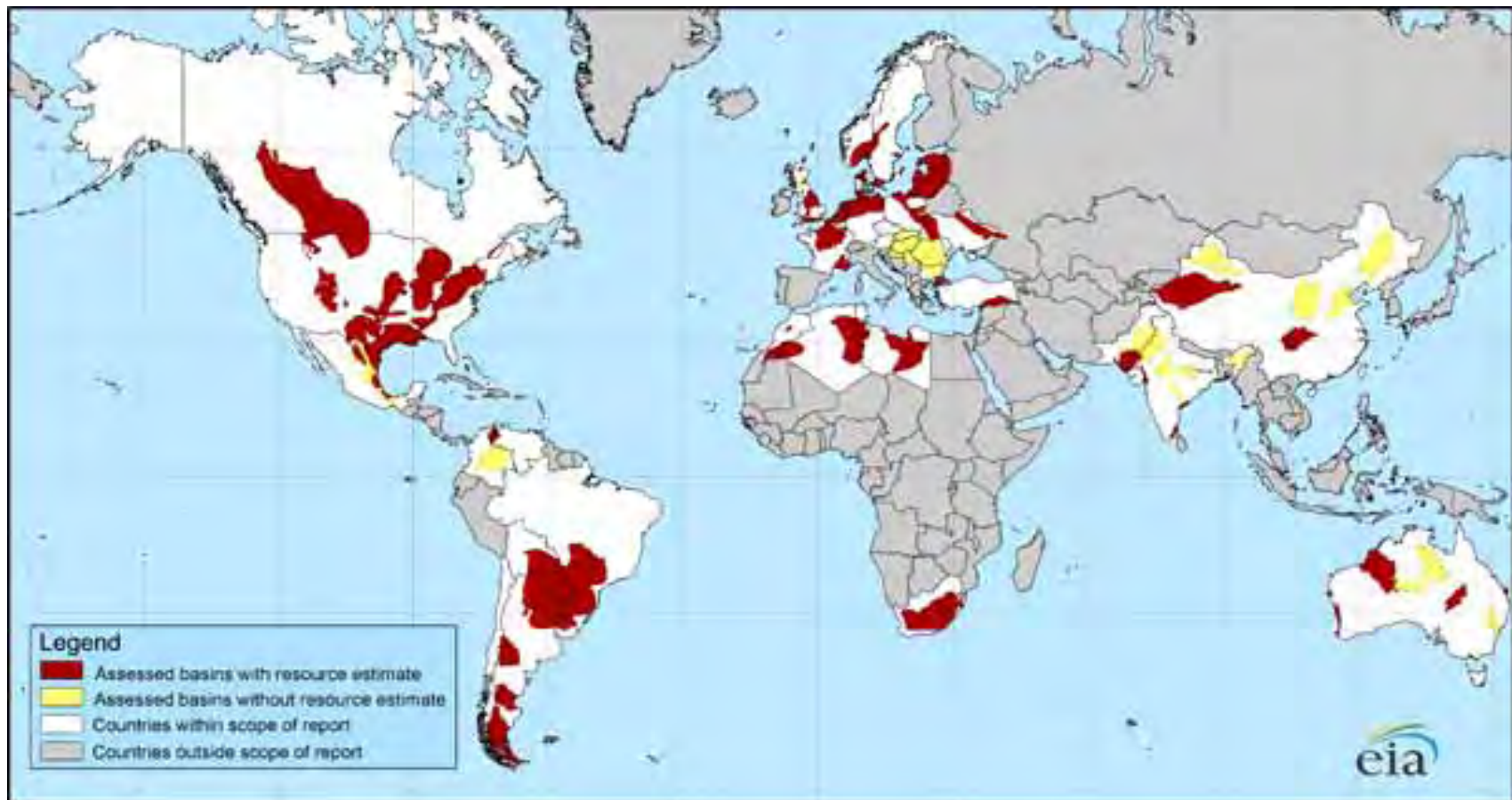


Shale Plays in Other Parts of the World

2011 Report on Global Shale Gas Reserves

- U.S. Department of Energy released a new report on April 5, 2011 that assessed 48 shale gas basins in 32 countries, containing almost 70 shale gas formations around the world.
 - Prepared by Advanced Resources International

<http://www.eia.gov/analysis/studies/worldshalegas/>




Estimated Shale Gas Technically Recoverable Resources for Select Basins in 32 countries

Continent	Risked Gas In-Place (Tcf)	Risked Technically Recoverable (Tcf)
North America	3,856	1,069
South America	4,569	1,225
Europe	2,587	624
Africa	3,962	1,042
Asia	5,661	1,404
Australia	1,381	396
Total	22,016	5,760

United States

862

Source: Advanced Resources 2011



The Shale Gas Development Process

Steps in the Shale Gas Process

- Steps involving water are shaded

Gaining Access to the Gas (Leasing)

Searching for Natural Gas

Preparing a Site

Drilling the Well

Preparing a Well for Production (Well Completion)

Gas Production and Water Management

Moving Natural Gas to Market

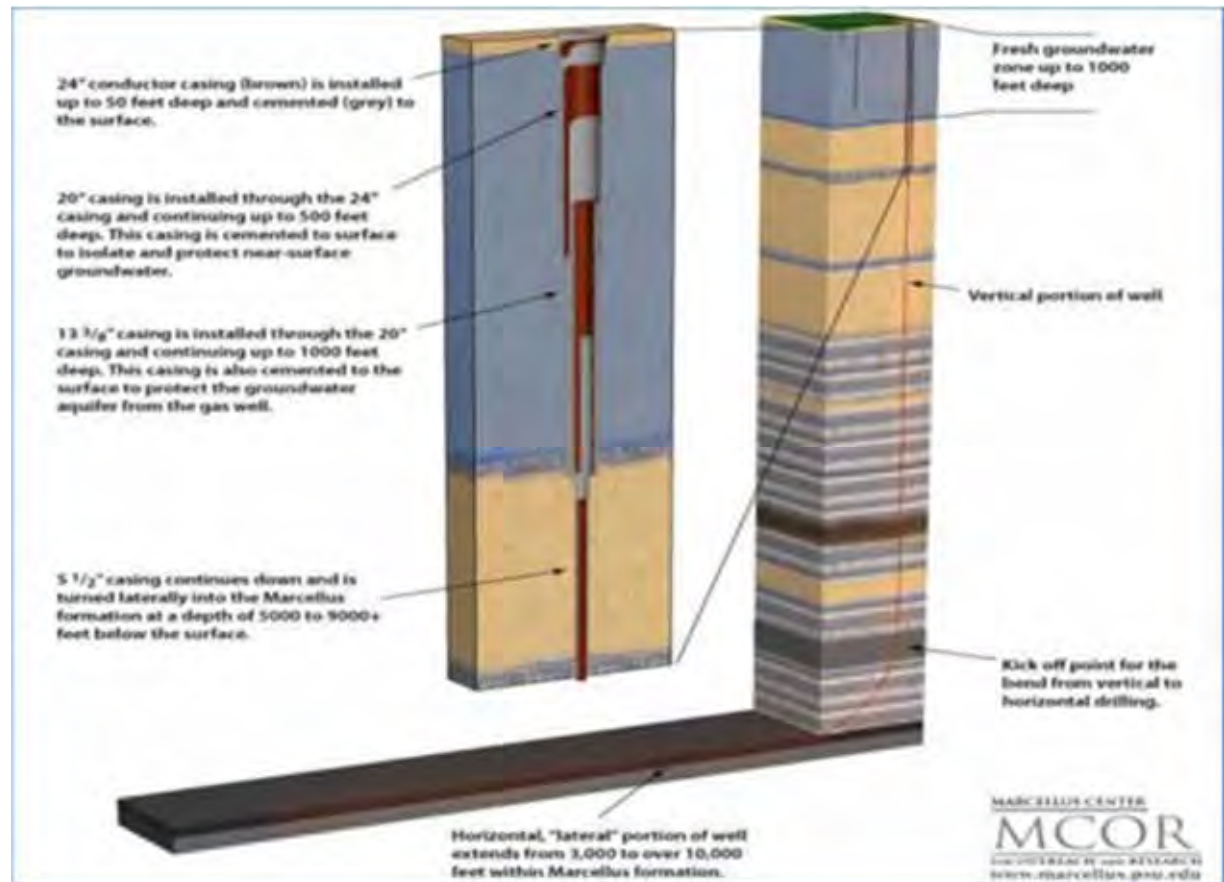
Well Closure and Reclamation

Source: Fayetteville Shale
Information website

<http://lingo.cast.uark.edu/LINGOPUBLIC/index.htm>

Well Completion Process

- Most shale gas wells are drilled as horizontal wells with up to 1 mile of lateral extent through the shale formation
- In order to get gas from the formation into the wellbore, companies must follow two steps:
 - Perforation
 - HF



Source: T. Murphy – Penn State Marcellus Center for Outreach and Research

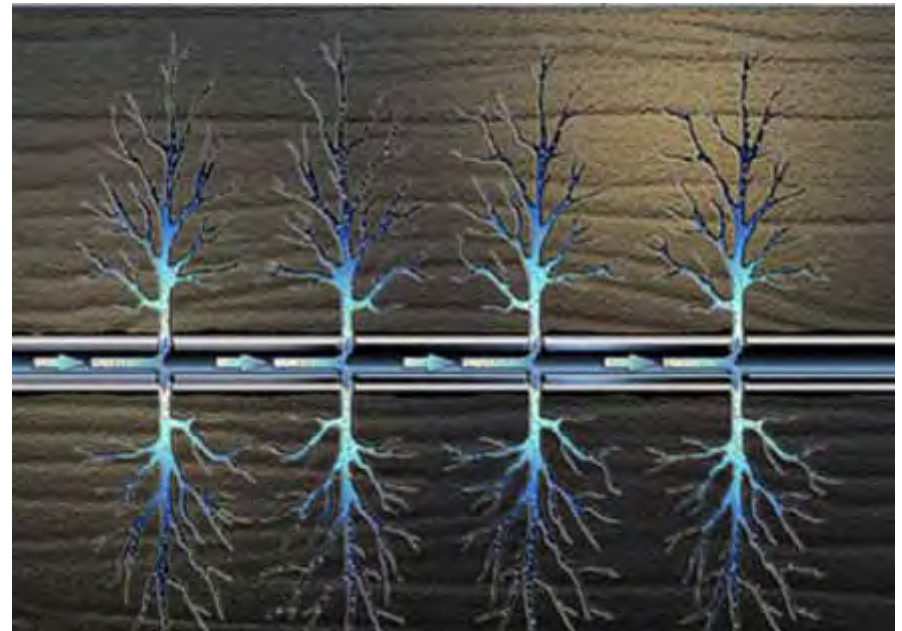
Visit <http://videos.loga.la/horizontal-drilling-animation> to see a good video of these steps

Well Completion Process (2)

- On a long horizontal leg, completion is done in a series of stages, each of which is a few hundred feet long
 - Perforations are made using small explosive charges that are lowered to the desired depth on a cable
 - HF is done for several hours for each stage
 - Pressure is held on the well and a plug is set to isolate that fractured interval and allow stimulation of the next stage
 - The next stage is perfed and fraced
 - When all stages are completed, the plugs are drilled out, and some of the water returns to the surface



Source: J. Veil



Source: Frac Focus website

Hydraulic Fracturing (HF)



Frac Job Pumps Large Volume of Water, Sand, and Additives into the Well in Stages





Why Is HF Used?

- Shale rock is very dense and has low permeability
 - HF creates a network of small cracks in the rock that extend out as far as 1,000 feet laterally and vertically away from the well
- Virtually no shale oil and gas wells in the U.S. would be developed unless HF is done
- It is controversial and expensive, but is a critical element in cost-effective production



Water Needs for Hydraulic Fracturing

Water Needed for Frac Jobs

- Most wells require up to 5 million gallons, but the trend is to have more stages and use more water
 - Individual volume is not critical, but collectively can be important within a region
- Source of water:
 - Stream, river, or lake
 - Well
 - Impoundment created by producer
 - Public water supply
- Piped to site vs. delivery in tank trucks





Estimate of Water Requirements for Marcellus Shale

- Make estimate of maximum volume of water needed to meet Marcellus Shale fracking needs
 - Estimate volume of water per well
 - Estimate maximum number of wells in a year

Pennsylvania Wells Drilled

Year	Marcellus Shale Wells Drilled
2007	113
2008	336
2009	814
2010	1,591
2011	1,987
2012 (Jan-July)	883 (note: lower rate than in 2011)

Source: PA
DEP website

- To get a hypothetical maximum, double the 2010 total =

3,974 wells

West Virginia Wells Drilled

Year	Marcellus Shale Wells Drilled
2007	408
2008	461
2009	170
2010	114
2011	52

Source: WV GES website

- To get a hypothetical maximum double the 2008 total =

922 wells

New York Wells Drilled

Year	Total Wells Drilled
2008	??
2009	??
2010	??
2011	??

- New York has moratorium on Marcellus Shale wells
- No good way to predict maximum number of wells
- Chose to estimate maximum New York wells to be the same as maximum

West Virginia wells = **922 wells**

Hypothetical Maximum Water Demand for Marcellus

State	Hypothetical Maximum Number of Wells Drilled in a Year	Annual Volume assuming 5 million gals of water needed per well
Pennsylvania	3,974	19.8 billion gals/yr
West Virginia	922	4.6 billion gals/yr
New York	922	4.6 billion gals/yr
Total	5,818	29 billion gals/yr = 80 MGD

Actual Water Withdrawals for 2005 (in MGD)

Category	New York	Pennsylvania	West Virginia	Total
Public Supply	2,530	1,420	189	4,139
Domestic	140	152	34	326
Irrigation	51	24	<1	75
Livestock	30	62	5	97
Aquaculture	63	524	53	640
Industrial	301	770	966	2,037
Mining	33	96	14	143
Thermoelectric	7,140	6,430	3,550	17,120
Total	10,288	9,478	4,811	24,577

Source: USGS report (Kenny et al. 2009)

Comparison of Marcellus Shale Water Needs with Actual Withdrawal

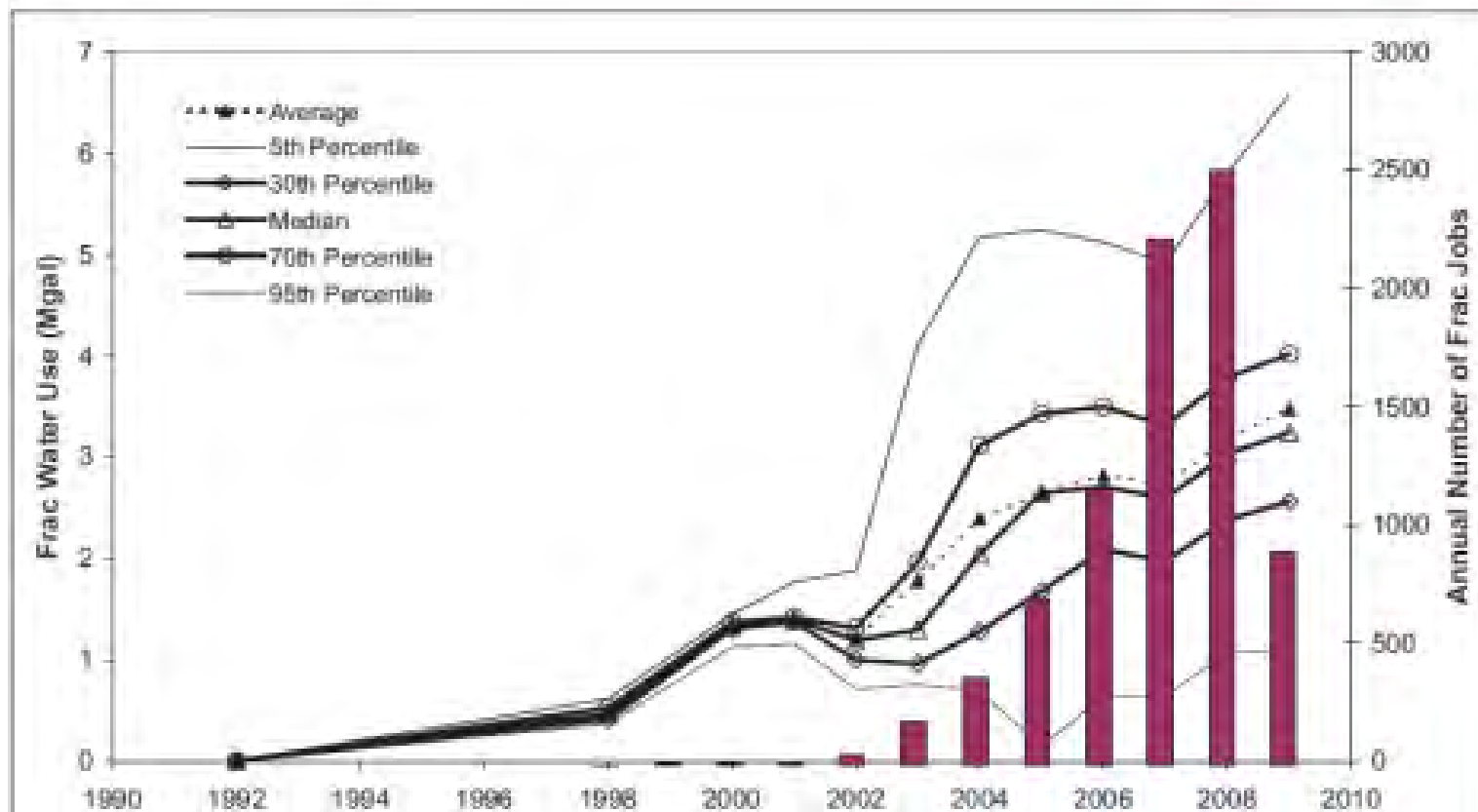
	Volume	Percentage Water Required for Shale Gas Production Compared to Total Withdrawal
Water needed for shale gas	80 MGD	-
Total water withdrawal	24,577 MGD	0.32%

Water Availability in Marcellus and Fayetteville Shales

- In both of these shale plays, the water needed to support a hypothetical maximum well fracturing year represents a fraction of 1 percent of the total water already used in the regions.
- This suggests that sufficient water should be available
 - *Not in every location or on every stream tributary*
 - *Not during every week of the year*
- Requires good advanced planning to withdraw water from rivers when flows are high and store the water until needed for fracturing.
- Will require local or regional fresh water storage impoundments.

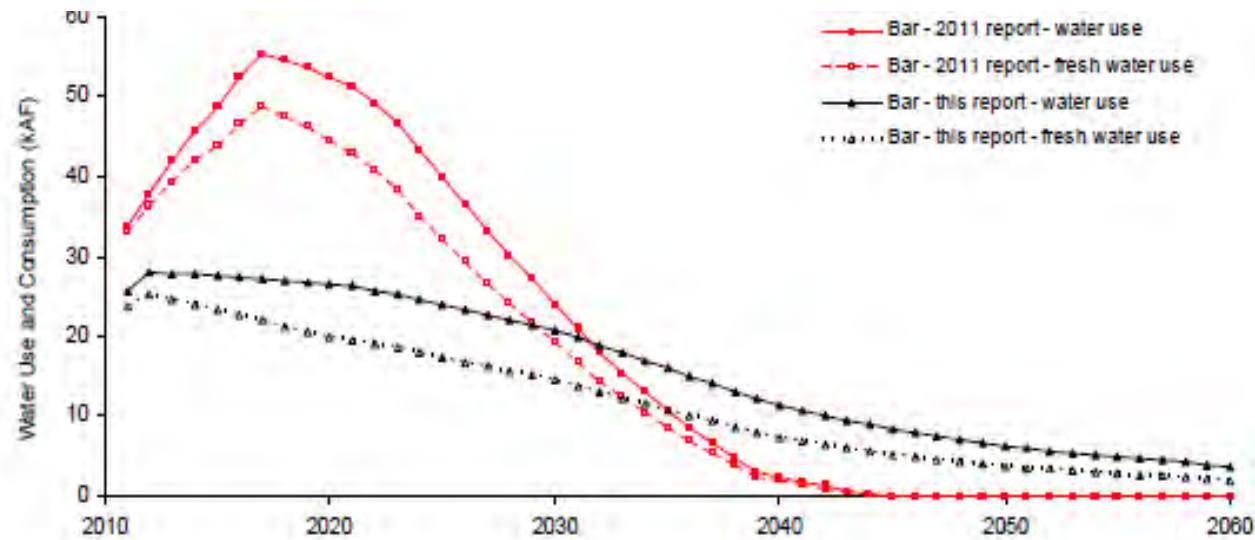
Water Needs for Barnett Shale

- According to June 2011 Texas Water Development Board report, the actual water used for fracturing in Barnett Shale in 2008 was ~8.3 billion gals



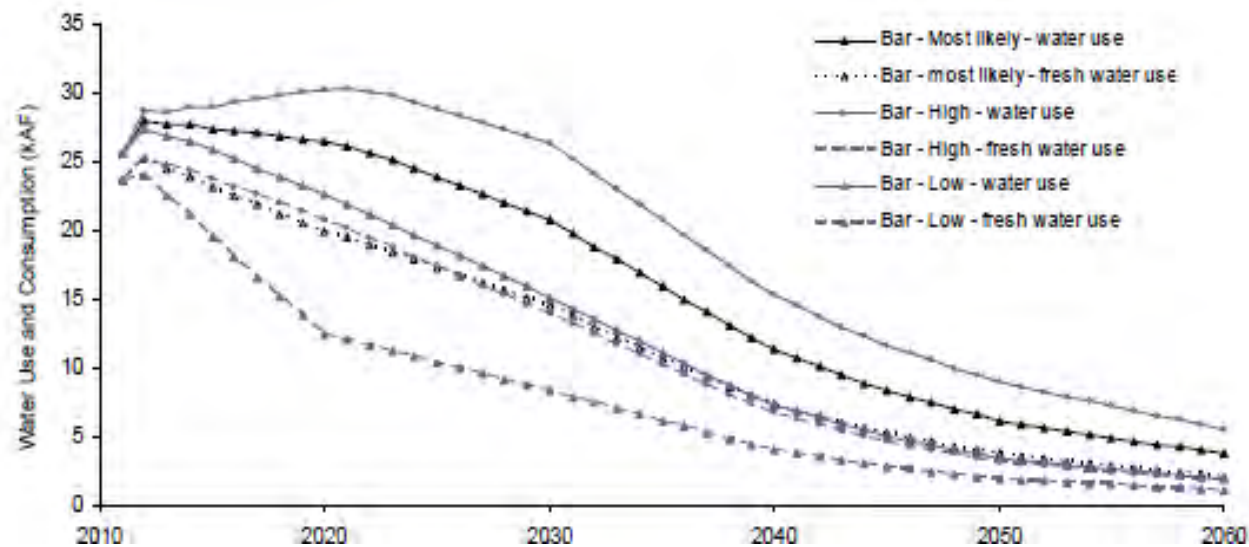
Source: Texas Water Development Board report, June 2011.

Barnett Shale Water Use and Consumption Projections

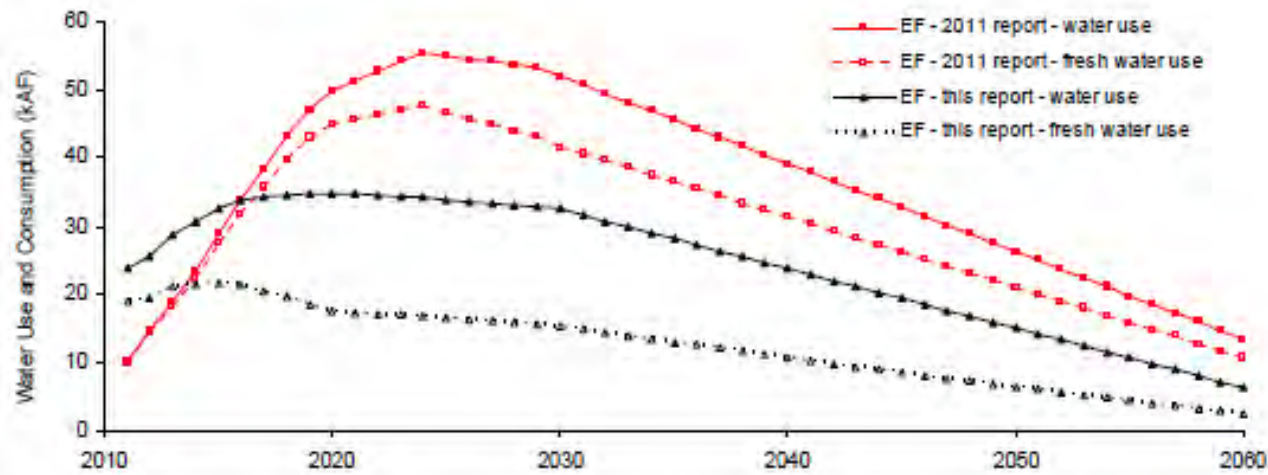


Source: J.P. Nicot et al (2012) Oil & Gas Water Use in Texas: Update to 2011 report.

(a)

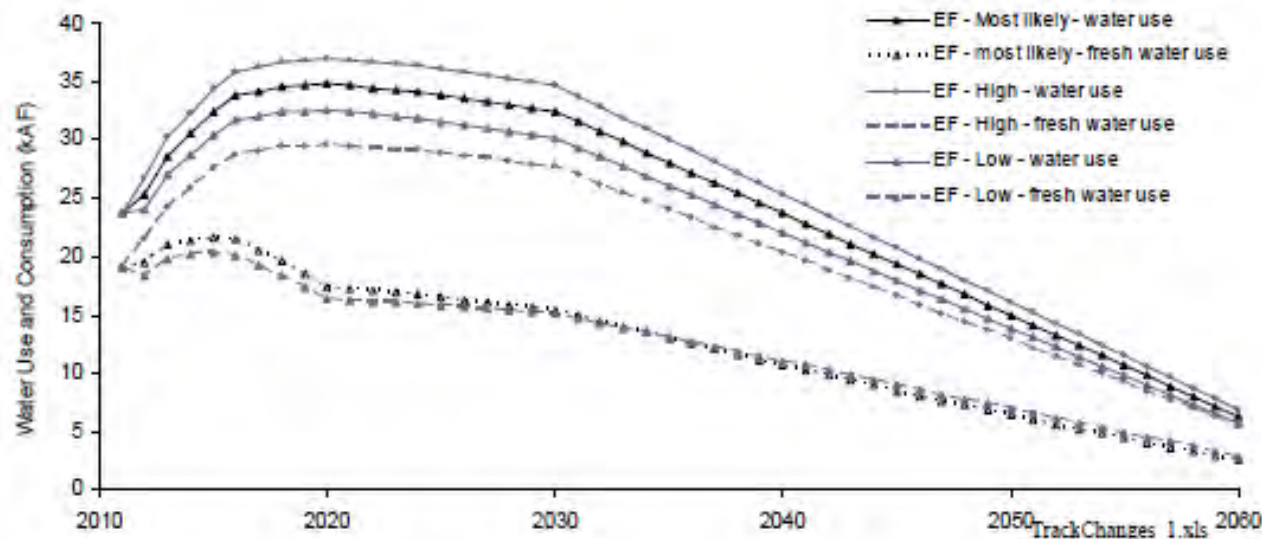


Eagle Ford Shale Water Use and Consumption Projections



Source: J.P. Nicot et al (2012) Oil & Gas Water Use in Texas: Update to 2011 report.

(a)





Water Conflicts for Barnett and Eagle Ford Shales

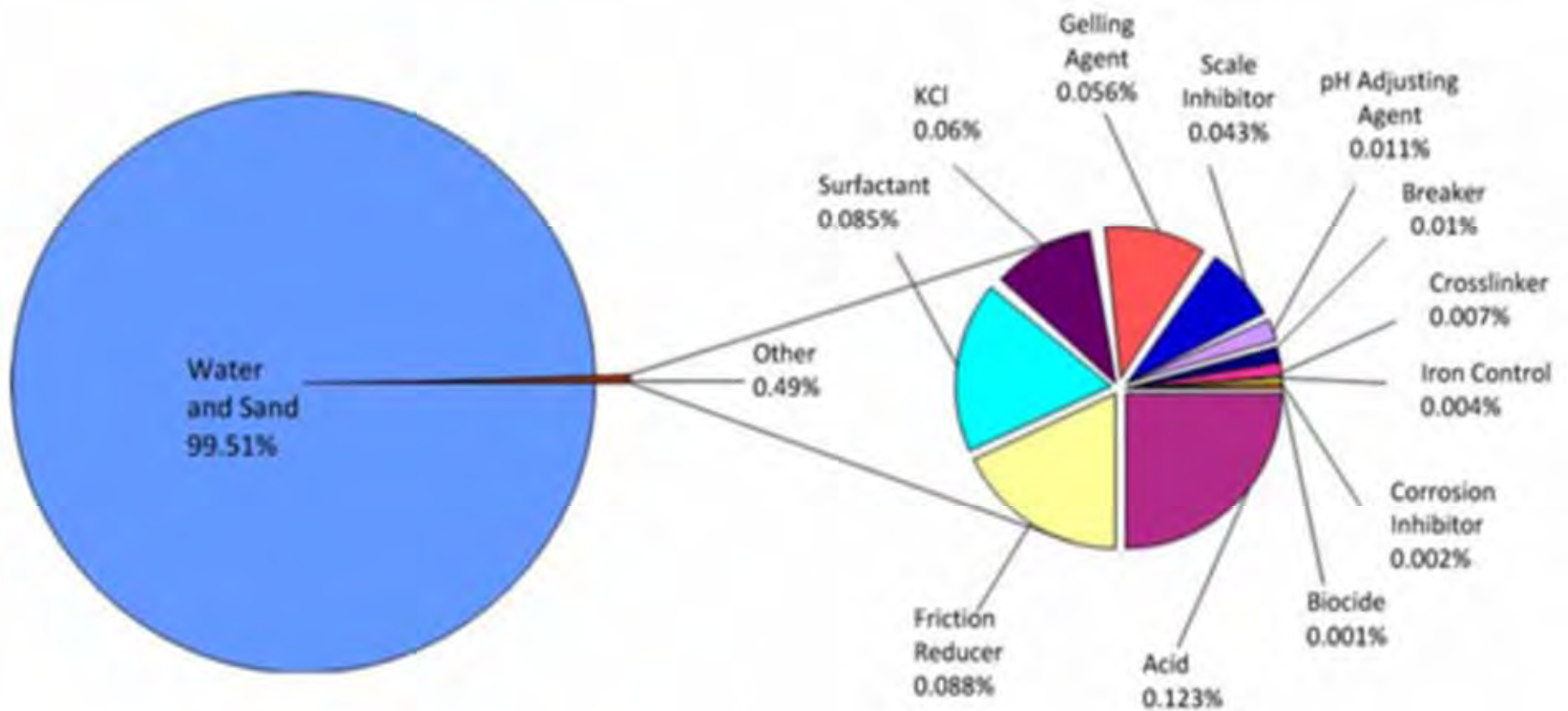
- The Barnett Shale appears to have adequate available water for the time being. Under the high demand scenario, groundwater resources may not be adequate.
- Less information is available for the Eagle Ford Shale since it is a newer play.
 - The local climate is somewhat drier than in the Barnett
 - There is some potential for future fresh water shortages



Chemicals in Frac Fluids

Frac Fluid Composition

- Water makes up ~90% of volume
- Sand makes up ~10% of volume
- All other chemical additives make up ~0.5% of volume



Source: Shale Gas Primer, GWPC and ALL

Why Chemical Additives Are Used

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

Source: Shale Gas Primer, GWPC and ALL

Why Chemical Additives Are Used (2)

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

Source: Shale Gas Primer, GWPC and ALL



Disclosure of Chemical Additives

- One of the most contentious issues surrounding HF is that companies have not historically shared detailed information with regulators or the public on which chemicals are actually used in frac jobs
- Even if the chemicals used are not harmful, the public has concerns over the unknown and does not trust the industry to safeguard them
- Some information can be obtained from the Material Safety Data Sheets (MSDSs)

Example MSDS

- Selected sections of the MSDS for NALCO EC 6116A are shown here

9. PHYSICAL AND CHEMICAL PROPERTIES

PHYSICAL STATE	Liquid
APPEARANCE	Clear Colorless Amber
ODOR	Mild, Disinfectant
SPECIFIC GRAVITY	1.20 - 1.30 @ 73 °F / 23 °C
DENSITY	10.0 - 10.8 lb/gal
SOLUBILITY IN WATER	Complete
pH (100 %)	1.5 - 5.0
VISCOSITY	138 cps @ 68 °F / 20 °C
POUR POINT	-49 °F / -45 °C
FREEZING POINT	-58 °F / -50 °C
BOILING POINT	> 158 °F / > 70 °C Decomposes
VAPOR PRESSURE	< 0.1 mm Hg @ 70 °F / 21 °C
VOC CONTENT	9.85 % EPA Method 24



SAFETY DATA SHEET

PRODUCT

EC6116A

EMERGENCY TELEPHONE NUMBER(S)

(800) 424-9300 (24 Hours) CHEMTREC

1. CHEMICAL PRODUCT AND COMPANY IDENTIFICATION

PRODUCT NAME : EC6116A

APPLICATION : BIOCIDES

COMPANY IDENTIFICATION :
 Nalco Company
 1601 W. Diehl Road
 Naperville, Illinois
 60563-1198

EMERGENCY TELEPHONE NUMBER(S) : (800) 424-9300 (24 Hours) CHEMTREC

NFPA 704M/HMIS RATING

HEALTH : 3 / 3* FLAMMABILITY : 1 / 1 INSTABILITY : 1 / 1 OTHER :
 0 = Insignificant 1 = Slight 2 = Moderate 3 = High 4 = Extreme * = Chronic Health Hazard

2. COMPOSITION/INFORMATION ON INGREDIENTS

Our hazard evaluation has identified the following chemical substance(s) as hazardous. Consult Section 15 for the nature of the hazard(s).

Hazardous Substance(s)	CAS NO	% (w/w)
Dibromoacetonitrile	3252-43-5	1.0 - 5.0
2,2-Dibromo-3-nitropropionamide	10222-01-2	10.0 - 30.0
Polyethylene Glycol	25322-68-3	30.0 - 60.0

Chemical Disclosure Registry

- MSDSs provide some but not necessarily all of the information that regulators and the public want or need
- In April 2011, the Ground Water Protection Council and the Interstate Oil and Gas Compact Commission opened a new online system to host information about the chemical additives used in frac fluids and their ingredients
- Any interested person can visit the website and search for data on a specific well
- As of end of October 2013, data had been entered on more than 57,000 wells representing over 540 oil and gas companies

www.fracfocus.org

Frac Focus Homepage

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HYDRAULIC FRACTURING
HOW IT WORKS

GROUNDWATER
PROTECTION

CHEMICAL
USE

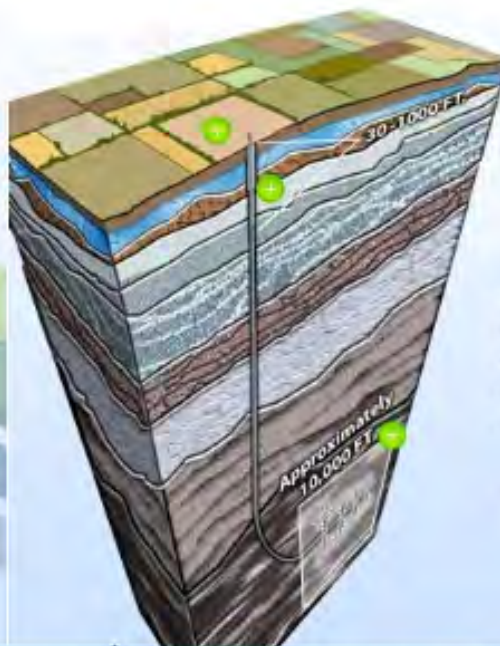
REGULATIONS
BY STATE

FIND A WELL
BY STATE

FREQUENT
QUESTIONS



[LEARN MORE >](#)



Hydraulic

This technique uses a
pumped into a well un
cracks in rock formati
the rock then allow oil
resource production.

[MORE ABOUT 1](#)

**Looking for information about a
well site near you?**



Search for nearby well sites that have been hydraulically
fractured to see what chemicals were used in the
process.

FAQs

◀ 1 / 3 ▶

any area that
when I search
why?

Q. Do states conduct ongoing
water wells and oil and gas
construction?

it either the wells
1, 2011 or they
the system.
any 1st will be

A. It depends on the state. When
water wells, many states have
construction standards but not
requirements. As regards the c

[Welcome](#) [Hydraulic Fracturing](#) [Casing & Cement](#) [State Regulations](#) [Chemical Use](#)

Is groundwater

Groundwater Protection: Priority Number One

Example of Registry Record for Well in Texas

Trade Name	Supplier	Purpose	Ingredients	Chemical Abstract Service Number (CAS #)	Maximum Ingredient Concentration in Additive (% by Mass)**	Maximum Ingredient Concentration in HF Fluid (% by Mass)**
Fresh Water		Carrier/Base Fluid				86.12903%
Sand (Proppant)		Proppant				12.83614%
Acid, 15% HCl	CUDO ENERGY SERVICES	Acid	Water	007732-18-5	85.00%	0.06070%
			Hydrochloric Acid	007647-01-0	15.00%	0.01071%
I-22	CUDO ENERGY SERVICES	Corrosion Inhibitor	Formic Acid	000064-18-6	60.00%	0.00053%
			Aromatic aldehyde	N/A	30.00%	0.00026%
			Haloalkyl heteropolycycle salt	N/A	30.00%	0.00026%
			Oxyalkylated Fatty Acid	N/A	30.00%	0.00026%
			Isopropanol	000067-63-0	5.00%	0.00004%
			Methanol	000067-56-1	5.00%	0.00004%
			Organic sulfur compound	N/A	5.00%	0.00004%
			Quaternary ammonium compound	N/A	5.00%	0.00004%
			Benzyl Chloride	000100-44-7	1.00%	0.00001%
SG-15M	CUDO ENERGY SERVICES	Gelling Agent	Petroleum Distillate	064742-47-8	55.00%	0.06860%
			Guar Gum	009000-30-0	50.00%	0.06236%
			Clay	014808-60-7	2.00%	0.00249%
			Surfactant	068439-51-0	2.00%	0.00249%
BUFFER H	CUDO ENERGY SERVICES	pH Adjusting Agent	Water	007732-18-5	94.50%	0.02070%
			Sodium Hydroxide	001310-73-2	51.50%	0.01128%
			Sodium Chloride	007647-14-5	5.00%	0.00110%
GB-4	CUDO ENERGY SERVICES	Breaker	Proprietary	N/A	100.00%	0.00120%
CX-14G	CUDO ENERGY SERVICES	Cross Linker	Petroleum Distillate Hydrotreated Light	064742-47-8	60.00%	0.01454%
GB-2	CUDO ENERGY SERVICES	Breaker	Ammonium Persulfate	007727-54-0	100.00%	0.00083%
NE-21	CUDO ENERGY SERVICES	Non-Emulsifier	Methanol	000067-56-1	30.00%	0.01218%
			Oxyalkylated alcohols	N/A	30.00%	0.01218%
			Ethoxylated Alcohols	N/A	10.00%	0.00406%
CX-14A	CUDO ENERGY SERVICES	Cross Linker	Sodium Tetraborate	001330-43-4	25.00%	0.00056%
CS-125C	CUDO ENERGY SERVICES	Clay Stabilizer	No Hazardous Components	NONE		0.00000%
FRA-4	CUDO ENERGY SERVICES	Friction Reducer	No Hazardous Components	NONE		0.00000%
MC B-8642 (WS)	MULTI-CHEM GROUP LLC	Anti-Bacterial Agent	Glutaraldehyde (Pentanediol)	000111-30-8	60.00%	0.01180%
			Quaternary Ammonium Compound	068424-85-1	10.00%	0.00197%
			Ethanol	000064-17-5	1.00%	0.00020%
MC S-2510T (WS)	MULTI-CHEM GROUP LLC	Scale Inhibitor	Ethylene Glycol	000107-21-1	60.00%	0.00605%
			Sodium Hydroxide	001310-73-2	5.00%	0.00050%



Flowback Water Management Processes

Disproportionate Media Emphasis on Shale Gas Wastewater

- Assumptions (tried to choose conservative estimates)
 - 20,000 shale gas wells are fractured in a year
 - Each frac job requires 5 million gallons
 - Only 50% of the frac fluid volume returns as flowback and produced water
- Total shale gas flowback and produced water for the U.S. = 50 billion gallons per year

Disproportionate Emphasis on Shale Gas Wastewater (2)

- U.S. produced water volume in 2007 for all oil and gas = 21 billion bbl (Source: Clark and Veil, 2009)
= 882 billion gal/year
- Compare shale gas water to all produced water
 - 50 billion/882 billion or about 5.7%.
- Putting this in perspective, ***shale gas receives more than 90% of the attention yet it consists of less than 6% of all the volume of produced water.***

What Happens to the Injected Water after the Frac Job Is Finished?

- Some of the water returns to the surface over the first few hours to weeks. This **frac flowback** water has a high initial flow, but it rapidly decreases
 - Over the same period of time, the concentration of TDS and other constituents rises

TDS values (mg/L) in flowback from several Marcellus Shale wells

Location	Day 0*	Day 1	Day 5	Day 14	Day 90
A	990	15,400	54,800	105,000	216,000
B	27,800	22,400	87,800	112,000	194,000
C	719	24,700	61,900	110,000	267,000
D	1,410	9,020	40,700		155,000
E	5,910	28,900	55,100	124,000	

* Day 0 represents the starting frac fluid conditions

Source: Tom
Hayes, 2009.

Flowback Water (1)

- Large volume of flowback returns to the surface in first few hours to few days
 - Typically collect in pits/ponds



Flowback Water (2)

- Many sites collect flowback in brine tanks or dedicated ponds
 - Filtered and reused in frac fluid for future well



Produced Water

- Over time, smaller volume of produced water flows to surface
 - Collected in onsite tanks
 - Picked up by trucks and removed for offsite management



Management of Frac Flowback Water

- Collected water must be removed from site
- Typically is collected by tank trucks and hauled offsite for:
 - Injection into disposal well (offsite commercial well or company-owned well)
 - Treatment to create clean brine (e.g., chemical addition, flocculation, clarification; advanced oxidation)
 - Treatment to create clean fresh water (one of the thermal distillation processes)
 - Evaporation or crystallization (allows zero discharge of fluids)
 - Filtration of flowback to remove suspended solids (i.e., sand grains and scale particles), then blend with new fresh water for future stimulation fluid.
- Long-term concerns when the number of new frac jobs is relatively low compared to the total volume of flowback and produced water from thousands of producing wells
 - “Cross-over point”



Injection into Disposal Well

- Injection wells offer several advantages, which lead producers to favor them where possible:
 - They are relatively inexpensive.
 - They can be located nearby to many shale gas plays.
 - Regulators are already providing oversight of injection wells.
 - Operators understand this tried and true technology.



Treatment to Create Clean Brine

- There was a network of wastewater treatment facilities in Pennsylvania set up to handle existing shallow gas wastewater prior to Marcellus development
 - Provided chemical/physical treatment to remove metals and adjust pH
 - Resulted in clean brine
- These facilities discharged to local rivers under permits issued by the government
- In April 2011, the oil and gas agency wrote to all gas producers advising them not to send flowback and produced water to these facilities because discharges may have had an impact of the surface water quality
- Other facilities came in that offered a similar level of treatment but returned the clean brine to the gas companies for reuse
 - No discharges involved





Treatment to Create Clean Fresh Water

- Additional treatment processes can remove most of the total dissolved solids resulting in fresh water
 - Thermal distillation technologies
 - Reverse osmosis
- Require pretreatment
- More costly than other technologies
- Water can be reused or possibly discharged

Thermal Distillation Technology

- Heats flowback to water vapor
- Condenses out clean water leaving a brine concentrate stream
 - Brine management costs can be significant
- Can operate in several modes
 - Permanent fixed facility
 - Short-term fixed facility
 - Mobile units



Reverse Osmosis

- Cost-effective up to about 40,000 – 50,000 ppm TDS
- Potential uses
 - For shale plays where flowback has low to medium TDS
 - The initial volume of flowback in all shale plays should have low to medium TDS
- Considerations about membrane fouling
 - Needs extensive pretreatment



Evaporation/Crystallization

- Technology can start with high-TDS flowback or with the concentrated brine from another treatment process.
- Can produce highly concentrated brine or dry solids
- Requires input of energy to evaporate salty water
 - e.g., excess heat from gas processing plant



Filter Flowback and Reuse

- Does not require high-tech filtration equipment
 - Often a simple sock filter
- Being used heavily in Marcellus due to lack of nearby injection options
 - Typical flowback volume is only 15% of original frac fluid volume
 - Even if flowback is filtered and reused, will need to supply 85% new water.
- May be used in other plays where fresh water supplies are limited.

Pennsylvania Flowback Management - 2009 vs 2013

2009	# individual entries (wells)	Bbls of wastewater	% of total wastewater managed using this method
Brine or Industrial Treatment Plant	233	3,437,556	37.6
Injection wells	1	14,530	0.2
Municipal Sewage Treatment Plant	111	2,038,227	22.3
Reuse	116	1,942,461	21.3
Other	106	1,703,936	18.6
Total	567	9,136,710	100

2013 (January-June)

Disposal Method	Total Volume (bbl)	% Using Method
Centralized Treatment Plant for Recycle	940,692	26.8
Injection Disposal Well	94888	2.7
Landfill	2186	0.1
Reuse Other Than Roadspreading	2,457,025	70.1
Storage Pending Disposal or Reuse	9,227	0.3
Centralized Treatment then Discharge	46	0.0
Total	3,504,064	100

Pennsylvania Produced Water Management - 2009 vs 2013

2009

Brine or Industrial Treatment Plant	635	11,987,679	66.2
Injection wells	33	122,571	0.7
Municipal Sewage Treatment Plant	218	1,806,124	10.0
Reuse	287	2,769,281	15.3
Other	1	75	0.0
Total	5185	18,104,507	100

2013 (January – June)

Disposal Method	Total Volume	% Using Method
Centralized Treatment Plant for Recycle	1,367,173	12.8
Injection Disposal Well	1287516	12.0
Landfill	197	0.0
Reuse Other Than Roadspreading	8,050,177	75.1
Storage Pending Disposal or Reuse	15,485	0.1
Roadspreading	105	0.0
Total	10,720,653	100.0

Decision Factors for Choosing a Produced Water Management Option

- Oil and gas companies will usually choose the lowest-cost option that:
 - Is physically practical at a location
 - Is approved by the regulatory agency
 - Is sustainable over an extended period
 - Poses little risk of long-term liability

Components Contributing to Total Cost of Wastewater Management

Category	Cost Component (Some or all may be applicable)
Prior to Operations	Prepare feasibility study to select option (in-house costs and outside consultants)
	Obtain financing
	Obtain necessary permits
	Prepare site (grading; construction of facilities for treatment and storage; pipe installation)
	Purchase and install equipment
	Ensure utilities are available

Cost Components (2)

Category	Cost Component (Some or all may be applicable)
During Operations	Utilities
	Chemicals and other consumable supplies
	Transportation
	Debt service
	Maintenance
	Disposal fees
	Management of residuals removed or generated during treatment
	Monitoring and reporting
	Down time due to component failure or repair
	Clean up of spills
After Operations	Removal of facilities
	Long-term liability
	Site remediation and restoration



Key Points

- Water is necessary to support drilling and fracturing
 - Companies need to plan ahead to ensure sufficient water resources are available to support long-term needs
- Management of flowback and produced water is a site-specific determination
 - Companies need to evaluate options to determine their feasibility, compliance with regulations, sustainability, and total cost

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