EVALUATING THE ENVIRONMENTAL IMPLICATIONS OF HYDRAULIC FRACTURING IN SHALE GAS RESERVOIRS

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Unconventional Natural Gas

- Unconventional resource plays are a growing source of natural gas in the U.S.
  - Coal Bed Methane
  - Tight Sands
  - Gas Shales
- Since 1998, unconventional natural gas has increased nearly 65%[1].
- Through 2007, total gas from unconventional plays approached almost 50% of total natural gas production in the U.S.[1]
- For gas shales, key technologies have included horizontal drilling and hydraulic fracturing.

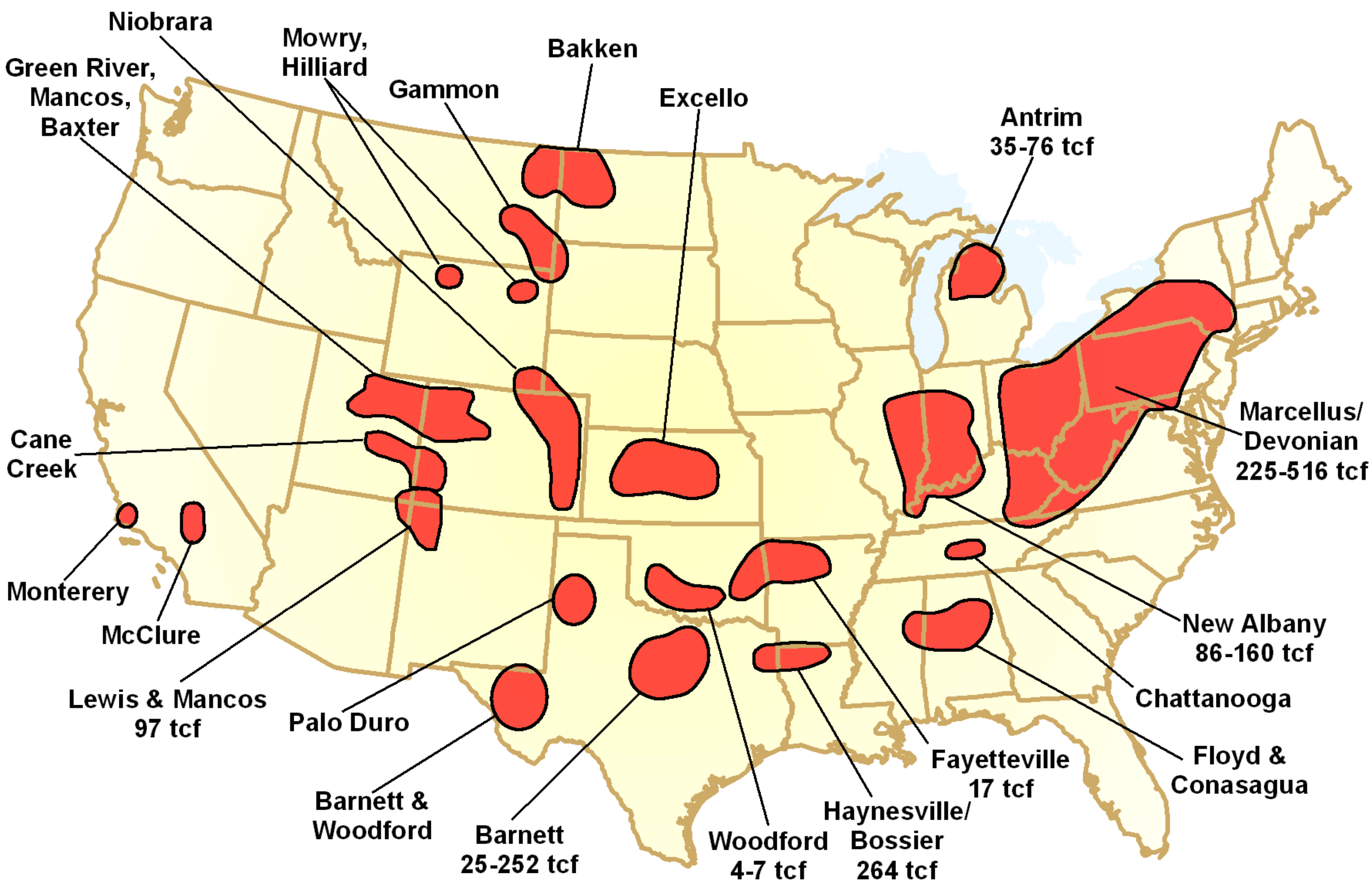
[1] *Source: Navigant, 2008*

Shale Gas and Technology History

- First Commercial Gas Well - Fredonia, NY (1821)
  - New York's "Dunkirk Shale" at a depth of less than 30 feet
- Ohio Shale – Big Sandy Field (1880)
- First Horizontal Wellbore in Texas (1930s)
- Hydraulic Fracturing first used in Oil and Gas Industry (1950s-1960s)
- Barnett Shale- Fort Worth Basin Development (1982)
- Horizontal Wells in Ohio Shale (1980s)
- Successful Horizontal Drilling and Completion Techniques in Barnett Shale (2003)
- Horizontal Drilling Technology Applied in Appalachian Basin, Ohio and Marcellus Shale, NY (2006)
- Estimated Shale Gas Reserves are 500-1,000 TCF (2008)
- First reported production from new shale gas development in Fayetteville Shale (May 2004)[2]

2 ALL Consulting and Ground Water Protection Council 2008. *Modern Shale Gas Development in the United States: A Primer*

Shale Gas Reservoirs in the U.S.



Data Comparison of Shale Plays

EXHIBIT 3. COMPARISON OF DATA FOR THE GAS SHALES IN THE UNITED STATES							
	Barnett	Fayetteville	Haynesville	Marcellus	Woodford	Antrim	New Albany
Estimated Basin Area, square miles	5,000	9,000	9,000	95,000	11,000	12,000	43,500
Depth, ft	6, 500 - 8,500	1,000 - 7,000	10,500 -13,500	4,000 - 8,500	6,000 – 11,000	600 – 2,200	500 – 2,000
Net Thickness, ft	100-600	20-200	200[11]- 300	50-200	120-220	70-12	50-100
Depth to Base of Treatable Water, ft	~1200	~500	~400	~850	~400	~300	~400
Rock Column between Pay and Base of Treatable Water	5,300– 7,300	500 – 6,500	10,100 – 13,100	2,125 – 7,650	5,600 – 10,600	300 – 1,900	100 – 1,600
Total Organic Carbon, %	4.5	4.0-9.8	0.5 – 4.0	3-12	1-14	1-20	1-25
Total Porosity, %	4-5	2-8	8-9	10	3-9	9	10-14
Gas Content, scf/ton	300-350	60-220	100-330	60-100	200-300	40-100	40-80
Water Production, Barrels water/day	0	0	0	0		5-500	5-500
Well spacing, Acres	60-160	80-160	40-560	40-160	640	40-160	80
Original Gas-In-Place, Tcf	327	52	717	1,500	52	76	160
Reserves, Tcf	44	41.6	251	262, 500	11.4	20	19.2
Est. Gas Production, mcf/day/well	338	530	625-1,800	3,100	415	125-200	

NOTE: See paper for data sources (Arthur, et. al., November 2008)

Horizontal Wells

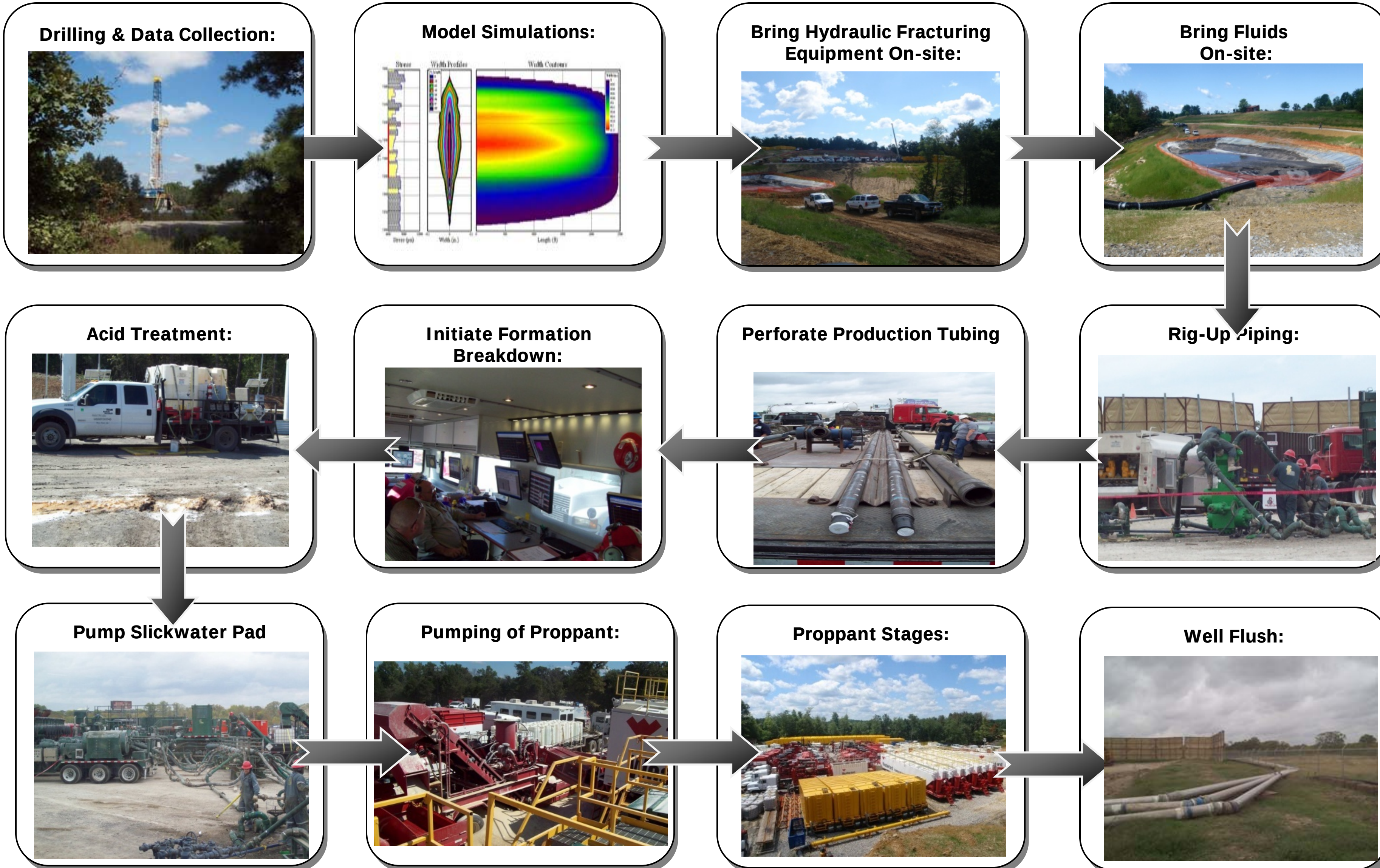
- There are Many Benefits of Horizontal Wells, these Include:
  - More Wellbore Reservoir Exposure
  - Less Disturbance to land, multiple wells on a single Pad, one lease access road
  - Less Potential for Erosion issues
  - Less Remedial and Reclamation issues
  - Less Pipeline for gathering systems
  - Less Production Facilities
  - Greater flexibility for surface location

Examples of multi-well pads from, upper photo is a 9 well pad near DFW, lower pad is a 4 well pad in rural area of Barnett Shale Development
Source: ALL Consulting 2008

Hydraulic Fracturing

- Hydraulic Fracturing is a formation stimulation practice used to create additional permeability which allows fluids to flow more easily toward the wellbore. Fracturing is used to overcome natural barriers to production from low permeability shale formations or to overcome damage to the near wellbore area that results from drilling.
- A key to successful hydraulic fracturing in many gas shales is ensuring the fractures created during the stimulation remain in the target zone.
- Fracturing out of the productive zone is usually not cost effective for the operator because it results in:
  - Added cost to fracture job directly, from additional fracturing fluids and proppant
  - adverse affects productivity of the well being treated or other nearby wells
- Fracturing is an evolving technology for each new shale gas development, early fracture treatments are based on experience with aspects of the design configuration, monitoring effectiveness, and effective treatment.
- Data collection in related to fracturing is common and may include: coring and core analysis, geophysical logging, reservoir characteristics research, correlation to other wells/stimulations, fracture pressure analysis and other research.

Hydraulic Fracturing Process



Drilling and Data Collection

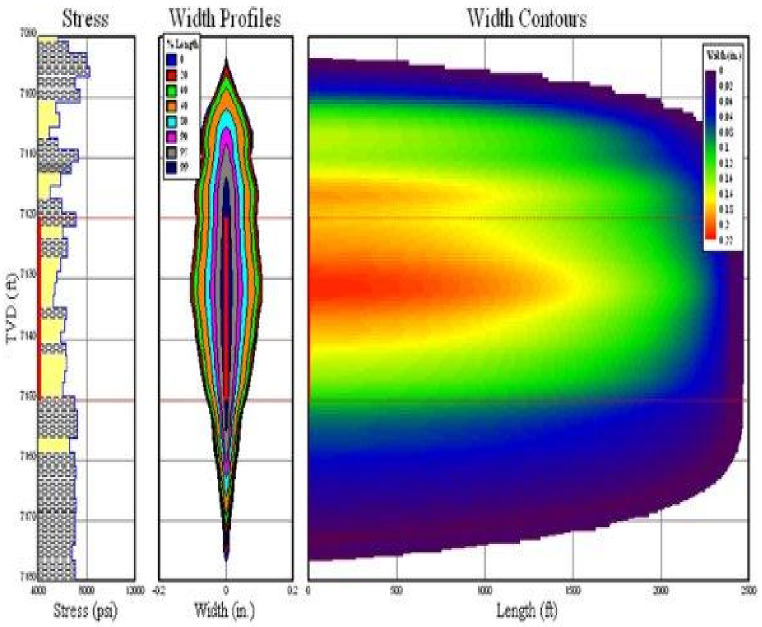
Drilling & Data Collection:

- Geophysical data collected prior to drilling
- Core Analysis
  - Natural Fracture Data
- Open and Cased Hole Logs
  - Porosity
  - Permeability
  - Fluid Saturation
- Offset Production Performance Analyses

Model Simulations

- Use data such as porosity, permeability, lithology, fluid saturation, fracture character and stress regimes collected to determine optimal fracture locations and possible fracture propagations
- Allows engineers to evaluate fracture stimulation design in controlled environment
- Continuously updated as new information becomes available

Model Simulations:



Bring Equipment On-site

- Technical Monitoring Vehicle
- Transfer Pump
- Frac Pumps
- Manifold Trailers
- Blender
- Chemical Body Load Float
- Boom Truck/Iron Truck
- Chemical Additives Truck
- Sand Storage Units
- Sand Dump
- Conveyors

Bring Hydraulic Fracturing Equipment On location (Fayetteville Shale):

Bring Fluids to Location

Bring Fluids On-site:

Water Availability

- Fresh Water Vaults
- Fire Hydrants
- Surface Reservoirs
- Company Constructed Diversions such as Chesapeake's Little Red River Reservoir
- Private Water Sources

Rig Up

Rig-Up Piping:

- Assembly of treating iron, hoses and equipment
  - Check valves to prevent fluid backflow
  - Plug valve or Isolation Valve
  - Adjustable Pressure Relief Valve located on the treating line to protect casing from over pressurization
  - Butterfly valves to control suction and discharge manifolds on Blender, Hydration Unit and Transfer Pump
  - Restraint systems in case of iron failure

Perforating

- Multiple clusters of perforations fractured in stages
  - Difficult to maintain pressures and injection rates to fracture the entire horizontal perforated interval
  - Multiple zones of perforations that are isolated during fracturing
- Charge size, shot orientations and density varies by operator

Perforate Production Tubing:

Formation Breakdown

Initiate Formation Breakdown:

- Slick-water pumped into formations to breakdown and initiate the acceptance of fluids in the formation
- Rates and pressures during breakdown can indicate if perforations are taking fluids or if competing fractures or other near wellbore tortuosity is occurring
- Data collected during breakdown can result modifications in stimulation design, such as additions of acid treatments or proppant slugs

Acid Treatment

Acid Treatment:

- Acid cleans up cement in perforations and provides accessible path to formation
- Hydrochloric Acid (HCl) is the most common acid utilized in stimulation treatments (same acid is used in regulating pool chemicals)
- Concentrations ranging from 3% to 28% are utilized effectively
- When acid is added to fracture fluid, it can be diluted in water up to 1,000 times
- Corrosion Inhibitors are used concurrently with acids to protect tubing, casing, tools and tanks from corrosion

Slickwater Pad

- Slickwater refers to a fluid with a friction reducer additive
- Slickwater Pads are used to lubricate well tubing and fractures in the formation aiding the placement of proppant sub-stages

Pump Slickwater Pad:

Proppant

- Proppant “props” open fractures, allowing fluids to flow more freely to the wellbore
- Typically sand is propping agent, but other compounds such as sintered bauxite and zirconium oxide are also used
- Resin coated sand is sometimes utilized in the final stages of a fracture job, when a stronger proppant is desired to ensure near wellbore permeability is maintained.
- Proppant concentration are generally low and proppant sizes are varied to ensure proppant reaches as deeply into the reservoir as possible.

Pumping of Proppant Stages:

Proppant Sub-Stages

Proppant Stages:

- Multiple sub-stages are used with increasing proppant concentration from sub-stage to sub-stage.
- Sweeps maybe used between successive proppant stages to minimize settling and duning of proppant in near wellbore area.
- Proppant size increases in later stages where fracture size is larger

Water Flush

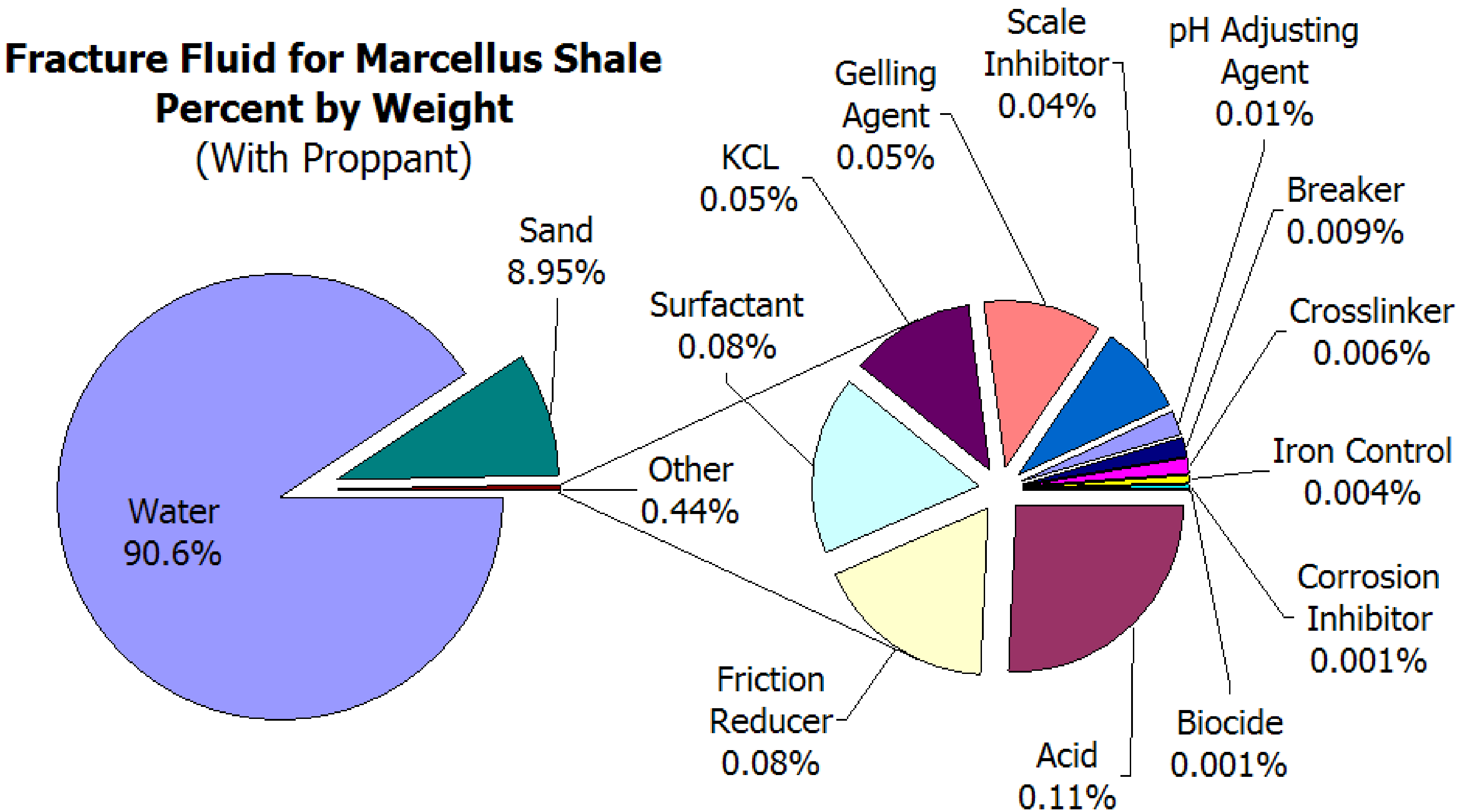
- A Water Flush is used to displace treatment fluids and Proppant into formation cleaning out fracture equipment.
- Some operators over-flush to ensure proppant is not mobilized and transported back into the wellbore.
- Water flush may include chemicals to active resin coating on proppants to "glue" resin together.

Water Flush:

Fracture Fluid Additives

- Biocides are used to prevent bacteria growth (Gluteraldehyde)
- Potassium chloride or other salts are often added to fracturing fluids for clay control
- A breaker is sometimes added towards the end of a treatment to break down the viscosity of the gelling agent to aid in releasing the proppant and enhance the volume of flowback water received after the completion (peroxydisulfates)
- Scale inhibitors are used to combat scale problems from high concentrations of calcium sulfate, calcium carbonate, and barium sulfate.

Fracture Fluid Composition



Water Flowback and Disposal

- Flowback water is primarily disposed of in Class II Injection wells in Barnett Shale
- Currently 60+ pending UIC permits in New York for Marcellus Shale

- Commercial and private land application facilities are being utilized in Fayetteville Shale
- Recycling is in pilot testing phases and may become more viable disposal option in the future

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