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HART ENERGY
1616 S. Voss, Suite 1000 | Houston, Texas 77057
Tel: +1 (713) 260-6400 | Fax: +1 (713) 840-8585
hartenergy.com

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For additional copies of this publication, contact Customer Service +1 (713) 260-6442.

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HARTENERGY

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The 2016 Hydraulic Fracturing Techbook is the 10th 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.

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Completion work on the Hayden Unit for Antero Resources on the Fritz pad in Doddridge County, West Va. *(Photo by Mike Robinson, courtesy of Hart Energy's* Oil and Gas Investor*)*

Low Risk, Low Cost per BOE are Industry's Holy Grail

Science-based technology is leading to smarter completions. In this price climate, operators cannot afford failure.

By Scott Weeden
Contributing Editor, Drilling

The rig count for the week of July 15 rose by seven rigs to 447 units. That was 43 rigs ahead of the low of 404 units that was reported on May 20. Lower-cost plays such as the Permian Basin or the Cana Woodford, which at 29 rigs is only two units below where it was at the same time last year, are benefitting from oil prices in the mid-$40s.

A recent Wood Mackenzie analysis of the global oil market showed 70% of new drilling in U.S. unconventional oil plays are commercial under $60/bbl Brent crude. Two years after the collapse in oil prices "the industry has started to adapt to lower oil prices, cutting costs and getting more projects over the economic threshold."

Weatherford and Cat personnel work together on a fracturing job using RamForce 2500 power units. *(Image courtesy of Weatherford)*

Patrick Gibson, global oil supply research director for Wood Mackenzie, said, "A total of 13 MMbbl/d of new supply could be developed from both tight oil and conventional projects by 2025. Of that amount, 9 MMbbl/d is commercial at $60/bbl Brent. This is more than at any point since 2009 and 1.5 MMbbl/d more than a year ago. Most of the 9 MMbbl/d is U.S. tight oil, with productivity improvements and cost deflation in the key growth plays making more tight oil economically viable."

According to a recent Gaffney, Cline and Associates report, "Rig count tends to lag increases in oil price by as much as a quarter. Oil has enjoyed a strong quarter; it's possible that will boost rig count in second-half 2016."

If the rig count does continue upward, operators will want to continue to minimize risk and maximize production. The service companies are offering new technologies to meet those challenges in a low-cost price environment. Even then operators are willing to look at new technology if it impacts the bottom line.

There are three things operators are looking for: low risk, reliability, and cost and time effectiveness. "The opportunity to have operators look at new technology is perhaps better than it was two years ago," explained Eric Schmelzl, vice president, strategic business at NCS Multistage. "It is still tempered obviously by the high cost of drilling and completions. And failure is not an option."

Satya Gupta, technology fellow at Baker Hughes, said, "We are hearing that operators want to increase initial production [IP] and sustain production for longer from a fracture treatment. It's all about production, sustainability and being socially responsible."

Baker Hughes fracturing equipment conducts a job near Brighton, Colorado.
(Image courtesy of Baker Hughes)

"When we stimulate a well, we have to get it right. The operators are looking at how they can maximize production by really tailoring the design of this completion to give them the best well they can. They are under a lot of capex pressure, and it is tough in some of these basins to be profitable at $40 oil," noted Jason McIntyre, strategic business manager, Production Enhancement (PE) at Halliburton.

"This year everybody knows we're in a very cost-sensitive environment, and most of the technological advances that they are asking us to do are to help them eliminate costs, eliminate services or do things much faster. Our strategy really is to provide the lowest cost per boe for our customers through a variety of solutions," he continued.

Rob Fulks, director of completion optimization at Weatherford, finds that "because of this downturn in activity, clients have spent more time in planning their completions—and it is paying dividends. Some of the completion efficiencies that are happening now, as well as the increases in average well productivity, are the result of straight-up better planning."

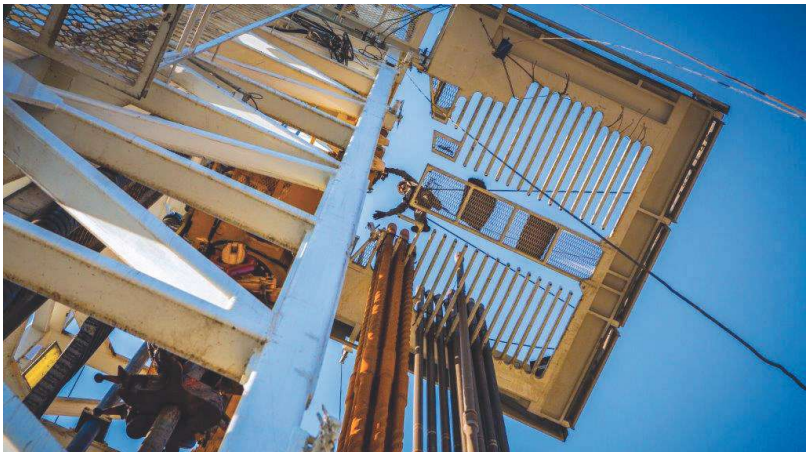
Technology and innovation will be critical in the industry recovery or even if it plateaus. Small operators have to adapt rapidly or go out of business.

Better IPs, longer sustained production

Companies are having success with some of the new approaches to completions. Continental Resources Inc. on May 17 reported an industry record well in the overpressured oil window of Oklahoma's STACK play. The Verona 1-23-14XH flowed at an initial 24-hr test rate of 3,339 boe/d. The well is producing from the Meramec reservoir through a 2,957 m (9,700-ft) lateral on a 34/64-in. choke.

"The Verona is another example of the exceptional results we are getting from wells drilled in the overpressured oil window of the STACK," said Chairman and CEO Harold Hamm in a press release. "Our STACK team also completed the Verona at a cost of approximately $9 million, which is $500,000 less than our year-end 2016 target cost for two-mile [3-km] lateral wells in the overpressured oil window. The company is in the process of completing four additional Meramec wells."

EOG Resources completed four gas-injection pilot projects with 15 producing wells in the Eagle Ford. The company is planning another project with 32 wells in 2016. The incremental production from these projects is about 1,000 net bbl/d this year. Capital investment is about $1 million per well with a finding cost of $6 per barrel.



The Utica is deeper and higher-pressured than the Marcellus, so usually more expensive to drill. Eclipse Resources worked this rig on the Fuchs/Dietrich pad in June 2015. *(Photo by Mike Robinson, courtesy of Hart Energy's* Oil and Gas Investor)

Higher intensity fracks, production performance

Since the downturn began operators have been using higher intensity fracks in longer laterals. Eclipse Resources Corp. completed an extended-reach lateral test well in the Utica with a length more than 5,640 m (18,500 ft). The well was completed with 124 stages in 24 days. The operations were performed by Halliburton, using its Frac of the Future dual-fuel fleet, Q-10 pumps, SandCastle PS-2500 sand storage units and its Obsidian Frac plugs, according to a May 31 press release.

"Going 10,000 ft, 11,000 ft or 12,000 ft [3,049 m, 3,354 m or 3,658 m] is no longer that rare," Fulks said. "If your lease lines allow it, longer laterals are the number one determinant of completion effectiveness and production success."

Longer laterals lead to higher intensity fracks. "By higher intensity, I mean more proppant and more fluid per stage. There is also increased stage and perf cluster density with tighter spacing. When you combine this with more proppant per lateral foot, now you've got the makings of a higher intensity frack," he continued.

One measure that operators are beginning to utilize is production per foot. "There are ways to get into the top percentage group of performers by using a little bit of science. Most wells exhibit a significant variation in geology along their full length. Further, the variation does not have to be severe for it to be impactful," Fulks said.

It would be nice to be able to take away that variability and make each stage contribute. However that won't change. But operators can plan better for that variability by using as much information as possible from logs, core data over the interval, drilling cuttings data, data from other operators in the area, production history, data from commercial databases—all different kinds of data, which can be called Big Data.

"There's more science being used. There's more attention paid to the information you can get during the drilling phase. It can be used to design your completion so that when you get to the fracking stage you can take all these data into account," Fulks explained.

Weatherford uses a process called a geoengineered completion that integrates petrophysics, geomechanics and—at least equally important—the best preferred practices in that area.

The company's FracAdvisor service takes Big Data into account. "We don't start a completion design anymore until we consider what the best practices are for that particular area. That's the starting paradigm now," he emphasized.

Sliding-sleeve refrack

"More recently there's a growing awareness of the inefficiency of multicluster plug-and-perf (PNP) operations, which is leading operators to pinpoint the stimulations," Schmelzl said. "I would say it is the trend toward tighter frack spacings that is leading the surge in that direction."

NCS works with cemented wellbores using sliding-sleeve manipulation to replace the perforating operation. "The upside is that the newer generation of sleeve design for multiple cycles of opening and closing provides an opportunity to shut off unwanted water or gas influx. There is also potential for placing the fracks out of sequence instead of sequentially from the toe to the heel," he explained.

The company recently completed its first refrack operation in a well equipped with multicycle sliding sleeves. "The sleeves were placed into the closed position before the refrack operation began. Then we placed the treatments through the sleeves individually and pressure tested successfully at the end of that refrack operation before reopening the sleeves and putting the well back on production," Schmelzl continued.

"That's a significant step change in risk reduction and operational efficiency vs. a conventional refrack operation," he emphasized. "This is really the first proof

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Many operators are reducing DUC inventories instead of drilling in 2016. Drilling is expected to increase in 2017. *(Image courtesy of Baker Hughes)*

of concept for a refrack operation benefitting from the original completion and design."

Integrating services, technologies

Halliburton is working with its clients to help them understand exactly where to drill, where the real pay zones are and what the stimulation package should look like. "For part of that we came out with Frac Insight Analysis, which really gets into the perforation placement so we're not just doing perforations every so many hundred feet. We're really selecting where to perforate based on data from the well," McIntyre said.

For refracturing, the company's ACTIVATE refracturing service has four steps to the methodology—screen, design, execute and diagnose. "We've got a very consistent methodology to screen the best well candidate for a refrack," he explained.

Then the refrack treatment is designed for that particular well. The treatment is executed leveraging the company's other services such as AccessFrac Restimulation Service. Finally the refrack efficiency is diagnosed and learnings are applied on future wells.

"Operators in this climate are looking at how they can be profitable with $40, $45 or $50 oil [and] how they can get over that threshold to make it economically feasible," McIntyre continued. "It's not like it was a couple of years ago. It's not just mass quantity with these cookie-cutter well designs. It is really all about quality."

Ben Wellhoefer, product manager, openhole isolation systems at Halliburton, noted the company is integrating its product lines to further efficiency for PNP operations. "We are now integrating the PNP wireline-run operations into the wireline truck and often into the frack van so that we're monitoring the entire process. We're integrating all those systems [in] real time so that we can monitor it, reduce risk and improve the efficiency of the PNP operation."

McIntyre added that the integration isn't just across product service lines but also across divisions. "Wireline is in our Drilling and Evaluation division while completion tools and PE are in the Completion and Production division. Using our automated pumpdown technology, we're actually controlling the frack pump truck based on the data we're getting from the wireline truck," he said.

Fracturing with seawater

When looking at the hydraulic fracturing market, there are essentially two geographical areas involved—North America and international. "When you look at the international market, it is really still tight oil and tight gas, though many people refer to it as unconventional, except in a few countries like Saudi Arabia, Argentina and China, which are looking at shales," Gupta said.

International operators are taking lessons learned in North America and are applying them internationally. "They are more focused on understanding the reservoir and applying science-based technology as opposed to the trial-and-error approach that was initially deployed in the U.S.," he continued.

Water is one of the biggest problems in both North America and abroad, and the industry needs to find a solution to this. "Right now most of the water we are using is freshwater. We can recycle the water. Can we use brine instead of freshwater?" Gupta asked. "Right now in the Middle East, we're working on using seawater for fracturing."

One of the other challenges internationally is the need to import a lot of proppants. "We're looking at technologies where a company can use local sand as opposed to high-quality sand imported from the U.S.," he said. ■

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Innovation Keeps Players in the Game

Companies aren't pumping the brakes on prepping for the upturn.

By Ariana Benavidez
Associate Managing Editor

Low oil prices continue to fuel the appetite for innovation, with new technologies and techniques making hydraulic fracturing more efficient. More than that, these new products and services are prepping the industry for the inevitable upturn.

Today, hydraulic fracturing accounts for more than half of all U.S. oil output. The technique has come a long way since 2000, when it made up less than 2% of American oil production, according to the U.S. Energy Information Administration.

With their thinking caps donned, companies are increasing efficiencies and optimizing production. The following section is a sampling of the leading players in the hydraulic fracturing market and an overview of their technologies and services.

Key Players

Advanced Stimulation Technologies Inc.

Founded in 2007, Advanced Stimulation Technologies Inc. (AST) provides frack fluids; borate-, titanate- and zirconate-based fracturing systems; instant and delayed crosslinked systems; slickwater systems; and emulsified acid systems. The company's A-Light acid gel system has a corrosion inhibitor, iron control and surfactant built into one package. The P-EMU poly-emulsion fracturing fluid, composed of 67% hydrocarbon and 33% water, can be applied when treating water-sensitive formations.

The company's services include treatment design, diagnostic testing (step-rate testing), minifrack analysis to determine closure parameters, fracturing, acidizing and cementing. Among AST's cementing offerings are long-string production casing, remedial casing, lightweight cement slurries and surface casing string. Full freshwater and production analysis also is available via the company's laboratory services.

AST provides laboratory analysis devices and cementing units with remote monitoring systems. The company's fracturing equipment, with 100,000-hhp capabilities, includes a hydration unit that works at 120 bbl/min and has a 200-bbl holding capacity.

Archer

Archer is a global oilfield service company with more than 40 years of experience, more than 7,000 employees and operations in more than 100 locations worldwide. The company's products and services include drilling services, production optimization, well integrity technologies and intervention to decommissioning. 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.

Archer's new Point System, an integrity management tool, allows users to investigate barrier leaks and flowpaths from surface, locate barrier leaks downhole, and locate barrier leaks and flowpaths downhole.

Baker Hughes

Baker Hughes' multistage fracturing portfolio includes hydraulic fracturing surface systems, fracturing fluid systems, proppant technology and completion tools as well as services including proactive flow assurance and 24/7 real-time production monitoring.

Baker Hughes fracturing pump trucks near Jordanton, Texas, in the Eagle Ford Shale play are shown. *(Image courtesy of Baker Hughes)*

Among the company's multistage completion tools are its FracPoint ball-activated sleeves; OptiPort and OptiFrac coiled-tubing-activated systems; and plug-and-perf technologies including QUIK Drill and FLASH composite frack plugs; and SPECTRE plugs.

The SPECTRE plugs, which disintegrate downhole after fracturing, provide a fullbore inside diameter without intervention. Additionally, both of the company's composite plugs can be outfitted with a flow-activated efficiency valve that can divert treatments without the need for frack balls, eliminating about 10 minutes and 150 bbl of water per stage, the company said.

Baker Hughes offers Sorb solid inhibitors that are designed to prevent downhole deposition and tubular damage, resulting in enhanced flow assurance. These solid chemicals are pumped with proppant in a stimulation treatment to inhibit scale, paraffin, asphaltenes and salt and to counteract bacteria and corrosion. Desorption is slow and residuals of Sorb chemicals have been measured in production fluids at effective levels more than five years after the initial fracture treatment. According to Baker Hughes, this offering can delay or eliminate the need for short-lived chemical squeezes or expensive well remediations.

Baker Hughes' BrineCare fracturing fluid systems reuse produced water in hydraulic fracturing and are engineered for fast, effective screening and application. Each system has been pre-engineered to ensure reliable performance with produced water across a specific range of total dissolved solids and formation temperatures, the company said. In addition, the company has implemented a policy of disclosing 100% of the chemistry contained within its hydraulic fracturing fluid systems without the use of any trade secret designations.

The company also offers hydraulic fracturing software tools that allow users to fully visualize complex fracture geometries and distributions. The software tools provide detailed history matching and fracture optimization studies.

Basic Energy Services

Basic Energy Services provides a wide range of wellsite services in Texas, Louisiana, Oklahoma, New Mexico, Arkansas, Kansas, and the Rocky Mountain and Appalachian regions.

Basic operates within four segments: completion and remedial services, fluid services, well servicing and contract drilling.

The completion and remedial services segment operates pumping units, specialized rental equipment and fishing tools, coiled-tubing units, snubbing units, thru-tubing, air compressor packages specially configured for underbalanced drilling operations, cased-hole wireline units and nitrogen units. The largest portion of this business segment consists of pumping services focused on cementing, acidizing, fracturing, nitrogen and pressure testing. The pumping services

feature a fleet of pumping units with capacity that exceeds 400,000 hp.

The fluid services segment uses a fleet of 1,000 fluid service trucks and related assets, including specialized tank trucks, frack tanks, test tanks, water wells, disposal facilities, water treatment and construction equipment and other related equipment that provide, transport, store and dispose of wellsite fluids.

The well servicing segment operates well servicing rigs and related equipment encompassing a full range of services.

C&J Energy Services

Operating in all the major North American and Canadian onshore basins, C&J Energy Services provides well construction, well completions and well services including cementing, directional drilling, fracturing, coiled tubing, wireline, rig services and fluids management.

C&J's hydraulic fracturing equipment is "designed to handle technically demanding well completions in conventional and unconventional high-pressure formations such as those with long lateral segments and multiple fracturing stages," the company said on its website. The company's fracturing services include pre-job testing, the LateralScience engineered completions process, real-time monitoring and onsite maintenance of equipment, and field fluid tests conducted during the rigup process.

In addition, C&J markets an assortment of fluids used in the drilling, completion and workover of oil and gas wells. The company has portable tanks and a sizable fleet of truck and trailer combinations for fluids storage and transportation. Full-service vacuum/kill trucks also are available for wastewater disposal and well-killing operations.

A C&J frack spread on location. *(Image courtesy of C&J Energy Services)*

Calfrac Well Services Ltd.

Calfrac Well Services Ltd. is an independent provider of specialized oilfield services, including hydraulic fracturing, coiled tubing, cementing and other well stimulation services.

About 90% of Calfrac's field activities and revenues are associated with fracturing. The company provides oil-based, gelled hydrocarbon, slickwater and emulsified (CO_2 and water) fracturing treatments.

The company's U.S. segment has provided fracturing services to oil and natural gas companies operating in the Bakken oil shale play in North Dakota, in the Rockies area and in southern Texas' Eagle Ford shale play. Calfrac also provides fracturing and cementing services to operators in the Marcellus and Utica shale plays in Pennsylvania, Ohio and West Virginia. The company temporarily suspended its Texas operations and its remaining cementing operations during first-quarter 2016 and also temporarily suspended fracturing operations in North Dakota in second-quarter 2016, according to Calfrac quarterly reports.

Calfrac's service line equipment ranges from high-capacity pumpers to combination frack pumper/blenders to deep coiled-tubing units with up to 21,000 ft of reel. The company's fracturing equipment includes trailer-mounted blenders, blend vans, hydration/buffer units, sand masters, SandStorms (large capacity on-location proppant containment), CO_2 pumpers, CO_2 queen storage units, CO_2 transports and boost pumps, ChemStar, computer vans and proppant transports.

Calfrac's new-generation trailer-mounted blenders are capable of rates from 6 bbl/min to 120 bbl/min. In addition, the computer vans are data acquisition units that include multipump controls capable of operating up to 24 frack pumps. The company also has quality control units that provide space for quality control, testing and analysis.

Additionally, the company has a technical center in Calgary, Alberta, that focuses on developing new tech-

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nologies, improving its existing fracturing fluids, cement blends and other product line chemistries, as well as supporting field operations through field sample testing and assisting with troubleshooting issues at the well site.

Consolidated Oil Well Services LLC

Founded in 1956, Consolidated Oil Well Services LLC serves the Midcontinent region and Rocky Mountains area. The company's services include cementing, acidizing, hydraulic fracturing, wireline and water hauling. Consolidated's fracturing services range from single pump scour fracks to high-rate, high-pressure horizontals in locations such as Kansas, Oklahoma, the Texas Panhandle and the Rocky Mountains region.

In addition, the company offers fluid systems, which include energized crosslinked carboxymethyl hydroxypropyl guar, gelled diesel and environmentally friendly liquid guar systems. Consolidated also provides ceramic proppant, resin-coated sand, white sand and brown sand.

Consolidated's subsidiary, Team CO2 Holdings LLC, enables the company to provide CO_2 products, CO_2 transportation and field storage, CO_2 booster pumps and downhole pumping services to the Permian Basin. Consolidated and Team CO2 also provide a full line of acidizing services in the Permian Basin.

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 and e-coil, 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 fracks to complex multistage, horizontal fracks. Where possible, CES incorporates stimulation with coiled tubing using the ZIPP BHA (bottomhole assembly) tool, developed by its sister company, Thru Tubing Solutions, for stimulation with coiled tubing. This application is a single-trip perforating fracturing system with multizone capabilities and abrasive perforating technology. 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 slickwater, linear gel, crosslinked gel, CO_2 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, coiled tubing and remedial.

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, the company said. The accompanying blenders, liquid additive systems and metering systems are automated.

FTS International

FTS International is the largest private well completion service company in North America. The company provides well completion services, including pressure pumping, wireline and reservoir optimization technologies, and operates in all major resource plays in the continental U.S.

E&P companies use FTS's products, services and expertise to enhance recovery rates from oil and gas wells, primarily in unconventional plays.

Gardner Denver

Gardner Denver has been a provider of petroleum and industrial pumps for more than 150 years. The company has 40 manufacturing facilities located in the Americas, Europe, the Middle East, Africa and Asia-Pacific with offices in 32 different countries.

Gardner Denver's new Thunder frack pump, available in both triplex and quintuplex fluid ends, is designed to meet the challenges of today's fracturing operations. With increasing pressures and 24/7 pumping duty cycles, users need equipment that can operate on longer maintenance intervals. Based on the GD-3000 pump platform, which is field proven in the most severe shale plays, the Thunder pump uses long stroke technology to operate at lower speeds while enhancing flow-rate capabilities. This ex-

The Thunder frack pump uses long stroke technology to operate at lower speeds. *(Image courtesy of Gardner Denver)*

tends the pump's maintenance overhaul life cycle while also reducing consumables and associated labor costs by $250,000 over the life of the pump, according to the company.

Gardner Denver provides full service and support to help maximize uptime through product training, parts on demand, customer service and repair.

Halliburton

Halliburton stimulation technologies are designed for fracturing, pinpoint stimulation, acidizing and near-wellbore cleanout, conductivity endurance and water management.

The CYPHER seismic-to-stimulation service helps users determine where to drill, how to drill, where to frack and how to frack. Halliburton uses the FracInsight service for new perforation placement and integrated sensor diagnostics for well and fracture spacing and stimulation design. 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. The AccessFrac stimulation service uses diversion technology and optimized multicycle designs to help each cluster realize its full potential.

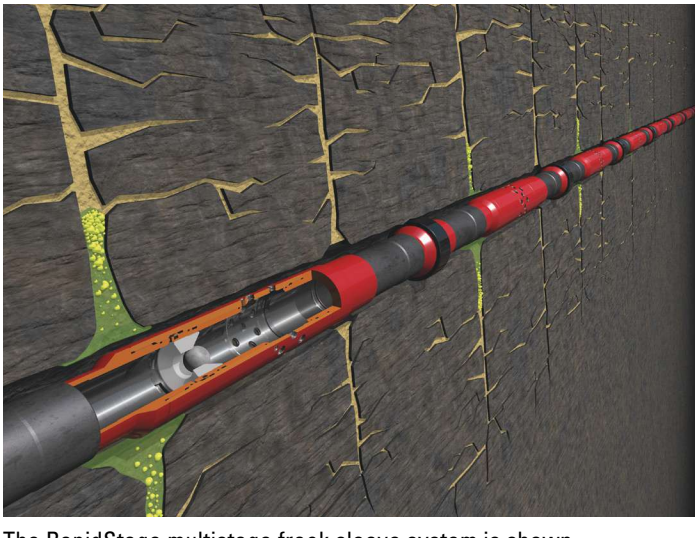
In addition, for refracturing treatments, the "ACTIVATE refracturing service helps enable recovery of bypassed reserves predictively and repeatedly at as low as one-third the cost per barrel of oil equivalent compared to new drills," according to Halliburton.

The company's Frac of the Future employs technologies including the Q10 pump, designed to cut nonproductive time by sustaining continuous pumping operations, and the SandCastle vertical storage system, designed to minimize footprint on site and emissions with the use of solar power.

Halliburton also offers the Illusion dissolvable frack plug, with a 10,000-psi rating, which dissolves fully without leaving large pieces in the well or restricted inside diameter.

With RapidStage multistage frack sleeve systems and AccessFrac stimulation service, operators have been able to double the number of stimulated fracks per zone compared to conventional methods and increase production on average by 35%, according to the company.

Additionally, the recently released Spectrum real-time coiled tubing services are designed to deliver real-time subsurface data to help optimize well interventions and completions performance.



The RapidStage multistage frack sleeve system is shown. *(Image courtesy of Halliburton)*

Keane Group

Privately held Keane Group offers hydraulic fracturing services, wireline technologies and coiled tubing services. Keane has operations in Pennsylvania, West Virginia, North Dakota, Ohio, Oklahoma and Texas.

Keane's hydraulic fracturing equipment includes 1 million hydraulic horsepower, high-rate blenders, nitrogen units and high-pressure capability. The work-site equipment is backed by an extensive logistics organization that has national sand contracts, 1,050 owned rail cars and a fleet of 125 sand haulers. The field operations include remote data monitoring, advanced pump and blender controls,

Keane's Engineered Solutions Center is located in The Woodlands, Texas. *(Image courtesy of Keane Group)*

fracture performance analysis and real-time fracture modeling software. The pumping units include Environmental Protection Agency-certified Tier IV and dual fuel fleets.

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

Keane designs well-specific stimulation and cleanout fluid technology at The Engineered Solutions 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. The company has a network of North American laboratories that extends the expertise of the center to every major basin.

In January, Keane Group acquired Trican Well Service's pressure pumping business for $247 million.

Liberty Oilfield Services LLC

Liberty Oilfield Services (LOS) was founded in 2011 with a focus on improving tight oil completions and on finding innovative answers to frack optimization for each area of each basin. Liberty's frack innovations in the Bakken, often called the Liberty "Signature" design, changed the way most wells are completed today in North Dakota, according to the company.

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 recent addition of Sanjel's U.S. assets, acquired in June 2016, LOS has a hydraulic fracturing capacity of 560,000 hhp.

Magna Energy Services

Serving the Rocky Mountain region, Magna Energy Services specializes in plug-and-abandonment operations, rig services (workovers, production and auxiliary equipment), wireline services, well completions and oilfield fluid management services. The oil and gas services company has locations in Colorado, Wyoming and North Dakota.

Magna's water transfer offerings include layflat hose, high-density polyethylene pipe, aluminum pipe, centrifugal pumps, 51,000-bbl above-ground storage tanks, pipe manifolds, inline heating, filtration and water sourcing. Magna has the capacity to pump several miles from source to destination at high volume and rate, according to the company's website. Magna's silent pumps can minimize noise for work near residential areas.

Fluid handling equipment includes vacuum and winch trucks, 500-bbl frack tanks in a variety of shapes and sizes, and 400-bbl standup tanks. Magna also has hauling heavy equipment capabilities with low boys. Plus the company has fast lane rights for saltwater disposal wells/facilities in the basins in which it operates that allow it to access multiple disposal outlets to offload fluids with no waiting, creating efficiencies for Magna and its customers, the company said.

The company also offers wireline services, which include cement bond logging, gyro logging, temperature logging, fishing MWD, vertical perforating and tubing-conveyed perforating. Magna operates a five-truck fleet, and the trucks can operate at depths up to 20,000 ft.

Oasis Well Services LLC

Privately held Oasis Well Services (OWS), part of Oasis Petroleum Inc., provides well services and well completion products to Oasis Petroleum North America LLC (OPNA), a subsidiary of Oasis Petroleum.

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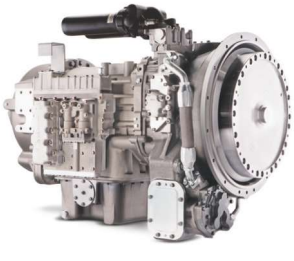

Allison Transmission®

Independent E&P company Oasis Petroleum kept production flat for six consecutive quarters at above 50 Mboe/d, with 50.3 Mboe/d in first-quarter 2016, according to a June 2016 investor presentation. The company had a planned 2016 capex of $400 million, with $200 being directed toward drilling and completions. The company expects to complete 46 gross operated (28.6 net) wells in 2016. Oasis Petroleum's frack crew is 100% focused on the Williston Basin, where the company has accumulated about 506,000 net leasehold acres.

OriginClear Inc.

OriginClear, formerly OriginOil, provides water treatment solutions. OriginClear's Electro Water Separation (EWS) technology, with advanced oxidation (EWS:AOx), is particularly effective in the treatment of produced and frack flowback water.

EWS:AOx efficiently removes nonsoluble organics and inorganics, such as free and dispersed oil and suspended solids, by applying catalytic coagulation and electroflotation to cause suspended organic particles and contaminants to clump up and then lift them to the surface so they can be raked off for disposal. Throughout the process advanced oxidation kills bacteria and oxidizes most heavy metals as well as many miscible and dissolved organic contaminants. EWS:AOx has been demonstrated to remove 99.9% of turbidity and reduce suspended solids and hydrocarbons to below detection limits on wastewater from Colorado gas wells, West Texas Intermediate wells and Monterey as well as Niobrara formations.

OriginClear has demonstrated the feasibility of recycling produced water from oil drilling operations in Kern County in California for steam production in EOR processes as well as reuse for irrigation purposes.

TriSep Corp., a specialty membrane company, and OriginClear Inc. released results in November 2015 from field-testing of a combined treatment system in a joint paper titled, "Produced Water Treatment for Reuse in Cyclic Steam Boilers and Crop Irrigation," authored by TriSep and OriginClear. The paper confirmed that electrochemical treatment and polishing membranes eliminate detectable levels of oil, enabling water reuse in agriculture and steam boilers, according to a company announcement.

The paper reported that OriginClear's EWS technology effectively pretreats produced water from oil wells. TriSep's iSep ultrafiltration membrane removes any remaining oil and suspended solids to acceptable reuse levels. Technology testing was conducted in California's San Joaquin Formation near Bakersfield, Calif.

OriginClear's 3,000-bbl/d EWS test unit is shown at a produced water site in the Monterey Formation. *(Image courtesy of OriginClear)*

ProPetro Services Inc.

Founded in 2005, ProPetro Services Inc. is an independent provider of oil and gas well drilling, stimulation, cementing and coiled-tubing services. The company has service locations in the Permian, Uintah-Piceance and Anadarko basins.

ProPetro's stimulation services include high-pressure pumping, acidizing and energized pumping services. The company's stimulation offerings include a ProBor crosslinked system, slick water and acidizing. In addition, the company's pressure pumping equipment provides more than 450,000 hhp for vertical and horizontal work, reaching all plays in West Texas and southeastern New Mexico. Also, the blenders and chemical additive units can work up to 120 bbl/min. Other fracturing services provided by the company include pre-job analysis, fluid testing, onsite sand sieve analysis and data acquisition.

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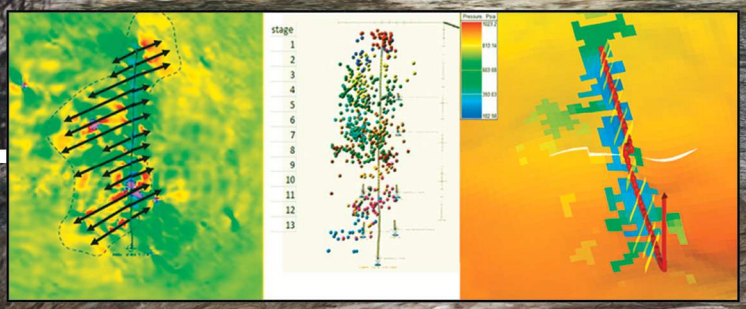
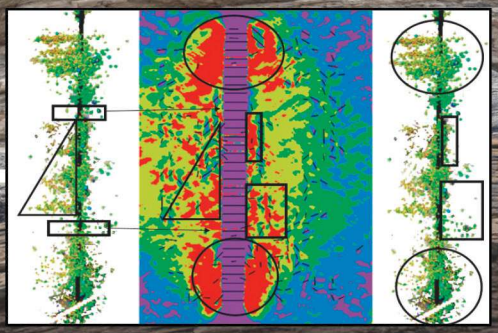
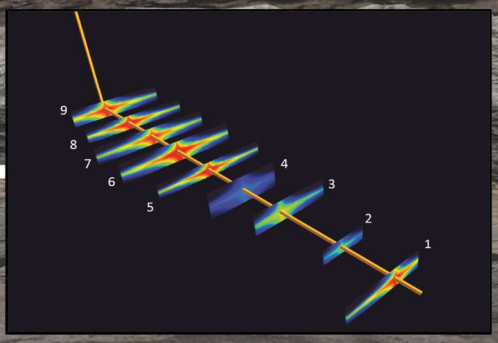
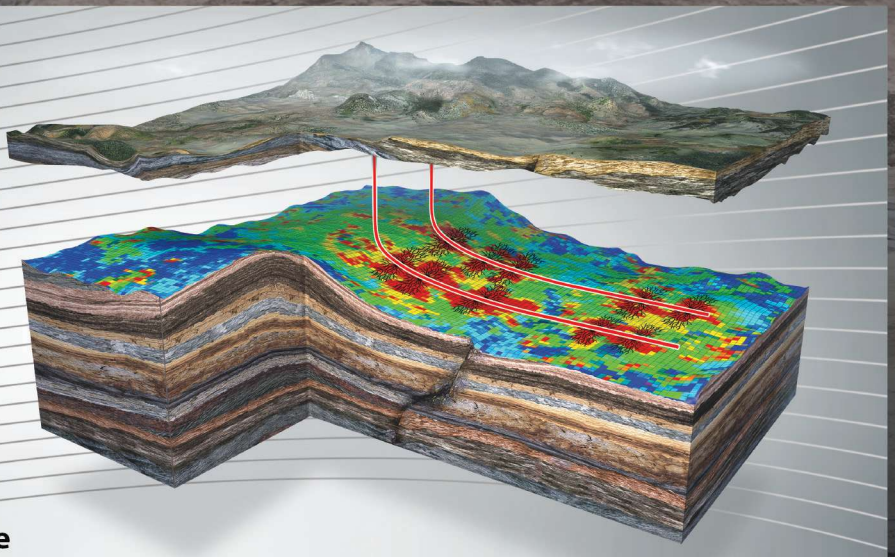


Can you predict and validate your SRV?



Where does your proppant go?





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The sun rises over a ProPetro Services fracturing job. *(Image courtesy of ProPetro Services Inc.)*

The company's Permian drilling services include vertical drilling as well as turnkey and day work. The company has seven MD Cowan Super Single Drilling Rigs, which are all equipped with top drive, an iron roughneck and triplex pumps. These rigs are designed to drill from 8,000 ft to 12,000 ft.

Additionally, the company's air drilling services include surface casing presets, air and fluid drilling, shallow-well drilling, and turnkey and day work. ProPetro has seven Atlas Copco RD 20 III top-drive rigs, three triplex pumps and four air packages.

ProPetro's cementing services include surface, intermediate, production and long-string casings, liners, squeezes and plugs. ProPetro's cementing equipment consists of five pump trucks, 10 bulk trucks and four field bins.

ProPetro offers a variety of coiled tubing services from 1.25 in. to 2.375 in. specializing in drill outs, acidizing, cementing, fishing and many more coiled tubing applications. The company offers dual quint fluid pumps and nitrogen equipment for low and high rate operations in any basin or shale play.

The company also offers pump-downs, toe preps, foamed acid, CO_2, nitrogen, rock salt jobs, small fracturing jobs, bulk acid delivery and acid transfers among its stimulation services. ProPetro has 10,000-hhp acidizing equipment for jobs in the Permian Basin as well as a 30,000-gal capacity for acid transport.

Quasar Energy Services Inc.

Formed in 1978, Quasar Energy Services Inc. specializes in cementing, acidizing and fracturing. The Texas-based company operates from its Fox, Okla., and Midland, Gainesville and Wichita Falls, Texas, locations. Services range from small foam fracture jobs to 120-bbl/min multistage fracks.

Quasar has three hydraulic fracturing crews with pressure pumping capability of 80,000 hp. The company also has three crews for acidizing jobs and 10 cementing crews. All of Quasar's cementing units are equipped with densometers and data acquisition.

Schlumberger Ltd.

Schlumberger supplies a comprehensive range of products and services from exploration through production and integrated pore-to-pipeline solutions that optimize hydrocarbon recovery to deliver reservoir performance. With locations in more than 85 countries, the company's technologies address seismic, drilling, characterization, completions, subsea, production, well intervention and well testing needs.

Schlumberger's multistage fracturing and completion services include fracturing with coiled tubing, multistage stimulation systems, PerfFRAC shale gas dynamic fluid diversion service and fiber-based fracturing services. The PerfFRAC service isolates each perforated zone within the stage, places treatments in each perforated zone, treats each zone at a relatively high flow rate and 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 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 operator was looking for a reliable, easy-to-deploy alternative to coiled-tubing-conveyed perforating when preparing the toe of the well for stimulation. According to the case study, the KickStart valve was deployed for the operator in 100 installations with a 100% success rate and zero nonproductive time, saving the operator $5.4 million.

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Schlumberger's ELEMENTAL degradable alloy fracture ball is designed to eliminate problems related to deformed and jammed balls. The ball is made up of a material that degrades completely within hours or days, which eliminates the risk of stuck fracture balls and the need to mill them, the company said.

Schlumberger also won Hart Energy's 2016 Meritorious Award for Engineering Innovation in four categories. The company was the drilling fluids/stimulation category winner for its BroadBand Services composite fracturing fluids; the drilling systems category winner for its ICE UltraHT drilling services; the intelligent systems and components category winner for its Manara production and reservoir management system (with Saudi Aramco); and a water management category winner for its xWATER integrated water-flexible fracturing fluid delivery service.

According to Schlumberger, the BroadBand unconventional reservoir completion services provide maximized wellbore coverage and reservoir contact designed to increase production and recovery. "Every fracture is stimulated and propped open from tip to wellbore to shift 40% of uneconomical wells toward 100% economic wells," the company said.

Stingray Pressure Pumping LLC

Stingray Pressure Pumping, founded in 2012, operates as a subsidiary of Mammoth Energy Partners LP, which is owned by Wexford Capital, Gulfport Energy Corp. and Rhino Resource Partners.

Operating in the Utica Shale, Stingray Pressure Pumping specializes in natural gas well completion services. The private company provides logistics, pressure pumping, energy and cementing services. The company's pressure pumping services include hydraulic fracturing services and pumping operations, and complete engineering, chemical and performance metrics programs.

Stingray Energy Services LLC supplies rental equipment such as telehandlers, manlifts, light plants and towers, generators, composite rig mats, steel rig mats and cranes. The company also offers water transfer and filtration services, with crews able to transfer filtered freshwater at a rate of 100 bbl/min, according to the company's website. Stingray also can transfer filtered brine through various line sizes at a rate of 20 bbl/min.

Stingray Cementing LLC provides cement sheaths to support casing and zonal isolation. The company also offers laboratory testing of all slurries.

Superior Energy Services

Superior Energy Services provides specialized oilfield services and equipment to service 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.

Pressure pumping services focus on horizontal well hydraulic fracturing used to complete and stimulate production in new and existing oil and gas wells. The company offers a complete fluid inventory, including slickwater fracks with the appropriate friction-reducer loadings and gelled water fracks using gelling agents to increase viscosity. Superior can provide stable, crosslinked fluid systems designed to address any range of temperature. The company also offers several pumping techniques, including treatments on single-well pads, "simul" or zipper fracks on multiwell pads and pump-down assists for plug-and-perf jobs.

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

TAM International Inc.

TAM International, an independent oilfield services company headquartered in Houston, offers R&D, product development and operating techniques. The company provides multistage frack 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 frack 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

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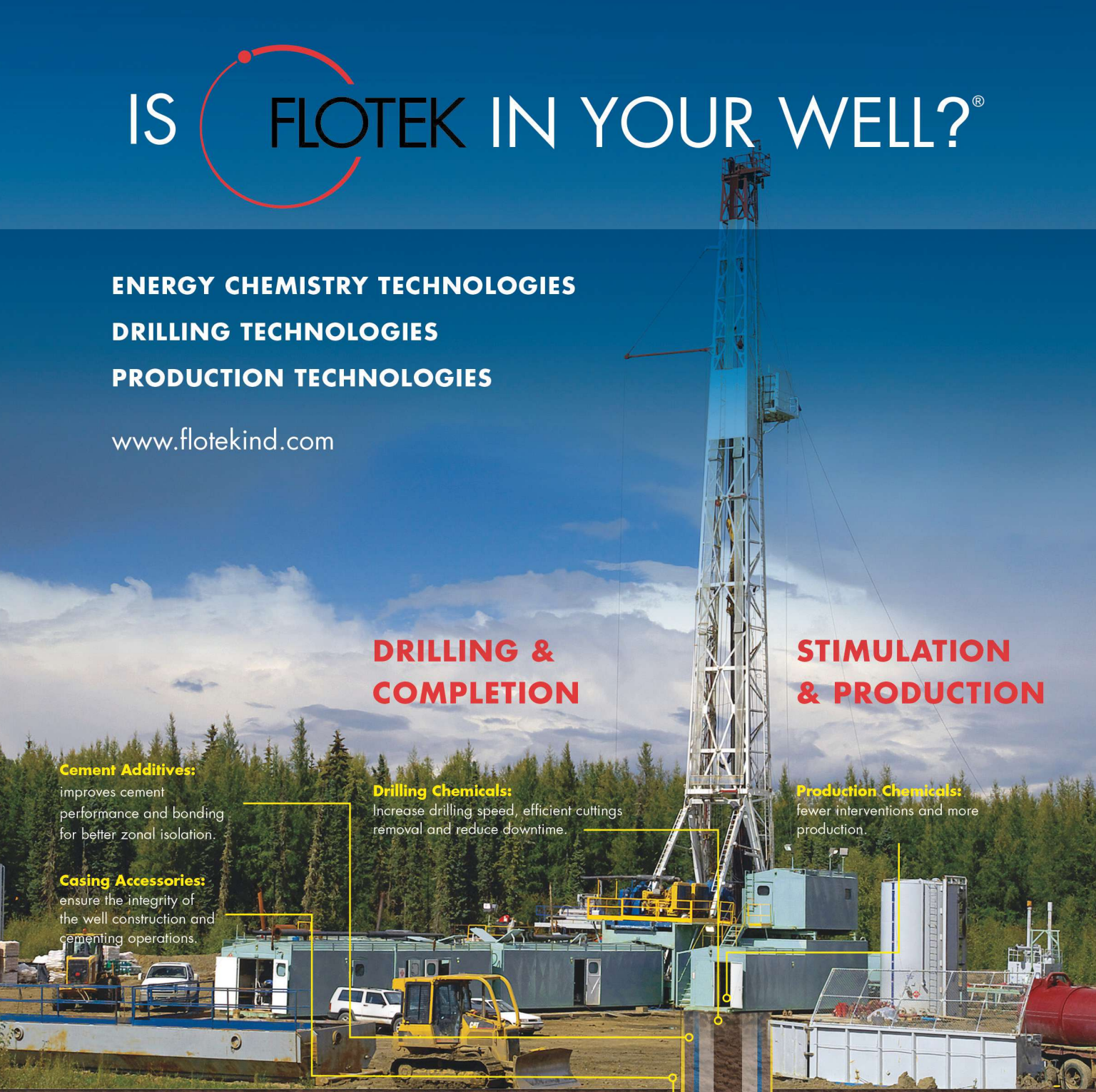

DRILLING & COMPLETION

Cement Additives:
improves cement performance and bonding for better zonal isolation.

Casing Accessories:
ensure the integrity of the well construction and cementing operations.

Drilling Chemicals:
Increase drilling speed, efficient cuttings removal and reduce downtime.

STIMULATION & PRODUCTION

Production Chemicals:
fewer interventions and more production.

Drilling Motors:
vertical and directional motors with Sealed Bearing and Mud Lube configurations.

Downhole Drilling Tools:
full range of drill string components to make drilling more efficient and reduce non-productive time.

Stimulation Chemicals:
increase load recovery, hydrocarbon production, lower pumping friction and increase ROI.

Teledrift Measurement While Drilling:
continuous measurements to surface while drilling, satellite-based remote monitoring and certification for faster and more accurate drilling.

Stemulator:
improve penetration rate by inducing axial vibration in the drill string to reduce friction drag and sticking.

Artificial Lift:
novel pump systems, reliable support to help lower cost, improve reliability and deliver more production.

TAM PosiFrac Toe Sleeve was the winner of Hart Energy's 2016 Meritorious Award for Engineering Innovation in the hydraulic fracturing/completions category. *(Image courtesy of TAM International)*

pressure to open the sleeve. The PosiFrac HALO, a HydraWell Inc. technology licensed exclusively to TAM, uses a three-piece design that offers the latest functionality in expandable and dissolvable technology. Within days after the fracture, the ball seat, frack ball and lower cone dissolve leaving one of the largest inside diameters on the market, according to TAM.

The company won Hart Energy's 2016 Meritorious Award for Engineering Innovation in the hydraulic fracturing/completions category for its PosiFrac Toe Sleeve.

In addition, 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.

Tucker Energy Services

Privately owned Tucker Energy Services (TES) operates in seven countries and offers products and services that include hydraulic fracturing, openhole and cased-hole logging, pipe recovery, perforating, tubing-conveyed perforating, production logging, slickline, cementing, coiled tubing, stimulation and completion services, drilling tools, treating chemicals and logging equipment sales. Services available in the U.S. include hydraulic fracturing, openhole and cased-hole logging, and coiled tubing.

The company's completion services include engineering, wellbore preparation, completion equipment and sand control, and TES offers these services in Colombia, Trinidad, Venezuela and Suriname. The company also has pumping equipment designed for sand control applications, including high-horsepower pumps for high-rate gravel packing and frack packing, the company said on its website. TES' pumping equipment is typically for onshore use in Venezuela, Suriname, Barbados and Colombia. The company provides services for both onshore and offshore operations in Trinidad.

In addition, TES' production tools, permanent and retrievable packers, and flow-control tools are designed for use in harsh environments, such as in corrosive, thermal or high-pressure conditions.

Stimulation services include acidizing and hydraulic fracturing. TES' main U.S. facilities are in McAlester, Okla., and DeBerry, Texas, which serve operators in the Midcontinent region. TES also offers these services in other regions of the U.S. and in Colombia, Trinidad, Suriname, Barbados and Venezuela. The company's stimulation equipment consists of 2,500-hp triplex fracturing pumps, 2,500-hp quintuplex fracturing pumps and 130-bbl/min fracturing blenders.

Additionally, Tucker Drilling Services, a division of TES, provides coring services, directional/steerable motors, drillstring design, hydraulic drilling jars, hole openers, horizontal well planning, stabilizers and reamers in Trinidad.

Universal Pressure Pumping Inc./ Universal Well Services Inc.

The Universal brand is made up of Universal Pressure Pumping Inc. (UPP) and Universal Well Services Inc. (UWS), subsidiaries of Patterson-UTI Energy Inc., a provider of contract drilling and pressure pumping services. The two pressure pumping companies offer a combined total of 1.1 million horsepower and offer multiple services, including hydraulic fracturing, cementing, nitrogen and acidizing services. The companies also provide natural gas-powered fracturing equipment. According to Universal, UWS has the largest dual-fuel fracturing fleets in the Appalachian Basin. Both companies offer refracturing experience and data acquisition for reservoir enhancement.

UWS, headquartered in the Appalachian Basin, provides well services in the Marcellus and Utica shales in the U.S. UPP is located throughout Texas and provides these multiple well services

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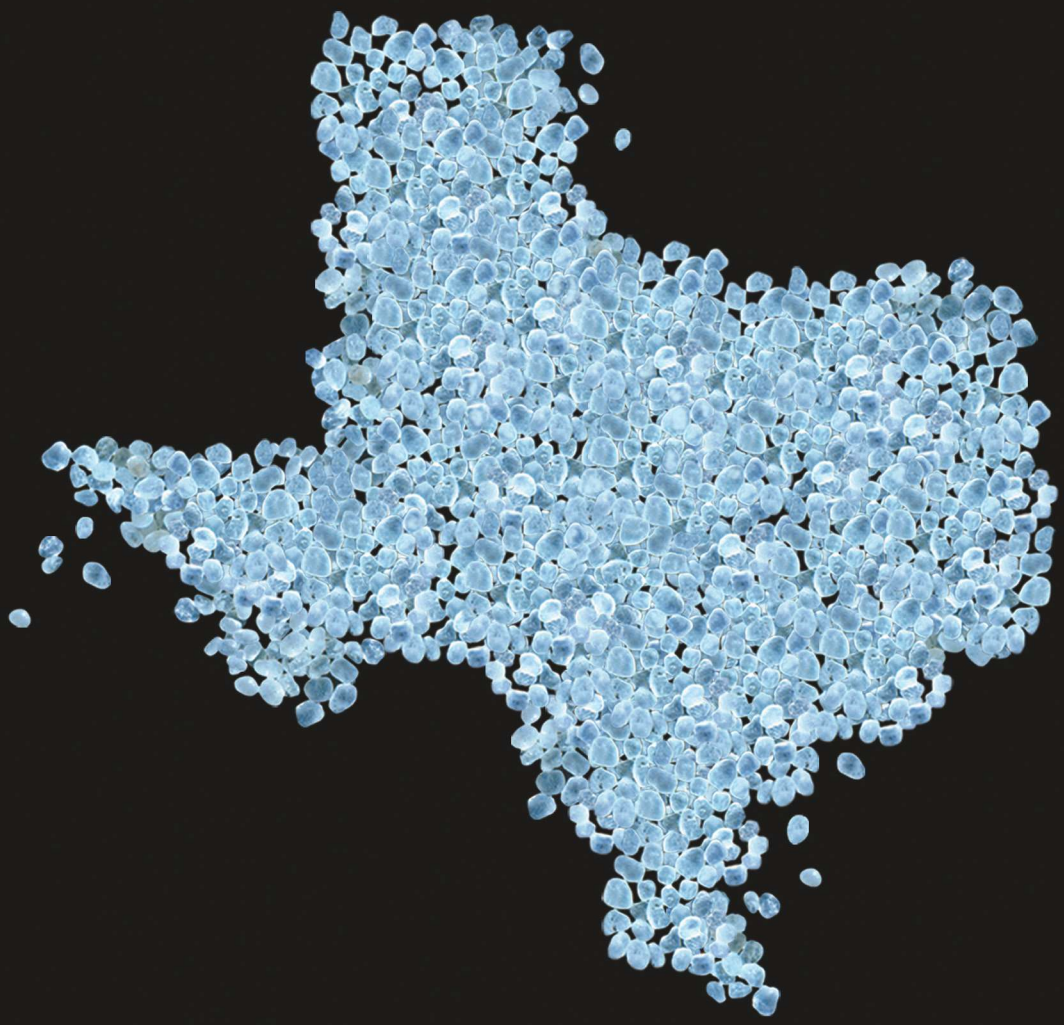

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A dual-fuel frack spread in central Pennsylvania utilizes natural gas produced from nearby wells to power the frack pump engines. Dual-fuel technology is a huge costs savings for producers and eliminates much of the diesel fuel that would otherwise be used to power the units. *(Image courtesy of Universal Well Services Inc.)*

in Texas, New Mexico and Oklahoma, to serve the Permian Basin and Barnett, Woodbine/Eaglebine and Eagle Ford shales.

Universal'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, the company said on its website.

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_x 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.

And 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.

USWS operates in Colorado's Denver-Julesburg Basin. *(Image courtesy of U.S. Well Services)*

Weatherford International Plc

Weatherford International Plc operates internationally in every major oil and gas region onshore and offshore. Weatherford's completion and stimulation products and services include coiled tubing services, reservoir stimulation services, acidizing systems, chemicals and additives, fluid systems, and completion and stimulation equipment.

The FracAdvisor service leverages the full spectrum of Weatherford products and experience

to deliver geoengineered completion designs. The three-step collaborative process starts with multisource data analysis. The company's proprietary, basin-specific algorithms provide consistent stage and perforation placement and are validated using production records from nearby wells. Completions engineers use these data to determine optimal stage and cluster placement.

The company's StealthFrac system is cost-effective in large-bore, extended-reach wells. The TBlockSure diverting agent and stimulation enhancer provides fluids-loss control for multistage fracturing, refracturing or workover operations. And among Weatherford's openhole isolation products are the ZoneSelect completion system, the Fraxsis annulus swellable packer, and the Apollo and ARES II hydraulic packers.

The company won Hart Energy's 2016 Meritorious Award for Engineering Innovation in the HSE category for its Hand and Finger Injury Prevention Program. ■

A hydraulic fracturing operation from a bird's-eye view. (Image courtesy of Weatherford)

Is the Industry Ready for Shale 2.0?

Since the frenzy has subsided, operators are taking a closer look at new technology.

By Rhonda Duey
Executive Editor

It's easy to ignore mistakes at $100 oil. Once the North American shale boom overcame its growing pains, which coincided with a significant uptick in global commodity prices, it adopted a "factory drilling" or manufacturing approach to its wells, which vastly improved drilling and completion efficiencies.

According to data from the Energy Information Administration, oil production per rig shot up 267% in the Eagle Ford, 231% in the Bakken and an astonishing 578% in the Niobrara between 2012 and (projected) 2016. During the period from 2012 to 2015, EOG's drill time dropped from 22.3 days to 7.7 days, according to the company. EOG also increased its wells per rig per year by 190%, its 30-day average IP rate by 88% and its IP additions per rig per year by 407%. If people are still wondering why the price of oil has dropped so dramatically since 2014, perhaps these figures give some indication.

It's a different story now. After dipping to the $27/bbl mark, oil prices are back up to near the $50/bbl mark. Many shale plays are profitable at this price. But producers are forced to be much more aware of operational efficiencies across the board, not just during drilling and completions.

What is Shale 2.0?

Definitions vary, but the general consensus is completion efficiency, that is, putting perforations and

Shale formations are heterogeneous and can't be optimized by a cookie-cutter approach. *(Photo courtesy of Sigur,* shutterstock.com)

fractures where they make the most sense, not just in a uniform pattern. Shale formations are anything but homogeneous and therefore can't be expected to react in an optimized fashion to a cookie-cutter approach.

The key is data. According to Mark Mills of the Manhattan Institute, private markets invested close to $1 trillion in the shale gale, some of which went into infrastructure that's not really state-of-the-art. And more than 100 petabytes of data have been collected.

"We have a huge new infrastructure that's immature, massive amounts of data that have not been plumbed or fully utilized, and we're going through a classic cycle of overinvestment," Mills said. "I think there will be a resurgence, Shale 2.0, because demand will rise, and the fastest response will come from shale."

This response will be different from the response in the past, he continued, because the industry has 10 years of experience now in these unconventional plays. "People already have been there and done that," he said. "They have an expertise that didn't exist 10 years ago. My expectation is that people will be smarter because they've learned a lot and not just smarter because they've been burned. Because they have been burned a lot."

His anticipation is that operators will begin to deploy maturing technologies in robotics, data analytics and other technologies that weren't available to them in the early days of the shale gale. "These technologies have matured contemporaneously with the shale revolution but independent of it," he said.

In a recent presentation, Mike Vincent of Fracwell LLC argued that multidisciplinary teams are necessary to optimize resource plays. During development, he noted, misperceptions abound regarding the roles of the various disciplines. Most frack jobs, he said, are not engineered but rather are replicated from a standard design with minor tweaks along the way, questioning the need for engineers. Most horizontal wells are completed without being logged. "If we don't care about geology, why do we need geologists and geophysicists?" he asked.

Citing the oft-mentioned statistic that 30% of the perforations in these wells are not producing measurable hydrocarbons, Vincent added that mathematical spacing of perforations fails to honor petrophysics and the correlation of seismic attributes to productivity. Production logs, tracer data and fiber-optic sensor data all back up this claim.

Furthermore, the industry has underestimated its fracture lengths. Fractures can extend 457 m (1,500 ft), yet some companies are spacing their wells as close as 50 m (165 ft), meaning that the fractures are interfering with each other. Several examples in the Eagle Ford indicated that offset laterals were intersecting.

Vincent stressed the need for multidisciplinary teams to optimize future wells. In an example in the Pinedale Anticline in Wyoming, the trial was designed to answer specific questions:

- Does fracture conductivity matter in microdarcy formations?
- Does proppant sieve distribution matter in microdarcy formations?
- With variation in reservoir quality, is it even possible to conduct a field trial that gives statistically reliable answers?

The team concluded that proppant selection affected gas production and that stages receiving 20/40 sieved intermediate density ceramic proppant provided much higher gas rates than similar stages receiving a broadly sieved intermediate density ceramic proppant. High statistical confidence was obtained by using a large dataset that honored geological variation, minimizing the variables to just examine the proppant, the use of 13 techniques to analyze production while honoring petrophysics and statistical analyses of the full dataset and subgroups to provide consistent conclusions.

Overall, Vincent concluded that the industry must address these problems with nonunique interpretations and recognize interrelated ramifications. "This is a very different mindset than just simply presuming fracks were perfect and continuing to infill drill until we exhaust the economic opportunities," he said.

Finding the right parameters

One type of dataset that was not fully plumbed in Shale 1.0 is seismic data, and much of this was due to the time it takes to acquire, process and interpret a seismic dataset. But with activity dwindling, operators have more time to analyze these datasets in detail.

Global Geophysical has developed a methodology to relate seismic attributes to production data. This already has been done with engineering data, but Ross Peebles, former acting CEO of Global, said that engineering datasets are not very dense in 3-D space, whereas seismic datasets are quite dense. "If you can find seismic attributes that relate to production, you can get a very rich 3-D model of production," he said. "Of course, the secret is that you're not searching for the attribute; you're search-

ing for the little portfolio of attributes that together tell the story."

The idea behind the methodology is to consider all of the variables that drive production and find proxies for them. "Then you've got to find the right proxies and the right grouping against real data," he said. "That's the secret. You ground-truth mathematically against real data, and you leave some wells out as a blind test, and then you double-check it. This helps find the group of reservoir characteristics from the seismic, as a group, that are able to predict production."

He added that the company has done around a dozen of these projects and has gotten validation that the attribute prediction method works. However, he cautioned that it's not just crunching numbers. It's a very iterative process, and each project takes three to four months to complete. But updates and improvements are quick.

"It becomes a useful everyday tool after the beginning," he said.

Global also is using ambient seismic, which helps clients see natural fractures before stimulating the wells. The ambient seismic also can monitor the frack job and detect changes in the fracture network over time as the well is produced. This type of reservoir monitoring is faster and much less expensive than traditional time-lapse seismic, he said.

Machine learning

"The nice thing about machine learning is that it can evaluate a ton of different variables at once and extract valuable insight," said Mike Hogan, CEO of DeepData. "But trying to do fine-grained optimization with public data is not only challenging; it's probably wrong."

The idea behind DeepData is to deliver a social hub for well data, sort of a LinkedIn of well data, that captures information about each well from every company that worked on it. The operator then chooses whom, if anyone, it wants to share specific well data with. The operator can invite nonoperators, private-equity investors, data sharing partners or potential acquirers to share well data and functionality specific to each company. Using this tool, one operator's well data can be blended with offset data from data sharing partners and public data to extract meaningful optimizations that boost production and reduce costs. DeepData provides more than 40,000 different visualizations in addition to head-to-head comparisons, reporting, mapping and more.

Data availability, quality and diversity—achieved through controlled data sharing—were the drivers behind the startup. Hogan mentioned Kaggle, a data science company that runs regular competitions to provide the best ways to analyze data. "They took the best and brightest data scientists from those competitions and said, 'We're going to go where there's a lot of data and where we can do a lot of good things.' And of course they got into oil.

"Then they found that the data [were] an absolute mess, and they got back out."

Machine learning is already being used for things like predictive maintenance, where devices can be outfitted with sensors that anticipate failure. "That's all well and good," Hogan said. "But it doesn't solve the completions cookbook." The solution was to create a "software as a service" approach to allow companies to run their data analytics on the web.

"We recognized that the problem was that we needed to get well-structured, well-understood data first, so that is where we started," he said. "We've created almost a social network around these data. Instead of the operator taking responsibility for importing all of the data, we provide interfaces for the service providers to put in their pieces of data. They can upload their data, and in exchange we give the service providers tools to manage their own business.

"All of those data are aggregated so the operator has one solution for all data about that well. We then enrich the data with a variety of key metrics and powerful visualization tools. We even provide Dropbox-type capability for storing anything about those wells: pictures, invoices, drone video, anything."

The company is young, but Hogan hopes that eventually the site will go viral as operators invite their service providers, nonoperators and data sharing partners to join. "Whether it's data visualization, machine learning, reporting, whatever you want to do with the aggregated data, we want to be the central repository."

Material point method

Ahmed Ouenes has been working in reservoir modeling for 30 years, and his entrance into the unconventionals dates back to the '90s with the development of "sweet spots" for tight sands projects. For shale reservoirs, he developed the concept of "shale capacity," which assumes that a rock has to have multiple characteristics to be suitable for shale development.

"During that process, we realized that you could have a very good rock that has everything you want from a geology perspective, but when you frack it, it doesn't produce," Ouenes said. "That got us interested."

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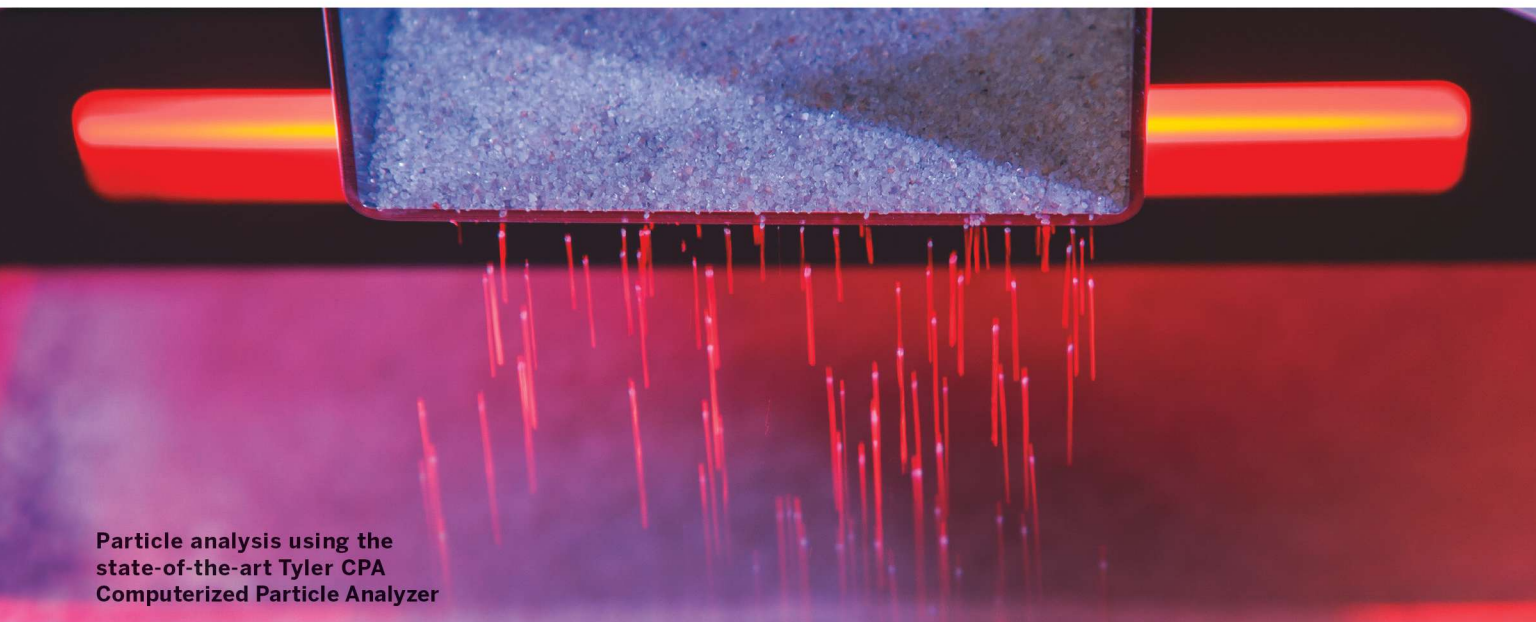

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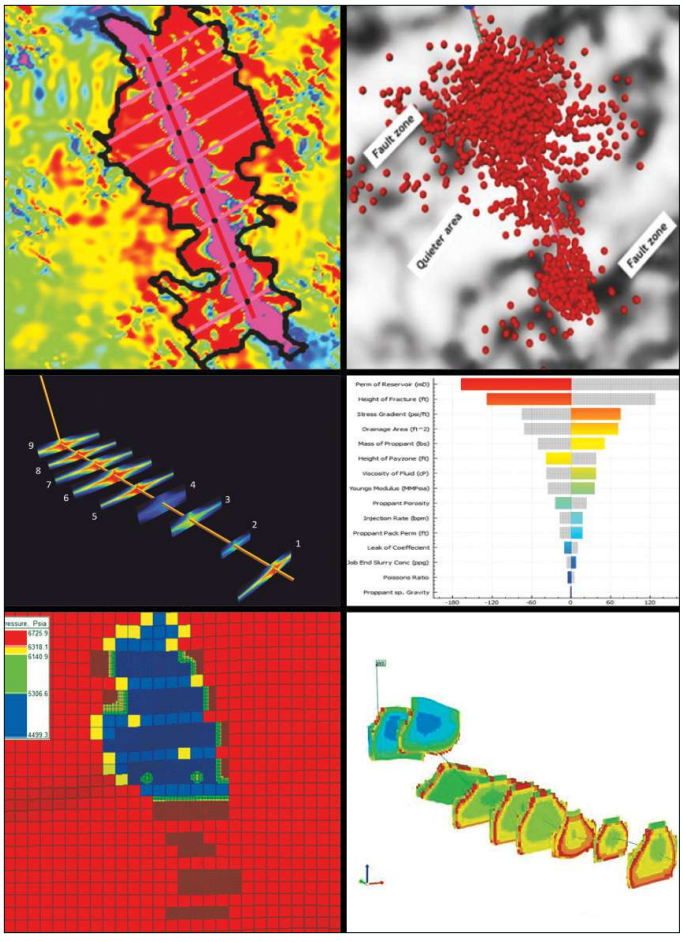

Eagle Ford reservoir infill and refrack opportunities were identified with a material point method geomechanical simulator. The geologically driven asymmetric hydraulic fracture model captured stimulated permeability and reservoir pressure distribution to optimize field development. *(Image courtesy of FracGeo)*

Ouenes concluded that geomechanics play a greater role in production than had previously been thought. "There are really two types of sweet spots," he said. "There are the geological sweet spots, which we knew how to get—we used seismic and well data to come up with the models in 3-D to see everything we wanted to see.

"But then we realized that we also needed to find the geomechanical sweet spots, which were completely misunderstood. We had no idea this was so important."

Ouenes created FracGeo to handle this problem. The system looks at three sources of stress gradients that control fracking performance: elastic properties of the rock, natural fractures and faults, and pore pressure. He said that the interaction between the natural fractures and the hydraulic fractures plays a major role in the overall performance of a frack stage. And understanding this interaction boils down to a complex engineering and computational problem.

He adopted the concept of the material point method from national laboratories to solve this computational challenge. Ouenes collaborated with Oregon State University in a research project to include a realistic distribution of natural fractures in the material point method.

"It worked," he said. "And we realized that it opened the door for a lot of things."

One was the ability to predict complex field data such as microseismicity and production logs. The company used Marcellus, Eagle Ford, Montney and Wolfcamp datasets, which had difficult hydraulic fracturing behavior. By using the new methodology the researchers were able to understand the behavior of the fracturing much better than they could through the use of microseismic technology alone. Other case studies followed, validating the technique.

Now the company is able to not only understand behavior but predict it as well. It uses both 2-D plane strain theory and 3-D workflows and can now understand proppant distribution, which Ouenes said is like the holy grail in the industry. In 2015 the company published two papers describing the first method that models proppants at the well scale. The company workflows allow the practical use of geomechanics in frack design and reservoir simulation to optimize the fracking and well spacing.

"What it shows is that sometimes when you have a specific objective or goal or problem, maybe you have to think outside the box to find the solution that is most appropriate rather than trying to retrofit existing tools," Ouenes said. "This has come out of desperation because I was not able to find a solution."

Overall, the downturn has enabled these and other technologies to find a foothold after the frenzy of the shale gale. "Three years ago, I said to an engineering manager, 'If I could show you that you don't need every stage, would you be willing to drop some stages?'" Peebles said. "He said, 'Yeah, I would. But you've got to convince me.' That was when things were booming. Now I think they're totally open to the idea. They just need some confidence." ■

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Understanding of Reservoirs Takes Center Stage

Failure is not an option for operators in this low oil price environment. Big Data is key to maximizing production.

By Scott Weeden
Contributing Editor, Drilling

Placement of clusters and stages, tighter spacing, staying in the zone, fracture propagation, higher production efficiency—everything operators are doing to be more efficient and maximize production are based on trying to help lower the costs per barrel of oil equivalent and improve effectiveness of the stimulation.

All of the completion design and execution starts with understanding the reservoir. The entire workflow involves reservoir characterization. For Halliburton that includes building an earth model, understanding where to drill, using its FracInsight Analysis to choose where to perforate based on data and eventually building a complex frack model.

"We are trying to keep up with the unconventional market just as fast as it changes, and it changes so quickly because of the amount of information now available," said Jason McIntyre, strategic business manager, Production Enhancement (PE) at Halliburton.

"For the stimulation treatment, we want to focus on directing the frack where we want it to go. We are using science and technology to help identify the best places to frack. When we go to execute that frack, we want the tools to be able to put the frack exactly where it was planned for our stimulation so that our results are as close as possible to what we expected," said Ben Wellhoefer, product manager, openhole isolation systems at Halliburton.

"Customers want completion designs that are low risk and reliable. That's primary above all else because the cost of a failure is so high," emphasized Eric Schmelzl, vice president, strategic business at NCS Multistage. "We are focused on achieving predictable fracture placement and optimized frack dimensions across the entire length of the lateral."

Rob Fulks, director of completions optimization at Weatherford, explained, "We've got geophysicists, petrophysicists, log analysts, reservoir engineers, completion engineers and geologists involved in this process. It is a lot of fun actually.

"If you have good information, whether it comes from public databases, cores that are run or production histories, there is a lot of emphasis on using all of that information in designing the completion. In addition, wellbore placement and quality have a great deal to do with completion efficiency. That's where you get started on the completion side," he added.

Focusing on three-stage process

Satya Gupta, a technology fellow at Baker Hughes, explained, "To maximize stimulation efficiency and effectiveness, and ultimately optimize production, operators must focus on three important phases of the process: modeling, stage placement and long-term production monitoring."

Modeling the fracture prior to implementing the stimulation program is key to understanding the best places to fracture and perforate to maximize reservoir coverage. Currently, the industry uses 2-D or pseudo 3-D frack models, which don't incorporate all of the reservoir parameters, and as a result, don't provide an accurate prediction of the fracture, he said.

"Baker Hughes is working on a true 3-D frack model, which uses science to help us fully understand the reservoir properties of these complex, highly heterogeneous formations, so we can create more conductive fractures and cover the reservoir more ef-

ficiently with proppant. True 3-D models also can be incorporated into full reservoir models to optimize field development," Gupta continued.

Stage placement is another important factor for a successful fracturing program. Understanding the reservoir parameters and stress contrast helps to precisely place the well in the sweet spot and perforate it to maximize treatment coverage and efficiency. Proper stage placement also helps avoid crossovers and other potential production-related issues.

Gupta explained, "We also are working on technologies to monitor long-term production. Understanding where production is coming from and the effectiveness of the frack treatment helps us confirm whether we've reached our objectives and enables us to adjust our approach for future stimulation programs. Long-term production monitoring also allows us to identify various stages of the fracture-treated horizontal well that were either under- or not stimulated originally so we can focus on those stages for future rejuvenation efforts."

Ambient seismic technology for completions

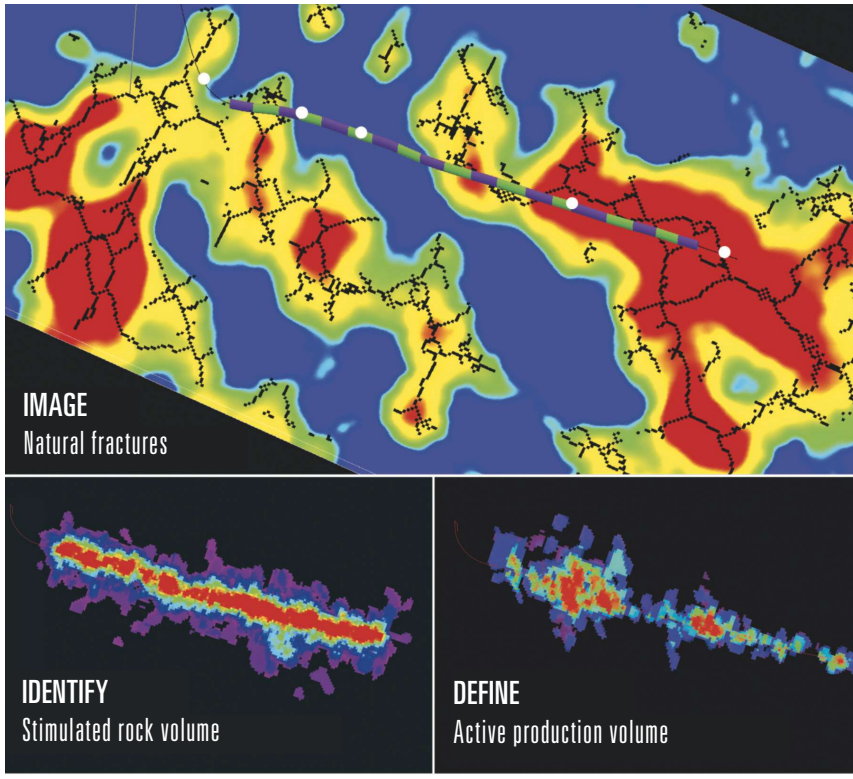
Global Geophysical's ambient seismic technology transforms microseismic from a tool used for evaluation of well completions to a predictive methodology used for developing unconventional reservoirs before, during and after completions. Using proprietary processing techniques, ambient seismic reveals the geometry and extent of natural fracture networks; the size, orientation and complexity of induced fractures; and the volume of rock activated during stimulation and active during production. Fully 3-D fracture surface maps are extracted from the volumes.

Ambient seismic can be collected during the acquisition of traditional 3-D seismic surveys or with an array designed specifically for reservoir planning, monitoring fracture stimulation and production. Post-acquisition processing steps include velocity model building, trace processing for noise suppression, imaging and fracture network extraction.

One application for this technology is the ability to predict the effectiveness of completions. Ambient seismic collected during stimulation allows the characterization of induced fractures and of the overall impact the stimulation has on the reservoir and nearby wells. Monitoring production volumes periodically over time allowed identification of missed pay, refrack candidates and planning for infill drilling. This information was used in customized drilling and completion plans.

In a case study, Global Geophysical was contracted to acquire and process ambient data both before and during a well completion. The pre-frack data were used in designing the completion. While fracking the early stages, problems were encountered breaking rock to place proppant. Global performed a stress inversion on the imaged fracture network data, which showed high differential stress at the wellbore. The completion strategy was modified, and proppant was successfully placed in the remaining stages.

A hexagonal surface array (Global's AutoSeis system), covering 7.5 sq miles, was deployed to acquire three days of ambient data. After the pre-frack and well completion data were processed, the natural fracture map showed more highly fractured rock at the toe of the horizontal than at the heel. The completion design was customized with optimized perf locations.



Ambient seismic directly images natural fractures before fracture stimulation (top) and also captures induced fractures and the stimulated rock volume from the frack job itself (bottom left). Finally, ambient seismic defines the volume of reservoir active during production of a well (bottom right). *(Images courtesy of Global Geophysical Services)*

Customizing well stimulation

Working with clients to help them understand exactly where to drill, where the real pay zones are and what the stimulation pack should look like is what Halliburton is targeting. There is more of an appetite in this down market for customized engineering and tailoring services to the well.

"When we bring tools to bear like fiber-optic monitoring, FracInsight and things of that nature, we are using science and technology to help identify the best places to frack. It is all based on our lower costs per boe [barrel of oil equivalent], improved efficiency and improved effectiveness of the stimulation," Wellhoefer said.

McIntyre said, "With our CYPHER seismic-to-stimulation service we are helping operators to design the well, the treatment and even the interval spacing. There is more appetite for customizing the well whether it is the rock, permeability, surfactant or clay control. They don't have the mass number of wells they used to have. Surprisingly they are interested in some of the advanced tools to make the best well in this kind of environment."

Operators are looking at a suite of technologies to give them better information.

For example, what information can they get about proppant information in terms of which zones are producing and which ones are not? Are we not getting proppant into the fractures? Are we not making that connectivity with the formation? What information from a diagnostic perspective can they learn about the well, package and fluid systems? Those are some of the questions the operators are facing, McIntyre continued.

The CYPHER starts with building an earth model using some of the company's Landmark technology. Then a reservoir model is built to get an understanding of where to drill. The FracInsight Analysis help us determine where to perforate based on data. Finally, a complex frack model is built, he explained.

Putting Big Data to work

After building the subsurface model, completion engineers create designs based on the best practices in any given area. "It's not about what you did last month or that you have a design that worked in the Bakken and you want to try it in the Eagle Ford. That doesn't work," Fulks said.

The Weatherford FracAdvisor completion-design solution integrates Big Data from multiple sources—including production history, logging, cuttings/gas analysis, LWD and wireline logs, core samples and SCADA records—to design new completions. The new designs have been proven to deliver more consistent production contributions across stages and clusters.

"As an example, consider a completion design composed of 250-ft stages. Within each stage operators typically place five perforation clusters that are 50 ft apart. What if, instead, you studied the rock stresses and then divided your stages and clusters unevenly based on geological properties?" he asked.

"You no longer have stages that are evenly, geometrically divided every 250 ft. Now you have a stage that's 200 ft, one at 180 ft and one that's 270 ft. Why do it that way? It's because you fully consider the potential of the rocks. If you reduce the variability of the rock properties within a stage and the variability of the stress or closure force where clusters are placed, you get better completions and better production," Fulks said.

Pinpointing stimulation

Most of NCS Multistage's operations are on cemented wellbores with frack sleeves, replacing the perforating operation with a sleeve manipulation. The newer generation of sleeve design is capable of multiple cycles of opening and closing. The company's record is 114 stages in a single wellbore.

"Our methodology is so repeatable. The design of our system from the grassroots is to facilitate its use in high sand environments. It tolerates both screenouts and high sand concentrations better than any other system on the market," Schmelzl said.

Operators are asking for fracturing with tighter and tighter frack spacing in pursuit of lower and lower permeability reservoirs. "Unless you have uniform and tight frack spacings, one cannot be as sure of effective reservoir drainage. Just as importantly, by placing each fracture discreetly, frack geometries can be reasonably estimated because you know where each fracture was initiated and how much was pumped. We can model what the resulting frack geometry is and can avoid things like well bashing.

"More and more operators are starting to recognize that pinpoint completions offer both reliability and the route to optimization they can't get any other way. The many variables that can be changed during a frack can be used only to optimize the frack design when there is knowledge about how many fracks were created and what their approximate dimensions are," he said. ■

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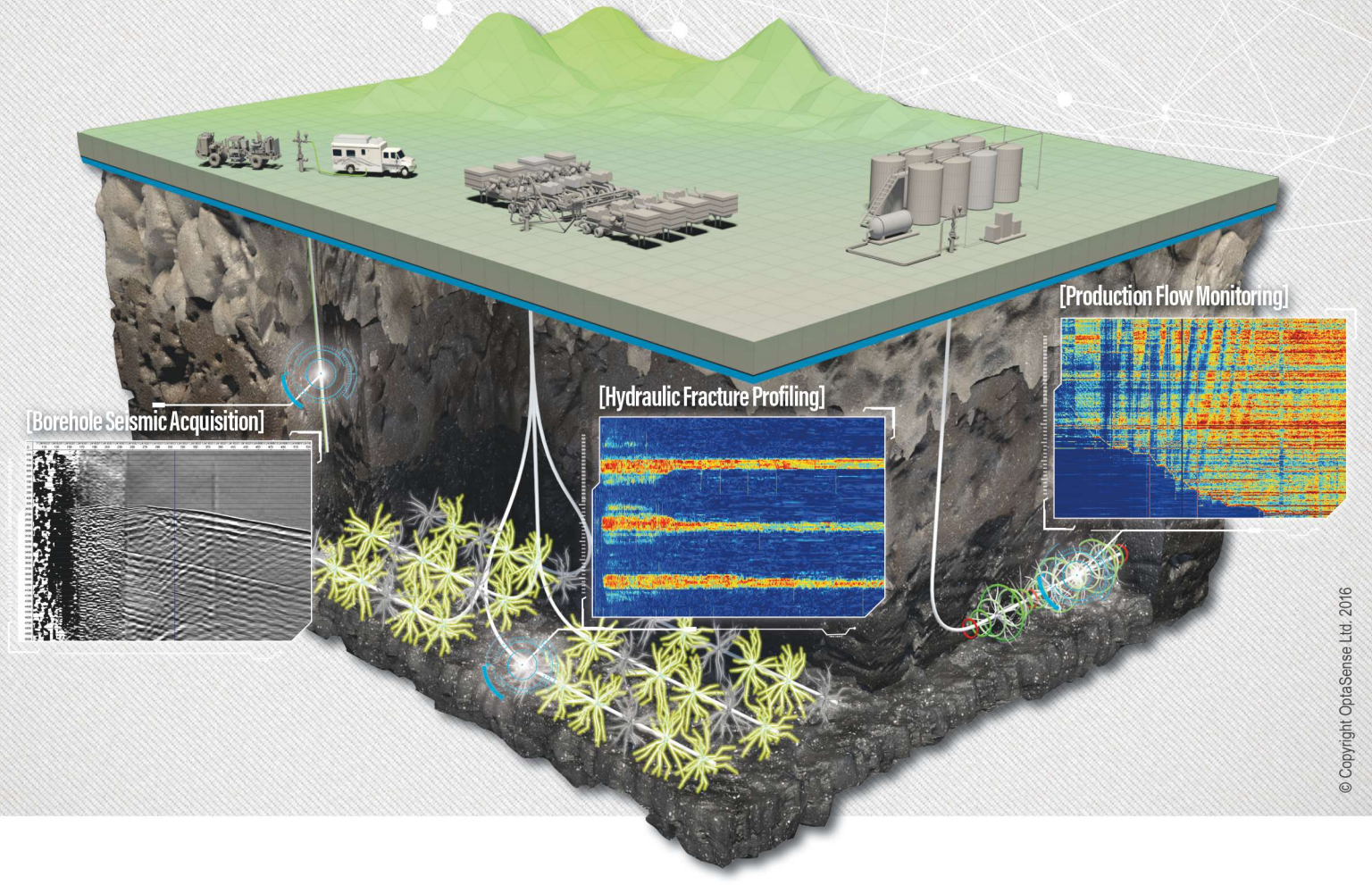

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Technology Aims to Reduce Overall Cost of Hydraulic Fracturing

Although operators have their eyes on the bottom line, they still are interested in new technology to improve production.

By Scott Weeden
Contributing Editor

While the first wave of horizontal drilling and hydraulic fracturing of shale plays resulted in record production of natural gas and restoration of crude oil yields, the second wave of technology will focus on increasing efficiency and total recovery of hydrocarbons from those formations.

From the surface facilities to the toe of the well, the technology being developed by service companies and equipment manufacturers is focused on reducing the environmental footprint of hydraulic fracturing operations, decreasing the time needed downhole and cutting the costs. Hydraulic fracturing remains the largest portion of the cost of drilling and completing a well.

The following technologies were entered into *E&P*'s 2016 Meritorious Innovation and Engineering Award competition in the completions category. These technologies deal primarily with hydraulic fracturing.

Green technology for hydraulic fracturing

Clean Fleet is a system developed by U.S. Well Services that incorporates existing industry equipment configured with the latest technology to provide fracturing services with enhanced safety features, smaller physical and environmental footprints as well as reduced noise levels at a lower cost relative to traditional fracturing equipment.

Clean Fleet is a fully mobile, fully electric, hydraulic fracturing system that is fueled entirely by natural gas whereby conventional diesel engines are completely replaced with electric motors.

As confirmed by independent third-party testing, it decreased emissions by 99% compared to conventional diesel-powered fleets. This reduction is achieved by eliminating all conventional diesel engines and replacing them with electric motors powered by natural gas turbine generators.

The Clean Fleet Whisper Technology was designed for quiet, low-noise impact hydraulic fracturing by reducing noise pollution, making the workplace safer and less disturbing to surrounding communities.

The second Clean Fleet was deployed in Colorado's Wattenberg Field in September 2015 by U.S. Well Services before being moved to the Marcellus Shale. *(Image courtesy of U.S. Well Services)*

In a case study U.S. Well Services deployed its second Clean Fleet in Colorado's Wattenberg Field in September 2015. Electric-powered hydraulic fractur-

ing operations began on Sept. 22 and concluded on Oct. 24 with 392 stages completed across 12 different wells.

The actions performed were a combination of plug-and-perf (PNP) and sliding-sleeve operations with up to 21 stages completed in a single day. Four Taurus 60 turbine generators were used to produce up to 23 MW of electricity to power all of the fracturing equipment, thus eliminating the need for any diesel motors. These turbines consumed an average of 3,030 cu. m/hr (107,000 cf/hr) of natural gas while powering more than 10,000 hhp of fracturing equipment during stimulation.

Dissolving frack plugs reduce trips, costs

The ability to enhance PNP operations by reducing the need for cleanout trips has been addressed by several service companies, including Halliburton, Schlumberger and Baker Hughes. By developing dissolvable frack plugs and seats, the companies have reduced the need for coiled tubing (CT) to drill out composite plugs.

In today's marketplace any operation that can reduce costs and maximize return on investment for an operator leads to higher efficiencies and increased production.

Halliburton noted that the lateral lengths in horizontal wellbores are limited by the ability of CT to reach farther to drill out composite plugs. The company's Illusion dissolvable frack plug combines the company's expertise in frack plug design with advanced dissolvable metal and rubber materials.

The frack plug's compact design aids in pump-down efficiencies and allows faster run-in-hole line speeds while setting the tools on wireline. Field runs have been seen as high as 213 m/min. (700 ft/min.) on wireline in the horizontal.

This metal frack plug is rated to 10,000 psi for zonal isolation during wellbore stimulation. Following the fracture the large-bore inside diameter (ID) allows operators to produce through the tool while the plug dissolves.

Since these plugs dissolve away, they can be set in the toe of the wellbore without the need for CT removal. Production might be brought on sooner to improve the net present value of the asset.

In early 2015, Halliburton completed an operation with 5½-in. Illusion dissolvable plugs for a major operator in South Texas. The well consisted of a 15-stage, 5½-in., 20-lb/ft cased well with a measured depth of 4,070 m (13,351 ft).

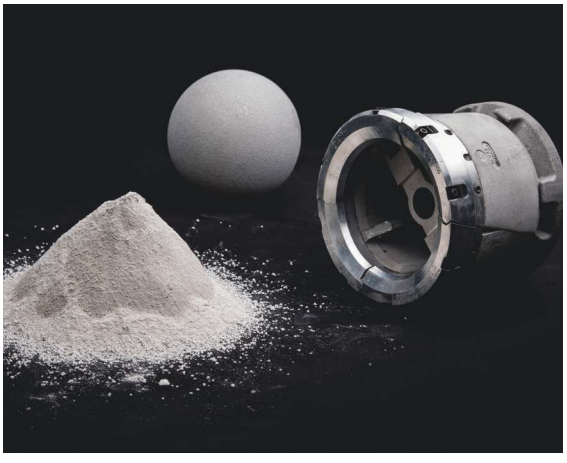
Well conditions required a frack plug to withstand well temperatures of 110.5 C (231 F) and with sealing capability of 10,000-psi differential pressure to isolate zones during the fracture. All 15 Illusion frack plugs were successfully pumped downhole, set and sealed during the operation. The plugs averaged run-in speeds of 107 m/min. (350 ft/min.) in the vertical section and 85 m/min. (280 ft/min.) in the horizontal section, while being pumped down at 14 bbl/min.

During one stage a screenout occurred, but the large ID of the frack plug allowed the operator to flow back through the plug at 18 bbl/min, cleaning out the casing and avoiding a CT trip.

In a step change that overcomes the need for mechanical intervention, Schlumberger devised the Infinity dissolvable PNP system to provide fullbore multistage stimulation with fully degradable seat assemblies instead of plugs to isolate zones. The system is run with standard wireline perforating equipment and can be deployed in all well types and lithologies. The Infinity system is rated to 177 C (350 F), supports differential pressure up to 10,000 psi and maintains functional viability for 24 hours to 72 hours after placement, depending on environmental conditions. The system uses a metal-on-metal seal instead of elastomers. It also replaces hard-to-remove slips that can catch on casing or be left as debris in the well that can trap future intervention equipment.

Following stimulation, 99.7% of the material turns into a fine powder, allowing fullbore access without the additional cost and risk of running a CT unit.

Zavanna LLC recently deployed the Infinity dissolvable PNP system to complete its Blackjack 24-13-1H and 24-13-2TFH wells in the Bakken. The two wells were successfully stimulated with 100 stages and placed immediately on flowback.



The degradable fracture ball and seat dissolve completely, eliminating the need for milling and enabling fullbore production. *(Image courtesy of Schlumberger)*

Baker Hughes released its SPECTRE disintegrating frack plug, which disintegrates downhole after fracturing to eliminate post-frack intervention requirements, accelerate completion times and leave behind an unobstructed ID for maximum flow area and simplified future access for recompletions.

The SPECTRE plug includes controlled electrolytic metallic (CEM) nanostructured material technology, a proprietary packing element system and a specially engineered anchoring grip to provide reliable zonal isolation during PNP completions.

CEM technology, which was developed by Baker Hughes, is a highly engineered composite material that provides both high strength and a unique chemical disintegration property that conventional materials lack. The chemical disintegration property enables the plug body, anchoring grip and packing element to disintegrate completely downhole when in contact with produced fluids.

Because the SPECTRE plug is run on wireline, its placement is not determined until it is set in the wellbore, so operators can analyze well logs and optimize stage placement on the fly throughout fracturing operations.

In the Woodford Shale in Oklahoma, the SPECTRE disintegrating frack plug helped an operator increase pay zone coverage by 30% while eliminating the need for CT intervention in the deepest stages of the well. The operator had drilled an extended-reach well to a total measured depth of more than 6,772 m (22,000 ft) with a 2,167-m (7,109-ft) horizontal section.

The Baker Hughes dissolvable frack plug uses CEM nanostructured material that enables the plug body, anchoring grip and packing element to disintegrate completely downhole when in contact with produced fluids. *(Image courtesy of Baker Hughes)*

To eliminate plug-related obstruction risks and the need for CT intervention in the farthest section of the well, Baker Hughes recommended the final completion design have 45 stages, which included a combination of 10 SPECTRE plugs and the rest of composite plugs.

The SPECTRE plugs were run first and successfully set in the lower section of the well from 6,123 m to 6,773 m. IN-Tallic frack balls were used to divert treatments. This section would have been too risky to complete using composite plugs. Eliminating post-frack intervention in the lower stages saved about eight hours of completion time.

Toe sleeve supports valid CITs

A number of products have been developed to establish a flow path from the casing ID to the annulus in cemented PNP completions so perforating guns can be pumped downhole on wireline *in lieu* of being deployed on CT for stage-one stimulation. TAM International pointed out that the vast majority of these tools are unable to perform a valid casing integrity test (CIT) before starting stimulation operations.

The industry has devised several methods for performing CITs that could lead to delays or require drill-out operations, adding to the time and cost. TAM developed its PosiFrac Toe Sleeve (PTS), which is a flow-path initiation and stage-one stimulation tool that is actuated during the final bleed-down cycle following one or more successful CITs.

A major operator in the Utica Shale in eastern Ohio required a tool that would enable them to perform CITs prior to establishing injection in cemented PNP applications. Due to high fracture gradients in the area, it was not possible to exceed the required maximum test pressure to open the tool, precluding the use of the majority of available product offerings.

In September 2015, TAM International successfully installed two 5½-in. toe sleeves in a trial well for an operator in Harrison County, Ohio. The operator decided to run two sleeves, one joint apart at the toe to optimize stage-one fracture performance.

After testing all surface lines, 9,500 psi was applied to the casing and held for 30 minutes. At the conclusion of the first successful CIT, pressure was increased to 12,500 psi and held for an additional 30 minutes.

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At every stage, the Multistage Unlimited frac-isolation system records pressures and temperatures at the frac zone and in the wellbore below (see charts at right). The data reveals the presence and type of any interzone communication (e.g., natural fractures or cement failure) and identifies the presence and source of near-wellbore restrictions. These stage-by-stage details provide critical insights operators are using to optimize frac design and frac spacing.

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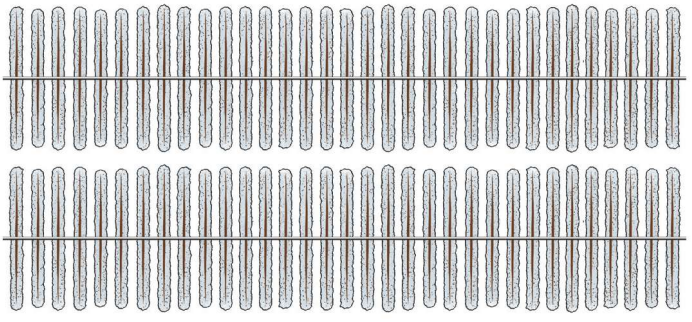
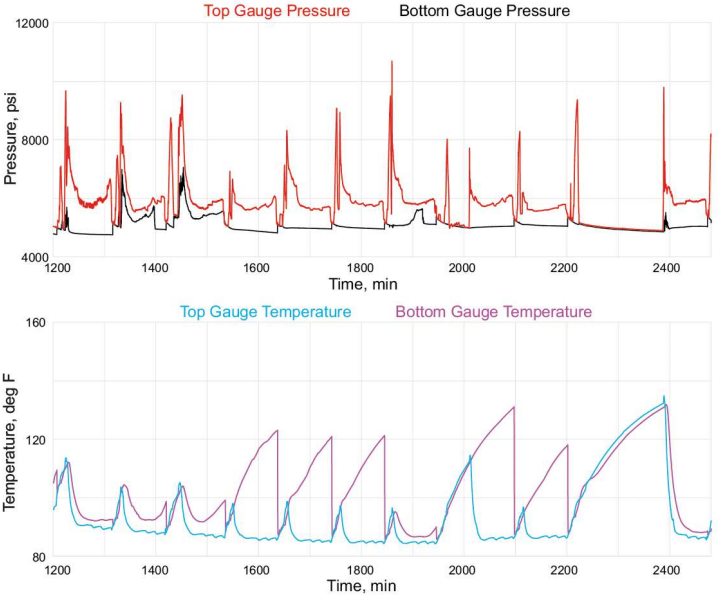


Predictable, verifiable, and repeatable frac spacing and propped volume facilitate formation-specific, well-to-well optimization across entire fields



Recorded pressure and temperature at and below the frac zone for ten stages. The data identifies any interstage communication and describes important frac and formation characteristics.

The Multistage Unlimited frac-isolation system is the world's leading coiled-tubing frac technology, with more than 137,000 stages completed.

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Diverting agent enhances stimulation

Weatherford developed its TBlockSure diverting agent, which is made of a self-degradable mesh that dissolves downhole. It also minimizes clean-up after the operation is complete. The planning and testing phase took about three months.

The agent was deployed in two wells in the Eagle Ford Shale to promote higher production by creating a complex fracture geometry that maximized the number of perforations. The client was particularly concerned about loss of fluid efficiency, which might diminish the effectiveness of the fracturing operation.

The operator selected the TBlockSure low-temperature agent for its capability to provide efficient zonal isolation and mechanical diversion of stimulation fluids to new perforations.

First, in collaboration with the client, Weatherford created a fracturing design for the two wells that would be treated with the agent. During deployment of the TBlockSure agent, the team observed average pressure increases of 1,164 psi and the successful breakdown of new perforations.

Over a 30-day period, the agent improved overall IP by 83% compared to two similar untreated wells. In the two wells treated with the agent, oil production increased by 81% and gas production increased by 40%.

Real-time perforation and activation system performs selectively

Schlumberger's ACTive OptiFIRE CT real-time selective perforating and activation system provides a safer, more efficient and cost-effective method for selective-perforating and plug-setting with CT. The system selectively fires multiple guns for up to 10 zones at different depths in a single run, which minimizes downtime, environmental footprint and formation damage.

The system can be used with a broad range of perforating guns compatible with Secure2 radio-frequency-safe electronic detonators and switches. Guns can be armed on demand, and each gun can be fired individually to provide greater control of the perforation operation.

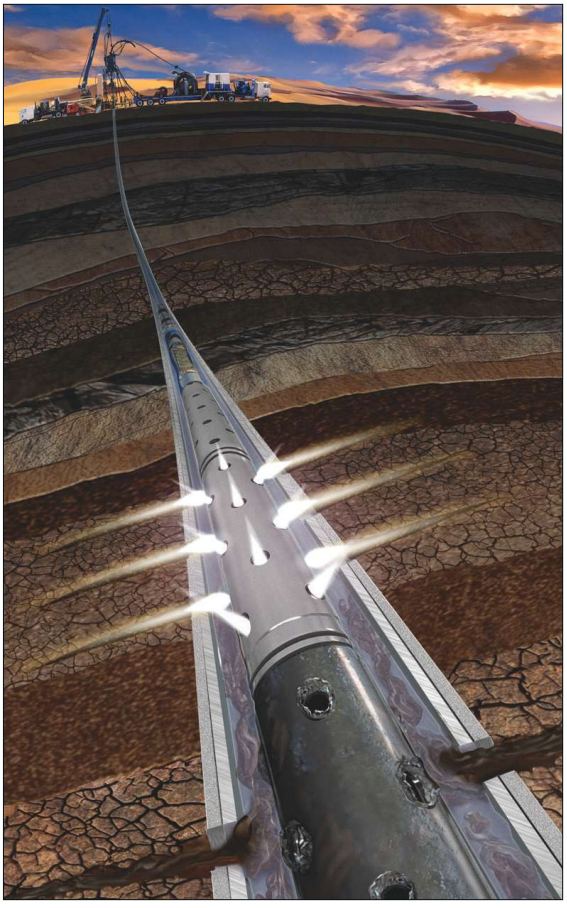
The use of fiber-optic telemetry includes determining depth correlation between each detonation and the ability to transmit signals, which eliminates the need to pump fluids downhole to initiate detonation. Operators can maintain an underbalanced environment, reducing formation damage while perforating and avoiding overdisplacing fractures when running plug-setting tools.

Prior to activation, depth control is performed with the ACTive services casing collar locator and gamma ray tool. The system is armed after it is run in the hole and programmed using wireline protocols through a surface system in the CT cabin.

In a case study Pemex was seeking to boost declining production in a mature field. The operator wanted to perforate two new intervals and reperforate a critical producing zone.

The challenge was to perform the perforation operation on the live well during underbalanced conditions to prevent deferred production and remove formation damage. PEMEX selected the ACTive OptiFIRE CT system. Using advanced fiber-optic telemetry, the operator was able to accurately place the perforating guns into the three selected zones and perforate the well.

Following the intervention, PEMEX realized a production increase of 18%. The system also reduced perforating detonation time by 75%. ■



Accurate depth control and real-time confirmation to ensure target zone coverage in a single run can be attained with the ACTive OptiFIRE CT real-time selective perforating and activation system. *(Image courtesy of Schlumberger)*

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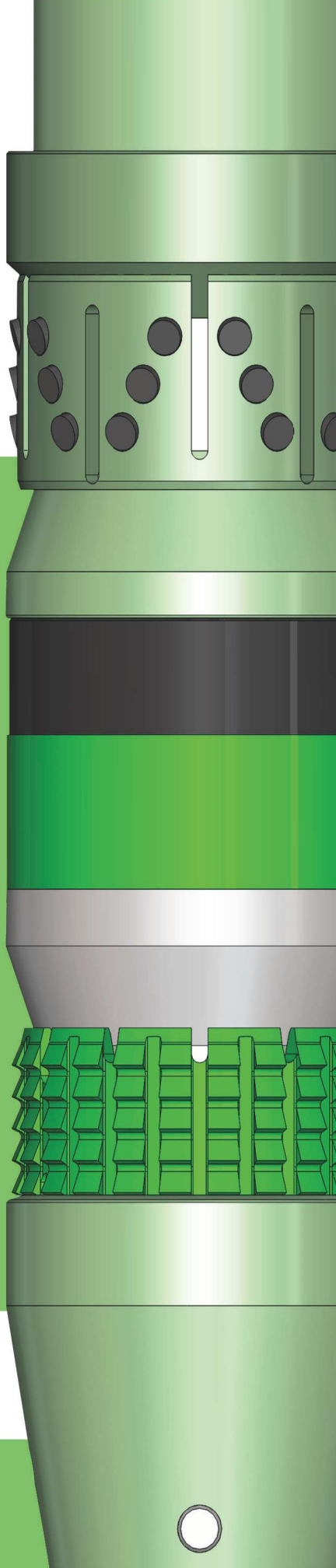

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Digital Splashdown

The industry looks to harness the cloud to help manage its water needs more efficiently.

By Jennifer Presley
Senior Editor, Production Technologies

The shale gale that rocketed out of the Barnett over a decade ago triggered a near instantaneous chain reaction of too many questions and too few answers. For the petroleum industry, keeping up with the demands for the iron, sand, water and manpower necessary to free the deeply trapped oil and gas resources were significant. The loudly voiced cries from the public for more transparency in hydraulic fracturing intensified the challenge.

At a time when most anyone with a question could hop online and Google their way to expert level on any topic in under five minutes, the answers to some of the public's more pressing concerns regarding the sourcing, use and disposal of the water used to fracture shale were not readily available. Of particular concern were the chemicals used to treat the well to ensure an efficient and effective fracturing job.

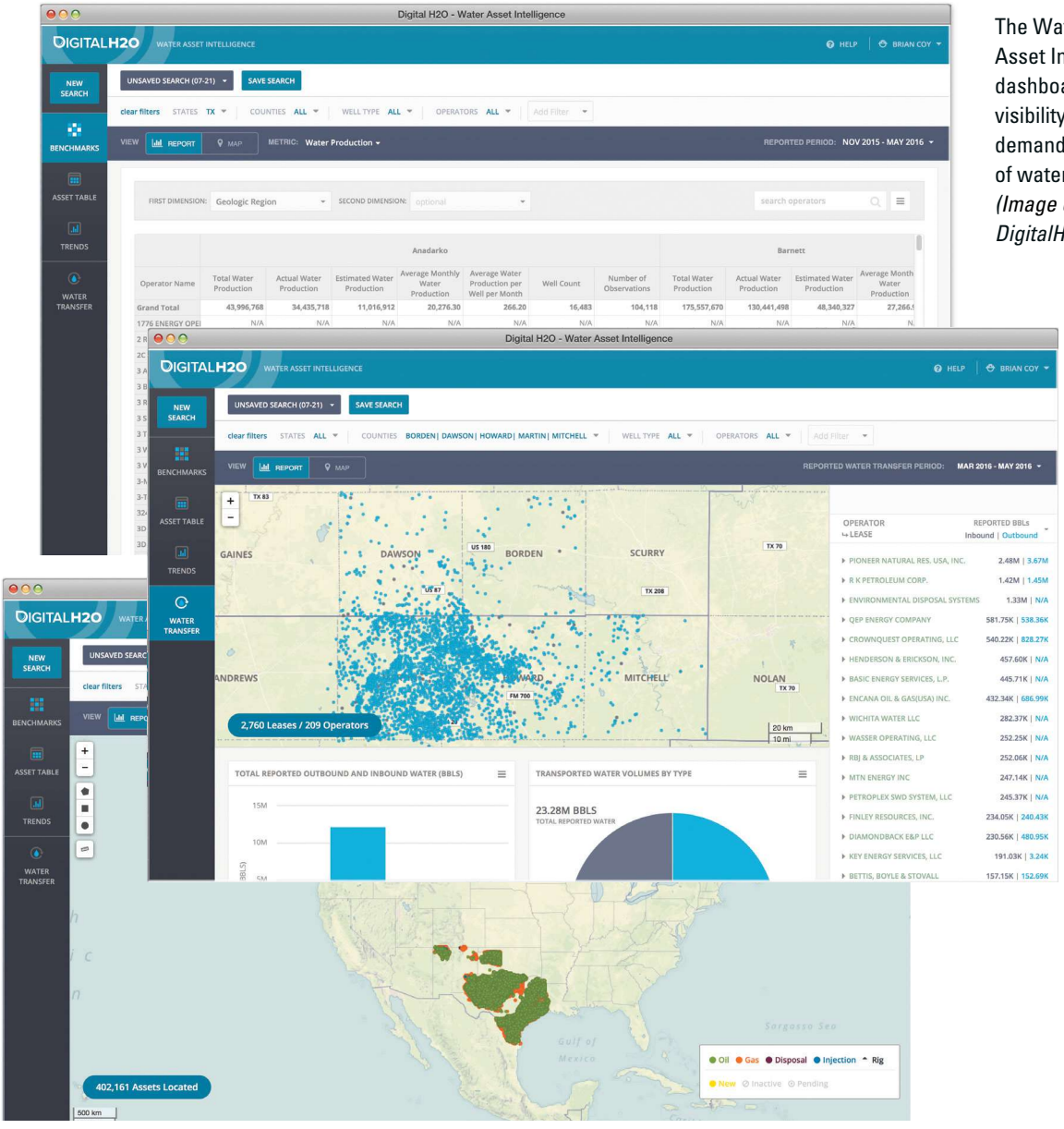
Enter FracFocus—the first national hydraulic fracturing chemical registry. This online repository harnessed the power of the Cloud to deliver public access to the data and answers in a nonbiased manner. FracFocus was one of the first steps that unconventional oil and gas companies took onto the information superhighway. In the five years since its initial launch, FracFocus and the unconventional oil and gas industry it supports have evolved considerably through their use of Big Data.

Big Data

Dealing with large volumes of data to make technical decisions is not a new concept for operators. Seismic interpretation and reservoir visualization are just two of many areas to experience the significant advancement of computing power. The rise of affordable sensors capable of collecting and transmitting data, in addition to new analytic tools and advanced storage capabilities, has made it possible for operators to capture detailed data in real time and make better-informed decisions related to both subsurface production and optimizing logistics on the surface. Not only have the sensors, analytic tools and transmitters improved along the way, but so has the collective understanding of the unconventional basins being developed for production. One important facet in that evolution is water management.

"Unconventional oil and gas is undergoing the same transformation that the automotive industry made about 100 years ago. You had a couple hundred car manufacturers in the U.S. alone, all building cars by hand. Then Henry Ford came along and realized that automotive manufacturing was really about process, efficiency and scale," said Piers Wells, CEO of Digital H2O. "He introduced the production line, turning process and data into very important enablers for efficient, cost-effective production. I think we're seeing a similar transformation in unconventional oil and gas. Given the market downturn, there is a huge push to increase efficiency in all aspects of production, but especially in water management. Data are really important to make good decisions around water investment, management and operations. We have seen a significant shift in the last six to eight months with a growing emphasis on deploying digital and software-driven tools that focus on oilfield water management.

Digital H2O offers a portfolio of such tools that they describe collectively as Digital Oilfield Water Management. As a software-as-a-service company, its Water Asset Intelligence platform uses a proprietary data model and predictive algorithms to provide a digital tool that enables cost-effective and sustainable use of water in upstream oil and gas. Digital H2O accomplishes this by leveraging advanced digital data aggregation techniques and sophisticated machine learning analysis.

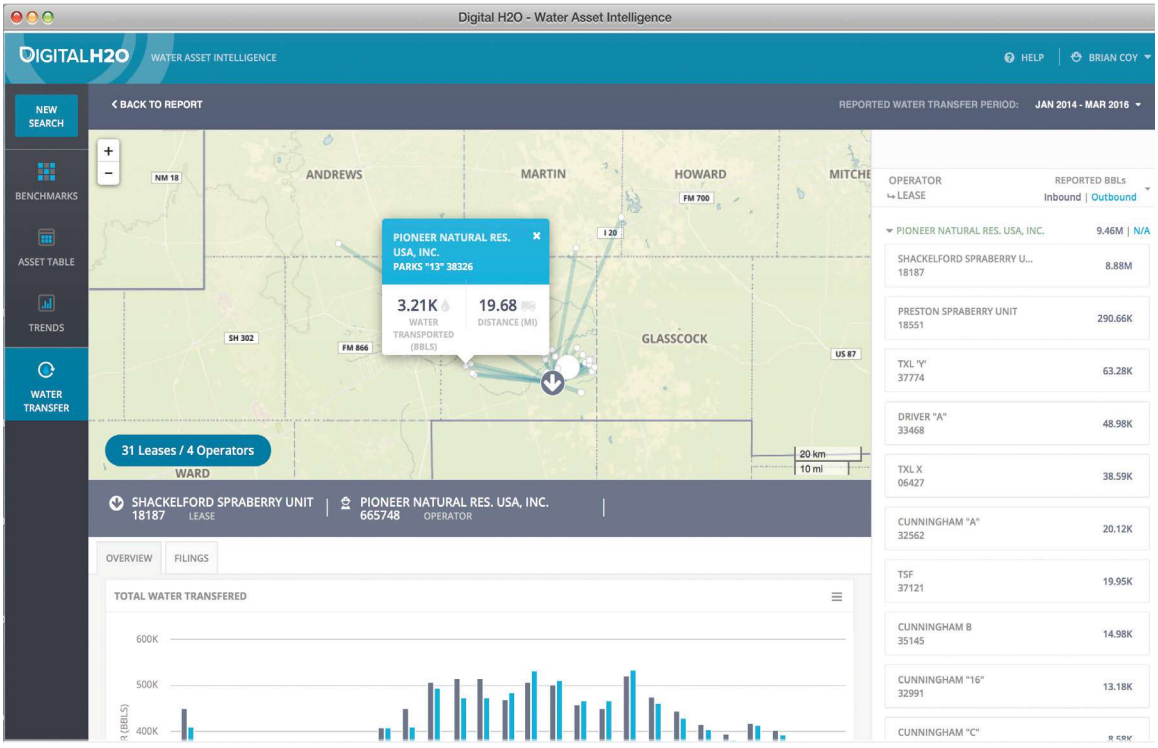


The Water Asset Intelligence dashboards offer visibility in the supply, demand and logistics of water in the oilfield. *(Image courtesy of DigitalH20)*

The platform's predictive water modeling capabilities help in water planning, forecasting and transportation optimization, according to Wells. In addition to this, Digital H2O also is developing tools that will give producers and service companies real-time visibility into their current water inventories and mine their historical data, using their machine learning algorithms, so they can predict and plan for upcoming activity.

"Water Asset Intelligence is a unique product in the industry in that it provides visibility into the supply and demand for water on the oil field. We capture and model water data at the individual asset level so that our customers can understand the production and logistics of water at the lease level or across whole basins," Wells said. "Our users are able to understand the capacity and utilization of water disposal assets in a given geography in terms of the volumes of water they're actually taking and where that water is coming from."

"In major producing basins, we have visibility into water logistics, and we can look at market shares in terms of volume on an individual lease basis. That's extremely helpful information because it helps operators and service companies alike determine whether they're making optimal decisions with respect to water disposal and transport, and ultimately the costs associated with managing that



The volume of water and distances water travels between leases can be tracked via Water Asset Intelligence. *(Image courtesy of DigitalH20)*

produced water." Launched in the late fall of 2014, there are more than 40 enterprise customers on the Water Asset Intelligence platform, Wells said.

"We capture all of the data for our Water Asset Intelligence product from the public domain. There's a fair amount of water data out there, but it's extremely fragmented. A lot of it hadn't been digitized, so we digitized those datasets. We then took that data and leveraged machine learning to develop predictive models," Wells explained.

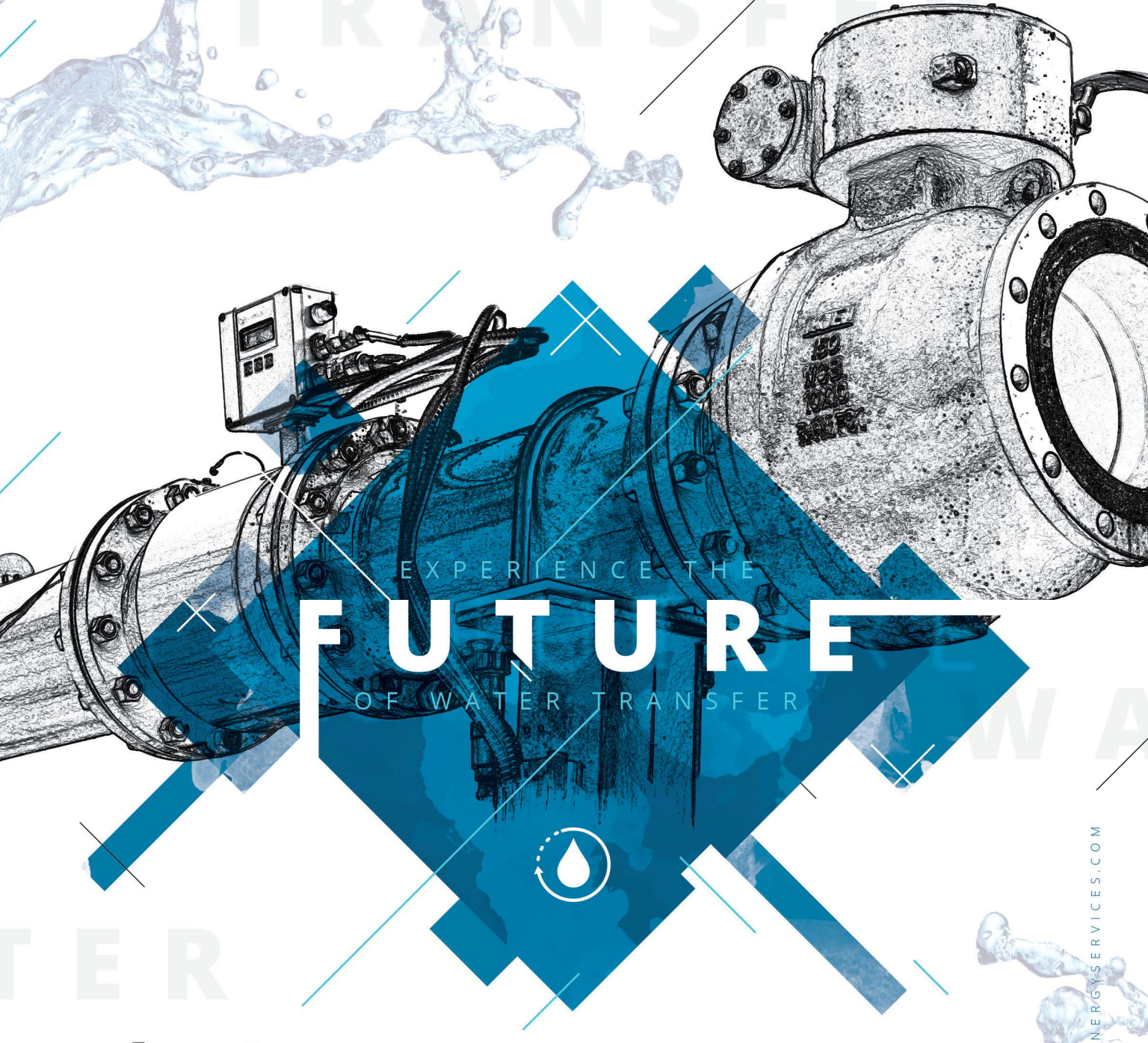
"For example, in the state of Texas there's no other data source where you can look up a well and understand exactly how much produced water it is generating today. We mined over 25 million water-to-oil observations and then associated them with other predictors to very accurately estimate how much water an oil or a gas well is producing. This is a unique application of machine learning to oilfield water management."

Online marketplace

The sourcing, transport and disposal of water are among the most significant challenges that every oil and gas company faces on a daily basis. In fact, water management comprises the majority of oil and gas production cost. An online marketplace, called Sourcewater, offers those looking to source, recycle, transport and dispose of water for energy production a one-stop shop to minimize time and cost of water management.

"It's like Expedia for water management," said Josh Adler, founder and CEO of Sourcewater. "Rather than making lots of phone calls every day to figure out what's going on out there in terms of finding water, disposal, hauling, treatment—all the things for water management—you can go online and see what's available for any particular date range and location and select the best vendor options by your criteria, whether that's lowest cost, highest safety and performance ratings, technical capabilities or total capacity. Sourcewater enables you to optimize water services procurement in five minutes per day rather than in 8 hours, and it produces a much better, more competitive and reliable result than just calling the regular supplier every day."

The idea for the Sourcewater marketplace originated from a conversation Adler had with a friend from the energy industry while he was a Sloan Fellow at Massachusetts Institute of Technology four years ago. Adler learned that the biggest challenge in unconventional operations was the enormous logistical cost associated with the disposal of flowback and produced water.



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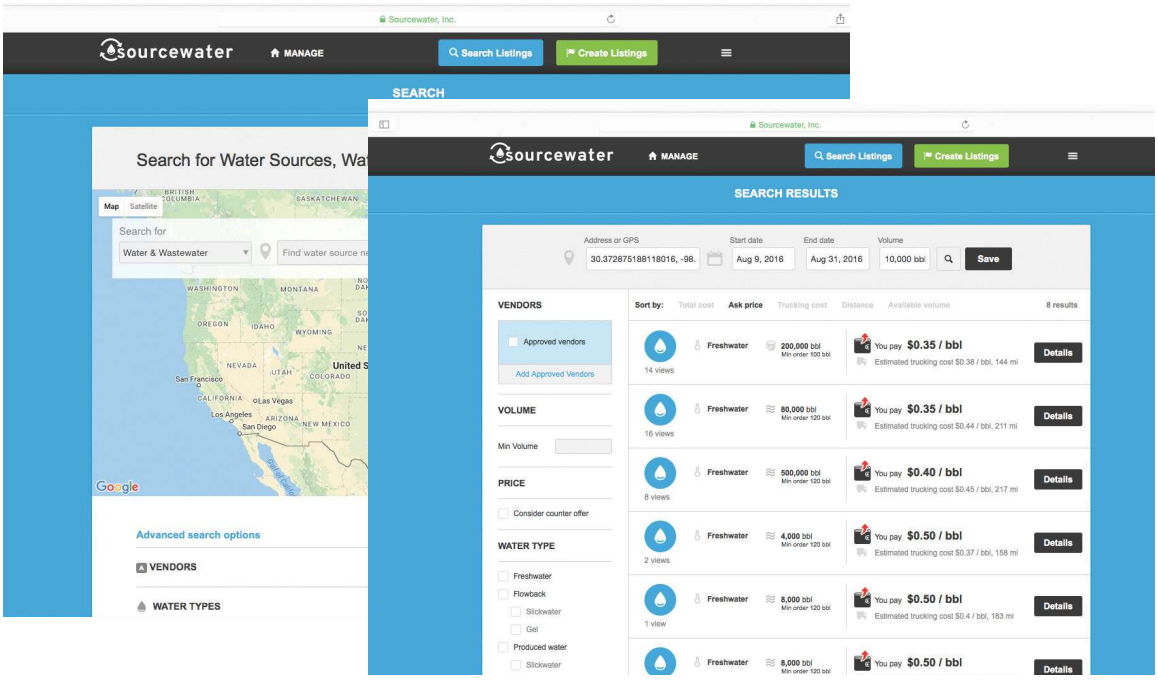

With the Sourcewater Online Marketplace, operators looking to sell water can create searchable listings so those looking to buy water can easily locate and compare options. *(Image courtesy of Sourcewater)*

"Most of what E&Ps spend in their operating budget—from half to two-thirds of the cost of producing a barrel of oil—is the cost of hauling and disposing of the produced water that comes up with the oil or gas," he said. "In Pennsylvania, the cost of disposing of a barrel of produced water can be as much as $20, and it's usually over $10. In the Permian the cost of hauling and disposal might only be $2 per barrel, but there's 100 times more produced water for disposal."

This conversation inspired Adler to search for solutions. "If the operators pay each other to recycle instead of dispose, they massively reduce the cost of completions by getting paid to reuse produced water instead of buying freshwater," Adler said. "That was the original inspiration, along with the realization that scheduling thousands of truckloads with dozens of vendors can take days of phone calls. By maintaining a real-time database of truck price, location and availability we can optimize regional scheduling logistics, eliminate downtime and help keep all trucks working with the shortest routes at the lowest possible cost. It's a lot like booking plane flights and hotel rooms online."

The energy price collapse in late 2014 brought operator attention to water management cost for the first time since the start of the shale boom, according to Adler. "Companies realized that if they wanted to stay in business in a world where oil is $30 to $50 per barrel, they had to figure out how to get their opex down. Shale production doubled opex per barrel, and all of the increase came from water logistics. That's where Sourcewater comes in," he said. "The benefit of having an online procurement system with real-time market data is that buyers save time and money every day while sellers eliminate downtime and lower cost per sale."

Unconventional collaboration

The oil and gas industry is known for playing its cards close to the vest when it comes to finding and developing prospective fields. The strength of programs like Digital H2O and Sourcewater are realized long after the field is found.

"Our perspective is that when it comes to water management for E&Ps, there's not a competitive aspect to it. After producers have secured their leases and begun drilling, it really is about collaboration," Wells said. "Operators should be willing to share as much information as possible related to water and upcoming activity because it's going to help them share resources and enable their suppliers to make better-informed investment decisions.

"Better decisions translate to lower operating costs. It really is a win-win for both producers and service companies alike. I do believe there is a growing awareness that the industry is better off collaborating when it comes to water." ■

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The Frack Crew Conundrum: When Will Activity Return?

The industry is on the path to more sand use but how to achieve that goal varies with commodity price forecasts.

By Todd Bush and **Brandon Waiter**
Energent Group

Recent increases in rig activity are a welcome and positive sign that the market is coming back. June 2016 started with level rig activity only to experience the largest increase in weekly rig count that the market had seen in a year. However, completion activity was continuing to fall as operators waited for higher sustainable oil prices.

Three common scenarios across the industry revolve around the price of oil: what happens if it stays in the $40s, what if oil stabilizes at or around $50 and how will companies react once oil rises above $51? Each of those scenarios will have a different impact on well stimulation services and on proppant consumption going forward.

Bear scenario at $48 and below: returns industry to 2015

If oil prices hold in the $40 range, completion activity will continue to decline in concert with depressed drilling activity. Operator budgets in 2016 reflect minimal levels of activity as management focuses on addressing large debt loads, which hampers field activity. Figure 2 displays the total debt of selected publicly held operators at the end of first-quarter 2016.

In this scenario, expect operators to sell additional assets and leases while those operators still active apply additional downward pressure on oilfield service pricing. For example, Memorial Production Partners announced the

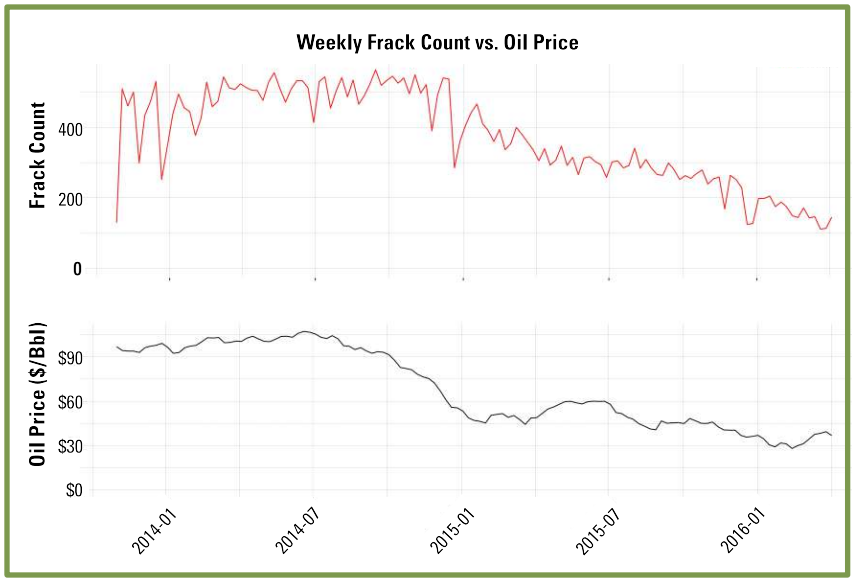

FIGURE 1. Frack count historically tracks the direction oil prices. *(Data courtesy of Energent Group)*

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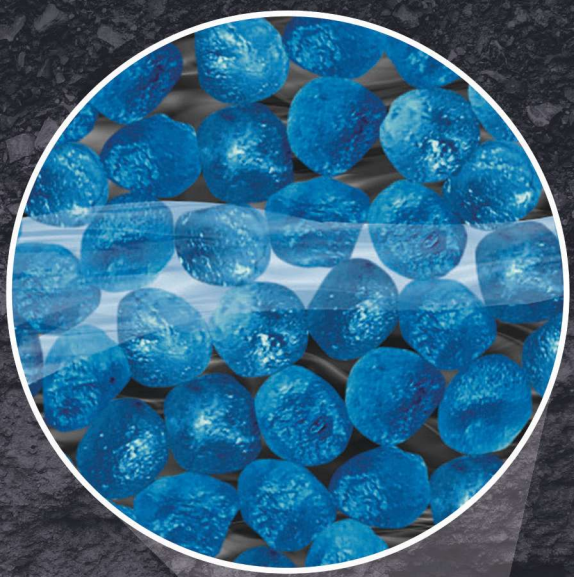

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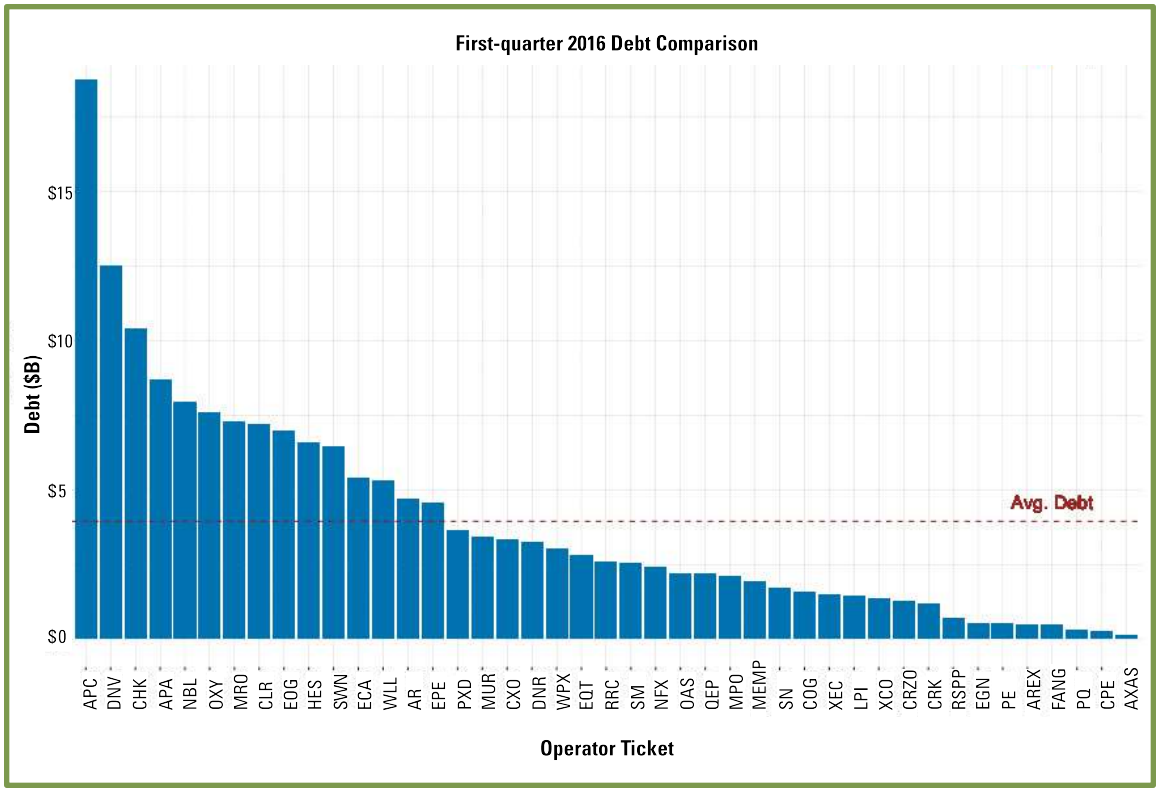


FIGURE 2. The total debt of selected publicly held operators at the end of first-quarter 2016 is shown. *(Data courtesy of Energent Group)*

divestiture of noncore Permian assets in June 2016. The acquisitions and divestitures market had begun to heat up in second-quarter 2016 as operators found buyers for noncore assets in the Permian Basin, Midcontinent and Appalachia. Under this commodity price scenario, operator pressure on oil service pricing will continue for frack crews and drilling day rates. Operators also will allocate work to smaller, regional service companies to retain buying power vs. the bigger service firms when the market improves.

Also, many sand transload facilities will remain full as demand and consumption slow. Even with higher intensity fracks and longer laterals, total demand for frack sand will decrease and pressure pumpers will continue to fight for work while awaiting higher oil prices.

In this scenario, rig and frack crews remain sidelined with little to no work. Drilling contractors limit hiring and focus on acquiring longer term contracts. Similarly, frack crews in each of the tight oil plays find little relief when oil prices are at this level. As of May 2016, there are about 12 to 15 frack crews in North Dakota.

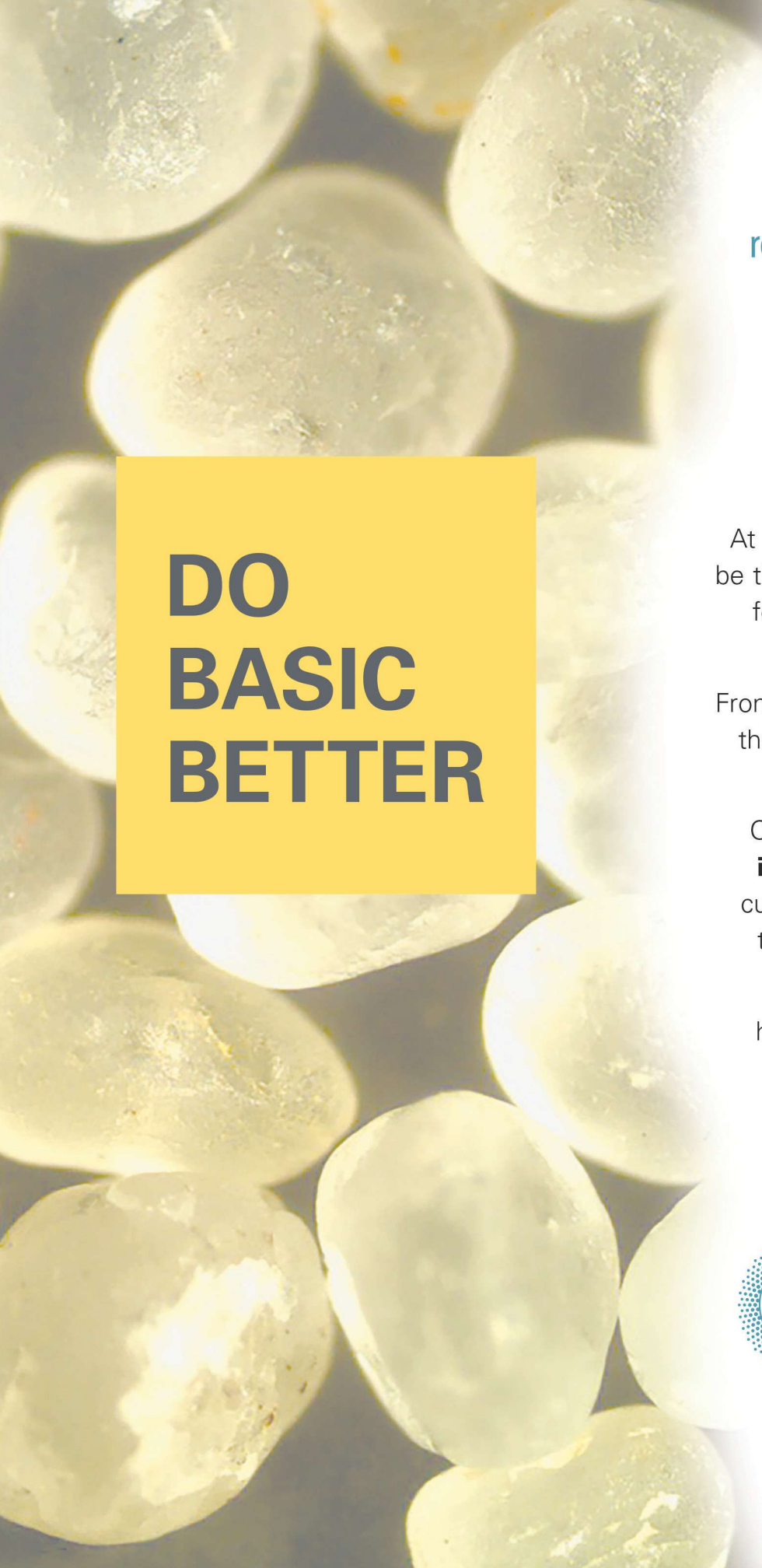
A market dichotomy is taking shape. The large public, global pressure pumpers continue to operate crews on razor thin margins or bundle frack services with other wellsite activities while smaller, regional pressure pumpers can no longer provide service at low oil prices.

Base scenario at $48 to $50: industry fights to find stability

Recent improvements in commodity price provide hope for oil service firms but need to be sustained for activity as a whole to come back. If prices can hold for several weeks at this level, operators will start to complete the backlog of drilled but uncompleted wells (DUCs) and look to add rigs to maintain production levels.

Several operators are profitable with oil prices in the $40 to $50 range with some able to earn attractive rates of return on new well completions. Still, many operators will tread water as they try to keep ahead of looming debt load while investigating alternative strategies like sales of noncore acreage. This oil price scenario holds oil services activity steady and allows operators to continue with planned budgets for 2016. Figure 3 shows the number of frack jobs across basins as a benchmark for steady state activity.

Suppliers and service companies alike start to prepare for increased activity with commodity prices in this range. How will suppliers ramp up activity? Will there be enough crews, and where will they be added? These are essential questions that the pressure pumping community will face when operators relax restrictions on activity budgets. At the same time, watch for operators to lock in today's service prices



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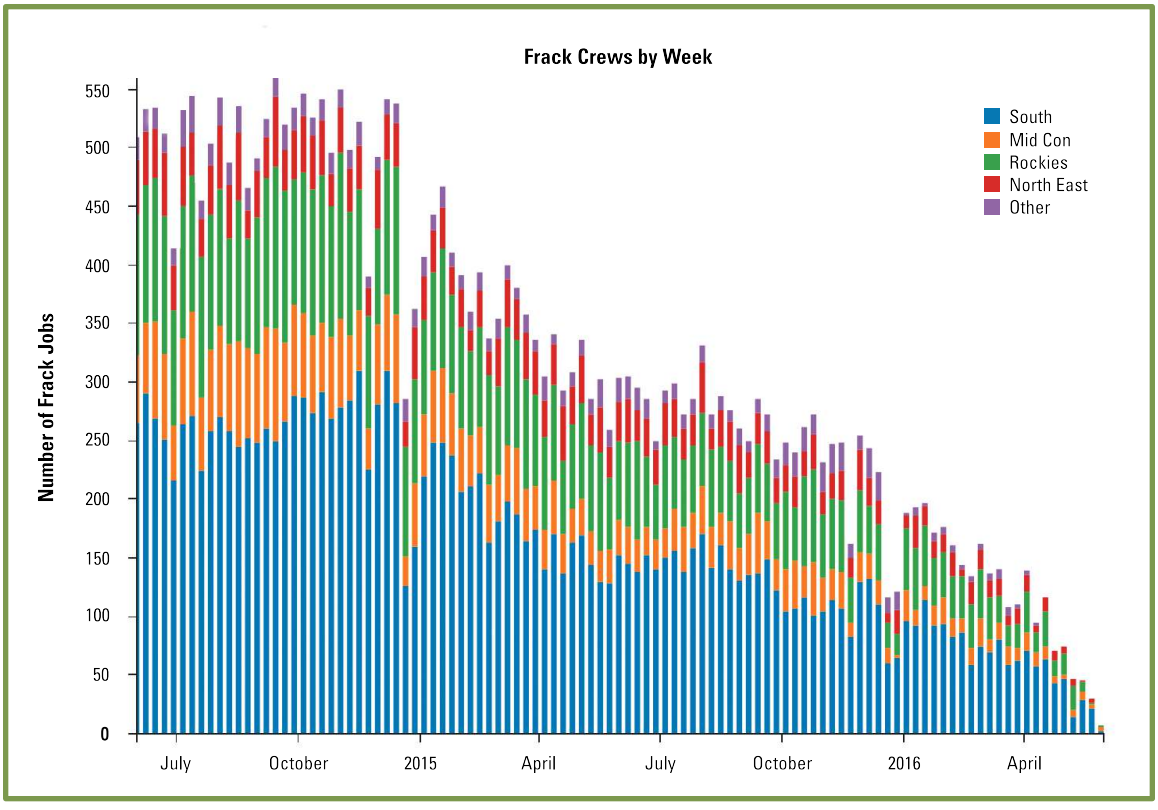

FIGURE 3. This figure shows the number of frack jobs across basins as a benchmark for steady state activity. *(Data courtesy of Energent Group)*

through longer contracts before pressure pumpers see increased demand.

Bull scenario at $51 and above: services see new demand

Evidence of how higher commodity prices will impact the completions market is evident from a couple of events. Continental Resources made headlines in June 2016 when CEO Harold Hamm stated the company is devoting frack crews to its uncompleted Bakken wells. According to Energent Group DUC data, Continental Resources added 146 uncompleted wells over the last two years. The rush to bring activity back will happen when oil prices rise above $50 on a sustained basis. Many operators will consider increasing budgets and adding drilling rigs. Operators with strong balance sheets already have built a foundation for ramping activity in second-half 2016. Completion activity will increase first as operators seek to open the valve and increase production while service pricing is still depressed.

Additional activity and commitments will impact the labor market for oil services. EOG Resources CEO Bill Thomas told investors during a first-quarter earnings call that $60 oil is required to restart the growth cycle. This growth cycle will require additional frack crews, though it is not clear at this point how quickly crews can be brought back. Estimates range from 60 days to 90 days and include a quick rise in capacity as well stimulation companies return to 24-hr workloads, but a slower ramp thereafter as operators must hire and train additional personnel.

Idled and abundant hydraulic fracturing horsepower is available across all basins; however, the limiting factor in the intermediate term will be crew availability. Higher oil prices bring stronger service demand and will attract talent back to the industry. Operators and service companies want to see sustained oil prices before making commitments to personnel and equipment.

Proppant market implications

Each pricing scenario has a different impact on the proppant market. At one end of the spectrum, oil prices remain low and pressure pumpers fight to stay afloat. At the other end, pressure pumpers struggle to meet demand from rapidly rising activity.

The proppant market in the bear scenario will remain oversupplied with pressure to reduce costs despite already low frack sand pricing. Many customers look to buy in-basin to reduce transportation costs. Evidence is available when reviewing tactical moves by companies like Hi-Crush Proppants LLC and

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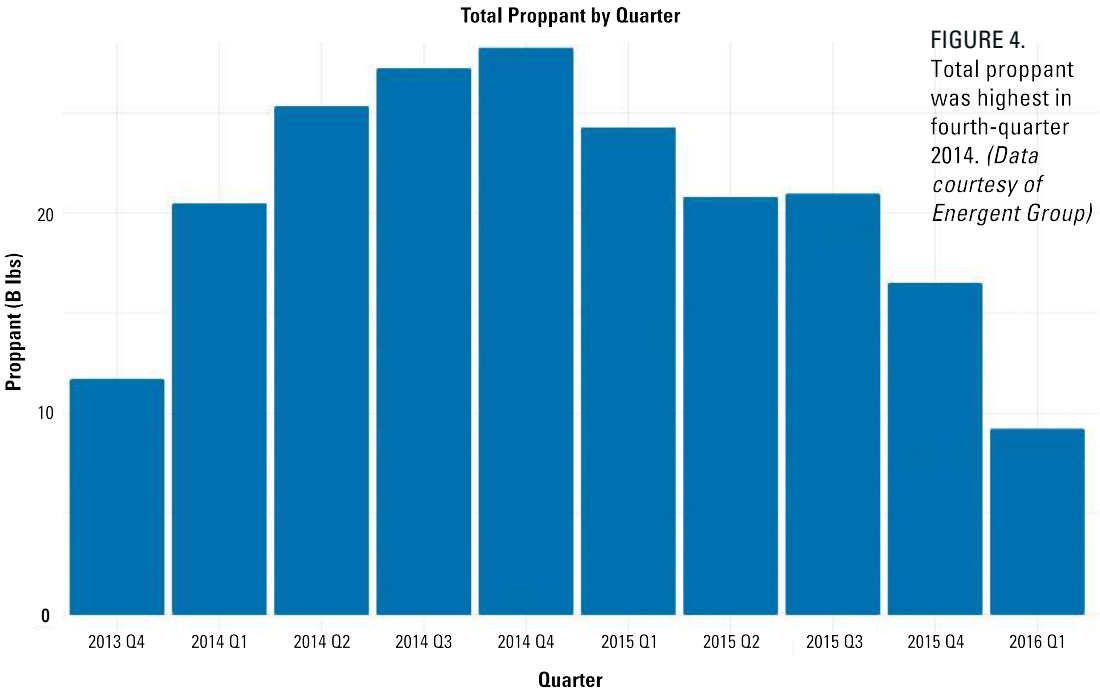

FIGURE 4. Total proppant was highest in fourth-quarter 2014. *(Data courtesy of Energent Group)*

Low-density Ceramic Proppant Boosts Utica Deep Gas Production

Contributed by CARBO

CONSOL Energy integrated CARBO's KRYPTOSPHERE LD ultraconductive, low-density ceramic proppant in the completion program of a well targeting the Utica deep gas horizon underlying its existing Marcellus Shale field in Greene County, Pa. As the well design called for a true vertical depth of 13,500 ft with a 6,141-ft lateral, the excessive downhole stresses required a proppant with maximum conductive strength and the capacity to increase propped fracture volume and sustain maximum production.

Compared to intermediate and low-density sand and conventional ceramic and bauxite proppant, the mono-sized KRYPTOSPHERE LD is designed to deliver high conductivity across the entire range of low- to high-stress well conditions.

The technology is designed to create a fracture with significantly more uniform pore throats, thus increasing the space for maximum hydrocarbon flow. The smooth proppant surface minimizes erosivity to protect downhole equipment during high-rate hydraulic fracturing operations, while the low beta factor minimizes non-Darcy flow effects to reduce pressure drop across the fracture.

The deep Utica well, which was completed in 30 stages at a rate of four stages per day, flowed at an IP rate of more than 61.9 MMcf/d in a 24-hr period, which at the time made it one of the Utica's highest producing gas wells. Furthermore, by employing this ceramic proppant, the operator eliminated the need for gel and crosslinked fluids, reducing overall completion costs.

Fairmount Santrol Holdings Inc. to move 5,630 rail cars into storage and delay delivery of previously ordered new rail cars as the capacity is not needed at this time. Hi-Crush has idled its Augusta, Ga., production facility and is only running its lowest cost plants.

With oil in the $48 to $51 range, proppant suppliers will work with operators to reduce costs while managing the size of rail car fleets. Operators already have moved away from more expensive products like ceramic or resin-coated proppants but are still using high-quality white sand. A few operators have moved to lower quality brown sand to reduce costs where they believe lower grade proppant will not hurt production.

As oil prices improve, demand for proppant will increase disproportionately due to the increase in proppant per well, which is now on average more than 3,000 tons per job. During the downturn, longer laterals and increased proppant per well partially offset the impact of DUCs and lower well completion counts across the U.S. The trend toward greater proppant loading per lateral foot is

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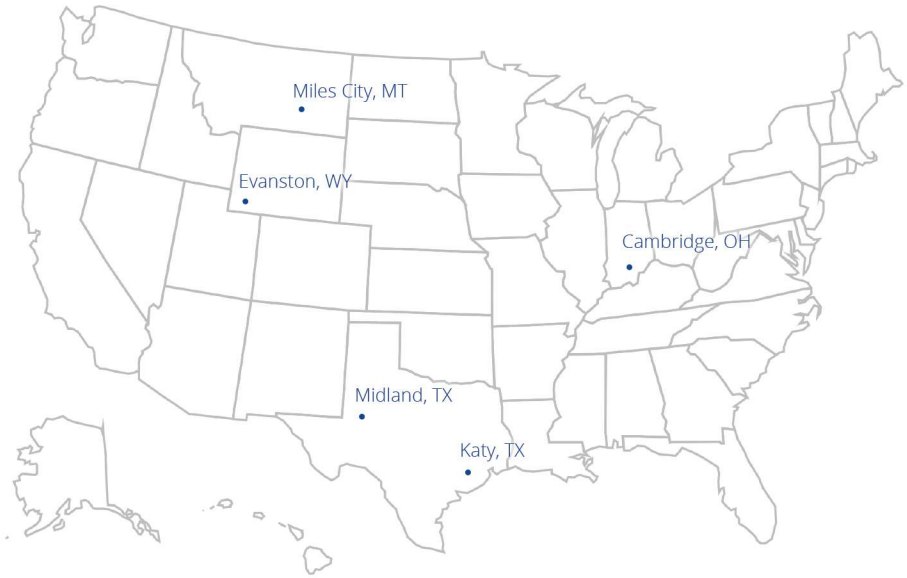

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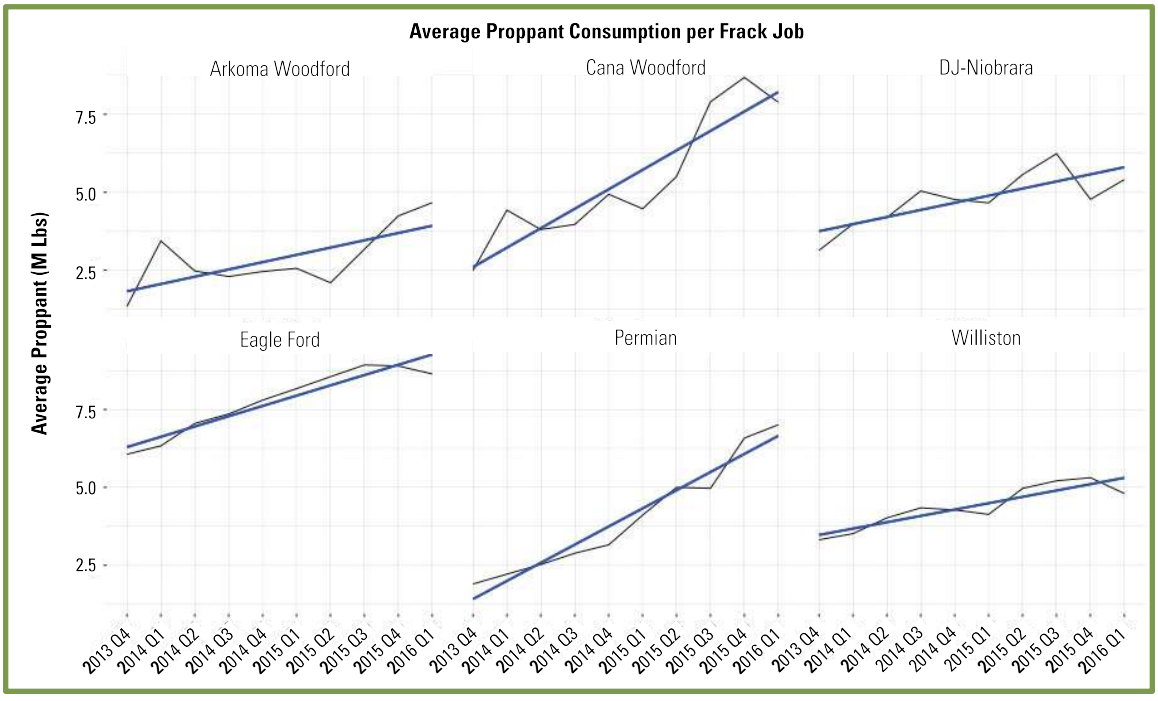

FIGURE 5. The average quarterly proppant consumption per fracture job is shown for various areas. *(Data courtesy of Energent Group)*

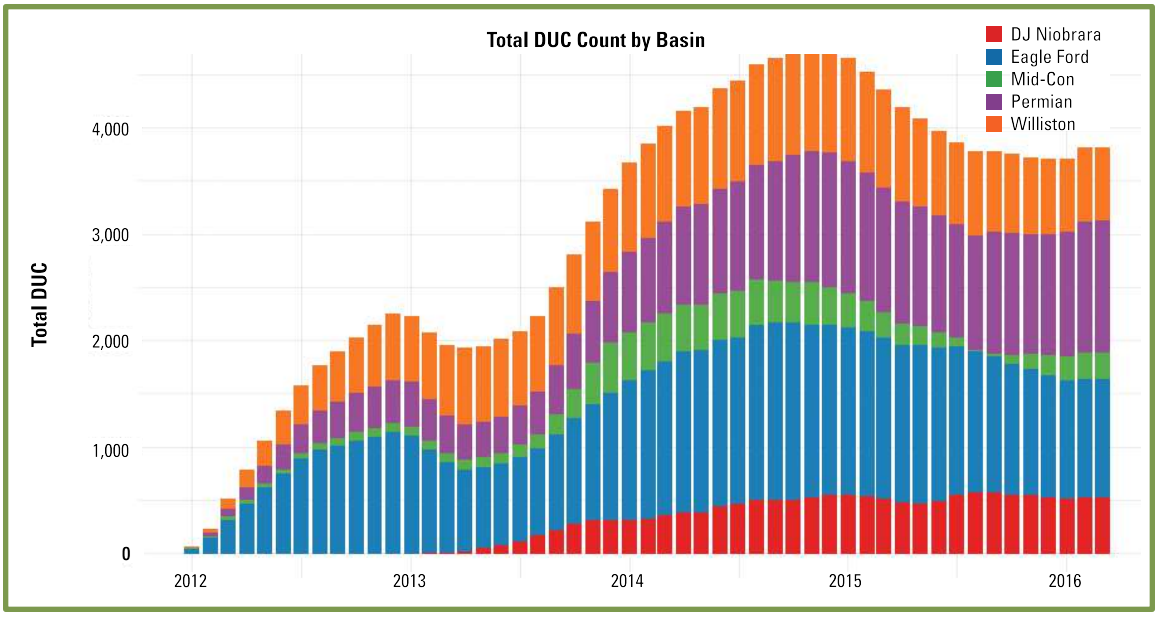

FIGURE 6. The total DUC count by basin has fluctuated over the years. *(Data courtesy of Energent Group)*

becoming standard across the industry in both oil and gas plays.

No easy answer: When will operators complete more wells?

Continental Resources' Hamm stated publicly that the market will see $60 oil by year-end 2016. At that point Continental will complete its DUC inventory waiting for additional stability in oil prices before bringing rigs back to work. Conversely, Pioneer Natural Resources Co. announced the addition of five rigs in second-half 2016 at current commodity price levels, adding $100 million to their 2016 budget. The two disparate outlooks indicate there is not a clearly definable answer to when industry well completion activity returns as each operator evaluates economics basin by basin through the lens of their individual financial, asset and company strategic outlook.

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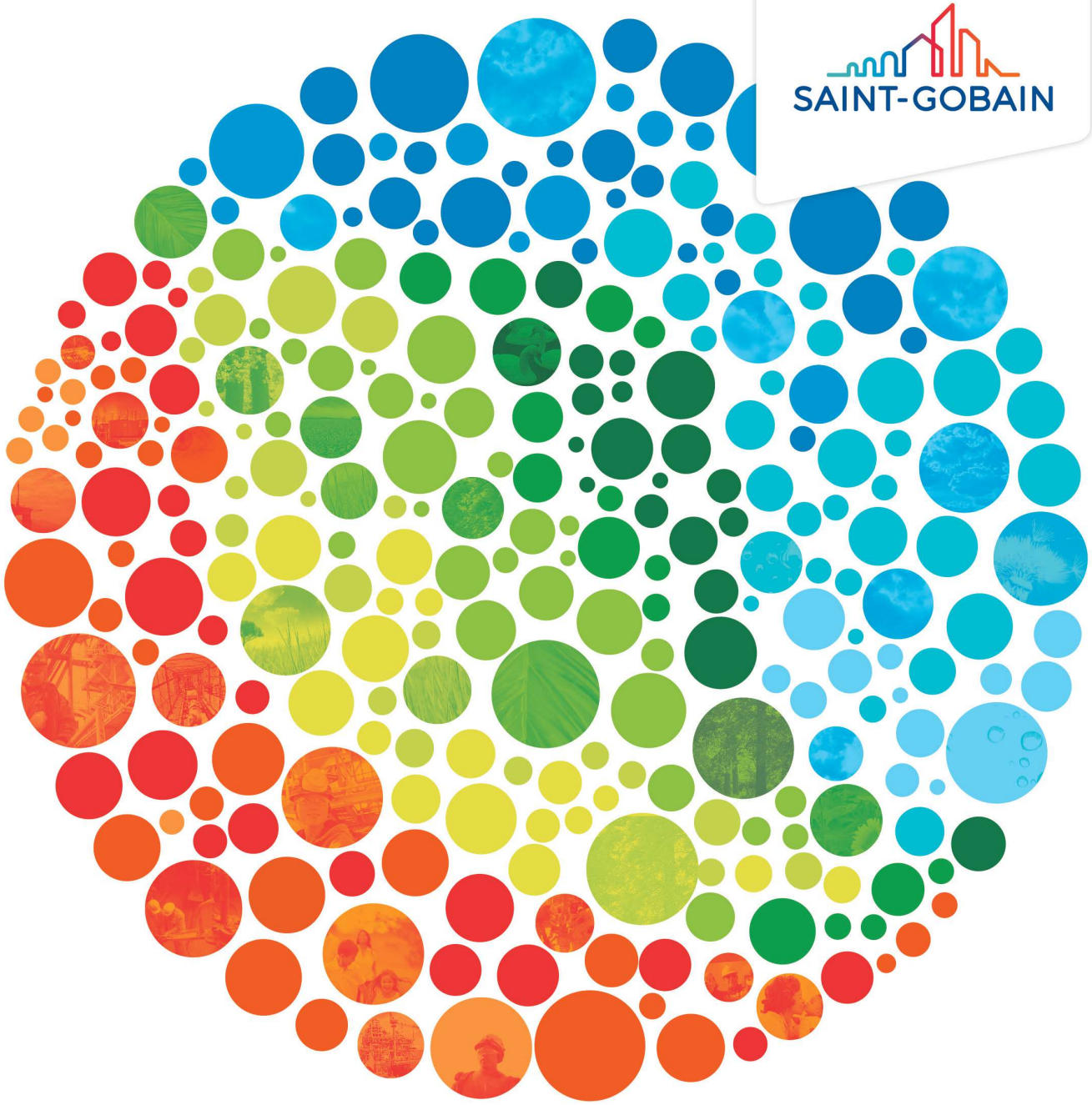

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DUCs have been a highly debated topic during 2015 and into 2016. Many operators have grown a large inventory of uncompleted wells that still need to be completed. It is assumed those wells will be completed first. The question is what impact will these wells have on production once they are brought online? Will the production gain create an oversupplied market? Or will the lower effective capacity in a service sector beset by an 18-month downturn act as a governor on how fast supply returns to the market?

As pricing improves, ample evidence indicates operators will draw down DUC inventories and fast-track completion activity to reap the benefits of an improved financial environment for energy production. Operators presume the crews and capital are in place on the completion side or can be activated quickly. The accuracy of those perceptions will not be clear until the long-anticipated rebound in demand for oil services places greater stress on proppant suppliers and well stimulation capacity. ■

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Rulings Targeting the Oil and Gas Industry Continue Despite Downturn

What happened in 2015 and first-half 2016 is a predictive indicator of what's to come as 2016 draws to a close.

By Martin T. Booher and **Alexander K. Obrecht**
Baker & Hostetler

Despite the continuing downturn in oil and gas markets, the promulgation of new federal regulations impacting the industry has disproportionately and obtusely boomed. The regulatory onslaught gained considerable momentum through 2015 with the completion of high-profile regulations aimed at hydraulic fracturing and the definition of "waters of the U.S." Thus far in 2016, the Environmental Protection Agency already has added to the high-profile list by publishing its final "methane" rule for new oil and gas sources. Hidden underneath these high-profile announcements, however, are many regulatory updates affecting the day-to-day operations of every facet of oil and gas development. As the Obama administration pushes to finish its regulatory onslaught before a new administration takes office, it is important to understand what happened in 2015 and first-half 2016 as a predictive indicator of where regulatory changes in a sure-to-be-busy second-half 2016 will head.

More than 1.5 million public comments were received before the BLM issued a hydraulic fracturing rule in March 2015, the federal government's first attempt to address fracturing on federal lands. The rule has been challenged in court. *(Image courtesy of* shutterstock.com)

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SELECT FINAL RULES

Methane rule

On May 12, 2016, the Environmental Protection Agency (EPA) issued its methane rule aimed specifically at emissions from oil and gas sources. Titled "Emissions Standards for New, Reconstructed and Modified Sources," the new rule updates the New Source Performance Standards in an attempt to curb emissions of methane and volatile organic compounds from new, modified and reconstructed oil and gas sources. Specifically, the rule mandates new monitoring technologies to limit unintended emission of methane during the production and transportation of oil and natural gas and requires new procedures, like periodic leak inspections.

As the industry digests the new rule, no legal challenge has yet been filed. But the significant economic costs compared to the speculative and questionable "climate-related benefits" will weigh heavily in counseling industry's decision to sue. Furthermore, industry could be motivated to pursue a legal challenge to the methane rule in hopes to stall early stage action by the EPA to develop similar regulations for existing oil and gas sources, which experts estimate will have a far greater impact on the industry.

Hydraulic fracturing

After a five-year regulatory development process that included more than 1.5 million public comments, the Bureau of Land Management (BLM) issued its long-anticipated hydraulic fracturing rule in March 2015. The rule marks the federal government's first attempt to specifically address hydraulic fracturing on federal lands.

The rule focuses on three areas: chemical disclosure, well integrity and wastewater storage. The rule requires operators to disclose the chemicals used in fracturing fluids on the FracFocus website within 30 days of completing a well, with limited exceptions to protect trade secrets. The rule also requires drillers to adhere to new standards for well integrity testing, including testing for pressure and cement returns. And the rule mandates strict storage requirements for fracturing wastewater before it is transported and permanently disposed of. This regulation does away with open-pit storage permitted in many states, although many companies already use aboveground tanks for wastewater storage and recycling.

The Independent Petroleum Association of America and the Western Energy Alliance immediately filed a lawsuit in the U.S. District Court for the District of Wyoming, challenging the BLM rule, in which a number of states and sovereigns later joined, including Wyoming, Colorado, Utah, North Dakota and the Ute Indian Tribe.

On Sept. 30, 2015, the district court granted a motion for a preliminary injunction, preventing the BLM from enforcing the rule. The district court concluded that the industry challengers had presented credible evidence that the rule lacked a rational justification and was not supported by substantial evidence. In addition, the court held that BLM likely lacks the authority to regulate hydraulic fracturing at all. The imposition of such a legally infirm rule, the court concluded, would likely result in irreparable harm to oil and gas operators on federal and Indian lands, which existing federal and state rules already protect from environmental harm.

Chemical additives are mixed with hydraulic stimulation on a completion pad in West Virginia. *(Photo by Mike Robinson, courtesy of Hart Energy's* Oil and Gas Investor)

Currently, the merits of the challenge are fully briefed before the district court and could be resolved as early as summer

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2016, subject to appeal. The BLM and special interest groups have also appealed the district court's preliminary injunction to the U.S. Court of Appeals for the Tenth Circuit. However, the appeal is unlikely to be resolved before the district court rules on the merits.

Clean Water Act: Redefining 'waters of the US'

In June 2015, following closely on the heels of the hydraulic fracturing rule, the EPA, in conjunction with the U.S. Army Corps of Engineers, issued a new definition to "waters of the U.S." under the Clean Water Act. Although not specifically targeted at oil and gas, the rule will have significant impacts on current and future development. The scope of the "waters of the U.S." definition is not limited to just federally controlled surface or minerals. The "waters of the U.S." definition instead applies to all operations everywhere.

incorporated into a number of programs under the Clean Water Act, among others: (i) the section 402 National Pollutant Discharge Elimination System permit program; (ii) the section 404 permit program associated with placement of dredged or fill material; (iii) the section 311 oil spill prevention and response program; (iv) the water quality standards and total maximum daily load programs under section 303; and (v) the section 401 state water quality certification process.

The agencies contend that the new "rule makes the process of identifying waters protected under the [Clean Water Act] easier to understand, more predictable and consistent with the law and peer-reviewed science, while protecting the streams and wetlands that form the foundation of our nation's water resources." The rule has four functional takeaways: (i) the rule applies everywhere; (ii) "waters of the U.S." does not require water"; (iii) jurisdictional determinations submit-

FOR OIL AND GAS COMPANIES, the lack of a consistent definition of "waters of the U.S." adds uncertainty to important aspects of planning and development.

The agencies' redefinition of "waters of the U.S." is the latest attempt to resolve a three-decade legal dispute over the scope of federal regulatory power under the Clean Water Act. In 1972, Congress passed the Clean Water Act, prohibiting (among other provisions) the discharge of "any pollutant to navigable waters from any point source." But while the Clean Water Act defines "navigable waters" as "waters of the U.S.," the act omits any definition of "waters of the U.S."

Since at least the late 1970s, the agencies have attempted to fill this statutory gap through controversial regulations. But legal battles over the meaning of "waters of the U.S." have proliferated in federal courts across the country, reaching the Supreme Court at least three times. Yet this litigation has provided little clarity.

For oil and gas companies, the lack of a consistent definition of "waters of the U.S." adds uncertainty to important aspects of planning and development. The concept of "navigable waters," which necessarily includes "waters of the U.S.," is

ted before June 2015 will likely be decided under the new rule (absent the preliminary injunction discussed below); and (iv) more sites will be categorically jurisdictional.

The "waters of the U.S." rule already has been the subject of successful legal challenges in courts around the country, primarily the U.S. District Court for the District of North Dakota and the U.S. Court of Appeals for the Sixth Circuit. In August 2015, the district court granted a preliminary injunction motion, blocking the EPA and Corps of Engineers from enforcing the rule within the 13 states that had filed legal challenges before the district court. Roughly five months later, the Sixth Circuit stayed the rule nationwide. The legal challenges will continue to wind their way through the judicial system, with a final resolution unlikely in 2016.

Tribal rights of way

In November 2015, the Bureau of Indian Affairs (BIA) published its final rule for rights of way

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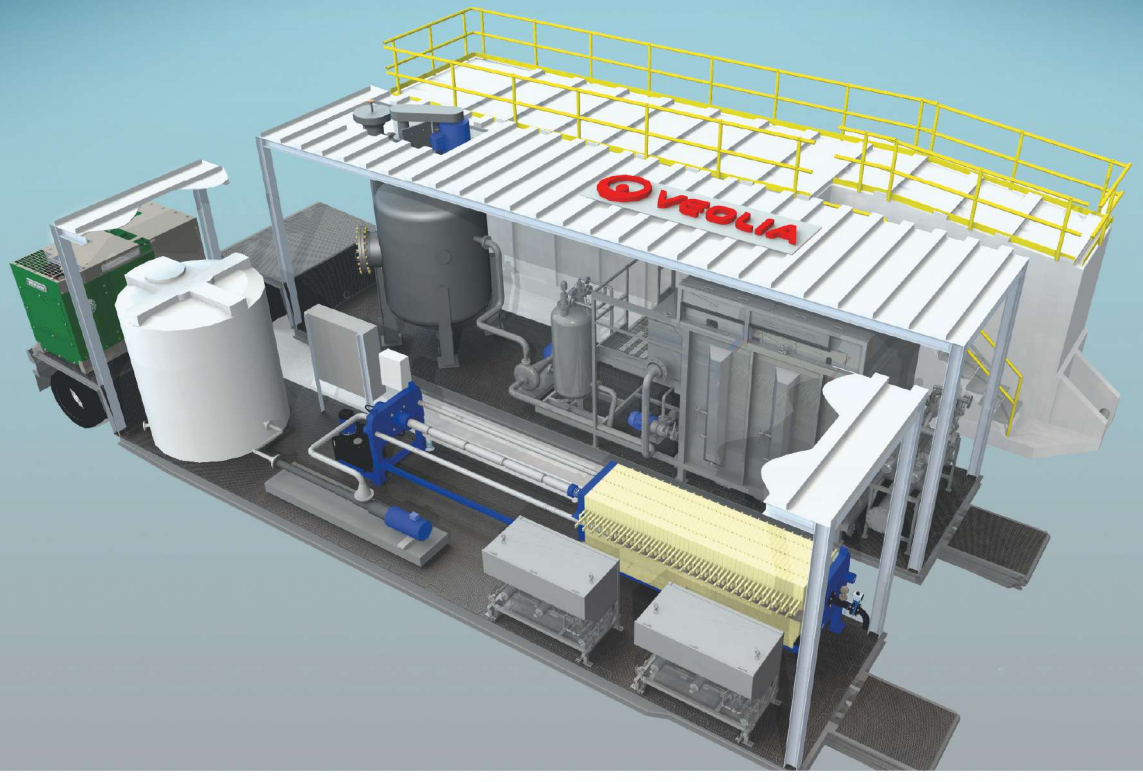

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on Indian land. The rule will not only affect oil and gas development on Indian lands, like the construction of roads, gathering systems and lease infrastructure, but the rule also will affect transmission lines, phone lines and railroads, among others.

Of primary concern to companies that must obtain rights of way, the rule gives tribes and Native American landowners more power to negotiate compensation and terms. But the rule also removes requirements for lessees to obtain BIA permission to conduct surveys before submitting an application for a right of way and imposes shorter deadlines on the BIA.

The BIA's rule was challenged by industry groups in the U.S. District Court for the District of North Dakota. In April 2016, the district court denied the industry group's motion for a preliminary injunction. The rule is currently in effect.

SELECT PROPOSED RULES

Royalties, rentals, bids, bonding and civil penalties

In April 2015, the BLM published an advanced notice of proposed rulemaking, soliciting input from stakeholders on updates to BLM's regulations on royalty rates, annual rental payments, minimum acceptable bids, bonding requirements and civil penalty assessments.

BLM issued the advanced notice of proposed rulemaking to address concerns raised by the Government Accountability Office and the U.S. Department of the Interior's Office of Inspector General through a number studies from 2007 to 2013. In large part, the studies recommended specific actions for the BLM to take to ensure the federal government receives a fair return on federal minerals. Relative to ensuring a fair return, the BLM requested information to help it consider the impacts of increasing the royalty rate, rental rate and minimum bid amount for competitively auctioned federal leases.

But the advanced notice of proposed rulemaking also contains provisions targeted at bonding and civil penalty requirements. Relative to bonding, the BLM seeks input on the adequacy of bonding levels, last updated in the 1960s, for individual, statewide, nationwide and unit operator bonds. In regard to civil penalties, the BLM requests information about the effectiveness of the current civil penalty levels in encouraging regulatory compliance.

Although a proposed rule has yet to be issued, BLM's advanced notice or proposed rulemaking foreshadows an increase in the government's take, in other words, an increase in operating costs for oil and gas companies. The magnitude of that increase, however, remains unclear.

Onshore oil and gas operations

From July to October 2015, the BLM published three separate proposed rules for certain onshore oil and gas operations, specifically onshore orders 3, 4 and 5. With the proposed updates to Onshore Order 3, the BLM hopes to properly measure the amount of oil and gas produced from federal and Indian leases. The proposed rule includes updates to facility measurement points, site facility diagrams, the use of seals, bypasses around meters, documentation, recordkeeping, commingling, off-lease measurement and the reporting of incidents of unauthorized removal or mishandling of oil and condensate. The proposed changes to Onshore Order 4 update oil meter technology, measurement documentation, recordkeeping requirements and penalties associated with measurement errors. The proposed changes to Onshore Order 5 updates gas measurement at production facilities.

Taken in isolation, any one of the three updates might seem relatively innocuous. In fact, that was one of the major complaints lodged by industry groups against the proposed rules. The trifurcation of the proposed rules disregard the proposed updates to operational infrastructure, sets unrealistic timelines for making such updates and underrepresents the true economic and regulatory impacts as the onshore orders are inseparably intertwined. Considered with the additional oil and gas regulatory updates, the revisions to the technical aspects of onshore orders 3, 4 and 5 are, in reality, anything but innocuous.

Venting and flaring

In February 2016, the BLM published a proposed rule on venting and flaring on federal and Indian lands, which contains several requirements that, if enacted, will significantly impact operations. Phased in over three years, the rule would impose a monthly flaring limit of 1,800 Mcf per well and compel operators to capture, flare, use or reinject

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gas released during well completion and production operations.

The proposed rule would prohibit operators from venting gas in most situations and disallow operators of new wells from purging emissions into the atmosphere. It would require operators to replace high-bleed pneumatic controllers with low-bleed controllers and pneumatic pumps with solar pumps. Moreover, the regulations would mandate that operators use "best management practices" when unloading liquids from existing wells, capture or flare gas vented from all storage tanks that vent more than 6 tons of volatile organic compounds per year, and use infrared cameras to survey producing sites for emissions at least twice annually.

The proposed rule already has drawn vociferous criticism from the industry. Aside from disagreement with the numerous new technical requirements, the rule sits on a shaky foundation. A central question will be whether BLM has the regulatory authority to regulate air quality and emissions. With fundamental questions striking at the heart of the proposed rule, the BLM is unlikely to escape the rulemaking process without a lawsuit.

Conclusion

Since April 2015, the EPA and the U.S. Department of the Interior have issued 49,226 pages of proposed rules. These proposed and final regulations will have lasting negative economic and operational impacts on future oil and gas development. Although legal challenges to final regulations have been increasingly successful and might continue to be effective, some of the rules will nonetheless take effect. As second-half 2016 expires, 2015 to 2016 will likely go down as the busiest two years in federal oil and gas regulation. But before 2017 comes, currently pending regulations will likely be finalized, providing one more opportunity for the current administration to kick the industry while it is down. ■

Major Oil and Gas Regulatory Timeline 2015-2016

Following is a list of several of the regulations affecting the industry. It is not all-inclusive and excludes offshore regulatory updates and wildlife-specific regulations that might affect oil and gas operations.

2015

March 26
Bureau of Land Management issues final rule for hydraulic fracturing and well construction on federal and Indian lands.

April 21
BLM issues advanced notice of proposed rulemaking for potential updates to royalty rates, rental rates, minimum bids, bonding, and civil penalties for federal and Indian leases.

May 8
PHMSA and Federal Railroad Administration issue final rule for transportation of crude oil by railroad.

June 29
EPA and U.S. Army Corps of Engineers issue final rule that redefines "waters of the United States" under the Clean Water Act.

July 13
BLM issues proposed rule updating Onshore Order 3, affecting facility measurement points, site facility diagrams, the use of seals, bypasses around meters, documentation, recordkeeping, comingling, off-lease measurement, and the reporting of incidents of unauthorized removal or mishandling of oil and condensate.

October 13
BLM issues proposed rule updating Onshore Order 5, affecting gas measurement at production facilities.

October 26
National Park Service issues proposed rule for permitting and planning for private oil and gas development within National Parks.

November 19
Bureau of Indian Affairs issues final rule for rights-of-way on Indian lands.

2016

February 8
BLM issues proposed rule for venting and flaring on federal and Indian land.

March 10
EPA announces preliminary steps to develop new regulations intended to reduce methane emissions for existing oil and gas sources.

March 25
Occupational Safety and Health Administration issues final rule for exposure to crystalline silica.

April 8
PHMSA issues proposed rule for safety of gas transmission and gathering pipelines.

May 12
EPA issues final rule for methane and volatile organic compound emissions from new, reconstructed and modified sources.

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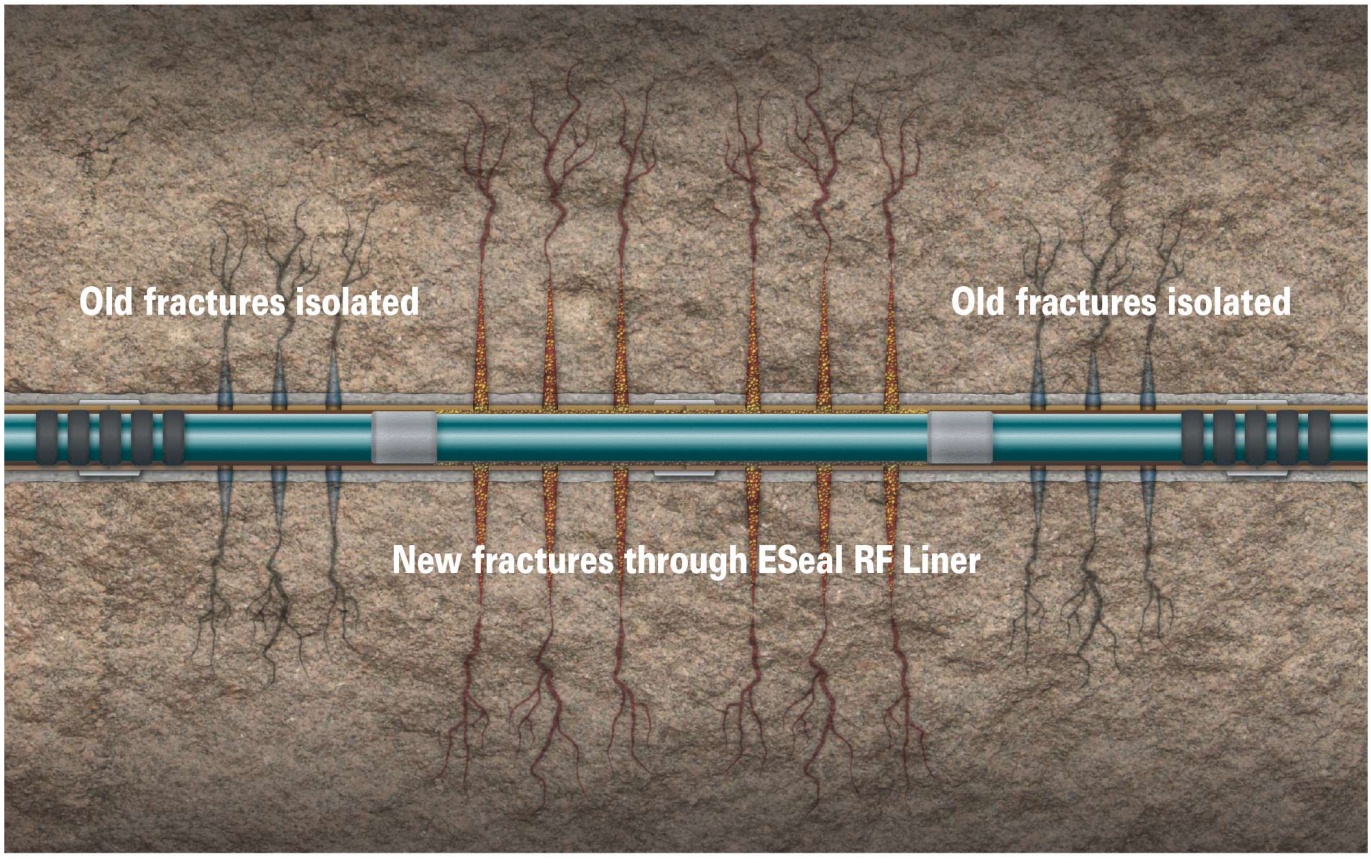

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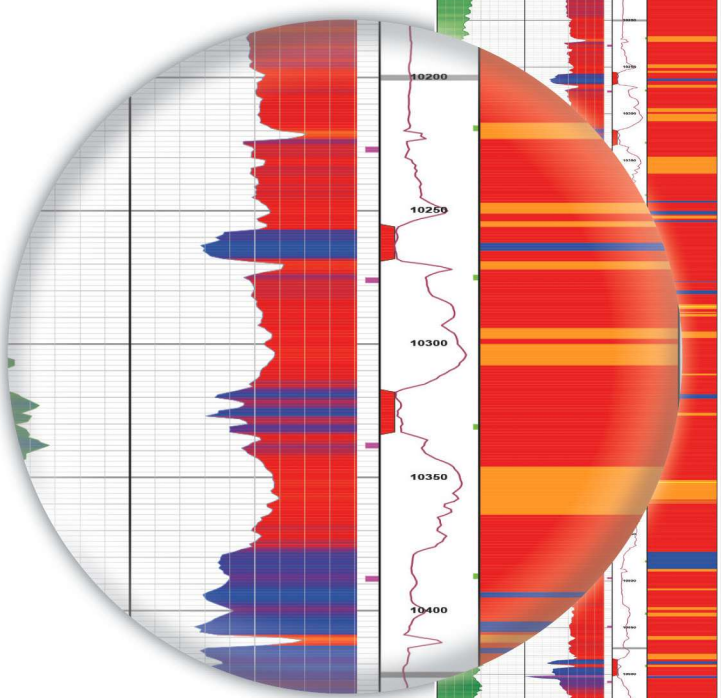

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