

HARTENERGY

2017

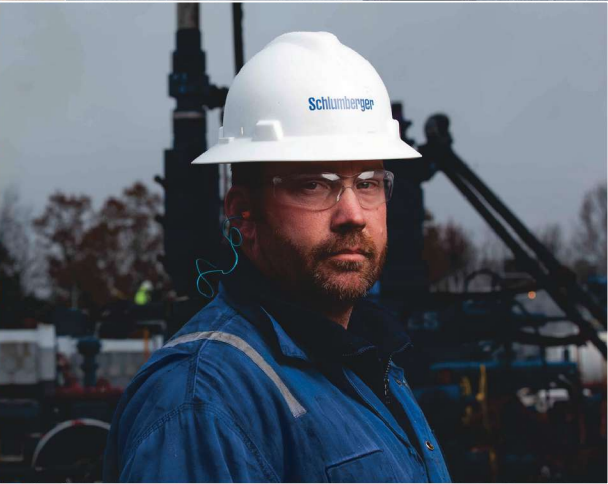

# Hydraulic Fracturing Techbook

A supplement to

**E&P**

Oil and Gas  
Investor





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stimulation  
efficiency.  
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## Hydraulic Fracturing The 2017 Techbook

A supplement to **E&P** and *Oil and Gas Investor*

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## Hart Energy's Techbook Series

The 2017 Hydraulic Fracturing Techbook is the 14th in a series of techbooks in which Hart Energy will provide comprehensive coverage of effective and emerging technologies in the oil and gas industry. Each techbook includes a market overview, a sample of key technology providers, case studies of field applications and exclusive analysis of industry trends relative to specific technologies.

To learn more about E&P technology trends, visit [EPMag.com](http://EPMag.com).

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On the cover: An operator at work in the hills of North Dakota looks to increase production by using more sand and more technology in its Bakken Shale well completions. (Photo by Miekko Mahi, courtesy of *Oil and Gas Investor*)





Solid wellhead economics and a deep bench of productive formations keep the valve wheels spinning for well service crews in the Permian Basin. *(Photo by Tom Fox, courtesy of Oil and Gas Investor)*



# Fracturing the Future

Six years prove ample time to make evolutionary advances in hydraulic fracturing technologies.

**By Jennifer Presley**

Senior Editor, Drilling Technologies

The year was 1859 when Edwin Drake brought in the first commercial oil well using a steam engine and a cable-tool derrick for the Connecticut-based Seneca Oil Co. Six years later, Edward Roberts received the first fracturing-related patent for his “oil well torpedo” design. During his time as a lieutenant colonel in the U.S. Army during the Civil War, Roberts saw the impact that explosives had in narrow spaces. He took inspiration from that experience to design a system that made it possible to place a waterproof flask of gunpowder downhole with the necessary mechanisms to “cause certainty of explosion at the proper time,” as stated in the patent awarded to Roberts.

According to the American Oil & Gas Historical Society, Roberts quickly determined that it would take more than simply cracking the rock with the pressure of an explosion to improve oil flow. Using a process he called “fluid tamping,” effectively filling the borehole with water, he found success.

“The technique had an immediate impact—production from some wells increased 1,200 percent within a week of being shot—and the Roberts Petroleum Torpedo Company flourished,” the society said.

While the first commercial application of the process we know today as hydraulic fracturing wasn’t until 1949, it was based on Robert’s technique. In the 150-plus years since the development of the first oil well torpedo, the industry has made significant advances on all fronts.

In a six-year span Drake and Roberts set the cornerstones to what would eventually evolve into today’s oil and gas industry. In a similar six-year

span, from 2011 to 2017, the accelerated rate of technological innovation witnessed by the industry added a whole new level of sophistication to the art of drilling and then hydraulically fracturing an oil or gas well.

Drake’s Titusville, Pa., well reached total depth of 69.5 ft before hitting a crevice that would eventually fill with oil. Today’s wells reach extraordinary depths vertically and horizontally. Take, for example, the Great Scott 3H well drilled in 17 days by the Pennsylvania-based operator Eclipse Resources. Reaching a total measured depth of 27,400 ft the well extends laterally 19,300 ft into the liquids-rich Utica Shale of Ohio and is set to be completed in the third-quarter 2017.

The advanced technologies and techniques used to make wells like the Great Scott possible are featured in this edition of Hart Energy’s Hydraulic Fracturing Techbook. The discussion opens with a look at the leading companies bringing hydraulic fracturing technology advances to the market. Also included in this annual techbook is an extensive look at the significant gains made in deciphering the geomechanics of shale. A selection of completion technologies and a detailed look at how one company incorporates integrated workflows to boost production and efficiencies in shale plays are provided. In-depth reviews of the sand and water markets finish up the edition.

While we’ll never know what Drake and Roberts think of today’s modern oil and gas industry, it is easy to imagine they’d be astonished by how far we’ve taken cable drilling rigs and flasks of gunpowder. ■



# Players Keep Head in the Game

Despite the downcycle, companies continue R&D to bring new fracturing technologies and services to the industry.

**By Ariana Benavidez**  
Associate Managing Editor

**T**he global hydraulic fracturing market was valued at \$42.83 billion in 2015, according to a 2016 report by Grand View Research. And by 2024, hydraulic fracturing market share is set to exceed \$68 billion, according to a Global Market Insights report.

According to Scott Treadwell, vice president of Capital Markets and Strategy for Calfrac Well Services, "Demand for fracturing services has grown rapidly through the first half of 2017, driven by an increase in rig activity and productivity but also a continuing trend by producers to maximize stimulated reservoir volumes by placing larger fracturing treatments at tighter intervals along longer wellbores."

Nathan Markert, NOV's vice president of Pressure Pumping Equipment U.S., added, "This year has been a welcomed change as manufacturers respond to pressure pumpers' demands to increase available horsepower through newbuilds and rebuilds of idled equipment. We are eager to see the implementation of new technologies developed during the downcycle and the cost reduction impact in this lower commodity price environment."

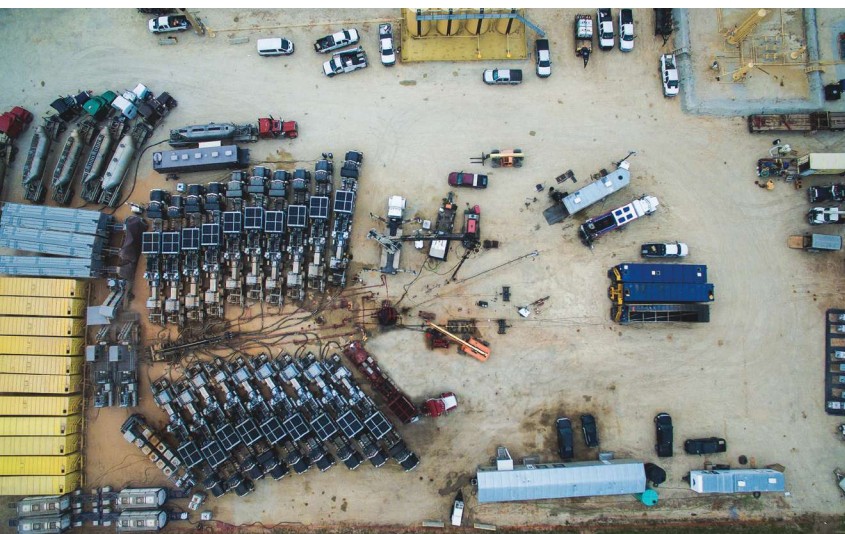
According to Kevin Fisher, president and CEO of PropX, "Hydraulic fracturing is becoming a proppant supply 'numbers game' for the industry. Can sand mines provide the supply needed in 2018 and forward? Can rail logistics deliver that sand to the basins, and can last-mile storage and trucking infrastructure deliver it to the well site on time? If frack sand intensity (pounds of sand pumped per lateral foot) continues to grow while at the

A well is completed in Madison County, Texas, in the upper Eagle Ford Shale play. (Photo courtesy of NOV)

same time the number of lateral feet to be stimulated continues to increase, then our industry will require an all-of-the-above solution to last-mile proppant logistics."

In the following section, Hart Energy profiles 43 of the most active hydraulic fracturing companies and briefly reviews some of the products and services they offer.

**Key Players**





## AFGlobal

AFGlobal is an oil and gas original equipment manufacturer specializing in technology, products and services with fully integrated manufacturing capabilities. The company offers managed-pressure drilling (MPD) equipment and services including FEED studies, from concept to development, flow modeling, rig surveys, and integrated control software and training. The company also offers pressure pumping technologies, including fracturing pumps, hydration units, data vans, blenders, manifolds and cementers. For large integrated fracturing operations, AFGlobal offers up to a 140-bbl/min single-trailer mounted blender designed for harsh shale environments.

In addition, the company provides subsea connection systems as well as life-cycle services that include buoyancy and riser inspection and repair.

In 2016 AFGlobal acquired Managed Pressure Operations, a subsidiary of MHWirth. The new business group within AFGlobal's oil and gas segment is known as Advanced Drilling Systems. The complete portfolio includes riser gas management systems, early kick/loss detection, MPD, dual gradient drilling and continuous circulation.



AFGlobal's hydraulic fracturing operations are shown taking place in West Texas. (Photo courtesy of AFGlobal)

## Archer

Archer is a global oil services company with more than 40 years of experience. It operates in 40 locations across 19 countries providing drilling services, well integrity and intervention, plug and

abandonment, and decommissioning to upstream oil and gas companies.

Archer drilling teams secure the production on more than 35 platforms and operate more than 75 mobile land rigs. In North America Archer's areas of expertise include horizontal and vertical wellbore stimulation using high-pressure, high-rate hydraulic fracturing services, cased-hole wireline, pressurized fluid pumping, coiled tubing and rig-assist snubbing. Additionally, AWC Frac Valves, part of Archer, manufactures and provides high-integrity gate valves for hydraulic fracturing.

With Archer's new Point System, an integrity management tool, users can investigate barrier leaks and flowpaths from surface, locate barrier leaks downhole, and locate barrier leaks and flow paths downhole.



AWC Frac Valves, part of Archer, manufactures and provides high-integrity valves for hydraulic fracturing. (Photo courtesy of Archer)

## ArrMaz

Founded in 1967, ArrMaz provides specialty chemical services across multiple industries in more than 70 countries worldwide. For the oil and gas industry, the company offers a silica dust control technology for hydraulic fracturing operations.

SandTec, ArrMaz's patented next-generation silica dust control coating technology, reduces respirable crystalline silica dust by up to 99% to within The Occupational Safety and Health Administration's new permissible exposure limit and action level, according to the company. When applied to fracture sand, SandTec provides silica dust protection across



the hydraulic fracturing supply chain from the sand plant through transload sites to the wellhead. The product does not require drying or curing time, is compatible with a variety of fracturing fluids and will not adversely affect well performance, the company said.

In addition, SandTec does not require any set-up, breakdown or maintenance of mechanical dust abatement systems and does not occupy valuable real estate at the fracturing site. The technology reduces site dust that can adversely affect equipment and is an environmentally friendly, U.S. Department of Agriculture-certified 100% bio-based product under the BioPreferred program.



This comparison shows untreated fracture sand vs. fracture sand treated with SandTec. (Photos courtesy of ArrMaz)

### Baker Hughes, a GE company

The multistage fracturing portfolio at Baker Hughes, a GE company (BHGE), includes hydraulic fracturing surface systems, fracturing fluid systems, proppant technology, completion tools and flow assurance technology as well as 24/7 real-time production monitoring services.

One of the most recent additions to the company's plug offering is the TORPEDO fracture plug, which is designed to improve the efficiency and reliability of plug-and-perf operations. With only a single set of ultradurable slips vs. the traditional two sets, the plug cuts millout times by 50% or more without sacrificing strength or reliability, according to the company.

In addition, the company's SPECTRE plug completely disintegrates downhole after fracturing and is designed to allow operators to avoid post-fracture intervention altogether, further shortening the gap between the completion and production phase.

For wells that have declining rates but still have more production to offer, the company's OptiStriker straddle packer system is designed to enable aggressive, targeted treatment of individual perforation clusters, which allows operators to boost production from existing assets, the company said. BHGE also offers production chemistry, including its Sorb and Sorb Ultra solid inhibitors, to inhibit scale, paraffin, asphaltenes and salt, in addition to controlling bacteria and corrosion.

BHGE's ultralightweight proppants and neutral wettability proppants are engineered to provide consistent fracture support and to enable fluids to flow freely through the fracture network.

The company also offers a complete acid fracturing service as well as a prime enhanced conductivity fracturing service, which is designed to create tailored proppant pillars for long-term fracture support. Advanced diverter technology is also available. Additionally, the company's hydraulic fracturing software tools allow users to fully visualize complex fracture geometries and distributions.



The TORPEDO fracture plug cuts millout times by 50% or more without sacrificing strength or reliability, according to the company. (Image courtesy of Baker Hughes, a GE company)

### BJ Services

BJ Services is a North American-focused, pure-play pressure pumping services provider and operates within all major basins across the U.S. and Canada.

The company's fracturing technologies are designed to stimulate reservoirs, enhance proppant transportation and improve existing perforation treatment. The company also offers specialized fracturing fluid solutions.



The company's ThinFrac line of linear gels are designed to help create large, complex fracture networks. The fluids are water-based and contain gelling agents or polymers that can have some proppant transport capabilities and reduce friction pressure when pumped, resulting in lower hydraulic horsepower requirements, according to the company's website. BJ also offers formulations for different temperature ranges and varying water qualities.

The company's RheoFrac line of crosslinked fracturing fluids have lower polymer loadings through its advanced crosslinker formulations and breaker technology FracCare BR. RheoFrac fluids can be engineered in a variety of crosslink times and temperatures, polymer types and concentrations, downhole temperature stability and can be mixed with different water qualities, the company stated on its website.

In addition, BJ has R&D facilities in Tomball, Texas, and Calgary, Canada. The Tomball Technology Center is a laboratory used for product design, analysis and testing in the areas of stimulation, rock mechanics and surface equipment. The Canadian



BJ Services operates within all major basins across the U.S. and Canada. (Photo courtesy of BJ Services)

## **RUN** Uninterrupted

*with Frac Fuel's Direct Engine Fueling System*

Frac Fuel's Direct Engine Fueling System allow customers to realize significant cost savings with uninterrupted diesel fuel to frac pumps. This patented process is a turn-key operation and completely self-sufficient on-site. Only bulk loads of fuel are required to keep the site operational. There's no need to maintain a fuel company on location.

### **Additional Frac Fuel Solutions Benefits**

**Fail Safe:** allows continuous run-time — even during systems shut downs

**Safety:** keeps employees out of the hot zone and removes human error from pump fueling

**Cost Savings:** via reduced day rates, bulk fuel margins and operational efficiencies



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SOLUTIONS

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facility has capabilities that include examining core and drill cuttings in terms of mineralogy and possible rock/fluid interactions, and developing and evaluating new fracturing additives.

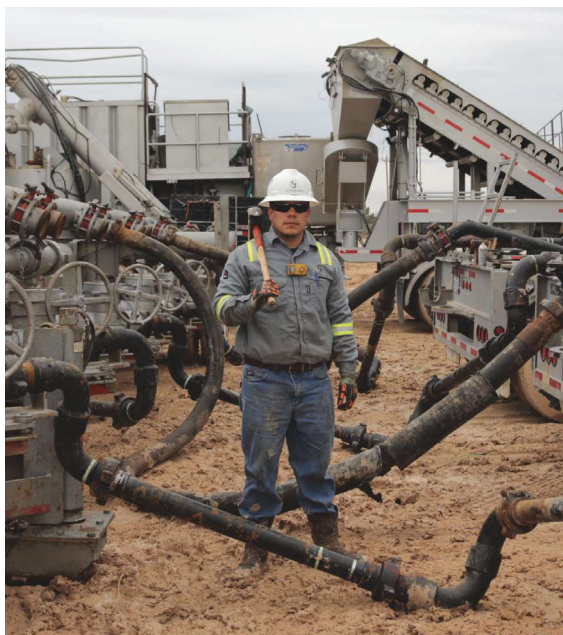
### C&J Energy Services

C&J offers a full, vertically integrated suite of services involved in the entire life cycle of the well, including fracturing, wireline, coiled tubing, cementing, rig services, fluids management services and other special wellsite services.

The company provides fracturing capabilities designed to handle the most technically demanding reservoir challenges. Fracturing services are provided by trained, experienced crews using modern, reliable equipment, the company said.

C&J's conventional and unconventional reservoir experience, combined with in-house research and technology capabilities, allows the company to offer a range of stimulation and restimulation techniques. These include the LateralScience engineered completion process as well as other reservoir stimulation services designed to help regain production and increase well recovery.

The LateralScience process leverages commonly available drilling measurements to derive reservoir parameters commonly used in fracturing designs. This helps guide the placement of perforation clusters, leading to uniform fracture treatment within each fracture stage.



A C&J fracturing fleet operates in the Permian Basin. (Photo courtesy of C&J Energy Services Inc.)

### Calfrac Well Services

Calfrac Well Services is an independent provider of specialized oilfield services, including hydraulic fracturing, coiled tubing, cementing and other well stimulation services. Calfrac operates in key basins in the U.S. including the Bakken, Rockies, Niobrara, Eagle Ford, Permian, Marcellus and Utica. Operations in Canada service the Viking, Cardium, Deep Basin, Montney and Duvernay.

The majority of Calfrac's field activities are associated with hydraulic fracturing. The company offers a nondamaging synthetic friction reducer that exhibits support characteristics for higher proppant concentrations. The company also offers diverter technology, slickwater tools for fresh and high total dissolved solids brine applications, and all traditional industry applications of gel-based, crosslink and energized fracturing needs. Treatment types and additives (such as surfactants and biocides) are customized to meet desired operational, treatment and production objectives.

Calfrac's HSE program includes procedures to ensure it meets or exceeds all applicable HSE regulations. The company develops and tests technologies that are designed to boost efficiency, reduce water consumption and minimize risk to the environment.

Regional laboratories are positioned in locations to ensure direct support is available to customers and at the well site.

Calfrac's supply chain, logistics optimization and asset management strategy includes access to sand mines and terminals, long-term leases on private railcars, barges and trucks, access to unit train facilities and third-party transloads as well as field storage for last-mile product management.



This aerial shot shows one of Calfrac's multiwell pad hydraulic fracturing operations. (Photo courtesy of Calfrac Well Services)

# CONTROLLED INTENSITY™

## *Bigger, faster pinpoint completions: more stages, more sand, higher rates—and no runaway fracs.*

Multistage Unlimited® pinpoint fracturing delivers maximum SRV with far less risk of frac hits and well bashing during infill and high-density field development, compared with plug-and-perf. You put fracs where you want them, and you control how much sand you pump into each one, preventing “super clusters” that can hurt production from offset wells. With repeatable frac placement from well to well plus recorded downhole pressure/temperature data, you can truly optimize stage count and spacing in a given formation with just a few wells.

### **More stages per well**

NCS pinpoint fracturing delivers more individual entry points with far higher frac efficiency than plug-and-perf. For example:

- 147 stages (Permian)
- 134 stages (Montney)
- 125 stages (Duvernay)
- 116 stages (Marcellus)

### **More sand per well**

More intensity means pumping a lot more sand, and NCS Multistage pinpoint fracturing handles it:

- 1,973 lb/lateral ft (Permian)
- 1,825 lb/lateral ft (Montney)
- 1,711 lb/lateral ft (Duvernay)

### **Faster execution**

NCS Multistage pinpoint completions are being executed faster than ever. Here's why:

**Higher rates.** Technology and design advances have boosted Multistage Unlimited frac rates through the coiled tubing/casing annulus to nearly 80 bbl/min in 5.5-in. casing, far higher “per cluster” than plug-and-perf and more than enough to transport sand (>12 ppg) with slickwater.

**Fewer coiled tubing trips.** Almost 90% of NCS Multistage jobs are performed in a single coiled tubing trip. As many as 134 sleeves have been fraced without tripping out of the hole.

**99+% sleeve success rate.** More than 120,000 NCS sleeves have been installed, with the highest sleeve-shift-success rate of any coiled-tubing completion system.

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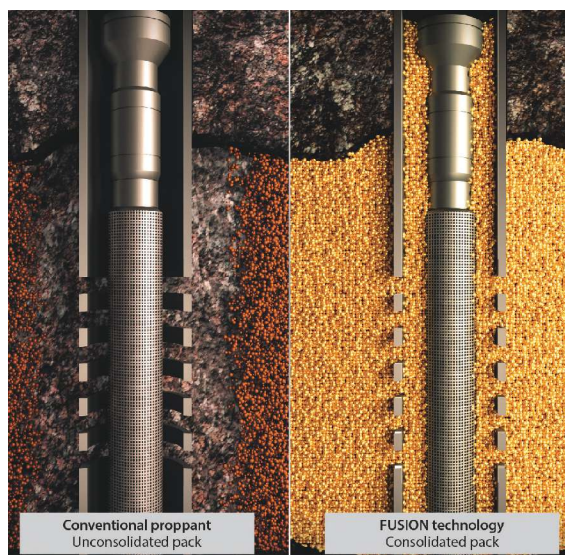


## CARBO

CARBO is a technology and service company that focuses on integrating technologies to provide engineered products and services that help E&P operators design, build and optimize a fracture.

The company's FRACPRO fracture simulation software is designed to help operators optimize fracture design and engineering. The toolset can model any type of pressure stimulation job, including limited entry wells, multiple perforated intervals and horizontal well fracturing, and it can model fracture growth in any formation, according to the company's website.

CARBO also offers a range of high-performance proppant and fracture technologies and services. KRYPTOSPHERE HD and KRYPTOSPHERE LD are ultraconductive ceramic proppant technologies that are designed to maximize hydrocarbon flow for the life of the well. KRYPTOSPHERE HD's durability, smoothness and roundness make it more resistant to cyclic loading and acids and is significantly less erosive on fracturing pumps and downhole tools. KRYPTOSPHERE LD, a low-density alternative, is engineered to have the same characteristics but also provides higher conductivity, improved proppant transport and increased propped fracture volume compared to intermediate-density and bauxite ceramics.



The FUSION proppant pack consolidation technology (right) is designed to improve well economics and increase EUR. (Image courtesy of CARBO)

In addition, the company recently launched CARBOAIR, a high-transport, ultralow-density ceramic proppant technology that is designed to

increase production and EUR from slickwater fracturing operations.

The company's FUSION proppant pack consolidation technology creates a bonded, high-integrity proppant pack without closure stress for use in high-rate production and water injection wells. The technology provides operators, "with the well integrity critical to inject and produce at the ultrahigh rates required to improve well economics and increase EUR," the company's website stated.

STRATAGEN is a fracture consulting services business that includes fracture design and evaluation, onsite fracture supervision and advisory services and well performance analysis. Its WELLWORX well performance evaluation service aims to help operators "quickly develop optimal completion designs and stimulation treatments for realizing faster payout and higher ROI [return on investment]," the company said.

## CoilChem

Formed in 2009, chemicals manufacturer CoilChem offers pressure control, hole cleaning, metal-to-metal friction reduction, and water treatment and cleaning services. Products include nonhazardous biocide, corrosion inhibitors, foamers, H<sub>2</sub>S scavengers, nondamaging acid, drilling lubricants, drilling fluid additives, dry drill beads, pipe wash, inhibitor stabilizers, fluid loss additives, paraffin treatment and various friction reducers, among others. The company also offers chemical training, onsite testing and 24-hr support services.

CoilChem's water treatment system recycles up to 1 million gallons of water per day. The system instantly removes solids suspended in water, recovers hydrocarbons, kills bacteria and destabilizes dissolved organic matter for faster removal, according to the company's website. The system also converts water soluble iron sulfides (Fe<sup>2+</sup>) to an insoluble form (Fe<sup>3+</sup>), allowing them to be more quickly and readily removed. In addition, the system provides a continuous, in-line process with no need for holding tanks.

The company's CoilChem FR-1400 pressure control tool is designed to lower pump pressure and lubricate the pipe contact. The friction reducer addresses friction and cleaning simultaneously.

According to the company, "CoilChem FR-1400 hydrates 441% faster than the old industry standard, emulsion polyacrylamide. Plus, unlike polyacrylamide emulsions, high bottomhole temperatures and chlorides don't slow CoilChem FR-1400 down."



# 1.6 Million HHP Covering These Major Plays

*Marcellus and Utica in  
Appalachia*

**Fracturing    Cementing    Acidizing**

*Stack and Scoop in  
Oklahoma*

*Barnett in  
North Central Texas*

*Permian Basin in  
West Texas and New Mexico*

*Woodbine and Eaglebine  
in East Texas*

*Eagle Ford in  
South Texas and Texas Gulf Coast*

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## Cudd Energy Services

Cudd Energy Services (CES) operates in more than 60 global markets, including the major shales across North America. The company provides customized completion, production and well intervention services for onshore and offshore operations including stimulation, coiled tubing (CT) and e-coil, coil drilling technologies, hydraulic workover, slickline and braided line, electric line, industrial nitrogen, cementing water management, well control and special services.

CES provides a variety of stimulation services including hydraulic fracturing and acidizing in conventional and unconventional oil and gas reservoirs. The company's hydraulic fracturing services range from single-stage fractures to complex multistage, horizontal fractures. Each operation includes pre-job analysis of the well, real-time monitoring (with the FracLink application) and a reporting system at the end of the job to meet state reporting requirements.

CES applications of hydraulic fracturing stimulation treatments include slick water, linear gel, crosslinked gel, CO<sub>2</sub> foam and nitrogen foam. The company designs custom-blended acidizing treatments to increase well productivity and assist in well cleanout applications. The acidizing services can accommodate bottomhole temperatures ranging from 100 F to 350 F. Acidizing applications include matrix, CT and remedial.



Cudd Energy Services stimulation equipment fleet includes about 935,000 hhp. (Photo courtesy of Cudd Energy Services)

In addition, CES offers additives and equipment that are custom-engineered for stimulations services. The company's stimulation equipment fleet includes about 935,000 hhp. Individual units can deliver up to 2,250 hhp and are capable of operating pressures up to 13,250 psi.

## DistributionNOW

In 2014 the Distribution segment spun off from NOV to form DistributionNOW (DNOW). DNOW has about 300 locations and is a global distributor of pipe and tubing, manual and actuated valves, fittings, flanges, gaskets, fasteners, instrumentation, power transmission products, mill and janitorial supplies, hand and power tools, machine cutting tools, safety products, personal protective equipment, electrical products, artificial lift equipment, pumps, fabricated equipment, drilling and production products, and industrial paint and coatings.

The company's drilling products include pipe-handling equipment, solids control equipment, fittings, gauges and sensors, chemicals, lubricants, valves and actuation, and more.

Onshore and offshore E&P products include line pipe, fittings, valves and actuation, gauges and sensors, production equipment, artificial lift systems, belts and sheaves, lubricants and adhesives, separator packages and heaters/treaters.

DNOW also offers a wide range of supply chain solutions designed to reduce costs and increase efficiency.

## Fairmount Santrol

Fairmount Santrol offers a range of proppants, proppant transport technology, diverting agents and activators for oil and gas. The company provides a full suite of curable resin-coated sands to prevent formation fines and proppant flowback as well as precured resin-coated sands to enhance conductivity and crush-resistance.

A major focus for the company is its Propel SSP proppant transport technology, which was limited to total dissolved solids (TDS) levels of 1,000 ppm and hardness of 500 ppm until January. Updates to the product resulted in a technology that hydrates quickly in high-salinity waters, tolerating TDS levels of up to 350,000 ppm and water hardness of 40,000 ppm. The product line extension, Propel SSP 350, assists operators facing high produced water management costs (e.g., Pennsylvania), constraints on freshwater availability (e.g., Delaware Basin) and disposal well restrictions (e.g., Oklahoma's Arbuckle Formation).

EST. 1859

# INNOVATION

— IS THE HEART OF OUR EVOLUTION —



For over 150 years, we've never rested on past achievements - we've built on them. We push harder. We create smarter. We work relentlessly to introduce innovative pumping technology to our partners in the industry. And with creation comes education. That's why, behind every Gardner Denver pump, there's a world of support and services - ensuring you get all that you expect and deserve from our products.

It's simple, our pumps don't quit - and neither does our commitment to creating innovative products that lead our customers into tomorrow.

**Gardner**  
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PUT OUR LEGACY TO WORK



With Propel SSP, proppant concentration is typically ramped up to 6 ppa for increased formation contact area. Operationally, higher proppant loads achieved with Propel SSP have reduced water consumption as much as 50% compared with slickwater designs pumping the same proppant mass, according to the company.

Regarding productivity, in 2015 a six-well field trial with Propel SSP increased initial 90-day oil production 39% compared with offset wells. Today, after 23 months of production, the same wells are producing 47% better—demonstrating slower decline, the company said.

tion and proppant-proportioning units can execute a fracturing pumping design controlling both suction and discharge functions, the company said on its website. The blender unit is equipped with two power units. A hurricane style or conventional tub is designed to automatically increase or decrease fluid based on the outgoing demand, the company stated. In addition, Freemyer's acid/fracture combo units are high-pressure acid pumping units mounted on a trailer or truck capable of pumping inhibited acids and other oil well servicing fluids. The units include a high-pressure pumping system, all required controls, instrumentation and a hydraulic system to drive fluid-handling equipment.



Propel SSP proppant transport technology swells and self suspends in water up to 350,000 ppm TDS, maximizing the effective propped area. (Photo courtesy of Fairmount Santrol)

### Freemyer Industrial Pressure LP

Formed in 2000, Freemyer Industrial Pressure offers hydraulic fracturing equipment, cementing equipment, electronics and automated control systems, and offshore equipment. The company's fracturing products include quintuplex and triplex fracturing pumps, hurricane fracturing blenders, hydration units, liquid additive units, mobile data vans and trailers as well as acid and fracturing combos.

Freemyer's fracturing pump units can be operated at the local control enclosure, remotely or from a data van. All discharge treating iron will be rated for 15,000 psi operating working pressure. The company offers up to 2,500-hp triplex and quintuplex pumps, which include gauge connection, discharge flanges, suction manifold with cleanout ports, and plunger size of choice.

The company has trailer- and truck-mounted fracturing blenders. The fracturing fluid prepara-

tion and proppant-proportioning units can execute a fracturing pumping design controlling both suction and discharge functions, the company said on its website. The blender unit is equipped with two power units. A hurricane style or conventional tub is designed to automatically increase or decrease fluid based on the outgoing demand, the company stated. In addition, Freemyer's acid/fracture combo units are high-pressure acid pumping units mounted on a trailer or truck capable of pumping inhibited acids and other oil well servicing fluids. The units include a high-pressure pumping system, all required controls, instrumentation and a hydraulic system to drive fluid-handling equipment.

For the past three years, the company's total recordable incident rate was less than half of the industry average, according to FTSI, and during first-quarter 2017 it reached a milestone of more than 10 million man-hours without a lost time incident. Recent examples of the company's initiatives aimed at improving HSE conditions include deploying dual fuel engines that can run on both natural gas and diesel fuel; electronic pressure relief systems; spill prevention and containment solutions; dust control mitigation; and containerized proppant delivery solutions.

### FTS International

FTS International (FTSI) is one of the largest providers of hydraulic fracturing services in North America based on both active and total horsepower of its equipment. The company provides high-pressure hydraulic fracturing and wireline services with a particular expertise in stimulating production of oil and natural gas from wells in shale and other unconventional formation. Since 2010 the company has completed more than 130,000 fracturing stages across the most active major unconventional basins in the U.S.

FTSI is also a vertically integrated manufacturer. The



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FTSI also owns an interest in SinoFTS, a Chinese joint venture formed in June 2014 with Sinopec. SinoFTS fractured its first five wells in China in 2016.



One of FTSI's hydraulic fracturing sites operates in South Texas. (Photo courtesy of Sanchez Energy)

### Gardner Denver

Gardner Denver offers engineering and support for petroleum and industrial pumps in the global upstream oil and gas market.

With a 2,550-bottomhole pressure (BHP) and 3,000-BHP models, the company's latest innovation, the Thunder Series of well service pumps, offers operators and well servicing contractors increased horsepower and rod-load with longer life and service intervals that are aligned with those of the engine and transmission, according to the company.



Gardner Denver's five-cylinder Thunder Quintuplex Pump has a maximum input of 3,000 BHP and a maximum rpm of 300. (Image courtesy of Gardner Denver)

"The Thunder Series embodies a modular design with a focus on smooth operation, maintenance and serviceability. The Thunder Series crankshafts have been optimized with a specific firing order and added counter weights where necessary to absolutely minimize the vibrations and shaking forces of operation," the company said.

This new lineup also offers a longer 11-in. stroke (vs. the typical 8 in.). The additional three inches provides 37% more flow per cylinder, per rotation of the pump, thus accumulating fewer cycles over time, which decreases the overall wear and tear, according to the company. The result is longer time between scheduled maintenance intervals and a reduced rate of consumable part use.

### The GasGun Inc.

Formed in 1994, The GasGun Inc. has conducted more than 10,000 propellant fracturing stimulations in oil and gas wells worldwide.

The company's GasGun and Kraken solid-propellant fracturing devices are based on proprietary ballistic technology from the U.S. military. The products were designed to create fractures and increase formation permeability. The GasGun can be applied in horizontal wells, close water contact, pre-acid treatments, naturally fractured operations, on nearbore damage, prefracturing treatments, injection and in openhole operations.



The GasGun propellant fracturing stimulation device installed in Canada was designed to create fractures and increase formation permeability. (Image courtesy of GasGun)

Whether compared to hydraulic fracturing or explosives, a 2016 company brochure reported that GasGun logs about 10 milliseconds and 20,000 psi compared to about 1 hour and 5,000 psi for hydraulic fracturing and about 1 microsecond and 1 million psi for explosives.

Additionally, the company's Kraken perforates and stimulates in one trip, creates multiple fractures, bypasses skin damage, prepares the well for hydraulic fracturing and is designed to improve the effectiveness of acidizing.

### GEODynamics

GEODynamics provides perforating, limited entry perforating and completions products, among other tools. The company's perforating products are for conventional perforating as well as advanced perforating, such as reactive perforating or limited entry perforating for diversion.

Among the new technologies the company released in 2016 were its QuickStart Inject and Frac Valve as well as the FracIQ Limited Entry Perforating System.

This year the company's Engineered Perforating Solutions Division began field testing its SandIQ Optimized Perforating for Diversion technology in April in the Permian and Bakken, according to a press release. The system generates optimized perforating geometry that is designed to improve proppant transport in fracturing stages.

According to the company, SandIQ and FracIQ use constant and consistent perforating entry holes and penetration depths in wells regardless of gun position, well casing or formation type.

GEODynamics also offers simulation consulting. The company's iPerf simulator "uses the latest modeling developments to deliver realistic downhole system performance that is based on findings from over 5,000 laboratory charge tests conducted in formation rock under downhole conditions," the company stated on its website.

In addition, in January GEODynamics acquired Paradigm GeoKey's perforating business in Aberdeen, Scotland, as the base for its Eastern Hemisphere business.

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## GR Energy Services

GR Energy Services provides completion and production services.

The company developed the ZIP Intervention Platform, which is designed to improve safety, lower operating time and improve perforating placement for fracture stimulation. The redesigned wireline pressure control equipment, perforating guns, setting tools and monitoring systems maximize total available pumping time. Risks due to stabbing tools at height in a high-pressure zone have been eliminated, gun deployment and plug-setting time decreased, and total available pumping time increased, according to the company.

The ZipSquad plug-and-play perforating system is a portless, addressable, prewired and compact gun string that is designed to perform reliably for reduced lost time due to misruns.



The GR ZipLok system eliminates the need for a crew member to work at heights, which enables stimulation operations to continue during well-to-well wireline transitions. This wellsite efficiency maximizes total available pumping time. *(Photo courtesy of GR Energy Services)*

In addition, the company's PerfTactix service integrates drilling and formation evaluation data with advanced analysis software to optimally place stage and perforation clusters along the wellbore and to select the ideal shaped charge and gun system for the completion.

The company's Flex Flow service integrates a downhole hydraulic jet pump with a trailer-mounted horizontal pumping system that is designed to lower the total cost of operations of early flowback

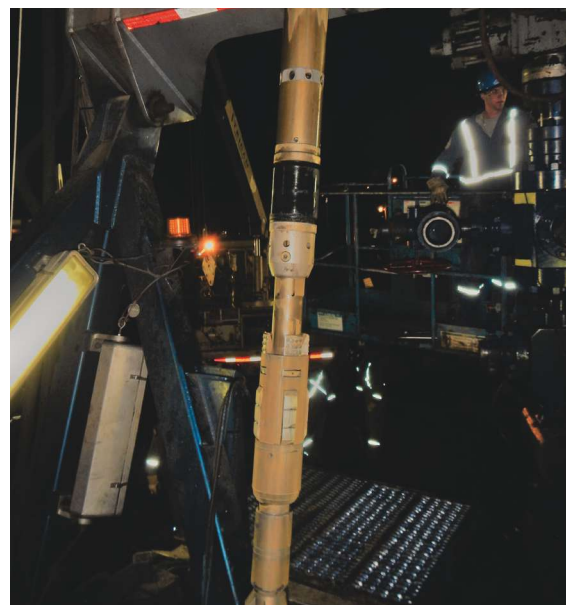
and production of hydraulically fractured wells, the company said. For saltwater disposal (SWD) with trailer-mounted or permanent installations, the company said the Flex Flow HPS SWD system offers cost and performance advantages over conventional triplex positive displacement pumps. According to the company, surface facilities engineers using these systems have documented lower maintenance and repair costs, longer runlife and greater operating flexibility and efficiency.

## Gryphon Oilfield Solutions

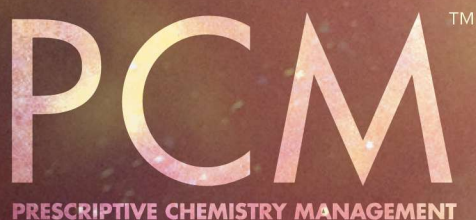
Founded in 2016, Gryphon Oilfield Solutions provides integrated solutions and products to upstream oil and gas companies. The company offers completion and remedial tools and a full array of casing equipment. Gryphon's tools cater to both openhole and cemented applications and covers plug-and-perf and fracture sleeve operations. A full line of composite plugs along with dissolvable characteristics are available for any downhole environment.

Gryphon focuses on operational service during installations of new tools as well as remedial work-over applications. The technology team can develop new tools to solve the latest downhole issues with immediate results.

Gryphon offers a full suite of casing equipment products along with global support. Casing equipment consists of centralizers, stop collars, float equipment, stage tools, packers and associated accessories. The Gryphon casing equipment team cur-



Gryphon's completion packer is shown in action at night. *(Photo courtesy of Gryphon Oilfield Solutions)*



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rently is focusing on developing products that will allow safe, efficient operation in both land-based and deepwater/close tolerance applications.

### Halliburton

Halliburton stimulation technologies are designed for fracturing, pinpoint stimulation, acidizing/near-wellbore cleanout and conductivity endurance. Halliburton focuses on both improving surface efficiency aspects of hydraulic stimulation as well as developing solutions to optimize asset productivity through subsurface evaluation.

From a surface efficiency perspective, the company's Frac of the Future employs technologies including the Q10 pump and is designed to cut non-productive time by sustaining continuous pumping operations, the company said. The ExpressKinect Wellhead Connection Unit is designed to minimize HSE exposure, footprint onsite and nonproductive time. Halliburton also offers the Illusion dissolvable fracture plug. With a 10,000-psi rating, the plug dissolves without any flow restrictions, so users never spend time milling out composite plugs or delaying production, the company said.



A Halliburton fracturing crew operates in the Permian Basin. (Photo courtesy of Halliburton)

Related to productivity improvements through subsurface evaluation, Halliburton leverages Integrated Sensor Diagnostics to optimize well and fracture spacing to improve asset recovery factors as well as its FracInsight service for improved perforation placement. The company also tests formation cuttings and reservoir fluids prestimulation to help customize a more cost-effective surfactant and

clay control package with the RockPerm service. Additionally, Spectrum real-time coiled tubing services are designed to deliver real-time subsurface data to help optimize well interventions and completions performance.

Using this subsurface knowledge, Halliburton's AccessFrac stimulation service uses flow constraint technology and designs to help each cluster realize its full potential. Combining RapidStage multistage fracture sleeve systems and AccessFrac stimulation service, operators have been able to double the number of stimulated fractures per zone compared to conventional methods and increase production on average by 35%, according to the company.

In addition, the "ACTIVATES refracturing service helps enable recovery of bypassed reserves predictively and repeatedly at as low as one-third the cost per barrel of oil equivalent compared to new drills," Halliburton said.

### Hi-Crush Partners

Hi-Crush is a provider of proppant and logistics solutions to the North American energy industry. The company's purpose-built production facilities are capable of producing 13.4 million tons per year of high-quality monocrystalline sand, a specialized mineral used as a proppant during the well completion process. The company's production facilities' direct access to major U.S. railroads enhance its delivery capabilities into consuming basins, while the company's owned and operated in-basin terminals and in-basin production facility positions it within close proximity to significant activity in all major oil and gas basins for advantageous truck transportation, the company said.



The Hi-Crush processing facility near Wyeville, Wisconsin, can produce 1.85 million tons/year of 20/100 fracture sand. (Photo courtesy of Hi-Crush)

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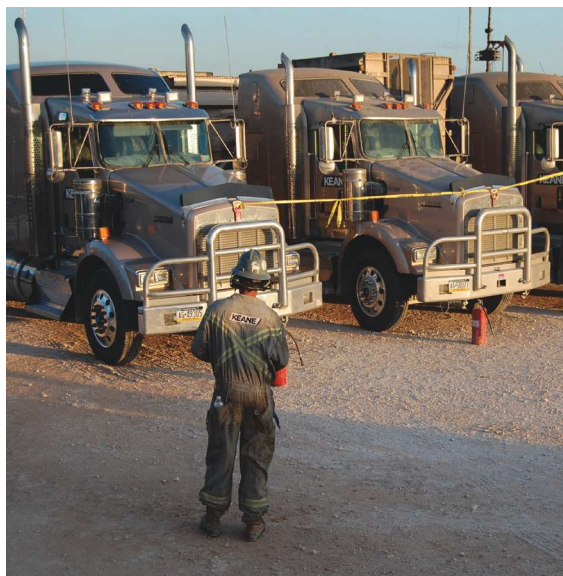
Hi-Crush's integrated distribution system, with its PropStream logistics product, delivers proppant the last mile into the blender, providing operators security of supply from the mine to the well site, the company said.

### Keane Group

According to the company, Keane is one of the largest pure-play providers of integrated well completion services in the U.S. The company focuses on complex, technically demanding completion solutions and its primary service offerings include hydraulic fracturing, wireline perforation and logging, engineered solutions and cementing, among other services. The company has locations in the Permian Basin, Marcellus Shale/Utica Shale, Bakken Formation and Scoop/Stack area.

Keane's hydraulic fracturing equipment includes about 1.2 million hydraulic horsepower, high-rate blenders, nitrogen units and high-pressure capability. Operations are backed by an extensive logistics organization that has national sales and contracts, 1,200 owned rail cars and a fleet of more than 120 sand haulers.

Wireline services are offered with specialties in plug-and-perf operations, mechanical services, radial cement bond logging and casing image calipers. Keane provides its own cranes, pressure control equipment up to 15,000 psi and greaseless wireline capability.



Keane deploys the latest chemical, fluid and equipment designs formulated specifically to increase overall production in the Permian Basin. (Photo courtesy of Keane Group)

Keane's technical team designs well-specific stimulation and cleanout fluid technology at the Engineering & Technology Center in The Woodlands, Texas. This laboratory is equipped for comprehensive pre- and post-job fluid analysis, along with fluid, proppant, cement, corrosion and microbial testing. District operations are additionally supported by a network of laboratories located in every major basin.

Keane has 24 fit-for-purpose units for cementing services; 12 rigs for well servicing, cleanouts or other workover services; and pressure pumping for toe prep and other pumping services.

### Kerr Pumps

Kerr Pumps manufactures pumps and provides repairs, maintenance and advanced diagnostics in the U.S. The company also offers complete pump overhauls and fluid end maintenance.

Kerr boasts that it has the largest machining company in Oklahoma. The facility includes live tooling lathes, five-axis boring mills, vertical machining centers and horizontal machining centers. In addition, the company has a full service fabrication shop that is equipped to weld up pumping skids such as reversing and closing units.

According to the company, "Everything at Kerr Pumps is designed, engineered, machined, assembled and tested under one roof."

### Liberty Oilfield Services LLC

Liberty Oilfield Services (LOS) has a focus on fracture optimization and on improving tight oil completions. Liberty has field offices in Henderson, Colo. (Denver-Julesburg Basin), Gillette, Wyo. (Powder River Basin), Williston, N.D. (Williston Basin), Odessa, Texas (Permian Basin) and Cibolo, Texas (South Texas/Eagle Ford). With the addition of Sanjel's U.S. assets, acquired in 2016, LOS has a hydraulic fracturing capacity of 560,000 hhp.

The company's services include completions and productions evaluations using LOS databases for U.S. liquid-rich basins in conjunction with detailed multivariate analysis. According to the company's website, LOS also assists in the coordination and evaluation of laboratory and field tests required to support the stimulation program; performs analysis of diagnostic data to obtain basic analysis anchor points and to help estimate achieved fracture dimensions; provides a fracture design tool that is tied to real measure-



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ments; and performs production data analysis and reservoir modeling.

In addition, LOS has spent two years developing a proprietary Quiet Fleet design, which is designed to reduce noise levels by three times more than a conventional fracturing fleet, a February press release stated. The Quiet Fleet, released in 2016, has lower sound levels at a distance of 500 ft from the center of a fracturing location, compared to a conventional fleet that would have 1,000 ft.

## NOV

NOV's Intervention and Stimulation Equipment business unit offers coiled tubing (CT), wireline, aftermarket and pressure pumping equipment. In addition, NOV's pressure pumping products include acid units, chemical additive systems, combo/frack blenders, data vans, fracturing blenders, fracturing units and hydration units.

The company offers skid-mounted, trailer-mounted and truck-mounted fracturing units. The skid-mounted fracturing units can be used for fixed offshore installations as well as portable onshore and offshore configurations. The truck-mounted fracturing units are designed for



In July Legend Energy Services was operating a CT site in the Eagle Ford in Milano, Texas. The 75,000-hp fleet, built by NOV in the first quarter, comprises fracturing pumps, sanders and unloaders, multisanders, hydration systems, blenders, and liquid additive systems. (Photo courtesy of NOV)

stimulation projects where tight roads and small locations require high horsepower in small maneuverable packages. And the trailer-mounted fracturing units are designed for oil well stimulation jobs where the most economical power-to-weight ratio on location is required.

In June the company released several new completions technologies, including the Bulldog Frac sliding-sleeve annular fracturing system, which is designed to provide pinpoint accuracy, zonal isolation and improved reliability; the Bullmastiff ball-drop openhole sliding-sleeve sand control fracturing system; the Rottweiler product line of compact, high-performance fracture plugs for the plug-and-perf market; and ReAct remote activation technology, which offers remote signaling capabilities for valves and sleeves for a variety of applications and completion designs.

In May NOV announced a joint venture (JV) with Saudi Aramco that will “manufacture high-specification land rigs, rig and drilling equipment, and offer certain aftermarket services,” a press release stated. The JV will establish a training center to develop Saudi technicians to maintain and operate the drilling technology produced by the JV.


## ProFrac Services

Based in Texas, ProFrac offers hydraulic fracturing equipment, manufacturing and distribution.

The company's five full fracturing fleets have 240,000 hhp and include blenders, hydration units, iron trucks, high-rate manifolds and data vans. ProFrac is currently adding four additional fleets (200,000 hhp) through early 2018.



A June aerial shot of a six-well pad is shown operating in the Marcellus. (Photo courtesy of ProFrac Services)



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ProFrac has operating districts in Midland, Texas, and St. Clairsville, Ohio, with plans to expand to additional operating areas.

The company can design, modify, rebuild and upgrade equipment at its manufacturing facility, which is 130,000 sq ft and sits on 20-plus acres. In addition, ProFrac's full-service 60,000-sq-ft distribution facility offers two 12.5-ton cranes, three receiving docks, three shipping docks and a print shop.

### Propell America

Operating under parent company TYCROP, Propell America manufactures pressure pumping equipment technologies and provides companies with pumping units, coiled tubing (CT) units, chemical vans and more. Propell has manufactured and renewed equipment for major well service companies in the U.S. and Canada since 2008.

In March Propell acquired the assets of Total E&S Inc. dba Total Equipment and Service (T.E.A.S.), a Texas-based oilfield equipment manufacturer, from C&J Energy Services. Propell expanded its oil and gas market offerings to include T.E.A.S.'s CT and well stimulation equipment.

Additionally, the company's SANDSTORM is a modular frack sand handling tool that sets up under 3 hours for the entire system and is designed to provide flexible storage capacities ranging from 550,000 to 3.3 million pounds. "Remote control automation allows the entire system to be operated by just two personnel," according to the company's website. "When combined with the high-rate ViperBelt Integrated Proppant Loader, the SANDSTORM system provides a smaller footprint and a single unloading point with the fastest turnaround in the industry resulting in lower total transport costs."

### ProPetro Services Inc.

Based in Midland, Texas, ProPetro Services Inc. is an oilfield services company that provides hydraulic fracturing and other complementary services to upstream oil and gas companies engaged in the E&P of North American unconventional oil and natural gas resources. The company is located and focused in the Permian Basin.

ProPetro's fleet has been designed to handle high-intensity, complex hydraulic fracturing jobs and is largely standardized across units to facilitate efficient maintenance and repair and reduce equipment downtime, according to the company.

The company's Cementing Department consists of 13 units, seven of which are in the Permian

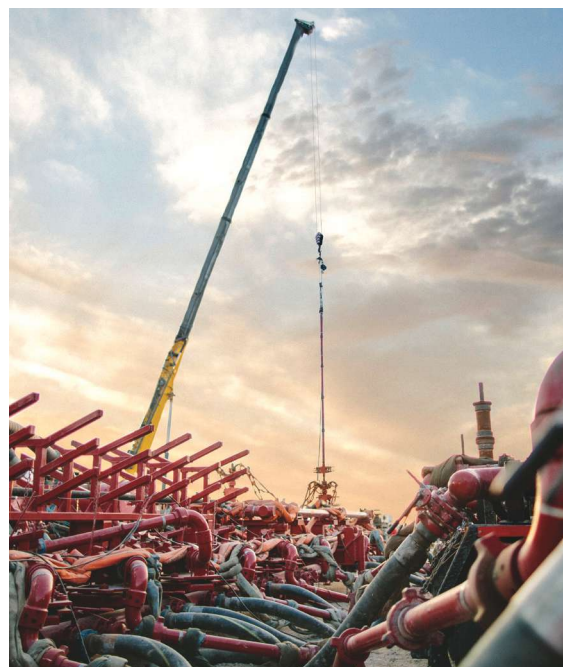
Basin and the other six are located in the Denver-Julesburg (DJ) Basin. All of ProPetro's cementing units are capable jobs that include casing, plugs and squeezes. The cementing division also has a laboratory for in-house testing.

In addition, ProPetro's Acidizing Department comprises 10 high-pressure pumps and four combo units, all of which are in the Permian Basin. This department is equipped to perform jobs such as toe preps, pumpdowns, acid jobs, salt/ball diversion jobs, energized acid jobs and acid delivery in lined transports. The acidizing division also has a laboratory as well as pumping equipment able to digitally monitor stimulations.

ProPetro's Coiled Tubing Division operates one 2-in. coiled tubing unit, one 2-in. unit and one 1¼-in. unit in the Permian Basin. These services are primarily used to drill out fracture plugs, apply nitrogen, fish and cleanout obstructed wellbores.

The company's Flowback Division provides methanol pumping and flowback control equipment rentals in the Permian and Midcontinent region. This division is equipped to monitor and control the return of fluid after hydraulic fracturing.

ProPetro's Surface Air Drilling Department provides preset surface drilling services to target depths of about 4,000 primarily in the Uinta-Piceance Basin and the DJ Basin. All of the company's rigs are very mobile and operationally efficient.



The sun rises over a Permian Basin fracturing job. (Photo courtesy of ProPetro Services Inc.)



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## PropX

Proppant Express Solutions LLC (PropX) is a privately held company headquartered in Denver, Colo.

The company's last-mile proppant delivery system is a patented containerized technology for last-mile proppant delivery to hydraulic fracturing operations. It is designed to be much quieter, lower last-mile trucking costs, provide less truck traffic, eliminate demurrage, offer more flexible maximized load volume and produce less dust than incumbent methods, according to the company. PropX systems reduce the hazard of silicosis.



PropX delivers sand on a fracturing site in the Permian Basin. (Photo courtesy of PropX)

"The ability to unload and load sand containers in less than 10 minutes (vs. 45 minutes for the same proppant mass with pneumatic transfer) dramatically reduces the truck 'staging' problem and the resultant waiting time or demurrage fees charge by the truckers while standing by waiting on their turn to unload," the company stated on its website.

In addition, "PropX, because of its gravity driven system of unloading sand coupled with our fully enclosed conveying system, does not require pneumatic blowers, resulting in a safe, fast operation, which generates very little noise or dust," the company said. PropX systems have delivered billions of pounds of proppant to customers in numerous oil and gas basins across the U.S.

## Rubicon Oilfield International

Established in 2015, Rubicon Oilfield International is a manufacturer of drilling, completions, fishing and production products, providing tools for well construction, hole conditioning, cementing and

fracture plug milling and other stages of the life cycle of a well.

In 2016 Rubicon acquired Tercel Oilfield Products, a manufacturer of drilling and completions products; Logan International Inc., a supplier of fishing, intervention and production equipment; and Top-Co Holdings Inc., a supplier and manufacturer of casing, cementing and completion products.

In May 2017 Rubicon acquired Choice Completions Systems LLC, an emerging technology company specializing in the supply of downhole

products for conventional and unconventional completions. And in June Rubicon acquired World Oil Tools Inc., a manufacturer and supplier of specialty inflatable products and downhole completions technology.

The company's SwivelMASTER tool allows rotation in areas where additional weight and reduced friction are required to reach total

depth by rotating the upper workstring. According to a company case study, the tool was included in "the world's longest horizontal well at 14,892 m [48,858 ft]" in a recent run for an operator offshore Sakhalin. To date, the SwivelMASTER has completed more than 550 runs with zero failures.

Through the acquisition of Choice Completions, the company is also providing a new fracture plug technology with a composite product at 5 lb in weight that is thought to be the lightest plug available, according to the company.

## Schlumberger

Schlumberger offers hydraulic fracturing and matrix stimulation treatments for all types of environments.

Multistage fracturing and completion services from Schlumberger include fracturing with coiled tubing, multistage stimulation systems, shale gas dynamic fluid diversion services and fiber-based fracturing services.

The PerfFRAC shale gas dynamic fluid diversion service isolates each perforated zone within the stage, places treatments in each perforated zone, treats each zone at a relatively high flow rate and

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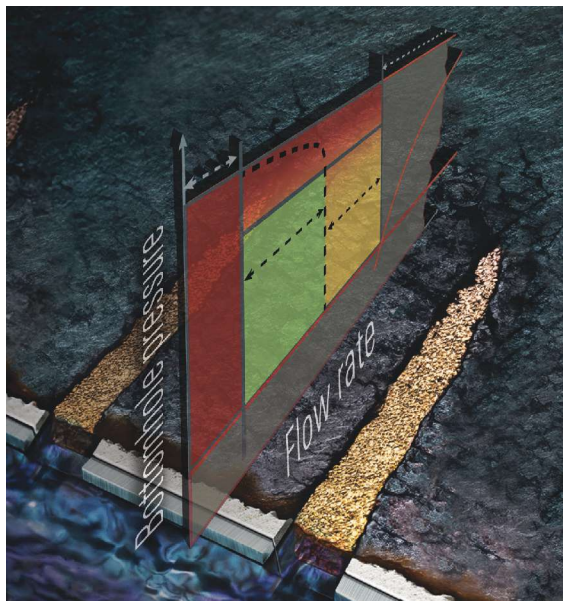


completes each stage in one wireline trip, according to the company's website.

Schlumberger multistage stimulations systems include plug and perf (PNP), dissolvable PNP and continuous pumping stimulation. The systems can be used in vertical, deviated and horizontal wells.

According to a 2015 case study, the company's KickStart rupture disc valve eliminated the need for mechanical intervention for toe preparation during PNP operations in the Woodford Shale. The valve was deployed for the operator in 100 installations with a 100% success rate and zero nonproductive time, saving the operator \$5.4 million, according to the case study.

In addition, Schlumberger's AvantGuard advanced flowback services are designed to protect the connection of the hydraulic fracture to the wellbore to optimize productivity in conventional and unconventional wells. The company won Hart Energy's 2017 Meritorious Award for Engineering Innovation in the hydraulic fracturing/pressure pumping category for its AvantGuard services.



AvantGuard is based on the application of the secure operating envelope, which is a combination of operational parameters that preserve the connection between hydraulic fractures and the wellbore. (Image courtesy of Schlumberger)

In April 2016 Schlumberger and Cameron International Corp. completed their merger. For hydraulic fracturing needs, the company offers CAMShale fracturing fluid delivery and flowback services, fracture tree systems, fracture manifolds,

and flowback and well testing, among other services and equipment.

## Shale Support

Shale Support supplies white fracture sand as well as logistical support throughout all major shale plays in the Americas. The company mines fracture sand from its properties in Picayune, Miss., and can transport its proppant via road, rail or barge through North and South America.

After treating fracture sand, Shale Support uses its particle analyzer to quality test sand from each batch. "With the particle analyzer, facility operators know within five minutes whether or not the sand meets American Petroleum Institute and customer standards," according to a Shale Support article that appeared in *E&P*.

In addition, the company's Delta Pearl proppant is clean, white sand produced for shale applications in a variety of mesh levels. Used regularly in the Marcellus/Utica, Permian, Eagle Ford and Haynesville/Tuscaloosa shale plays, Delta Pearl fracturing sand is designed to provide low turbidity.

## Superior Energy Services

Superior Energy Services provides specialized oil-field services and equipment that are focused on servicing the life cycle of the well for oil and gas companies worldwide. The company has a full line of completion and production services, including pressure pumping, equipment rentals, fluid handling and well servicing operations in several active resource plays in North America.

As part of the Superior Energy Services family of brands for completion-related services, Pumpco Energy Services delivers hydraulic fracturing services focused on horizontal well completions and stimulation. Pumpco can deliver a variety of fluid designs including diverter, slickwater and gelled water fractures using gelling agents to increase viscosity. If required, Superior has the ability to provide stable, crosslinked or hybrid fluid systems designed to address any range of temperature, the company said. The company also offers several pumping techniques, including treatments on single-well pads, zipper fractures on multiwell pads and pumpdown assists for plug-and-perf jobs.

Superior's rental equipment supports conventional and unconventional completions, with specialized BOPs, choke manifold equipment spreads, fracture heads, and flowback and well testing services. Fluid handling includes services used to obtain, move, store and dispose of fluids involved in



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the development and production of oil and gas reservoirs, including specialized trucks, fracturing tanks and other assets that transport, heat, pump and dispose of fluids.



An aerial shot shows a Pumpco job site in Mentone, Texas. (Photo courtesy of Superior Energy Services)

### TAM International Inc.

TAM International, an independent oilfield services company, offers R&D, product development and operating techniques. The company provides multistage fracturing systems for both openhole and cemented unconventional wells. The systems consist of technologies to enable positive placement and isolation of acid stimulation or hydraulic proppant fracture treatments. The tools are designed to work with specific fluid requirements, offering flexible options.

TAM developed the PosiFrac Toe Sleeve and the PosiFrac HALO fracture seat for plug-and-perf completions. TAM's PosiFrac Toe Sleeve assembly is designed for cemented or uncemented completions where a casing pressure test is desired to confirm casing integrity prior to opening the toe sleeve. It allows a casing integrity test without the need to pressure above the test pressure to open the sleeve. The PosiFrac HALO, a HydraWell Inc. technology licensed exclusively to TAM, uses a three-piece design that offers functionality in expandable and dissolvable technology. Within days after the fracture, the ball seat, fracture ball and lower cone dissolve "leaving one of the largest inside diameters on the market," according to TAM.



The PosiFrac Toe Sleeve assembly is designed for cemented or uncemented completions where a casing pressure test is desired to confirm casing integrity prior to opening the toe sleeve. (Image courtesy of Tam International)

In addition, the PosiFrac Straddle System assemblies can be used for a wide array of applications including acidizing, fracturing, flow testing, washing perforations and pressure testing. It is designed for multiset operations and is reliable in both horizontal and vertical applications. An option on the Straddle System utilizes the Insta-Set Valve, which does not require a ball to drop from surface.

### TechnipFMC

In May 2016 FMC Technologies and Technip announced intentions to combine to form TechnipFMC. The merger was completed in January 2017.

TechnipFMC provides subsea, onshore and offshore services as well as surface technologies. The company offers drilling, completion and production wellhead equipment, chokes, compact valves, manifolds and controls. In addition, the company can treat iron, manifolds and reciprocating pumps for stimulation and cementing. Other surface tech-



TechnipFMC offers drilling, completion and production wellhead equipment, such as the surface wellhead shown. (Photo courtesy of TechnipFMC)

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nologies and services the company offers include advanced separation and flow-treatment systems; flow metering products and systems; marine, truck, and rail car loading systems; installation maintenance services; frack-stack, manifold rental and operation services; and flowback and well testing services.

### TETRA Technologies

Based in Texas, TETRA Technologies is a global company with operations on six continents providing completion fluids, water management, flowback and production well testing services.

With operations located in all North American shale basins, the company delivers products and services to manage all fluids during hydraulic fracturing completion operations.

The completion fluids product line provides a broad range of solids-free clear brine fluids to effectively complete a well and initiate an economically viable production flow. All fluids are engineered to certify that they meet all reservoir specifications to maximize completion efforts.

The water management product line supports hydraulic fracturing operations that require large volumes of water. The company's services support the transfer, storage and treatment of fresh, brackish, produced and flowback water. Each project is custom-designed using the company's proprietary planning and engineering software. TETRA's newest technologies were released to maximize the reuse of produced water and ensure that the water is con-



In the first four multiwell pads, new technology enabled one operator to increase produced water usage with no impact on the fracturing job. (Photo courtesy of TETRA Technologies)

sistent throughout the entire fracturing operation, the company said.

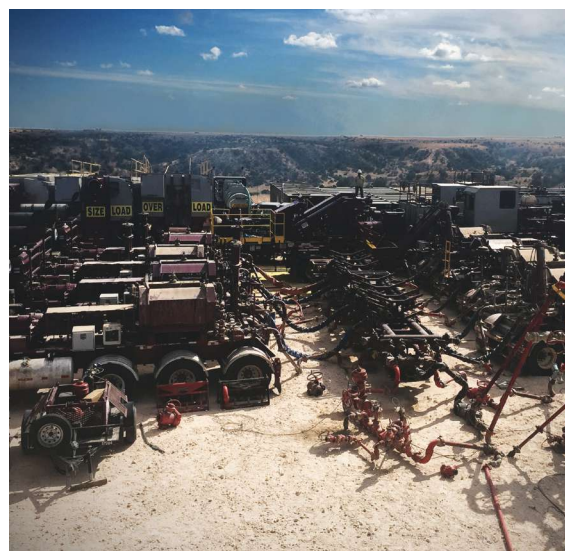
The production testing product line delivers flowback and well testing services that cleans the well, tracks its production capability and documents its performance for state regulatory agencies. The company also provides choke manifolds, flare stacks, flowline systems, sand separators, test separators and plug/debris catchers.

TETRA provides water management, completion fluids and production testing services to support land completion activity in all basins in the U.S. and Canada.

### Thru Tubing Solutions

Thru Tubing Solutions (TTS) specializes in down-hole equipment and services.

Released in January, the company's SlicFrac diverter system is an inter-wellbore diverter utilizing Perf PODs to selectively divert fractures to virgin formation efficiently stimulating the entirety of each stage. Perf PODs were designed to seal both circular- and irregular-shaped holes for new completions and refracturing operations.

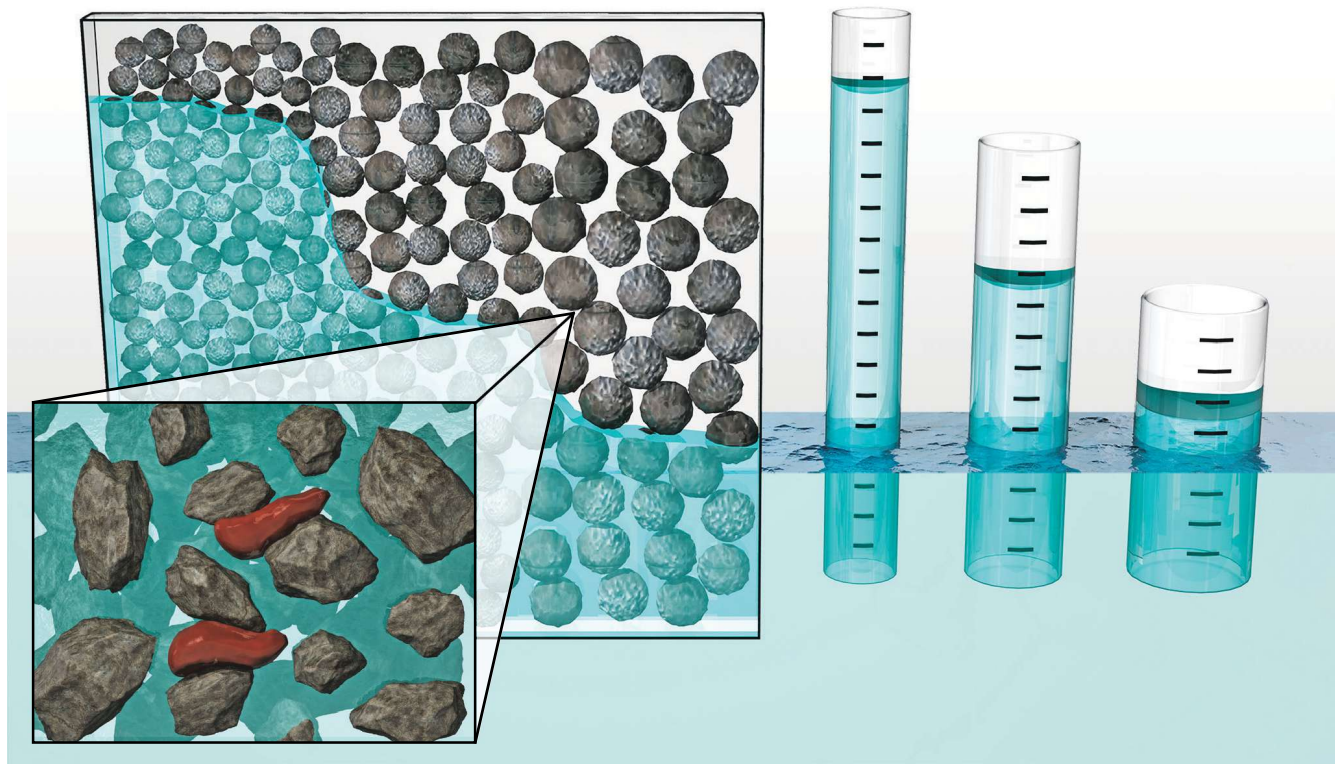


Thru Tubing Solutions utilized SlicFrac Perf PODs in the Midcontinent region. (Photo courtesy of Thru Tubing Solutions)

SlicFrac diverting technology allows operators to reduce the total number of bridge plugs within a wellbore, while maintaining the advantages of closer stage spacing and adding additional clusters, the company said. The risk of a preset plug can be drastically reduced, along with pump downtime, completion cost and resources associated for the cor-

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responding wireline runs and subsequent millout work. According to the company, applying SlicFrac diversion technology between bridge plugs allows the operator to achieve maximum cluster efficiency, while stimulating the entire stage, without leaving orphan clusters behind. The diverter also allows the operator to maintain a more consistent stimulation volume into each perforation cluster, ultimately providing a more balanced treatment and reducing the probability of a runaway fracture, which could potentially damage offset wells.

SlicFrac Perf PODs are available in both degradable and millable materials. Perf PODs can be deployed with wireline bottomhole assemblies or launched from surface during the fracturing to divert flow, allowing subsequent breakdown and perf isolation.

### Unimin Energy Solutions

Unimin Energy Solutions offers API-quality quartz proppants, resin-coated sands, cementing additives, gravel packing media and drilling mud additives for drilling, cementing, stimulation and production operations.

The company's two stimulation products are PropStar (resin-coated proppants) and UNIFRAC (hydraulic fracturing sands). Nearly 1 billion pounds of PROPSTAR has been pumped by more than 70 operators in North and South America, according to the company's website.

### Universal Pressure Pumping Inc.

In 2017 Patterson-UTI, a provider of contract drilling and pressure pumping services, merged Universal Well Services Inc. (UWS) and Performance Technologies into its subsidiary of Universal Pressure Pumping Inc. (UPP). The combined company provides pressure pumping services.

UPP offers a combined total of more than 1.5 million horsepower and offers multiple services, including hydraulic fracturing, cementing, nitrogen, acidizing and related services. The company also provides natural gas-powered fracturing equipment, has the largest dual-fuel fracturing fleets in the Appalachian Basin, and offers refracturing experience and data acquisition for reservoir enhancement.

UPP, headquartered in Houston with regional locations in multiple basins across the U.S., provides stimulation services in the Permian Basin, Midcontinent, Appalachia as well as North, East and South Texas.

UPP's OffSiteFrac service displays near real-time hydraulic fracturing job data to operators at remote

sites, which allows viewing of job-critical data without leaving the office.



Universal Pressure Pumping fracturing equipment is rigged up on location in Appalachia. *(Photo courtesy of Universal Pressure Pumping)*

### U.S. Silica

U.S. Silica provides mining, processing, testing and distribution for the oil and gas industry's demand for sand in hydraulic fracturing operations.



InnoProp PLT is an ultrahigh-performance non-phenolic curable resin-coated proppant designed to prevent proppant flowback in low-temperature reservoirs without the use of an activator. *(Image courtesy of U.S. Silica)*



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	20/40	30/50	40/70
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90°F	5	5	5



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The company's premium fracturing sands, including naturally occurring sand and silica and resin-coated products, have been proven in tight gas, coalbed methane, and shale gas and liquid applications. U.S. Silica's newest product, Inno-Prop PLT, is a resin-coated sand that overcomes the challenges associated with low-temperature wells. In-house engineering and testing ensure grain consistency and performance under pressure. Proppants meet or exceed ISO 13503-2 and API RP 19C specifications for particle distribution, roundness and sphericity, turbidity, acid solubility and crush resistance.

Growth in regional mines coupled with a comprehensive rail and transload infrastructure—including more than 50 transload networks and 600 rail cars—give U.S. Silica extensive access to sand and silica resources.

Logistics assets, which also include truck and barge capabilities and the proprietary Sand-Box processes and equipment, mean U.S. Silica has the ability to deliver products to the destination wellhead.

### U.S. Well Services LLC

U.S. Well Services (USWS) provides high-pressure hydraulic fracturing services, with high-performing fleets that have the capability to meet demanding pressure and flow-rate requirements in the field. The company boasts it has high-performance, durable equipment and the ability to support high-asset utilization rates.

Clean Fleet, the company's proprietary, patented fleet design, is the first fully electric, fully mobile well stimulation system powered by natural gas. The system has demonstrated reduced fuel operating costs by as much as 90%, reduced NO<sub>x</sub> and carbon monoxide emissions by 99%, and reduced equipment and discharge iron vibrations by 80%, according to the company.

In addition, the company's Whisper technology delivers quiet, low noise impact hydraulic fracturing, designed to make the workplace safer and less disturbing to surrounding communities.

For predictive maintenance, USWS has developed "FRAC MD Machine Diagnostics, Minimizing Downtime" to mitigate fatigue and premature failures of the company's equipment.

To reduce the hazardous risk associated with the inhalation of respirable silica dust, USWS has developed SANDSHIELD to mitigate silica emission below Occupational Safety and Health Administration permissible exposure limit standards.

### Weatherford International Plc

Weatherford International Plc operates internationally in every major oil and gas region onshore and offshore. The company's completion and stimulation products and services include hydraulic fracturing, coiled tubing, cementing services, acidizing and water management systems, fluid systems, and completion and stimulation equipment.

The FracAdvisor service delivers geo-engineered stimulation and completion designs. The collaborative process integrates petrophysics, geomechanics, reservoir analysis, and completions and fracturing engineering that is designed to reduce geological uncertainty and enhance the production potential of the fracture operations. By grouping like rock with like rock and providing near-real-time guidance, FracAdvisor allows operators to make more informed decisions about perforation/cluster placement, number of fracture stages required and fracture job size to optimize the fracturing and completions designs, according to the company.

Similarly, Weatherford's refracturing efforts utilize an engineered approach to refine the can-



Weatherford operates internationally in every major oil and gas region. (Photo courtesy of Weatherford)

didate selection process, model refracture characteristics and estimate refracturing production. The TBlockSure diverting agent is a proprietary degradable material with proven success in many new well and refracturing case studies, the company said. Supported by proprietary fluid and particle modeling programs, the TBlockSure agent provides a temporary blocking effect that yields superior zonal isolation and diversion in comparison to traditional diverters. Once in place, TBlockSure creates a near-wellbore seal that has been known to withstand differential treatment pressures in excess of 4,000 psi.

In addition, the Weatherford WaterSure fluid system enables fracturing with 100% produced water, flowback water or seawater, either filtered or unfiltered, without sacrificing stimulation performance. When freshwater supplies are limited or water quality is inconsistent, use of the WaterSure system conserves freshwater supplies and reduces water costs, according to the company. The system adds environmentally friendly gelling and crosslinking agents to any available water at the well site. The result is a low-residue stimulation fluid that is unaffected by flowback additives and can handle waters high in salinity, total dissolved solids, divalent ions and boron. WaterSure fluids imitate the conductivity and permeability of freshwater, which protects formations from damage.

In March Weatherford and Schlumberger announced an agreement to create OneStim, a joint venture to deliver completions products and services for the development of unconventional resource plays in the U.S. and Canada land markets. "The joint venture will offer one of the broadest multistage completions portfolios in the market combined with one of the largest hydraulic fracturing fleets in the industry," said Weatherford in a press release.

### Weir Oil & Gas

Weir Oil & Gas provides well service and stimulation pumps, flow control products and replacement expendable parts from brands including SPM, Mesa and Novatech. Pressure control includes brands such as Seaboard, which provides wellheads, valves and fracture trees, and Mathena, which delivers drilling mud-gas separation equipment including chokes, separators and environmental containment equipment. The company offers mechanical and rotating equipment repairs and upgrades, oilfield and drilling equipment repair and certification, asset management and field services.

According to the company, its SPM QEM 3000 is the industry's first high-horsepower fracturing pump designed for continuous-duty pressure pumping operation at 275,000-lb force rod load and addresses the shortcomings that lead to premature pump failure. A case study stated, "It's estimated the new pump could lower customers' total cost of ownership by almost 20%."

In 2016 Weir Oil & Gas and Rolls-Royce company MTU formed a joint venture named EPIX.

Shortly after, EPIX released the industry's first integrated system for hydraulic fracturing. "Weir and MTU are developing a system, which integrates three critical components of fracturing operations—the engine, transmission and pump. The complete system will use smart controls, which provide continuous performance monitoring, optimizing performance for the operator and reducing downtime during fracturing operations," the case study reported. ■

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# An Unconventional Shift

Integrated workflows drive holistic trend to boost production, efficiency in shale plays.

This article highlights a speech, “A Holistic Approach for Unconventionals Improves Project Economics,” delivered by Mo Cordes, senior vice president, Unconventional, Schlumberger, at the Unconventional Resources Technology Conference July 2017 in Austin, Texas.

**By Mo Cordes**  
Schlumberger

**M**ore than a decade since the unconventional boom changed the paradigm for oil and gas development and unleashed a technological revolution that has had worldwide impact, the industry has come a long way in learning about the complex and unpredictable nature of shale formations. However, the learning process is an evolutionary one, as all sectors of the business continue to enhance their knowledge of unconventional plays and how to efficiently produce them in a challenging climate of depressed commodity prices.

From understanding the rock, to drilling and landing the well in the sweet spot to designing fractures that will enhance production, operators now know that a one-size-fits-all approach is not a viable option in developing these unique and heterogeneous reservoirs. That knowledge, bolstered by a host of sophisticated technologies, has enabled the industry to expand the potential of unconventional plays. On the surface, efforts have been focused on efficiency and cost reductions, decreasing cycle times, the footprint and the number of people on location, while increasing the number of stages completed each day. While every basin is different, lateral lengths, stage counts and sand volumes are growing. In general, stage spacing is decreasing, in some places to less than 150 ft. This further drives efficiency because crews are working for longer periods at a given location. In contrast, the subsurface is about improving productivity and recovery.

Along with efficiency gains, productivity is a key driver for achieving project economics in unconventional plays. Estimated ultimate recovery (EUR) rates have improved to 12% to 18%; however, they are still very low when compared to conventional well rates of 30% to 40%—or more with secondary recovery techniques. Even boosting unconventional recovery to 20+% for liquids-rich unconventional reservoirs would dramatically improve the economics of these wells. Better understanding of well spacing, fracture modeling, flowback and how interfaces in rock layers impact landing points and fracture design is key to reaching that next level of recovery in unconventional reservoirs.

There is no denying that \$45/bbl to \$50/bbl oil prices have changed the way the industry looks at unconventional reservoirs and contributed to an emerging holistic approach to developing these basins, a marked shift from the traditional practice where each phase of the well is carried out independently. Today, taking on an unconventional field involves a full cycle managed by sophisticated workflows encompassing multiple fields of expertise. It is the integration of technology, process and workflows at the subsurface and surface levels that will increase production and improve efficiency to impact the overall economics of the unconventional in a low-price environment.

Successful producers are seeing improved results by adopting this new way of thinking about field development. An operator in the Eagle Ford Play used the Schlumberger GeoEngineered Performance geocentric approach (Figure 1), which integrates the disciplines of rocks and fluid, drilling, completion and production systems, to improve productivity by as much as 80% over base wells in the play. The approach is rooted in the recognition that drilling impacts completion and completion impacts production—and it all starts with understanding the rock and fluid.

This same data is also critical for determining completion quality (CQ), a term used to describe how the rock properties impact the hydraulic fracture initiation and propagation both vertically and horizontally away from the wellbore.

This knowledge ultimately determines what areas of the reservoir are going to produce, and serves as the basis for developing integrated workflows—drilling to fracture, fracturing to produce and producing to recover—to drive performance.

### Drill to fracture

The drill-to-fracture process incorporates 3-D earth models that integrate seismic, core and log data to determine the best landing points to drill the well in the sweet spot based on RQ and, even more important, CQ.

The industry has come to realize that the interfaces—some weak, some strong—present in every layer of rock impact fracture height growth. Weak interfaces, in fact, are a more significant issue than previously thought, and a lot of testing has been done to learn what happens to the geometry of hydraulic fractures when they intersect the rock interfaces. For example, the fracture may move vertically, then horizontally, and back

to vertical, losing energy and reducing the fracture height growth needed in the area of contact (Figure 2).

Determining the optimum landing point of the well plays a central role in reducing the impact of weak interfaces. Using measurements along the lateral to steer within the landing point, a window that may be as small as 10 ft to 15 ft, helps ensure that a hydraulic fracturing completion will be successful. Tools that have had an impact in determining the optimal landing points from pilot well evaluation include litho scanners, magnetic resonance,

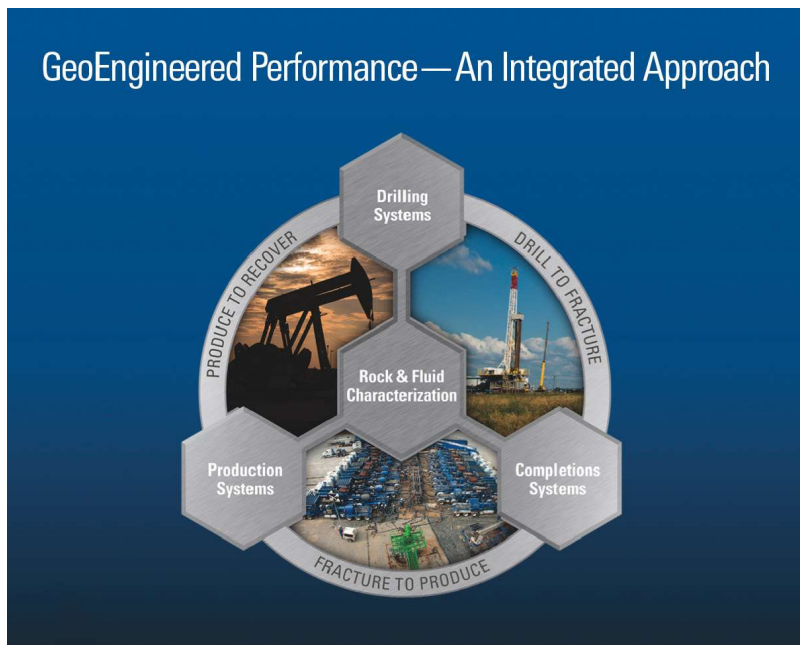


Figure 1: The shift to a holistic approach in developing complex and heterogeneous shale plays includes a GeoEngineered Performance workflow for the lifetime of the well. The workflow integrates multiple disciplines to improve field economics by boosting production and recovery. (Image courtesy of Schlumberger)

### Rocks matter

Determining whether an unconventional play has good reservoir quality (RQ) based on rock properties and their ability to produce hydrocarbons is a critical first step in reservoir development. To that end, technologies for obtaining and analyzing core, wireline log and seismic data have advanced considerably to help operators identify the geological, geophysical and geomechanical properties of the rock, including hydrocarbon pore and volume type, lithology, natural fractures, pore pressure and permeability.



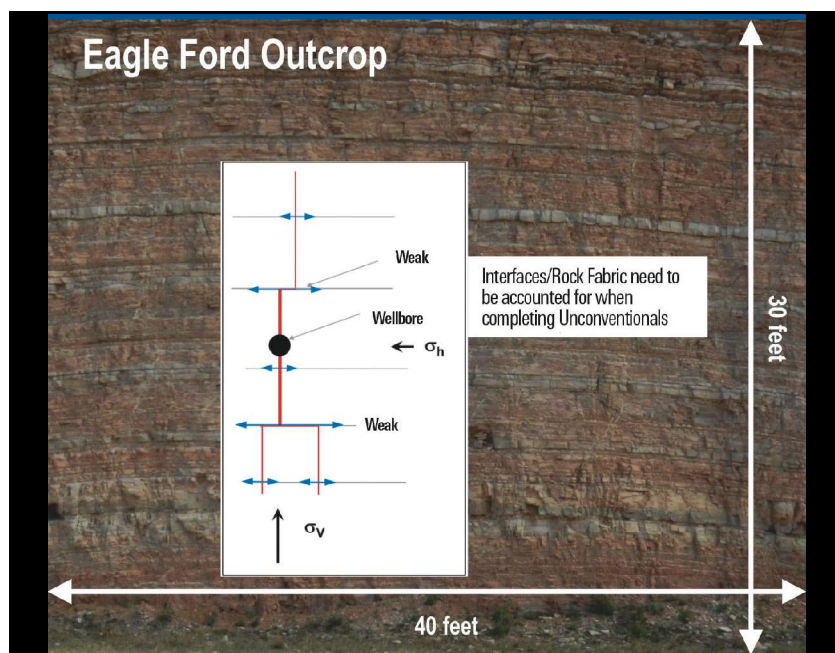


Figure 2: The Eagle Ford Outcrop is a typical shale reservoir with vertical heterogeneity and lots of interfaces. These interfaces can have a dramatic impact on the hydraulic fracture height growth. It is important to understand the strength of these interfaces when designing the optimum completion for a well. (Image courtesy of Schlumberger)

sonic scanners and image logs that identify the sweet spot from both RQ and CQ standpoints.

### Fracture to produce

Once the well is drilled, the next step is to fracture to produce, which is optimizing the completion, including fracture design, completion system and efficient single-well or pad development. Fracture modeling software has continued to evolve, and now allows the service provider or operator to efficiently model different scenarios, including stage length, cluster spacing, proppant loading and fluid volumes, to determine the optimum completion for each well that is drilled. Multiple scenarios can be run to determine what design will provide the best return on investment.

Optimum well spacing is a key question for all unconventional operators who are focused on infill development. It is estimated that billions of dollars will be squandered on drilling too many wells based on fixed well spacing. Drilling the right number of wells at the right well spacing can significantly improve an operator's ability to lower costs while achieving the same or even higher EURs.

Many operators are finding that when they drill infill, sometime referred to as "child" wells,

they are seeing much lower productivity than the parent wells due to interference between the parent/child wells. Enhanced understanding about the role of geomechanics in this scenario, specifically how pressure depleting from the parent well negatively impacts the ability to effectively fracture the children wells, has proved beneficial. In many cases, the parent well can be re-stimulated to re-pressurize the reservoir, enabling the children wells on the same pad to be successfully fractured the next day.

A well drilled in the right spot, in the right interval should produce; however, achieving a well's full potential is more

complicated. To address that challenge, advances in fracture modeling software to better stimulate the reservoir and increase wellbore productivity are yielding results, along with techniques that ensure the entire interval is producing.

### Produce to recover

Once the well has been completed, the next phase of the process is produce to recover. In this phase of the life of the well, one needs to take into account the drill-out of mechanical plugs, the flowback and the optimum artificial lift method needed. Over the last couple of years, it has become evident that the drill-out process and the flowback need to be better managed. A hydraulic fracture just created can be seriously compromised if the flowback is too aggressive. Too low a flowback rate can leave excess fluid trapped in the hydraulic fractures. Oftentimes, there is a very narrow window for producing wells to ensure they aren't damaged.

The final phase of the produce-to-recover process centers on appropriate artificial lift selection. Each well should be evaluated individually, and the right lift equipment installed, to maximize the production/EUR that gives the greatest return on investment.

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As unconventional activity continues to ramp up in North America, international markets, including the Middle East, Colombia, Australia, Argentina, the U.K. and Mexico, remain important frontiers. The Ahnet Frasnian shale gas field in Algeria is now estimated to rank third globally in the amount of shale gas resources, with 707 Tcf of technically recoverable shale gas and 5.7 Bbbl of technically recoverable shale oil resources. International operators are generally receptive to the

integrated workflow approach because they need to drill and produce wells with precision due to lack of infrastructure and low oil prices. In these markets, project economics are very challenging. Operators cannot afford to drill excess wells to develop their fields, so they need to get it right from when they first start their field development.

In the U.S., operators are increasingly embracing the methodology as they push for increased productivity and efficiency. Lonestar Resources

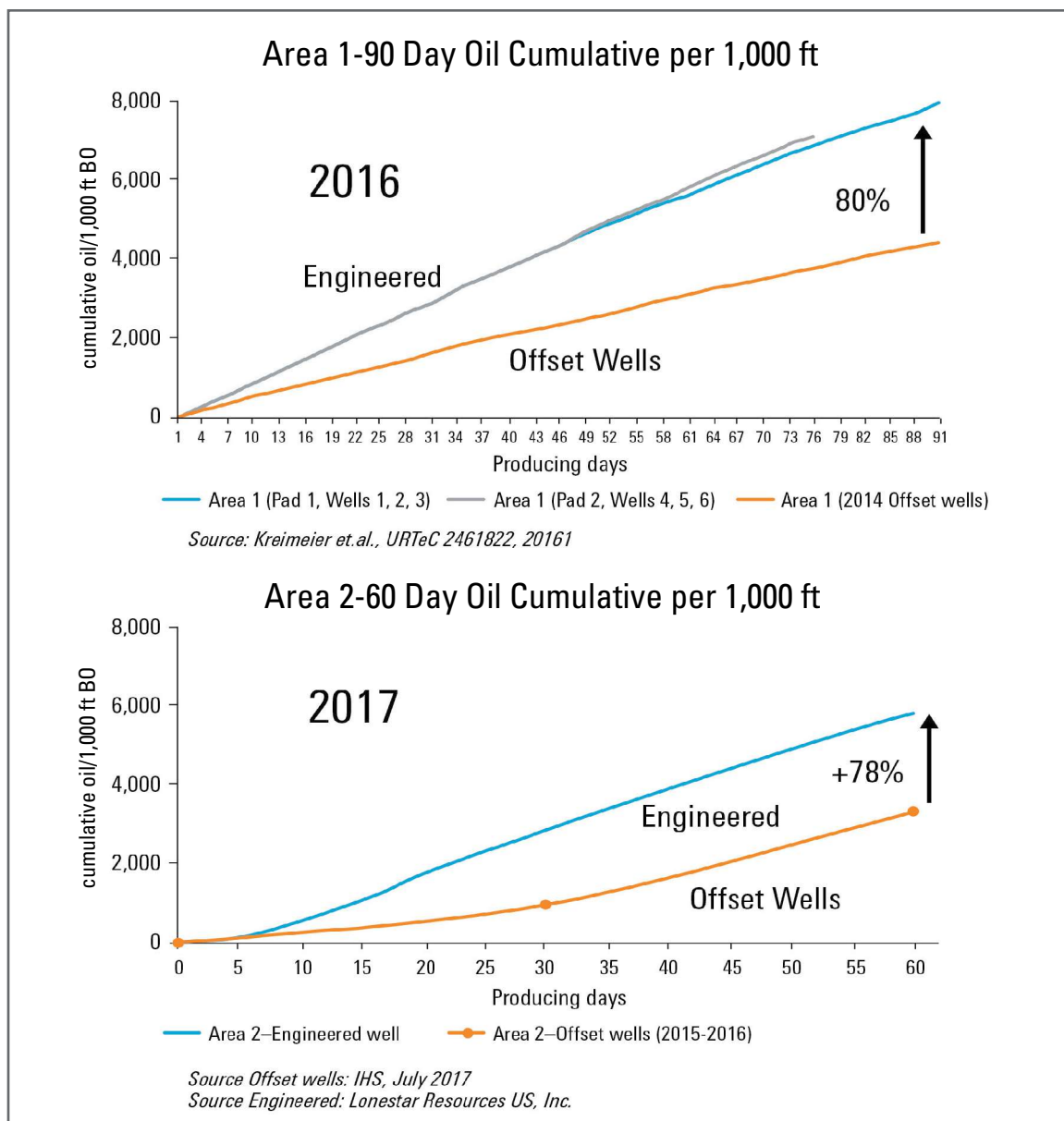


Figure 3: (Top graphic) Wells developed using the GeoEngineered Performance approach in one area of the Eagle Ford outperformed by 80% offset wells drilled, stimulated and completed using the traditional approach, including fixed, geometric well spacing. In a second field, engineered wells outperformed prior geometric completions by 78%. (Image courtesy of Schlumberger)

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has successfully implemented the GeoEngineered Performance approach since 2016 to optimize reservoir contact and dramatically improve performance for multiple wells in the Eagle Ford. Oil production has increased by as much as 80% over offset wells drilled, stimulated and completed using the traditional approach, including fixed, geometric well spacing. This process has continued with Lonestar Resources, with another field seeing a 78% improvement versus offset wells (Figure 3).

### Case studies

Lonestar Resources has used integrated workflows for all phases of the wells to analyze reservoir rock and fluid, determine the correct lateral landing point, optimize fracture design and engineer flowback. The use of advanced tools and technology has been instrumental in applying the workflows to improve production rates. To model the fractures and optimize the completion strategy, the operator has implemented the Kinetix shale stimulation-to-production software platform, which optimizes the completion strategy using a comprehensive set of simulators, models and workflows for hydraulic fracturing.

To maximize production from each interval, the Broadband Sequence fracturing service has been instrumental in facilitating sequential stimulation of perforation clusters to increase reservoir contact. Developed with a composite fluid comprised of degradable fibers and multimodal particles, the technique sequentially isolates perforations and fractures at the wellbore to ensure every cluster in each zone is fractured to deliver greater production and completion efficiency.

Lonestar Resources also has used the Schlumberger AvantGuard advanced flowback services to engineer a flowback design strategy that prevents damage to the well and the formation during the transition to production. The system uses a secure operating envelope based on multiple operational parameters defined from real-time pressure and production data, including solids-production monitoring. Changes in production rates are measured using a multiphase flowmeter, which accurately captures flow dynamics for all fluid and solid types. The service provides production monitoring over the lifetime of the well to ensure flowback is being managed within the operating envelope to protect hydraulic fractures and ensure operators are achieving maximum productivity.

An emerging trend in unconventional development centers on refracturing, which has significant potential for thousands of underperforming wells as technology continues to evolve. The key is to select the right well candidates that will deliver adequate incremental production. Good RQ and CQ, adequate reservoir pressure to produce the remaining reserves and sufficient recoverable reserves in place are important criteria to consider.

The advent of mechanical, expandable systems developed by Saltel Industries, a Schlumberger company, is helping to move the refracturing business forward, while the Broadband Sequence fracturing service, with its capability to divert composite fluids to higher stress regions for increased fracture stimulation and manage fracture geometry through far-field diversion, has already been an important game-changer.

In a collaborative undertaking with Schlumberger, Sundance Energy launched a successful multiwell refracturing campaign in the Eagle Ford that involved a rigorous candidate selection process and an engineered treatment design, including implementation of the fracturing service for near-wellbore diversion. The service effectively plugged perforation clusters and near-wellbore fractures, inducing temporary isolation, to stimulate more perforations and ultimately contact more of the reservoir.

Initial 30-day average incremental production was approximately 65 bbl/d of oil with more than 100% uplift in production compared to pre-refracturing rates. Estimated average EUR increased by 60,000 bbl, a 45% increase over the predicted base EUR.

### Moving forward

The industry has unlocked many of the mysteries of unconventional plays through greater reservoir understanding and technological innovation. The shift to a holistic approach, including an integrated, geo-engineered performance workflow that encompasses both the surface and subsurface aspects of the reservoir, through all well phases, is having a dramatic impact on production and efficiency.

Going forward, technical integration and the application of the workflows will be critical in reaching the next level of improved field economics in these complex and heterogeneous fields as the industry continues its quest to conquer the learning curve—which is what makes the unconventional so exciting. ■

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# A Breakthrough in Reservoir Characterization?

Geomechanics is not a new concept, but its application to unconvensionals could help turn the tide.

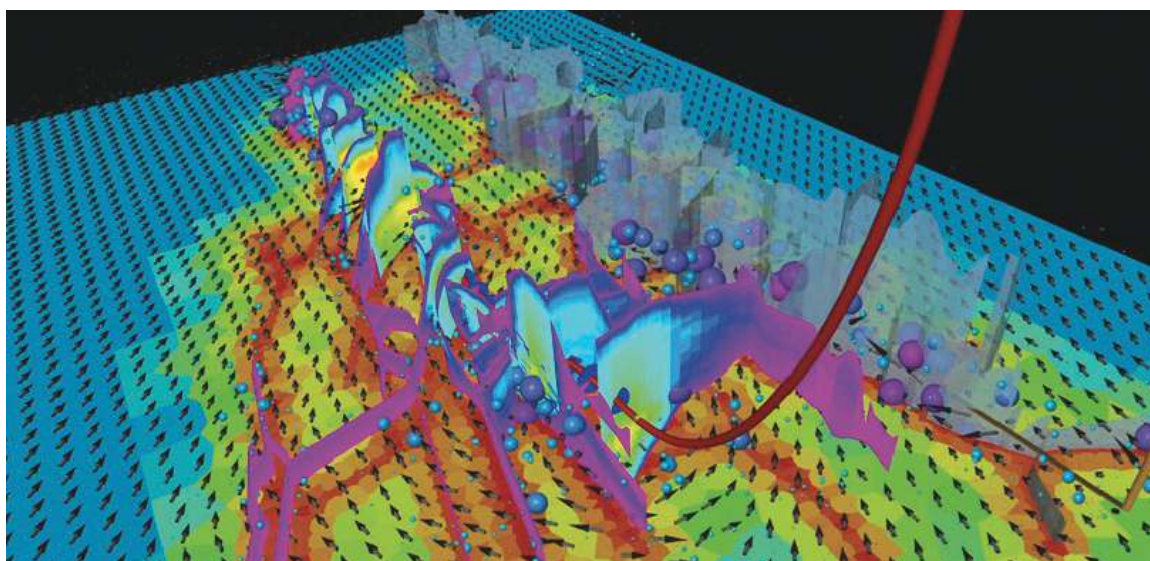
**By Rhonda Duey**  
Executive Editor

**T**he unconventional plays continue to stand the oil and gas industry on its ear, at least when it comes to reservoir characterization. Sandstones are easy, comparatively speaking. They're highly porous, and technology developed over the years has provided fairly repeatable results. Shales, not so much.

Many operators had abandoned reservoir characterization almost entirely in the "drill, baby, drill" days, when huge IP rates and \$100 oil made it seem unnecessary. "If the reservoir is thought to be fairly homogeneous and is easy to drill, then there might be less motivation to gather a lot of data as the cost of getting and analyzing the

data is outweighed by the numbers for production with the vast amount of wells drilled," said Adam Donald, technical director Geomechanics and Acoustics, Wireline for Schlumberger. "But if the reservoir is more heterogeneous and is difficult to drill and eventually frack, the customer is motivated to use technology to figure out how to extract the hydrocarbons effectively if there are enough reserves."

Now some operators have come to realize that "factory drilling" hasn't always been the best approach. Achieving and maintaining production from these inscrutable wells require a more scientific approach. But where to begin?



*This graphic shows drilling geomechanics in an unconventional environment.  
(Image courtesy of Schlumberger)*

## Geomechanics

Simply stated, geomechanics is the combination of understanding rock properties and the forces and pore pressure being imposed upon them. And that's about where the simplicity ends.

Rock physics plays a major role in determining things such as elasticity and rock strength. The stresses and pore pressure affect the stresses that these rocks are being placed under as the subsurface reacts to compressional and shear movement during tectonic deformation as well as the changing weight of the overburden during additional sedimentation or uplift as a result of tectonic events.

Geomechanics has always had an impact on safely drilling wells through troublesome zones using analytical models, according to Scott Mildren, geomechanics technical leader for Ikon Science. Mildren said that these models are developed by using well data to construct a 1-D analytical model. "You have the depth of the well, and you look at the changes in stress and strength with depth," he said. "These models are calibrated to observations and drilling experience so that you know at what point you might have stability problems in the well. And then you can be predictive about the next well."

But more recent development schemes, particularly in unconvensionals, revolve around things like where to place wells and determining fracture propagation. "From a characterization perspective, we see a sustained business in doing the geomechanics in drilling to efficiently land the lateral," Donald said. And as more horizontal wells have been drilled, geomechanics has helped operators calculate the rock mechanical properties and stress state along the borehole.

"This has helped operators infer the preferred orientation of the well trajectory and compute the mud weight window necessary to drill better horizontal wells with a lower incidence of well failure," said Nick Koutsabeloulis, geomechanics advisor, Schlumberger. He added that a deeper understanding of the magnitude and orientation of stresses aids in production. "Stimulating along the maximum horizontal stress provides for better outcomes," he said. "Geomechanics provides a means to calculate both the magnitude and the orientation of the stress state inside the rock and how this stress state changes during stimulation."

## The new paradigm

So why does this matter? Shale plays have long been characterized by geoscientists trying to crunch the numbers and drilling and completion engineers say-

ing, "Really? We just need to get this development plan sorted out." Geoscientists have been frustrated but have lacked any real ability to show their engineering counterparts anything that helps them solve the problem.

But geomechanics might be the missing link between geosciences and subsurface engineering. Unconventional reservoirs cannot be produced without hydraulic stimulation. The efficacy of a hydraulic stimulation campaign to enable high production rates from unconventional wells relies on, amongst other factors, the stimulated fracture to be contained in the resource layer, the creation of a fracture network that connects as much reservoir volume as possible to the well, the ability of the proppant to create a permeable pathway from the reservoir rock to the well and the drive energy given by a high pore pressure to transport the hydrocarbons from the reservoir through the hydraulic fracture to the well, according to Jorg Herwanger, director of MP GeoMechanics Inc. "Whether these factors are present for a specific play or prospect can be assessed using a geomechanical model," he said.

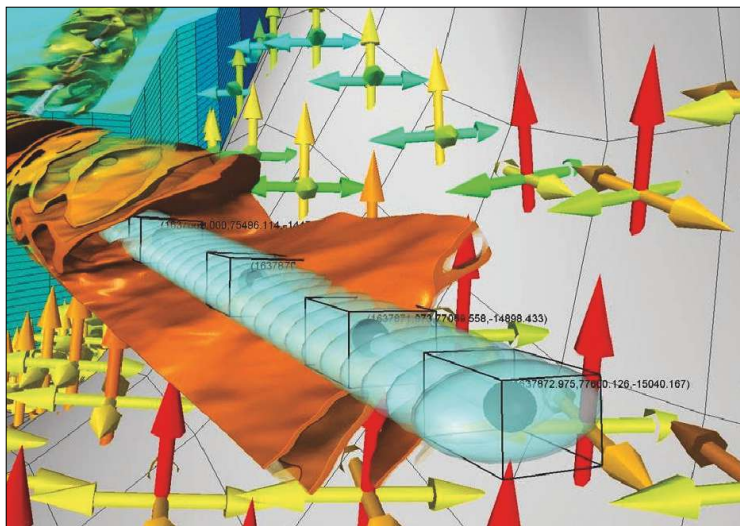
Added Scott Singleton, geophysical technical advisor with Independence Resources Management, a Permian Basin operator, "As exploration geophysicists, we often consider having an interpretation or an impedance inversion as the final product. In fact, those are not final products. The demonstration of this fact is that when you present this data to drilling or completion engineers, they look at you like you're from Mars."

Singleton's company realizes that to fully understand the Permian Basin, it is necessary to spend the time to characterize its reservoirs. While rock mechanics—toughness, brittleness—are a critical first step, the company knows that more is needed.

"This is only the start," he said, referring to a model that integrates petrophysics and geophysics. What is also needed is stress information from geomechanical logs and completions pressure data. "A well log is a single trace on the earth's surface that contains basic formation data," he said. "But more sophisticated logs can also include fracture data and principal stress information."

One of the more helpful measurements, he said, is the acoustic log. A tool like Schlumberger's Sonic Scanner provides directional acoustic measurements of particle motion that are transverse to the direction of the wellbore. "This tool pays attention to that sideways direction," Singleton said. "It breaks the measurement into an orthogonal set of particle motions that are parallel to each of the





*The Kinetix software suite optimizes production through stimulation in Schlumberger's Petrel workflow. (Image courtesy of Schlumberger)*

primary stress directions. This, in turn, can be fed directly into a geomechanical model.”

### Components of a geomechanical model

Regardless of the type of model, inputs matter. Mildren said that the major inputs are elastic properties, pore pressure, rock strength and stress.

“If the stress overcomes the strength, you get failure,” he said. “If the strength is higher than the stress, you won’t get failure. Ultimately, you can break any geomechanical problem down to that simple relationship.”

But where do these measurements come from? Basically, there are three major sources of information: cores, logs and seismic. According to Herwanger, each of these sources has benefits and disadvantages. Cores are the only means of directly testing rock elastic and strength properties, but they only sample a small part of the reservoir. Seismic data in the form of seismic inversions are the only way to directly measure elastic properties in three dimensions, but the vertical resolution is poor. Geophysical and petrophysical logs form a good compromise between sampling a good portion of the rocks and having a fair resolution, he said. In combination these three data sources, in conjunction with a good conceptual geological model, provide the input for a predictive geomechanical model.

All three data sources also can provide information about natural fractures in the reservoir. This information is important since natural fractures often add significantly to fluid flow

in low-permeability unconventional reservoirs. “Additionally, fracture analysis gives you a direction and possibly the magnitude of your horizontal stresses,” Singleton said.

Core test data can help an operator improve effective proppant placement in fracture-stimulated intervals. At Core Lab, a provider of core analysis services, Senior Geomechanical Advisor Igor Faoro said, “Testing for both mechanical properties and fracture conductivity as a function of proppant concentration can supply the needed information to clients who are having problems placing adequate amounts of proppant per unit fracture area. This is important

because at certain stresses the proppant is not effective any-more, the fractures are closing and their conductivities are then drastically reduced.”

### Modeling

Data are great, but they don’t make much sense until they’re put into a model. Numerical models can be used in addition to analytical models serving different purposes and solving different problems, Mildren said. But tying everything together requires a newer reality.

A recent presentation at a Reservoir Characterization Project (RCP) meeting at the Colorado School of Mines brought this home. RCP students have been working on Anadarko’s Wattenburg Field in the Niobrara Shale for several years and have determined that the integration of multiple types of measurements, including time-lapse seismic, provides a more realistic geomechanical model.

“This study proposes a more reasonable approach [that] allows for better treatments to be designed by incorporating geological heterogeneity within the simulation models to generate a more realistic reservoir response to stimulation,” the authors noted. “The technique uses a geostatistically derived 3-D geomechanical model [that] incorporates faults [and] lithological changes and lateral variation in reservoir properties and thickness within the horizontal well path as an input to the simulation model. The outcome of this process allows for more reasonable simulation results to be generated when designing

hydraulic fracture treatments in complex and heterogeneous reservoirs.”

The study incorporated a geostatistical approach representing the static conditions of the reservoir prior to stimulation that took into account lateral heterogeneity, pore pressure and overburden pressure. The authors noted that closure pressures were more sensitive to elastic moduli such as Poisson’s ratio and Young’s modulus (rock physics measurements) within the reservoir.


Volumetric calculations enabled models derived by sequential Gaussian simulation to calculate closure pressures within the reservoir, and diagnostic fracture injection test data from surrounding vertical well measurements were shown to have a good match.

### Next steps

Geomechanics studies might be considered to be the current “happening” thing in unconventional reservoir characterization. But there’s still room to grow.

“Artificial intelligence and machine learning will be used inside these types of platforms to accelerate computations by making use of previous learnings,” Koutsabeloulis said. “In addition, technologies such as cloud computing will be used to provide high-capacity, flexible, remote and fast computations in real time.”

“The real value of geomechanical models to hydraulic stimulation will be realized once geomechanical projects are shown to positively impact sustained reservoir production and reservoir economics,” added Herwanger, noting that geomechanics can become a game-changing technology for safe and economic production from unconventional reservoirs in the same way that 3-D seismic redefined deepwater seismic exploration. “The industry has started this journey,” he said. “Along the road ahead will be a closer integration of the subsurface disciplines where the impact of a high-quality geomechanical model on production becomes apparent and geo-mechanical studies become an indispensable part of unconventional reservoir management strategies.” ■



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# Eliminating Surface Variables

Surface technologies help deliver predictability in the multivariable world of well completions.

**By Jennifer Presley**

Senior Editor, Drilling Technologies

**B**usinesses are built on providing exactly what is the customer expects, with predictability ensuring satisfied customers. Therein lies the irony that is the oil and gas business as it is anything but predictable. It is the variability of E&P that drives operators and service companies to spend countless hours and days creating and refining the best processes using the best available technologies by which to conduct business.

It is through these that much needed measurability and repeatability are realized, as evidenced by reduced costs, increased efficiencies and greater production rates. The twin levers of cost reduction and efficiency increase were pulled as oil prices began to tumble in late 2014. Now, as the oil and gas industry continues its long climb out of sub-\$50/bbl oil, the two levers remain pulled, with technology carrying a fair piece of the load. Doing more with less is the mantra for today's lower for longer oil prices. It also was the focus of the opening plenary at the 2017 Unconventional Resources Technology Conference.

"When we say 'doing more with less,' essentially what we're saying is we need to be more efficient," said Gene Beck, senior vice president for U.S. Onshore at Statoil. "Efficiency is driving our business these days. Technology is the future."

Efficiency, aided by technology, is needed to materially improve recovery factors, he noted, adding that while larger completions contribute to it, the industry also needs to "look at other fundamentals to improving recovery factors and make sure we understand the basic physics of what we're doing so that we can learn and improve faster," he said. "We have to get to the optimum answer sooner."

According to plenary speaker, Alex Archila, president, North America Shale, BHP Billiton, and BHPBeck, there are three innovations that

vie for the title of "most significant" for adapting to the lower for longer market.

"The development of multilateral [wells] is going to be key in maximizing costs and maximizing recovery. Also, selected zone completions will help drive optimization," he said. "Finally, real-time optimization of wells, being able to monitor them better—not only as we drill, but also as we produce them—are going to help us learn faster."

For Beck, it is the way Statoil has integrated its shale-focused research and development technology team directly into the organization.

"The team works specifically on research-endorsed business ideas and to date they have delivered more than 24 technologies that have been directly implemented into the field," he said. "Probably the most significant would be where we stimulated a well using liquid carbon dioxide as a pad fluid, and created quite a phenomenal complex fracture network. Integrating R&D into our business has made the most significant impact."

Greg Guidry, executive vice president, Unconventionals, Shell told plenary attendees it is the industry's ability to integrate and learn quickly is the most significant innovation. However, given where the industry is at in relation to leveraging digitization, the industry is far behind other industries.

"If we can crack that nut, as an industry, then I think we can actually learn faster," he said.

That digitization nut goes by many names but Big Data analytics by far is the most common name given to a challenge that's been compared to sipping water from a fire hose at full blast. Hess is one of many operators currently tackling the Big Data analytics challenge with significant success in its Bakken Shale operations. For example, the company's completion design evolved from 35

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stages to 50 stages due to its Big Data efforts. That number has grown to 60 stages according to Hess COO Greg Hill's remarks during the second quarter earnings call in late July.

"We currently have six 60-stage wells online and 11 wells completed with proppant loading of up to 140,000 pounds per stage. While still early days, we continue to be encouraged by the initial results from our new completions," he said. "Drilling and completion costs for our 60-stage 70,000 pound per stage wells are averaging between \$4.5 million and \$5 million, which is approximately \$0.5 million below our initial guidance range."

Based on the encouraging production performance from the trials and the positive outputs that the company's predictive models are showing, the decision was made to move to 60-stage completions as the new standard. The company will continue to evaluate the impact of higher proppant loading up to 140,000 pounds per stage, he said.

"Early results and predictive model outputs suggest a potential 10% to 15% uplift in EUR as a result of the higher stage counts and proppant loading," he said. "In addition, we are able to raise full year 2017 average IP 90 guidance to between 800 and 850 barrels of oil per day, an increase of 100 barrels of oil per day compared to our earlier guidance."

The use of data analytics is a prime example of how producers are doing more with less in that rather than acquiring more data, they are looking at and maximizing the value of previously collected data. Doing more with that data also helps identify the variability in the E&P business world, and by doing so make it more predictable. Data analytics and the technologies that follow below are all examples of how producers can better control—at the surface—the risks associated with drilling and completing unconventional wells.

The following technologies were entered in Hart Energy's Meritorious Innovation and Engineering Award (MEA) competition for 2017. These technologies deal primarily with hydraulic fracturing.

**Editor's note:** The content below was culled from documentation provided by MEA applicants for review and consideration by the MEA judges.

### Degradable fibers deliver diversion stimulation service results

The MEA-winner for the drilling fluids/stimulation category, Schlumberger's OpenPath Sequence diversion stimulation service, is the first in the industry to use degradable fibers to suspend degradable multimodal particles—a combination that enables the sequential stimulation of zones and intervals to maximize near-wellbore coverage.

The service relies on composite pills that combine degradable fibers and multimodal particles. Particles alone—for example, conventional rock salt and benzoic acid diverters—are not always effective in isolating fractures of various sizes, but fibers bridge the gaps and capture the multimode particles to create impermeable temporary plugs that fully dissolve after stimulation operations are completed. Because the diversion



OpenPath Sequence diversion stimulation service uses the optimal acid identified for a particular reservoir to sequentially stimulate targeted zones and intervals. (Image courtesy of Schlumberger)

method is chemical rather than mechanical, OpenPath Sequence service is fast, easy and effective for both cased and openhole completions.

To optimize stimulation response, OpenPath Sequence service uses the optimal acid identified for a particular reservoir to sequentially stimulate targeted zones and intervals. The service is compatible with conventional acid, engineered acid designed specifically for OpenPath Sequence service and other proprietary acid systems.

The diversion technology can withstand differential pressure up to 4,500 psi for acid fracturing or matrix stimulation treatments. No specialized equipment is required, streamlining operations and reducing HSE risks as compared with conventional chemical diversion methods.

After treatment, the proprietary blend of fibers and particles fully degrades within hours or days at downhole temperatures from 130 F to 300 F without further intervention.

### **New shaped-charge design creates spherical fracture networks around perforation tunnels**

After drilling, running casing and cementing an unconventional wellbore, the casing has to be perforated using perforating systems with shaped charges. This pre-hydraulic fracture intervention has to be done to create a flow path through the casing and into the formation that will allow a point of fracture initiation. DynaEnergetics HaloFrac shaped charge line is designed specifically to enhance well productivity and operational ef-

iciency in unconventional reservoirs. The shaped charges generate an engineered jet that results in uniform casing hole entry diameter and shape independent of the gun phasing, shot density and position within the casing.

Uniform casing entry hole diameters provide for equal distribution of fracture treating pressures, fracture stimulation fluids and proppants, resulting in a symmetrical and uniform generation of fractures permeability around the wellbore casing and within the target reservoir. Previously bypassed and non-treated/fractured parts of the reservoir rock are now connected to the wellbore and allow contribution to the production and add to the total reserves recovered.

The entry hole diameter of HaloFrac minimizes the potential for proppant bridging and early stage screenouts. Perforating with HaloFrac creates spherical fracture networks around the perforation tunnels and ideal reservoir access conditions for hydraulic fracturing fluids and proppants.

The improved reservoir access through the casing and HaloFrac perforation tunnels result in

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# Innovation Delivers Solutions

Technology solutions are designed to meet new environmental regulations.

**By Matthew Mueller**

NOV

**M**any service companies are implementing changes in order to follow new environmental laws and/or reduce operating costs. NOV's Intervention and Stimulation Equipment business unit is helping customers implement those changes with improvements to the Rolligon line of fracturing equipment.

Traditional gels that are slurried in diesel or mineral oil have been used based on their ease of metering. As environmental laws and high costs continue to make it more difficult to use slurried gels, accurate dry gel additive systems are becoming a vital part of the well fracturing industry.

The Rolligon dry additive mix unit uses a custom-designed mixer to pre-mix the gel powder with water onsite, giving optimum gel quality even at high rates. The unit includes onboard bulk gel hoppers, which can be pneumatically operated, and a dust-collection system to filter the hopper exhaust during the filling process.

As fracture jobs continue to increase in size and duration, supply logistics become a crucial part of reducing the costs associated with downtime. A dry gel transport can carry more product per truck than a truck carrying slurried gel, and customers are able to run longer between transport swaps. This saves time associated with transport swap out on location and transportation costs of carrying the product to location, which translates to cost savings.

As some companies may still want to use slurry gels for specific jobs or as a backup option, hydration systems can be set up to accommodate both dry gel and slurry gel, giving the ability to choose the type of gel used on a job-by-job basis.

As downhole cement technology has changed, so has the equipment used to mix the dry cement. As job types have evolved, units have become more specialized to maximize performance in plug and abandonment (P&A), conventional cementing and regional equipment designs.

P&A work has been the topic of conversation for several companies in this current market. Large, high-horsepower, automated cementing units de-

signed for working in long lateral shale wells have many more features than traditional requirements for P&A work.

The Rolligon team at NOV developed a smaller cementing unit that still offers the robustness and accuracy of the larger unit while eliminating components not needed for smaller-scale jobs.

The unit has a batch-type tub for mixing smaller batches of cement. A new mixing head was developed for low-rate, low-volume jobs to ensure such jobs are completed accurately while maintaining homogenously mixed cement slurries. The new mixing head also allows higher rates if required for those jobs outside of the P&A work.

High-performance cementing equipment is also offered for those higher-rate jobs. Each unit is equipped with NOV's patented, high-energy recirculating mixing head and combined with the continuous automatic mixing system that fully automates the mixing of water, dry bulk, liquid levels and liquid chemicals. This allows the operator to continuously mix cement while pumping. When coupled with data acquisition systems, graphs and reports can be easily created onsite.

Additionally, various regions require equipment to meet local requirements. Areas such as Europe, Australia, the U.S. and Canada all require truck and trailers built to local regulations. In a recent project, the company was tasked with building a custom package for a high-horsepower twin cementing unit in the northeastern U.S. It required building a unit under 80,000 lb using the latest technology in Tier 4 engines. Through careful design and engineering, a 100,000 lb unit was reduced to 80,000 lb in gross weight with the tractor. Although the design weighs less, it is still just as robust as the original equipment and allows for quick callout requirements, typical of cementing operations in regions where it is difficult to get permits.

## Software solution

Fracturing jobs call for a host of equipment to get the job done. NOV's software combines the multitudes



The dry additive mixing unit uses a custom-designed mixer to pre-mix the gel powder with water onsite.  
(Photo courtesy of NOV)

of datapoints from each piece of equipment to address this industry need.

The Rolligon DASTRAC PC software provides the ability to control units equipped with Rolligon controls and allows communication with them. In addition, data can be acquired from other systems not equipped with Rolligon controls by using serial data or direct sensor cables.

The software was developed to pull data from all process units (liquid additive system, hydration, blender, proppant equipment, etc.) into one database rather than having data on individual units. This allows service companies the consolidation of information into one location for quick access to the data as needed for proactive assessment and adjustment.

The data gathered from the equipment can be displayed in multiple viewpoints depending on need. The data can be viewed as individual numbers, plotted on a multi-axis graph for treater feedback and on separate screens for customer review. NOV's current improvement plan for the software will enhance graphic appeal, make it more operator friendly and

add well calculations along with other features.

For customers currently using fracture analysis software, this provides two options:

Continue using current software or use DASTRAC to focus on the calculations and wellbore schematic needed. This will help to decrease costs, as purchasing additional software packages for some basic features will no longer be a necessity. The company also is moving toward Ethernet and wireless capabilities for increased data acquisition at a faster pace while decreasing the cost of the number of cables used.

As such an enormous amount of data is transmitted to DASTRAC, a tool that will log all engine data, process data from the units, alarms, settings and more onto files is currently being developed. The next step is to allow for secure, remote access to all of that data, which will enable access from the office when needed for maintenance and predictive analysis. ■

*Matthew Mueller is NOV's engineering group leader for the Rolligon product line.*



lower and more consistent breakdown pressures, higher pumping rates, uniform proppant placement, highly uniform fracture clusters and higher well productivity ratios.

HaloFrac charges lower the risk of nonproductive clusters and stages and delivers improved reservoir connection and increased total estimated ultimate recovery as well as a reduction in a well's total cost of operations. This creates the greatest certainty that fracture clusters will form as designed and production is optimized to produce as predicted.

### Microfracture stimulation leads to increased recovery rates

As more horizontal wells are drilled in tight shale formations and completed using multistage hydraulic fracturing treatments, operators rely on

pressure, leaving the complex secondary branches disconnected from the main fracture. Halliburton's MicroScout service provides a means of stimulating these microfractures to assist in increased recovery of hydrocarbons and maximized recovery of the injected fracturing fluid. The service helps overcome this hurdle by injecting ceramic microproppant (MP) as part of the pad fluid stages to help ensure naturally occurring or induced microfractures are penetrated and can remain open during production and contribute to the effective flowing fracture area, leading to an increased recovery factor for shales and tight reservoirs.

During experimental laboratory evaluation of MicroScout service, various shale core samples were split along the core length to create artificial microfracture faces. These fracture faces were then treated with diluted concentrations of

MP, and were then reassembled for core flow testing under closure. The MP formed agglomerations on the fracture face creating an optimal partial monolayer. This unique propping effect demonstrated a dramatic increase in terms of effective permeability of the MicroScout service treated cores.

Initial field treatments of MicroScout service involved injection of pad fluids containing MP to treat secondary azimuth complex fractures in the near-wellbore and far-field regions. Sequenced proppant slurries of larger size particulates (100-mesh and larger) followed propping the primary fractures and their larger branches. Production from wells treated with MP has

helped provide 25% to 40% improvement of liquids and up to 100% improvement in gas production compared to the production of control wells.

### Green technology delivers electrifying results

A MEA-winner in the hydraulic fracturing category, Evolution Well Services is a pressure pumping company with a focus on hydraulic fracturing



Power for the company's NextGen 100% electric fracturing services is generated by burning natural gas through a customized-for-purpose GE TM2500+ turbine system that has significant economic and environmental benefits.

*(Photo courtesy of Evolution Well Services)*

large volumes of proppant to help ensure the created complex fractures are propped and maintain conductive flow paths for well production. However, it appears that most naturally occurring and induced complex fractures are too narrow for even 100-mesh sand to enter.

As a result, most of the stimulated reservoir volume remains inaccessible as these microfractures tend to close soon after the release of fracturing



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that uses 100% electrically powered process equipment. Power for the company's NextGen 100% electric fracturing services is generated by burning natural gas through a customized-for-purpose GE TM2500+ turbine system that has significant economic and environmental benefits. The ability to use multiple fuel types such as field gas offers the highest amount of fracturing cost reduction potential.

For primary equipment, Evolution Well Services uses a blender with ambidextrous suction/discharge capability with rate capacity of up to 240 bbl/min on dual 120 bbl/min sides. The hydration unit is designed for 200-bbl capacity with compartmentalized sections for maximum mixing energy and dual gel pumps.

The chemical additive system uses low- and high-rate pumps and flowmeters for accurate monitoring and control. Fracturing pumps are mounted with dual pumps on each trailer capable of delivering up to 5,000 hhp per trailer while also offering a 40% to 50% reduced location footprint.

Strategically placed remote-controlled cameras monitor equipment and allow the removal of all personnel from high-pressure areas, exposure to chemical hazards and silica dust. With fewer needs for personnel, Evolution Well Services is able to reduce the amount of onsite personnel by 60% vs. conventional fracturing fleets.

### **Design delivers step change in rigup efficiency, safety**

Halliburton has developed the ExpressKinect manifold and the ExpressKinect wellhead connection unit (WCU), creating a step change in rigup efficiency and safety onsite. The manifold incorporates a simple yet reliable design that eliminates 75% of the pumping unit connections. The design reduces HSE exposure, the time required for rigup and rigdown and the number of potential leak points.

The WCU features a single treating line that connects to the wellhead using a hammerless hydraulic remote connector, eliminating the need for numerous separate lines and connection points, making rigup a faster and safer process. The WCU is rated for 100 bbl/min and 15,000 psi.

During multiwell operations, the WCU single line manifold is efficiently swapped from one well to the next in minutes. The wellhead adapter is compatible with wireline units, eliminating the need for expensive and complex zipper manifolds. The WCU eliminates more than

30 hammer connections and 10 overhead lifts for each wellhead, enabling a safer, more efficient operation at the well site. A conventional two-well, 100 bbl/min stimulation job requires 170 connections, with 12 of those at an elevated height. The ExpressKinect WCU reduces the total connections to 36, with no elevated height connections.

### **New pump design features long rod stroke for longer life**

Demand and expectations placed on well-servicing pump units have increased as the hydraulic fracturing industry has grown. Wells are drilled deeper and with higher pressures and more challenges, the greater the power requirements become on pressure pumps. The market drop forced E&P companies to scale back but with the recent uptick in drilling and production activities, operators are looking to capitalize on the innovations that have occurred in the industry over the last few years.

The new Gardner Denver Thunder series of well service pumps is designed to offer operators and well-servicing contractors increased horsepower and rod load with longer life and service intervals that are aligned with those of the engine and transmission.

The new design offers a longer 11-in. stroke (versus the typical 8-in.) to provide 37% more flow per cylinder, per rotation of the pump. This longer stroke design reduces the pumping speed required to achieve the same flow and pressure output of conventional shorter-stroke pumps.

The modular pump system was designed to run smoothly. Heavy vibrations in conventional pumps cause the components to wear out faster and can cause significant problems with unwanted



The new design of the Gardner Denver Thunder pump-series offers a longer 11-in. stroke to provide 37% more flow per cylinder, per rotation of the pump. (Image courtesy of Gardner Denver)





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ed cost, repair and downtime. The modular design of the Thunder series pumps focuses on smoother operation, with crankshafts optimized with a specific firing order. Counterweights were added where necessary to minimize the vibrations and shaking forces of operation.

The new pump series utilizes proprietary coatings on all critical wear surfaces in the power end. These new coatings, applied to all cross-heads, journal bearings and thrust bearings, these coatings provide dry film lubrication to reduce scuffing, friction and adhesive wear. On the pump's fluid end, a new design featuring high-strength, corrosion resistant stainless steel and patented twist-in retainer technology is used. The new design enables rapid valve and packing changes with no special alignment or tools necessary.

### Flowback monitoring service ensures well performance

Another MEA-winner in the hydraulic fracturing category is the AvantGuard Advanced Flowback Services that optimize well performance from post-stimulation operations through production. The service, developed by Schlumberger, provides ongoing, real-time monitoring to ensure the well is performing within a secure operating envelope (SOE)—protecting both the hydraulic fractures and return on investment during the lifetime of the well.

AvantGuard services are based on the application of the SOE, which is a combination of operational parameters that preserve the connection between hydraulic fractures and the wellbore. Operational parameters are defined from real-time pressure and production data, including solids production monitoring.

Damage to the well and the formation is actively prevented by tailoring a predictive flowback design strategy with a defined SOE—compared with conventional rate transient analysis used for identifying post-fracture impairment.

Changes in production rates are measured using the Vx Spectra surface multiphase flowmeter, which accurately captures multiphase flow dynamics in any flow regime for all fluid and solid types. Ongoing monitoring with real-time analysis minimizes proppant flowback and solids production.

Application of AvantGuard services for predictive flowback design during the transition to production protects and stabilizes hydraulic fractures to efficiently enable all the clusters in each zone to produce without productivity impairment.

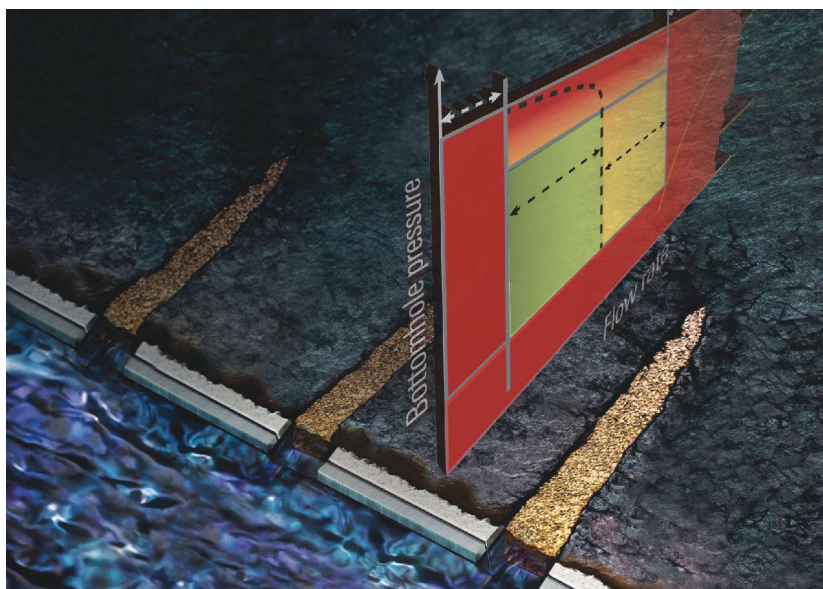
### A 'quieter' completion

The need to reduce the impact on stakeholders while operating in increasingly stringent regulatory environments has become a reality for many E&P companies.

Many states regulate noise levels emitted from well sites and Colorado's laws, for example, are on the stricter end of the spectrum.

Colorado regulations stipulate that noise levels do not exceed 75 dBA at 350 ft from the source and that a measurement in excess of 65 dBC, at a distance of 25 ft from the nearest occupied structure, shall require a low frequency noise study by the operator along with the identification of any reasonable mitigation strategies.

Liberty Oilfield Services developed its Quiet Fleet of pressure pumping systems with the goal of reducing



The AvantGuard Advanced Flowback Services provide ongoing, real-time monitoring to ensure the well is performing within a secure operating envelope, protecting both the hydraulic fractures and return on investment during the lifetime of the well. (Image courtesy of Schlumberger)

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# Returning Stacked Fracturing Equipment to Service

A critical understanding of how equipment was prepared for storage, where it was stored and its current condition is key.

**By Bill Jensen**  
Weir Oil & Gas

Equipment prepared for long-term storage typically has a plan for returning to service that is specified by the original equipment manufacturer (OEM) or operator. If these processes are adhered to the equipment is easier to mobilize with light maintenance.

But, in the recent downturn, many companies did not have the time or the funds to do this.

Understanding how the equipment was stored is critical and may impact the cost associated with re-commissioning by as much as 60% of new unit cost.

In addition to understanding equipment condition, it is equally important to understand what is expected once it is returned to service. Equipment can be returned to service in a number of ways—all of which have a cost. For example, the process may be changing fluids and replacing only known failed components. This is less expensive but may also create downtime and inefficiency.

Another alternative is a complete refurbishment of the asset by a third party. Options include repair of major parts or a completed unit redress including expendables, fluid ends and engine rebuilds. This is confirmed by the vendor through an operational re-commissioning test that details the asset's health. When dealing with an entire fleet of equipment the exposure to various OEMs and repair facilities needs to be considered. These factors make it critical to develop a comprehensive unstacking plan for returning assets to service. Without one, costs can quickly get out of control and the expected results may not be achieved.

## Establishing a plan

A plan begins with defining the objectives and identifying the condition of the equipment to be reinstated. Only then can a plan and budget be established.

To determine its true condition, each unit must be inspected, tested for performance and its overall condition assessed.

Begin with a list of potential issues that could exist. These range from whether the unit was assessed

before stacking, has components that have been removed to support the active fleet, and more.

Establish the testing parameters and inspections for each major component of the unit. The results should be compared to the manufacturer's equipment release to determine the status of each component.

This report helps determine which components can be economically rebuilt or repaired, and which should be replaced. Analysis of the cost and benefit should include warranties, repair vs. replacement considerations, the reliability factor for each component and payback time for the unit.

## Service for success

Companies typically stack equipment that requires the most maintenance. To ensure readiness and reliability, the highest level of service should be applied when unstacking.

Service actions are generally implemented in steps that inspect, test, measure, adjust, service, repair, replace or overhaul, along with calibration and updating software. These steps are applied in an approach that services the unit in component groups. This methodology builds operational reliability by ensuring the entire asset is serviced without any oversights.

## Optimizing the solution

The decision to return a pressure-pumping unit to the field is based on a complex mix of factors including but not limited to business priorities, equipment condition, costs and benefit of repair, rebuilding or replacement. Other considerations may be needed to achieve the optimal results for the company's objectives. Understanding these objectives and using them to guide the process allows for easier problem identification, assessing options and applying practical solutions, while keeping the cost under control. ■

*Bill Jensen is manager, Technical Services for Weir Oil & Gas.*



# Stainless Steel Fluid Ends Help Reduce Fatigue Cracking

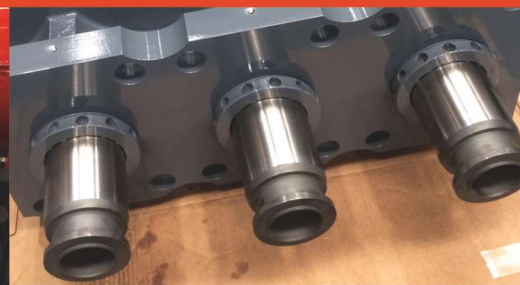
Fatigue cracking is the most common failure of frac pump fluid ends. It mostly occurs in alloy based fluid ends which fail earlier and are not as durable. The result is loss of pumping hours – aka lost revenue. Endurance brand fluid ends or pressure pumping are constructed of 100% premium stainless steel sourced solely for its ability to endure and meet the rigorous pressure standards. Stainless steel has proven to extend the life of fluid ends.

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The Quiet Fleet of pressure pumping systems were designed to reduce noise at the source to meet strict regulations. (Photo courtesy of Liberty Oilfield Services)

noise at the source. Analysis of data collected from several well sites, including the creation of a profile of the frequency and sound pressure emitted by each major sound source, showed that the primary producer of the noise were engines over 600 hp, with readings ranging individually from 98 dB to 103 dB at 23 ft from the source. The first Quiet Fracture fleet was introduced in the D-J Basin in July 2016 and it has fractured more than 50 wells. Results have shown a more than 10 dB reduction in noise at pressure pumps at every measured frequency from 20 Hz to 20,000 Hz and an overall reduction of more than 20 dBC for the pressure pumping fleet measured at the wellhead. Measurements by state regulatory officials indicate noise levels onsite are below OSHA requirements for hearing protection.

### Technology makes restimulation of individual perf clusters possible

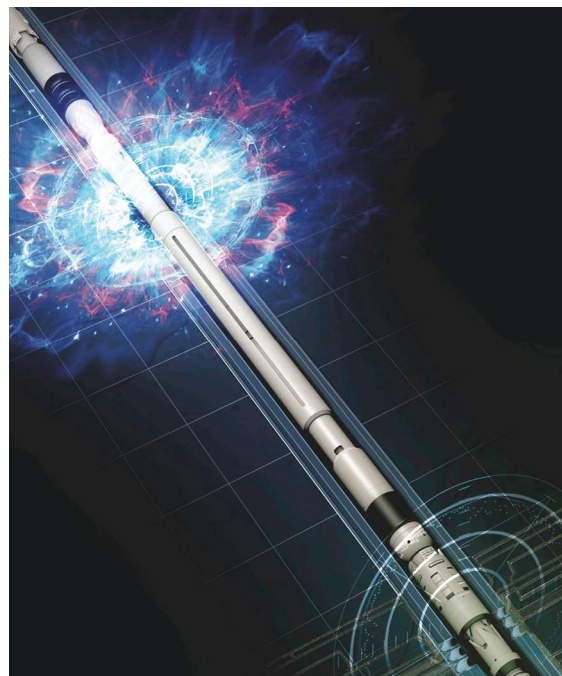
Well restimulations share a common problem regarding the lack of certainty and control over where fracture treatments are placed, which often wastes time and money. The OptiStriker straddle packer system developed by Baker Hughes, a GE company, makes isolation and restimulation of individual perf clusters within the well possible.

The dual resettable coiled-tubing-enabled packers and large internal diameter enable a pump rates as high as 20 b/m and a differential pressure rating of 10,000 psi. The two

packers work in unison to straddle and then isolate individual clusters or portions of the wellbore. Isolating and then targeting specific zones ensures that more precise fluid volumes and pumping horsepower are used to treat each cluster to its full potential. The system reduces operational costs by 30% compared to other restimulation techniques.

The OptiStriker packers only come into contact with the casing wall when set, minimizing damage and wear caused by

rubbing against the casing wall as the assembly is moved. The high-expansion capabilities of the system ensure that a complete seal is established by the packers. The robust seal ensures higher hydraulic fracturing pressure and no fluid leak off. Monitoring and analysis is performed during and after the job to confirm treatment effectiveness. ■



The OptiStriker straddle packer system makes isolation and restimulation of individual perf clusters within the well possible. (Image courtesy of Baker Hughes, a GE company)



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# Water Options Increase

Growing water midstream market provides operators with another option.

**By Jennifer Presley**

Senior Editor, Production Technologies

When it comes to water, unconventional oil and gas producers walk a fine line between too much and too little. Finding the right balance can be tricky in a commodity-driven oil business, where one day the market is up and the next day, not so much. The drop in oil prices in late 2014 triggered a significant shift in priorities, one that John England, vice chairman, U.S. Energy and Resources Leader for Deloitte LLP characterized as necessary on the “slow road back” in his “2017 Outlook on Oil and Gas.”

One positive that emerged from the downturn, according to England, was that it led to “oil companies learning how to operate in a lower price environment, returning to a healthier focus on capital and operating cost discipline.”

Producers, through a concentrated focus on reducing costs and maximizing efficiencies, are reaping the benefits that come with a disciplined application of new approaches and technologies. Take, for example, the rapid growth of the emerging water midstream market.

New businesses grow where there is a need, and meeting the supply and disposal demands of shale producers is proving to be fertile ground. The increasing number of companies specializing in water midstream demonstrates how pipelines and centralized storage facilities are checking all the right boxes for producers looking for a lower cost water option.

## Market resurgence

“Where there are risks, there are opportunities,” said the authors of the joint Barclays and Columbia University Water Center report, “The Water Challenge: Preserving a Global Resource.”

“Given the central role of water in oil and gas production, we believe the industry will rethink

conventional water acquisition and disposal methods and invest in more efficient and sustainable water technologies and practices,” the report said.

Echoing Deloitte’s England, the report’s authors note that, “the low oil prices in recent years have forced producers to cut capital spending and operating expense, which has encouraged more innovative and efficient water management.”

While oil prices are not as high as they once were, the price fluctuations have settled and the industry has returned to work. The stabilization in the oil market and industry innovations are the key factors contributing to a resurgence in water demand, according to the Bluefield Research report “Water for U.S. Hydraulic Fracturing.” Oil prices, up 62% from 12 months ago according to the report’s authors, are keeping plays like the Permian Basin hopping.

A quick look at the horizontal rig counts in the major shale plays compiled by Baker Hughes shows that more rigs are at work this year as compared to 2016. For example, a spot check of the

Shale Play	Aug. 26, 2016	Aug. 25, 2017
Cana Woodford	32	69
D-J Basin, Niobrara	16	30
Eagle Ford	30	66
Haynesville	13	44
Marcellus	25	43
Permian Basin	199	377
Utica	13	30
Williston Basin	27	52

Rig counts for the major shale plays demonstrate how the industry has returned to work now that market prices have stabilized. (Source: Baker Hughes, a GE Company)

Permian Basin count indicates there were 377 rigs at work in August 2017 as compared to 199 rigs one year earlier. For the Marcellus and Utica plays, there were a combined 73 rigs at work at this time as compared to a combined 38 in August 2016 (see table).

The Permian Basin and the Marcellus also stand out among the other shale plays with steady production growth, according to the Bluefield report.

“The monthly growth rate of production in the Marcellus gas play since the start of 2007 is 2.28%,” the authors said. “Monthly production levels have declined eight times since January 2015.”

The Utica also is making a good show with the EIA anticipating it to be one of the fastest growing sources of U.S. natural gas, outpacing the Marcellus at a 2.71% monthly production growth rate, according to Bluefield.

“Still in its early stages of development, production in the Utica grew 507% between January 2014 and May 2017,” according to the report. “The Permian Basin has increased 254% since January 2015.”

### Innovation delivers demand

While rigs and crews have returned to work, they’ve done so in a time when the drilling and completions processes and technologies are significantly more sophisticated than when the Shale Gale first started blowing more than five years ago. These innovations have, in turn, spurred on the increased demand for water. Industry’s ability to drill faster and the use of longer laterals are cited by the Bluefield Research report as contributors to the increase.

“While rig counts are a key barometer to well completions, rig operators have made significant improvements in drilling efficiencies by reducing well completion times from 30 to 20 days,” the report stated.

One example of this can be found in the Utica Shale. In 2016, Pennsylvania-based Eclipse Resources drilled its Purple Hayes No. 1H condensate well in Guernsey County, Ohio, to a total depth of 27,048 ft with a “super” lateral of 18,544 ft in 17.6 days.

The company completed the well with its 3.5-mile long lateral in 124 plug-and-perf stages in 23.5 days.

Less than a year later, the company set a new record for longest lateral drilled with its Great Scott No. 3H well. That well was drilled in 17 days to a total measured depth of 27,400 ft with a superlateral that extends 19,300 ft or 3.6 miles. The well is set to be completed in the third-quarter 2017.

While superlaterals are starting to take off, it is not unusual for laterals to reach a mile or more in length and found originating from multiwell pads.

“Multiwell pads have steadily increased quarter-over-quarter over the last two years,” according to Todd Bush, an analyst for Energent, part of the Westwood Global Energy Group, stated in a Westwood Insights report issued in July. “For many operators, the limiting factor is the lease size or acreage position to support the density of wells with long laterals.”

Permian-based operator Matador Resources drills one-mile laterals in the Delaware Basin and, in the last year, the company drilled a nine-well pad averaging 5,025-ft laterals and a six-well pad averaging 4,830-ft laterals targeting the Wolfcamp, the Westwood report stated.

“ExxonMobil used a NorAm Drilling Co. rig to drill the first well of two on the Hurley 56-18 1H pad in Reeves County, Texas,” Bush said in the report. “This 5,479-ft lateral well used multiple suppliers for six million pounds of frac sand. During



Sand is mixed in with water during fracturing operations for use in a Permian Basin oil well. (Photo by Tom Fox, courtesy of Oil and Gas Investor)



the last 12 months in the Delaware Basin, Exxon-Mobil drilled two-well and three-well pads with horizontal lateral lengths ranging from 4,500 ft to 10,540 ft.”

### More activity, more water

These longer laterals require more water to complete, with as much as 12 million gallons of water per fracture needed, triple the volumes needed five years ago, according to the Bluefield Research report.

“Demand is rising exponentially, particularly in West Texas, because of increased water volume per frack and an almost 30% reduction in time required to complete a well,” the authors said. “As a result, water demand has been quicker to rebound to pre-2014 market collapse levels than rig counts.”



The installation of water midstream infrastructure will help remove saltwater disposal trucks from Delaware Basin service roads. (Photo by Tom Fox, courtesy of Oil and Gas Investor)

There were more than 1,200 land rigs at work in 2014 and with the price of oil hovering just above \$100/bbl, water demand was 2.16 Bbbl with a total water management spend of \$10.9 billion, the Bluefield report said.

In 2017, at oil prices forecasted at roughly half of what they were three years ago, Bluefield projects a rig count of 650 and a 54% increase over 2016 in water demand at 2.09 Bbbl with a total spend of \$2.35 billion.

With increased water consumption per frack, so to comes the need to manage the increased volumes of flowback and produced water.

“Between 2017 and 2026, more than 20 billion barrels of water will be required to serve the U.S.

hydraulic fracturing market,” the report’s authors said. “A total of \$136 billion will be spent from 2017 to 2026 on the supply, transport, storage, treatment and disposal of water.”

In 2014, \$162 million of the \$10.9 billion was spent for water treatment and reuse. Reuse rates—highest in the Permian Basin and Marcellus—will increase, from \$198 million in 2016 to \$307 million by end of 2017, the report said.

Transportation of water represents the largest expense at 56% of the total water-related spend through 2026 across all U.S. plays, according to Bluefield.

“The role of transport has become a primary driver of cost improvements, which has resulted in the installation of water pipelines and alternative water supply contracts,” the Bluefield report stated. “Scaling volumes of flowback and produced water are steadily rising as a percentage of water demand...the simple takeaway is that this wastewater will need to be managed.”

Getting costs down and fewer transport trucks on the road are just a few of the many reasons why the industry is now seeing significant growth in the emerging water midstream sector.

### The emerging middle

The rebound in drilling activity and the increased water demand delivered a wave of new midstream water investments, according to a research note released by Bluefield Research. These investments are at this time are primarily centered on providing water infrastructure and management services for operations in the Permian Basin.

Private-equity-backed H2O Midstream announced in June its acquisition of produced water infrastructure from Encana Oil & Gas. Under the agreement, H2O Midstream will gather, dispose and deliver for reuse produced water for a “substantial portion of Encana’s acreage position in Howard County, Texas,” according to a press release issued by the company.

H2O Midstream will assume ownership and operation of the operator’s existing produced water gathering system consisting of more than 100 miles of interconnected pipeline and five salt water disposal wells totaling 80,000 b/d of permitted disposal capacity. The existing system will be expanded to include new water pipelines, additional disposal wells and a water storage and reuse hub.

“By 2018, H2O Midstream expects to have more than 200 miles of pipeline for gathering, 140,000

b/d of disposal capacity and over 2 MMbbls storage to serve Encana as well as other nearby producers,” according to the release.

Also in June, Layne Christensen announced that construction was nearing completion of a new high-capacity water pipeline and infrastructure system in the Delaware Basin. Sitting on nearly 1,000 acres of “highly-productive water-producing land near Pecos, Texas,” the system includes wells, pump stations and in-ground storage facilities, a company-issued press release stated. The system also includes more than 20 miles of high-capacity water pipeline extending north towards Orla, Texas.

“This infrastructure business is an expansion of our water-focused platform, leveraging our extensive experience to better serve the rapidly growing demands for water in the energy sector. The recent increase in drilling activity, coupled with technology advancements driving greater horizontal lateral lengths, is creating a growing demand for water in fracking operations,” said Michael J. Caliel, president and CEO of Layne in the press release.

“Today, many fracking operations require between 500,000 and 700,000 barrels of water per well completion. Based upon industry forecasts of longer lateral lengths and increasing drilling activity, we expect water usage within the energy sector to more than double over the next two years, with much of the demand in areas such as the Delaware Basin,” Caliel said.

The system has initial production and delivery capacity of 100,000 b/d of non-potable water, with significant capacity to support further expansion from both additional water sources and delivery points. The capital investment for the system is approximately \$18 million and water sales are expected to begin in third-quarter 2017.

These water midstream systems take inspiration from operator-led initiatives in the Permian Basin and in Oklahoma’s Stack play. Laredo Petroleum is one of many operators in the Permian Basin to seek out and develop efficient systems to meet and manage its operational needs. The independent’s operations are divided into four production corridors with centralized infrastructure. The largest of the four is the Reagan North corridor and is where the centralized facility is located, according to the Barclay’s report. In fourth-quarter 2016, the company estimated its production corridors reduced its lease operating expense by approximately \$0.51/boe, per the report.

Newfield Exploration Co. announced in March 2017 that it had started construction of its Barton Water Recycle Facility in the Stack play in the Anadarko Basin. The company has invested more than \$40 million to date in water management infrastructure in the play. The complex, located on a 30-acre site, will connect to seven pits with nearly 6.5 million barrels of storage capacity via more than 70 miles of underground pipeline. It is expected to process approximately 30,000 barrels of water per day upon its completion in the 3Q 2017, according to a company-issued press release.



Increased drilling activity in plays like Oklahoma’s Stack is placing increased pressure on water suppliers to meet increased demand. (Photo by Tom Fox, courtesy of Oil and Gas Investor)

“The Barton facility will utilize aerated biologic treatment technology to convert produced water into recycled water for hydraulic fracturing operations. The treatment process uses natural and enhanced bioremediation, or good bacteria and nutrients, to separate and breakdown any existing impurities that may be contained in the produced water,” the release said. “The end result is high-quality water primarily free of impurities—very similar to what is initially found in the reservoir rock.”

From input to output, operators are applying new techniques and rethinking others to find the best, most cost-efficient way to meet water demands. These demands will continue, in good times and in bad, but with careful planning and industrious private-equity investors, there should be plenty of water for drilling and completion activities for years to come. ■



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# Aligning Water's Value with Water Management Practices

Opportunities exist but much work remains before cross-sector water management planning achieves its objectives.

**By Scott B. Ahlstrom**

Primoris Services Corp.

and

**Jeffrey Hardin and Rudy Folds**

Nano Gas Technologies Inc.

Intuitively and objectively, we know water is a precious resource. We know water affects all facets of life and we are familiar with various platitudes often used to remind us of this point. But how well do our water management practices align with that understanding? When water is readily available, inexpensive and subordinate to the production of highly sought-after commodities, does it simply become a means to an end, a cost in the value chain to be minimized without consideration of broader implications? How do we improve our water management practices and transition from water simply being a cost of production to a vital resource tied to the health and economic future of the area? And how do we demonstrate that our understanding of the implications of our water use extends beyond those associated with its immediate use?

Much work remains before cross-sector water management planning achieves the objective of allocating the highest quality water to the highest value uses. Nevertheless, progress is being made and some cross-sector cooperation is occurring. Here are some examples and technical developments to be considered that better value water as a special resource for which there is no substitute.

## **West Texas water resource integration**

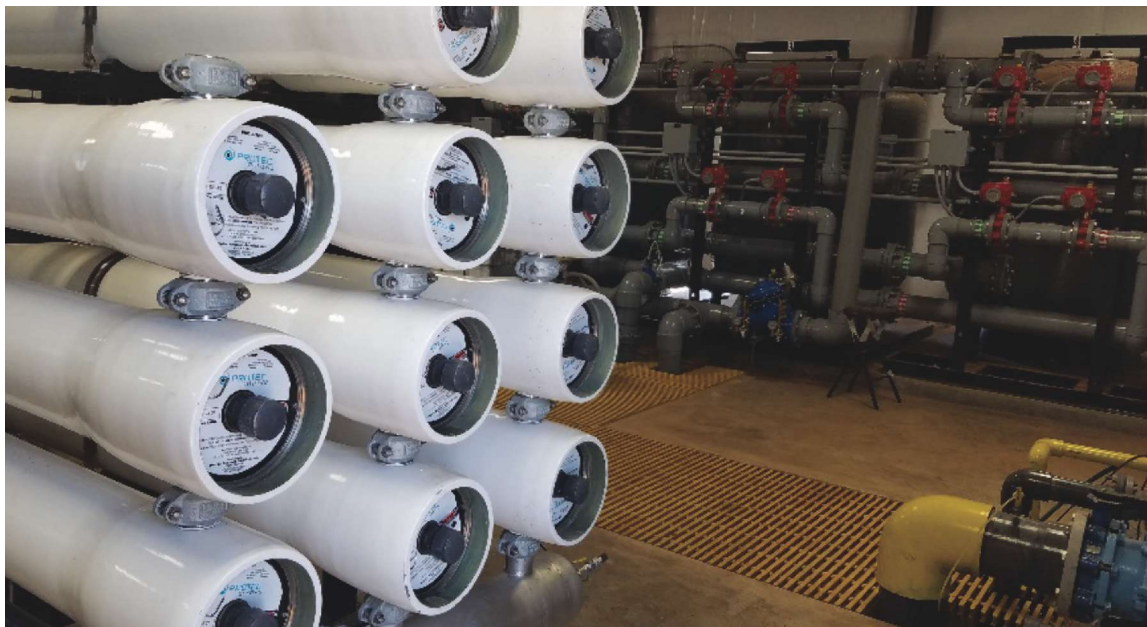
While still in the development stage, this concept

originated as a result of changes in the Safe Drinking Water Act and EPA's new standard calling for lower levels of arsenic in drinking water. Since arsenic occurs naturally in much of the groundwater in West Texas and since groundwater is the primary source of drinking water in this area, additional treatment is required. After treatment, approximately 80% of the treated water is available for potable supply and the remaining 20% must be disposed of as wastewater.

As a result, a city not only needs to replace that 20% loss in supply, it also must find a suitable discharge alternative for the wastewater. This became an excellent opportunity for the municipal sector to cooperate with the oil and gas industry. Since the wastewater quality is acceptable for use by the industry, it can become a new source of supply. And since industry has a new source of supply, it can sell some of its freshwater to the city to help meet potable water demands.

## **Municipal wastewater as a reliable supply**

Another opportunity for cooperation that is seeing increasing interest is the use of municipal wastewater treatment plant effluent. For example, in 2016 Pioneer Water Management (PWM) announced an agreement with the city of Odessa to provide Pioneer with millions of gallons of treated municipal wastewater for use in its op-



This drinking water treatment plant removes TDS, arsenic and fluoride. Wastewater generated is acceptable for industrial use. (Photo courtesy of Primoris Services Corp.)

erations. PWM constructed 20.3 miles of 24-in. polyethylene pipe from Odessa's Bob Derrington Water Reclamation Plant in Midland County to one of its water supply facilities. It is designed to flow 150,000 bbl/d of water. In December 2016, PWM announced a similar agreement with the city of Midland, except in this case, PWM would upgrade Midland's wastewater treatment plant to provide the requisite treatment so the effluent could be reused. These agreements significantly reduce PWM's need for freshwater and makes productive use of a non-potable resource that was previously unused.

### Shared infrastructure

Another growing trend is the construction of shared pipelines and treatment systems that provide a regional supply of water to various entities in a geographic area. Such shared infrastructure is common in the municipal sector and companies like Primoris Services Corp. are extending that strategy to the industrial sector. Since the cost of the infrastructure is shared, a more robust system that delivers water over longer distances can be put in place while maintaining cost and service benefits. When coupled with site-specific water-treatment technologies (either mobile or semi-permanent) shared infrastructure preserves flexibility, opens new sources of supply and offers the benefits of economies of scale.

### Water reclamation and reuse

Water reuse is a common practice in the municipal water sector and is becoming more common in the oil and gas sector. Several states are encouraging this practice by creating a regulatory framework that is friendly to reuse alternatives. As a result, recycling has reduced the use of freshwater in oil and gas production operations, the amount of produced water hauled by trucking and disposed underground has decreased, and produced water is now a resource and sold as a commodity for reuse in hydraulic fracturing operations.

New treatment options are aiding the transition to increased reclamation and recycling of produced water. One such technology that appears promising involves the introduction of nano-scale bubbles—estimated at 10 nm to 50 nm—in produced water, enabling operators to reduce residence time for settling solids, increase oil recovery and provide a cleaner water that can be repurposed for other applications. Full-scale use in the Permian has demonstrated that nano bubbles affect the fluid dynamics by changing the density, viscosity, electric potential, ionic potential and zeta potential enabling operators to handle produced water in a more efficient method.

### The science of nano bubbles

The smaller the droplet size the more stable the system. Nano scale gas droplets are colloidal (less





Effluent from the Nano Gas process is shown. (Photo courtesy of Nano Gas Technologies Inc.)

than 10  $\mu$  in size); therefore, a more stable system of bubbles.

When a system incorporates nano-scale gas droplets, Stokes' Law for the frictional force exerted on spherical objects with very small Reynolds numbers in a viscous fluid does not occur. Instead, a modified Stokes Law applies due to the higher osmotic pressure at the gas liquid interface, thus preventing nano bubble dissolution. Zeta potential is then reduced in the presence of higher ionic strength.

Nano Gas Technologies Inc. has developed and patented equipment to infuse nano-scale bubbles of various gases into different waters. The effect on aqueous constituents of solids, FeS<sub>2</sub> (iron sulfide), sand and oils of varying API gravity (from extra heavy to light) without the use of heat is promising. The infusion of nano bubbles decreases the density by adding millions of bubbles per cubic meter in the solution which increases the buoyancy of oils and enables them to rise to the surface. The nano bubbles decrease viscosity and surface tension enabling solids to fall more rapidly due to the decrease in the drag coefficient. They have also observed solutions at levels exceeding six times that of Henry's Law or the Ideal Gas Law at standard temperature and pressure at scale sizes common at saltwater disposal sites. The saturated solution remains stable with a half-life expectancy of 15.2 days. This means virtually 100% of the infused nano bubbles are available to achieve the desired goals and objectives.

The velocity that bubbles rise freely through an uncluttered solution is directly related to the square of their radius such that 100-nm-diameter bubbles will take well over two weeks to rise 1 cu. m whereas 10  $\mu$  diameter bubbles only take 2 to 3 minutes to rise that far.

Finally, the infusion of nano bubbles increases the ionic potential which enables the bubbles to attract the polar oil droplets to attach to the bubbles and increase buoyancy and rise to the surface.

The Nano Gas process takes a slipstream of cleaned effluent water and a gas or blend of gases and injects it into a 30-gal pressure tank. The mixture of water and gas is then continuously released into a 240 bbl to 1,000 bbl treatment tank via proprietary delivery systems to cause the desired reactions. The equipment has the ability to infuse different individual gases as well as blends of gases to achieve the desired results. Since each gas has known properties, Nano Gas Technologies manipulates the gas or gas combinations in a nano bubble phase to enhance and exploit the characteristics of the gases. Depending on the gases used, the process can break emulsions, float oil (to include extra heavy low API oil), change the oil viscosity, drop the solids, oxidize iron sulfide, BOD and COD; reduce H<sub>2</sub>S; and improve ORP.

Four different gases are currently used: nitrogen, carbon dioxide, oxygen and air. The different effects of each gas are described below.

**Nitrogen:** Nitrogen is an inert gas. Because it does not react it remains in a nano bubble state when infused into an oil/water emulsion.



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Oil collects on the surface of a Nano Gas treatment tank. (Photo courtesy of Nano Gas Technologies Inc.)

When put into an emulsion of oil and water in high quantities and in a nano bubble state, it separates the oil and water droplets at the molecular level. Due to increased surface density change, as bubbles reduce in diameter there is a decrease in van der Waals attraction. Because the nitrogen is inert there is no chemical change to the solution (pH stays the same), and the gas bubbles stay in solution. Solids can be drawn and dewatered for disposal, the oil is skimmed, collected and sold, and the water can be recycled and reused. Field use has shown hydrocarbon removal using the Nano Gas treatment system down to as low as 2.78 ppm total petroleum hydrocarbons, with averages ranging in the 10 ppm to 20 ppm range with-out the use of chemical additives, surfactants, polymers, filters, membranes or other filtering methods.

**Oxygen:** The application using oxygen in produced water environments that have high ORP and high COD requirements have been shown to increase redox reactions to eliminate  $H_2S$ , oxidize  $FeS_2$ , and increase oxidation of other solution constituents such as iron to iron oxide. Reactions with oxygen nano bubbles reduce  $H_2S$  to elemental sulfur (innocuous off-gassing). The application of Nano Gas can saturate solutions with oxygen nano bubbles at levels exceeding six times that of Henry's Law or the Ideal Gas Law at standard temperature and pressure while maintaining stability of the solute in solution with a half-life of up to 15.2 days if no BOD or COD is present. The gas stays in solution to enable absolute use until the dissolved

oxygen level reaches 0 ppm. The application of a nano bubble solution can achieve desired goals cost effectively and efficiently over that of traditional chemical applications.

**Carbon Dioxide:** It is well known that carbon dioxide in aqueous solutions produces a weak carbonic acid. It is miscible/soluble in oil, thus reducing oil viscosity. The solvent characteristics of carbon dioxide in oilfield applications has been utilized for more than 35 years, with over 13,000 carbon dioxide EO wells (injection and production) operating currently in the U.S. The corollary is increased production due to the ability to access constrained pore size influencing viscosity to break the geologic adhesion from oil. The decrease in surface tension enables the fluid to flow more freely due to decreased drag coefficient. Secondly, by using carbon dioxide in alternating cycles (WAG process) increased carbonic acid production can be minimized or controlled even as productivity increases. Further, controlling the vertical stratification of carbon dioxide nano bubbles in solution by suppressing its tendency to buoyantly rise to the top of receiving formation can be enhanced, thereby increasing ultimate oil recovery while minimizing solids uptake. Due to the miscibility of carbon dioxide and the reduction of viscosity in oil, it can also be used as a blend gas in conjunction with nitrogen nano bubbles for breaking emulsions.

**Air:** Air is made up of approximately 78% nitrogen, 21% oxygen and less than 1% other gases. Air is considered a blend gas. When using it to clean



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Sample Results Zone 5 - 4/7/2016				
Time (a.m.)	9:50	10:02	10:17	10:42
DO (% saturation)	8.6	14.1	153.4	289
DO (ppm)	0.7	1.11	13.14	24.89
Specific conductance ( $\mu$ S)	29759	29081	2612	27336
pH	7.27	7.33	7.4	7.44
pH mV	-37.1	-40.1	-44.1	-46.9
ORP	-207.1	-249.3	-165.8	-125.2

Table 1: Sample results from a 240 bbl continuous process tank with Nano Gas infusion of nano bubbles.  
(Data and graphic courtesy of Nano Gas Technologies Inc.)

produced water in a nano bubble state, the process can achieve multiple results simultaneously to recover oil, clean the water, reduce or eliminate  $H_2S$  hazards and iron sulfide.

Table 1 presents example operational data from a Nano Gas facility. The process flow was from the gun barrel into a 240 bbl continuous flow process tank. The ATI and YSI DO meters were cross-calibrated. Air temperature was 62.6 F. Total process time was 53 minutes at 3 bbl/min throughput. The saturation results show a significant ability to saturate high COD solutions to increase and maintain DO, decrease specific conductance, and have minimal to no impact on pH. ORP was reduced 39.6%. The tank turnover time is 80 minutes. Results in the table show complete saturation 65% of the time.

The Nano Gas process has been tested and/or applied to the following applications:

- **Water:** To clean produced water and tank bottom water; process removes solids to about 1  $\mu$  and oil to nearly non-detect.
- **Oil:** The process recovers virtually all the oil in produced water and tank bottom water to include extra heavy oil less than 10 API. Up to 66% of the solids and iron sulfide have also been separated from the oil.
- **Biocide:** The process can utilize oxygen as a biocide or can enhance the use of chemical biocides to prepare the water for reuse in an environment where microorganisms need to be eliminated.

### Enhanced oil recovery

Nano Gas Technologies has patent-pending subterranean tool designs to apply nano bubble

technology in formation to increase oil recovery. The use of carbon dioxide and nitrogen in formations is a known science. Applying these gases individually or as a blend in a nano bubble state should enhance oil extraction in a water flood or WAG environment while increasing the recovery from the water at the surface level separation. Nano Gas Technologies is currently writing protocols to conduct core sample testing.

### Enhanced chemical reactions

Nano Gas processes decrease the zeta potential and increase the ionic activity, thus increasing the potential of chemical reactions within the water with oxidizers such as hydrogen peroxide and chlorine-based chemicals. The reduction of surface tension due to the nano bubbles increases the performance of surfactants.

### Conclusions

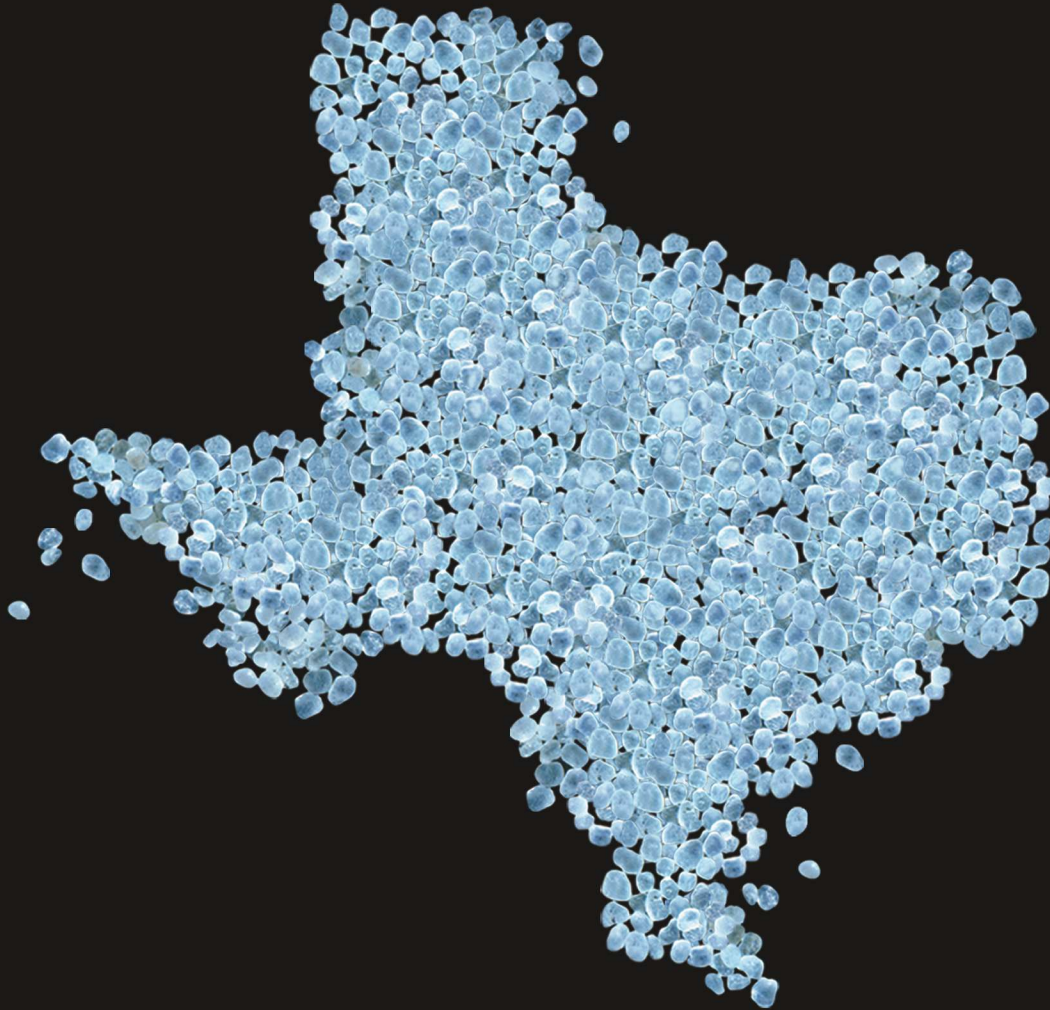
Significant opportunities exist to better align how we manage water with our understanding of its value as an irreplaceable resource. In addition, these opportunities offer benefits beyond just the social or environmental aspects often associated with recycling and reuse. It is likely that these practices will be necessary to remain competitive in a resource-constrained setting. ■

*References available upon request.*

*Scott B. Ahlstrom is president of BW Primoris. Rudy Folds is director of Operations/Project Development, Nano Gas Technologies. Jeffrey Hardin is vice president, Strategies/Chief Chemist, Nano Gas Technologies.*

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# Frac Activity Returns to a Dynamic Supply Chain

As oil prices stabilized near \$50 for the first half of 2017, E&P companies put rigs and frack crews back to work through additional drilling and completion programs.

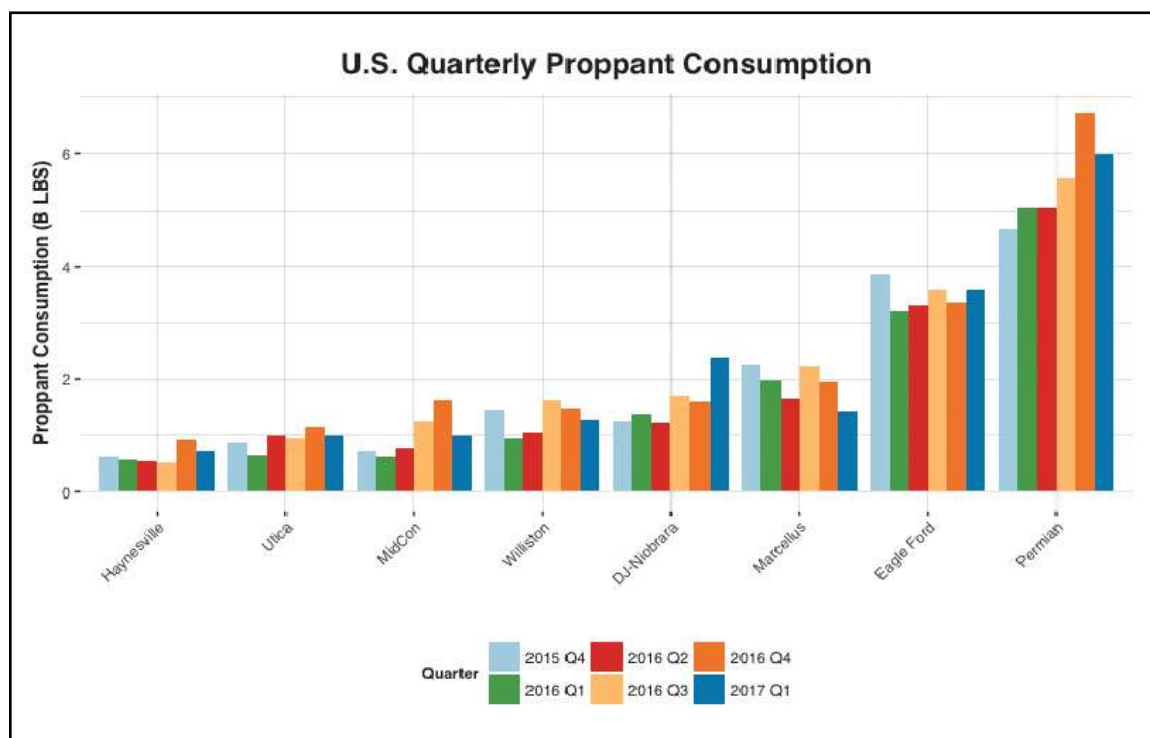
**By Todd Bush and Brandon Waiter**

Energent Group

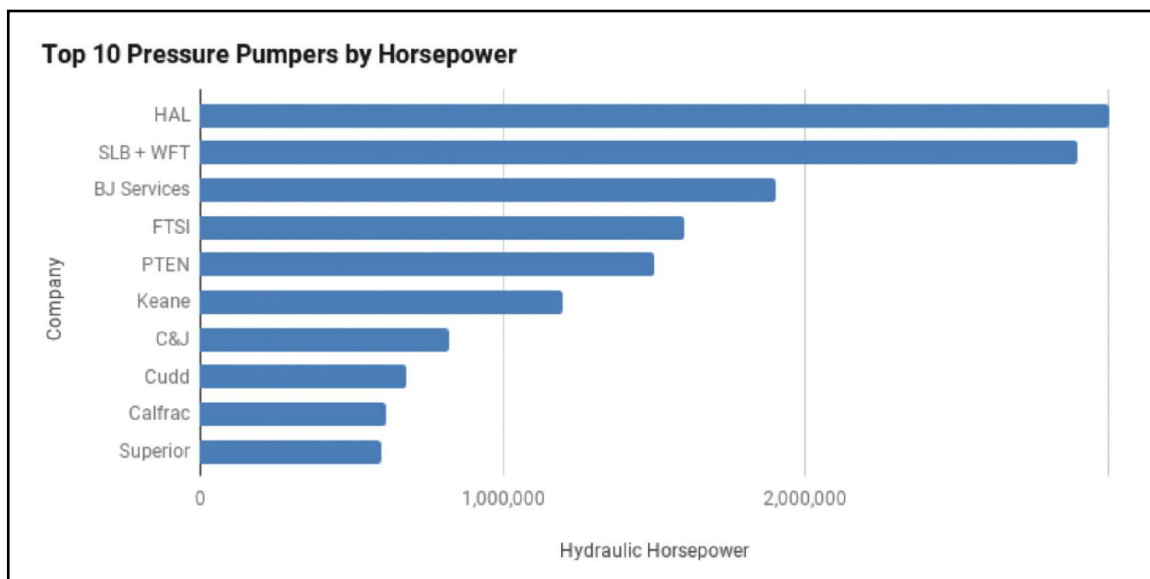
At the end of first-quarter 2017, there were 24.8% additional rigs and 5.1% more frack crews active on U.S. onshore. The increased proppant and water per well coupled with additional completion activity has forced E&P companies to rethink their supply chains. More E&P companies are self-sourcing sand and chemicals

to reduce costs and lock in volumes for future completion programs.

Service companies and suppliers have responded by activating frack crews, adding mine capacity and increasing last mile capabilities. Frack sand companies are developing regional sand mines in the Permian with capacity coming online as soon



(Source: Energent Group, data as of June 2017)



(Source: Company filings, Energent Group)

as at the end of the year. The pressure pumping market is shifting with historically smaller regional players taking market share and others forming strategic alliances.

### Pressure pumpers change the market landscape

Halliburton continues to be positioned as the leader in the U.S. land pressure pumping business. Currently, the company commands the supplier power to accommodate an E&P's completion and frack job from design to production; however, numerous operators are presenting a challenge.

The pressure pumping market is changing dramatically. As the market recovered, pressure pumpers across the U.S. made strategic acquisitions, filed for IPOs and partnered with former competitors to gain market share and regional presence in the Permian.

Schlumberger partnered with Weatherford to create OneStim, a pure-play hydraulic fracturing business serving North America.

BJ Services resurfaced as GE acquired the Baker Hughes business. The legacy pressure pumper is well positioned in the Lower 48 shale plays with 1.9 million hydraulic horsepower available to Permian, Bakken, Eagle Ford and DJ-Basin. With an outstanding reputation and one of the largest frack fleets, expect BJ Services to show a strong return to the market.

Patterson-UTI acquired 77 Energy's Performance Technologies fleet bringing its total horse-

power to 1.5 million. Patterson-UTI's Permian and Marcellus fleets are now combined with the strength of Performance Technologies Mid-Con and Eagle Ford assets.

FTSI intends to IPO on the NYSE as FTSI. As of early 2017, the company operates 32 frack fleets with a diverse customer base across the Permian, Eagle Ford and Scoop/Stack.

ProPetro added two more units in the first half of 2017, bringing the total to 510,000 horsepower. ProPetro is a pure play pressure pumper focused on the Permian.

Meanwhile, Keane acquired Rockpile, adding 245,000 horsepower, eight wireline trucks, 12 workover rigs and 10 cement units. For Keane, the Rockpile addition adds geographic coverage in the Bakken and DJ-Niobrara.

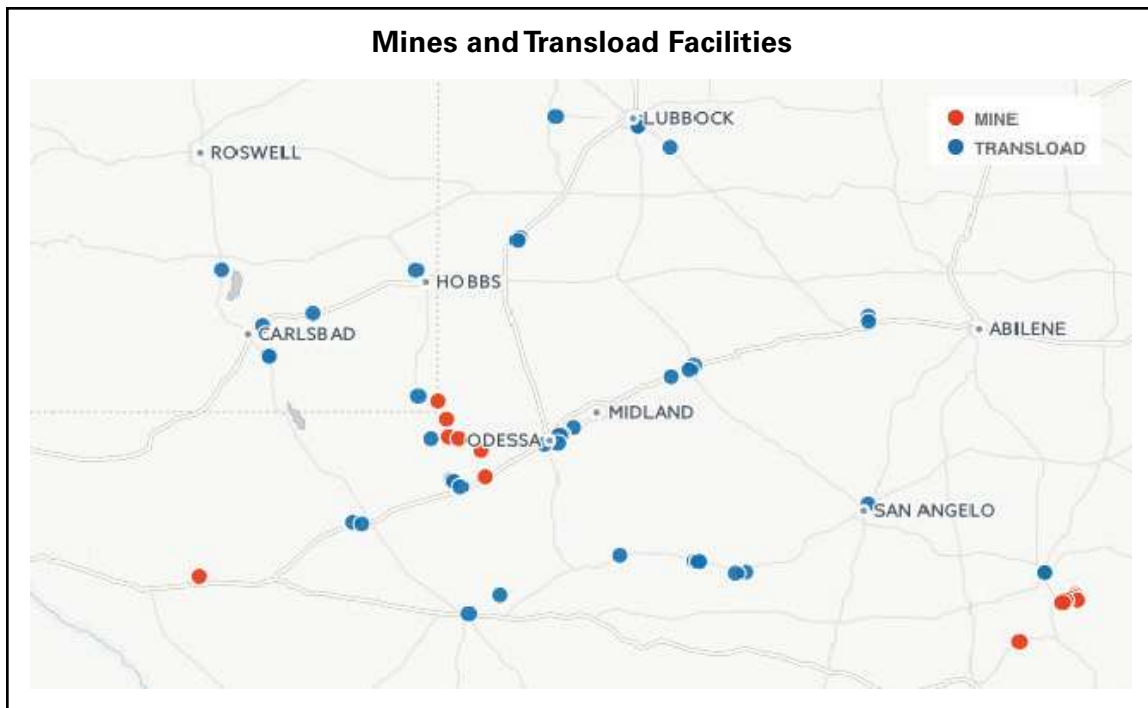
Liberty Oilfield Services filed for IPO and plans to list on the New York Stock Exchange under the ticker symbol BDFC.

Expect the pure play pressure pumping trend to continue. Other regional pressure pumpers include Mammoth Energy Services, Pro Frac and US Well Services.

### Riding the Permian frack sand wave

The Permian rig count is inching closer and closer to 400 rigs, having increased about 160% from third-quarter 2016. This has increased demand for frack crews in the area and an uptick in sand consumption due to more completions, increased sand volumes and longer laterals. Many operators are looking to lock in





(Source: Energent Group)

sand volumes with long-term contracts to minimize risk of sand shortages and increased future pricing. Sand companies have made a huge push to provide operators with in-basin sourcing options to reduce transportation costs and prevent supply from slipping.

### Permian mine influx

There have been almost 10 frack sand mines announced in the Permian this year. One of the latest is US Silica's announcement for a 4 million tons per year regional sand mine located between both the Delaware and Midland basins that should be online by the end of 2017. The largest one yet was announced during the first week of July which was Unimin's 6 million tons per year regional mine which will be operational in early 2018. Hi-Crush also announced earlier this year another mine in Winkler County that will have the capacity to produce 3 million tons per year. With all of this activity there could be as much as 40 to 45 million tons per year of regional sand in the Permian active in mid-2018 and there might be more to come.

The last mile logistics issues that have challenged the industry have forced transload operators to become more efficient and build sites that can keep up with demand. As operators increase

sand concentrations the number of truckloads to the well sites, transload facilities and in-basin mines rise creating a strain on timing when completing a well.

Most transload facilities can turn around a single truck carrying about 42,000 lbs of sand out in less than 20 minutes. Multiply this by the 357 truckloads it would take to complete a well using 15 million pounds of sand and it would take a full 75-car-unit train to complete a 7,500 foot lateral in the Delaware Basin. As this example shows transload facilities will need to increase efficiency to get trucks out to the well sites on time or plan ahead with onsite storage using containerized solutions. These logistical strains will continue as the number of wells per pad grows.

### Transload facilities evolve to meet logistic needs

High-intensity completions using 12 to 20 million pounds of sand per well require transload facilities and operators to become more efficient. The focus on facility design now includes the unloading and loading capabilities of the facility emphasizing reduced truck time onsite to improve efficiency and safety. For example, unit trains account for over half of all shipments today, so legacy facilities have been upgraded to meet this need



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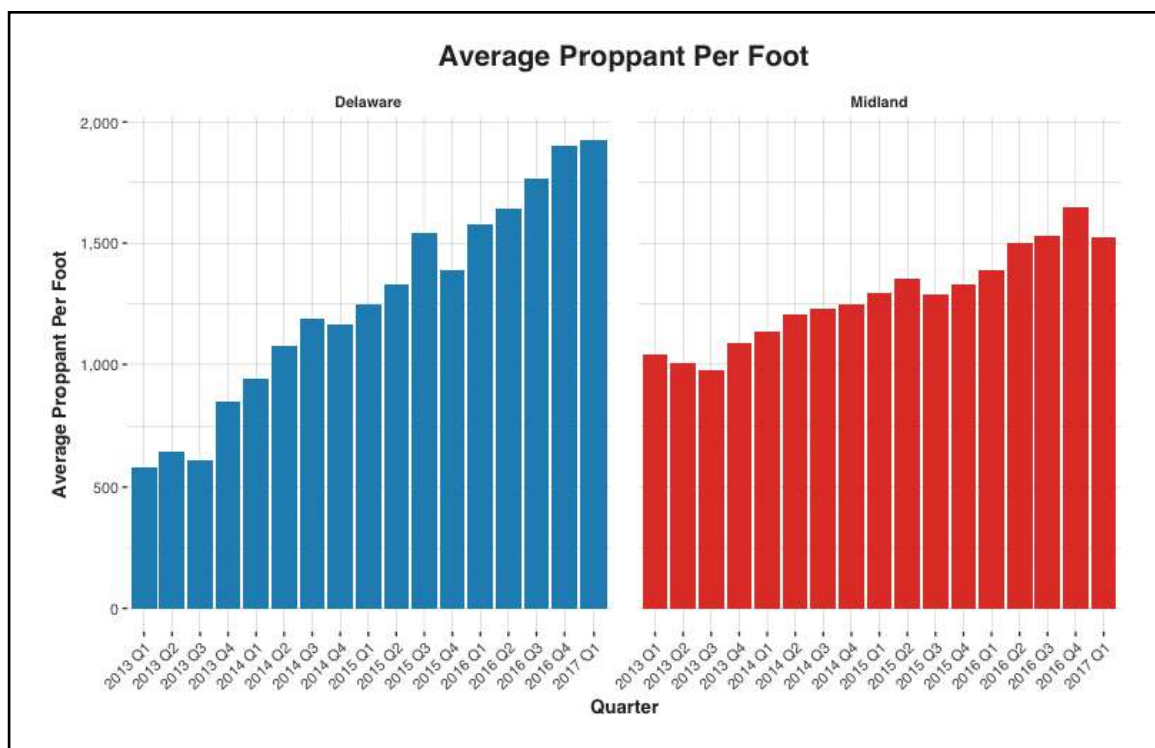
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(Source: Energent Group)

and newer facilities are being constructed from the start to have unit train capabilities. Storage is another critical feature at transload sites today, whether that is in vertical silos or flat areas and warehouses. There are many options with unique pros and cons but having the ability to store frack sand onsite to sell in-basin is imperative to keep up with market demands.

All of these factors affect truck load-out cycle time even down to requiring a driver to stay in the truck. Activities like opening and closing the hatches and getting the trucks tear and final weight tickets have all been scrutinized to include best practices as standard operating procedures. The automation of ticketing and real-time tracking of inventories is essential to how these facilities operate. The real time weighting of trucks has been a big improvement with drive through silos. This cuts out two stops compared to using sand transloaders, which are conveyor belt machines that move sand directly from the railcar to the truck.

From facility to pad site, the industry had not evolved for quite some time until the use of containerized solutions came about. US Silica's SandBox and Hi-Crush's PropX have seen an increase in use, giving operators the ability to store sand on the pad site, reduce dust emissions and

decrease operating costs. These containers range from 46,000 lb to 33,000 lb but are not always fully utilized due to state restrictions.

There will always be a need for transload facilities to bring in sand from other parts of the country like Wisconsin and other regional mines but how will the landscape change in the Permian with regional sand capacity that can meet the needs of operators? This is key to understanding the future transload landscape of the Permian. Some operators will continue to use Northern White sand, but how many will shift to regional sand and buy in-basin? This may take away the need for large transload facilities in the area and reduce the time and cost for sand delivery. The use of transload facilities in the future could mean overflow storage for operators and/or shipping to other basins like the Eagle Ford or Scoop/Stack.

### Permian operators take the reins to self-source

Some operators are taking these challenges head on and dealing with them internally. Operators like Encana Corp., Pioneer Natural Resources and EOG Resources have each looked to self-source materials and logistics to better control their supply chain. Pioneer has full control of its needs

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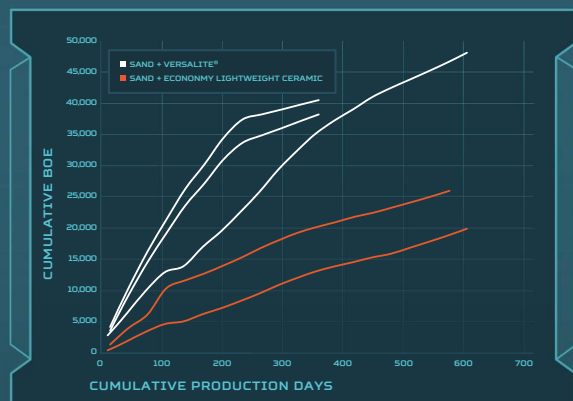
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for frack sand having a regional sand mine in Voca, Texas, and being able to ship to basins like the Permian through the loadout facility located in Brady, Texas. For smaller operators



**Cost cutting and efficiency gains continue to be major themes across the industry. Fewer rigs are required to drill the same number of wells.... Completion activity has returned to a new way of doing business for operators and service companies.**

not having the scale to implement self-sourcing and logistics themselves, sand companies have stepped in and are providing integrated mine to wellsite logistics, leaving out service companies and reducing costs.

Encana estimates about 35% of the drilling and completion costs of a well are directly from water and sand. The operator recently moved to self-source not only proppant but also water, OCTG, chemicals and drilling muds to control well costs and secure the supply of materials. The savings and efficiencies have been put to work in the field on the RAB Davidson pad as well as the Abbie Laine pad, both in the Permian. Encana will also be increasing the company's use of regional sand from around Monahans. These trends could point to a model where operators would only need to rent horsepower and bring all materials to the well sites themselves.

WPX started self-sourcing in the San Juan in mid-2016. Now, WPX has approximately 70% of drilling and completions cost contracted through 2017 to limit exposure to increased service prices. The drilling and completions costs include water, frack sand, stimulation services, drilling services, cementing and wellheads.

Devon Energy is unbundling drilling and completions spend as well. In 2017, the company's typical well in the Permian is averaging 6,236 ft laterals and 8.5 million pounds of proppant per well in the Permian.

Delivering equipment and material to the well site is a complex orchestration between operators

and numerous service companies. Larger service companies like Halliburton take full control of the supply chain, sourcing and trucking the sand to the wellsite. Some proppant companies, like Hi-Crush and US Silica, provide logistic services to bring sand from their mine site to the service company. A recent trend as described earlier is the operator sourcing from a sand company to then coordinate delivery to the well site.

A more unique scenario is one where the sand company works directly with the operator, providing sand logistics to the well as seen with Maalt and Vista Sand. Pioneer handling the sand from its own mine to the wellsite without using third-party services is yet another business model. There are other combinations of the models described that are less popular but overall the model varies by operator depending on what resources they have access to in their operating area.

### **All competitive advantages are temporary**

Cost cutting and efficiency gains continue to be major themes across the industry. Fewer rigs are required to drill the same number of wells. One-mile laterals are drilled in less than a week in some plays. Drilling contractors, pressure pumpers and operators are emphasizing lean operations to mobilize crews, get material to the pad site and reduce operational cycle times.

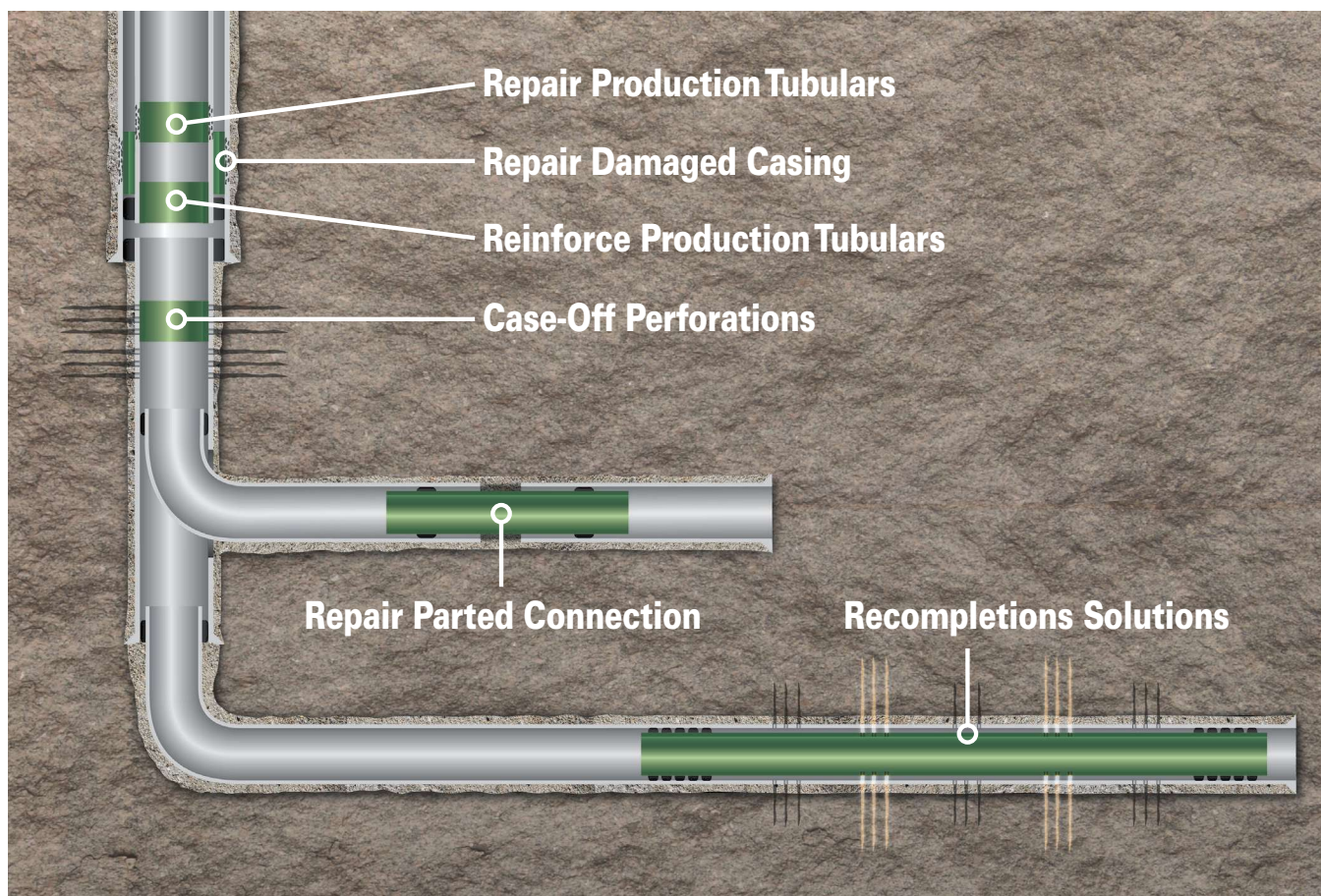
Completion activity has returned to a new way of doing business for operators and service companies. As pressure pumpers reactivate frack fleets, longer contracts and completion programs are expected to maintain the utilization of the frack equipment.

Savvy sand and chemical suppliers are meeting operator demand for services through longer term contracts. Frack sand companies are emphasizing their regional sand capabilities to meet operator demand for brown sand at lower costs. At the same time, operators unbundling of services will allow transload and logistics companies to capitalize on the need to deliver sand to the well site.

Static oilfield service companies rooted in legacy business models will not retain market share. The E&P supply chain will continue to evolve as leading oilfield service companies adapt to the operator's needs and demands. ■

*Todd Bush is principal, Energent Group. Brandon Waiter is an Energent Group analyst.*

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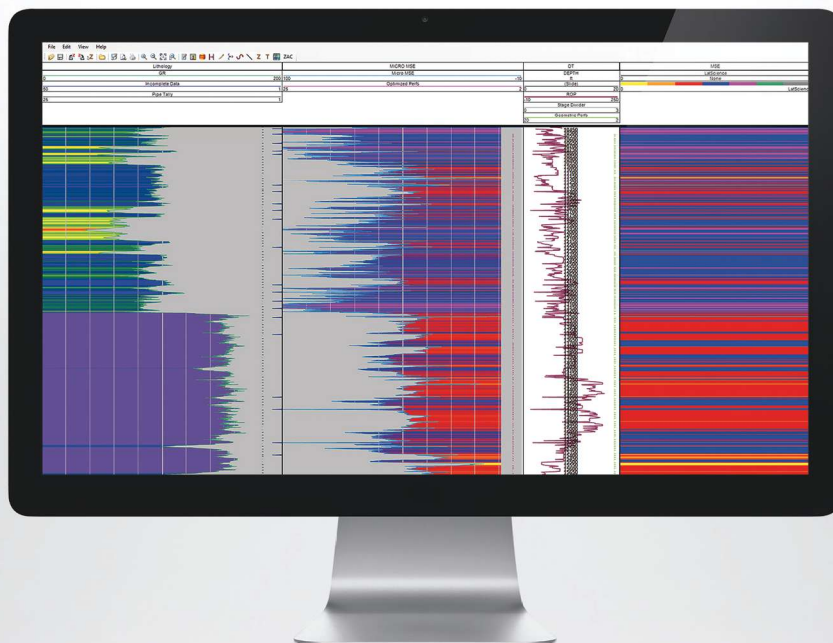
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