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The 2015 Techbook

A supplement to *E&P*

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The 2015 Hydraulic Fracturing Techbook is the eighth in a series of techbooks in which Hart Energy will provide comprehensive coverage of effective and emerging technologies in the oil and gas industry. Each Techbook includes a market overview, a sample of key technology providers, case studies of field applications and exclusive analysis of industry trends relative to specific technologies. **To learn more about E&P technology trends, visit *EPmag.com*.**

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Eclipse Resources conducted a three-well, interlateral spacing test on its Sawyers pad in the Utica Shale in Monroe County, Ohio. Halliburton performed the hydraulic fracturing on the three wells. (*Photo by Mike Robinson, courtesy of Hart Energy's* Oil and Gas Investor, *June 2015*)

Technology Strategies Keep Increasing EURs in Shale Plays

During this downturn, operators are more willing to use new hydraulic fracturing technology than in previous oil-price declines.

By Scott Weeden
Senior Editor, Drilling

Earth models, stacked plays, dissolvable balls and plugs, 110 stages per lateral, slick water, more sand, less sand, parallel well pairs, refracturing, delaying completion until prices go back up—the list of hydraulic fracturing strategies for surviving the oil price downturn keeps getting longer. There are almost as many strategies as there are companies.

Some of the more successful strategies are contributing to keeping production near its peak or lessening its decline. How do operators deliver improved production in the face of those lower costs? The answer is by focusing on technology, saving time, decreasing costs and reducing risks.

"There's a huge upside in driving efficiencies in our industry. One thing I think we sometimes overlook is effectiveness of our existing completion practices. Driving costs down is only part of it. Our goal is to move those cumulative curves up as well," said Dan Themig, president and CEO, Packers Plus Energy Services, speaking at Hart Energy's DUG Permian Conference on May 20.

What operators are doing "is looking at new technologies to achieve better conductivity to the wellbore and have the assurance that they have fully stimulated the formation at every point of injection," said Joe DeGeare, president USA at NCS Multistage.

Even in a down oil-price environment, some service companies are seeing increased demand for their products, especially rotary steerable systems (RSS) and dissolvable balls and plugs. One company was adding staff and seeing an increase in demand for the latter during first-quarter 2015. Those are examples of technologies providing the efficiencies and effectiveness that operators are demanding in a down market.

Uncertainty rules in frack markets

Estimates ranging from 1,500 to 5,000 wells that have been drilled but not yet completed indicate the size of the inventory for operators waiting for prices to turn around. Although that number could have a profound impact on putting pressure-pumping crews back to work, it also could have a detrimental effect by keeping drilling rigs on the sidelines longer.

At the beginning of June 2015, Rystad Energy estimated there were about 3,850 wells waiting on completion (WOC) in the Bakken, Eagle Ford and Permian Basin plays. Up to 35% of those wells were drilled seven to eight months ago, according to the company's June *Shale Newsletter*.

To counterbalance production decline in these three plays from the wells WOC, about 500 wells per

FRACK-ISOLATION TOOL STRING is pulled from the well after finishing an 80-plus-stage completion.

(Photo courtesy of NCS Multistage)

month would have to be fracked and completed—if no more wells are drilled. At that rate the current WOC inventory would maintain production through year-end 2015.

Rystad also noted that, depending on market conditions, the production growth trend could quickly be restored with current drilling activity of 500 wells per month and 250 wells completed from the inventory.

Another aspect of increasing production is by fracking and completing wells more effectively and efficiently. The operators and service companies are finding ways to increase EURs.

Refracking remains niche market

There are some companies and plays (mostly earlier ones) that have benefited from refracturing. Although the technology sounds attractive, other operators prefer drilling and completing wells in identified sweet spots.

"It worked a decade ago in the Barnett Shale because the original wells were completed so poorly. There have been a handful of experiments in the Haynesville, but this is pretty much a small niche factor in oil and gas," said Richard Mason, chief technical director at Hart Energy.

"The technology of diverting fluid, while improved, still leaves a lot to be desired. My sense is operators are instead pushing things like geosteering to keep the lateral in the very best rock window [drilling effectiveness] as a way to improve the results of the fracture stimulation process, shortening the distance between stages and increasing the amount of perforation clusters to get better near-wellbore penetration (completion effectiveness)," he said.

Several companies have said that it is very difficult to sell management to commit money to refracturing. "There is too much risk on throwing good money after bad. They would rather drill the next well and get it right. With the growing focus on net present value, it is going to take a significant change in sentiment among the people pulling the trigger for recompletions to amount to anything more than a single digit percentage of oilfield activity," Mason said.

However, some companies are being proactive about refracturing. In the second-quarter 2015 earnings call on July 20, Jeff Miller, president at Halliburton Co., said, "We've entered into a memorandum of understanding with BlackRock Inc. to provide up to a half-billion dollars in capital over the next three years [to fund recompletion and refracturing operations.] Although a rather small market today, we believe this market has significant potential in the coming years."

> **"WE'VE ENTERED INTO A MEMORANDUM OF UNDERSTANDING** with BlackRock Inc. to provide up to a half-billion dollars in capital over the next three years [to fund recompletion and refracturing operations.] Although a rather small market today, we believe this market has significant potential in the coming years."
>
> *—Jeff Miller, President, Halliburton*

"Although a rather small market today, we believe this market has significant potential in the coming years," he continued. The funding will allow Halliburton to perform candidate selection, execution and best-in-class returns while BlackRock will provide opportunities to its clients.

Addressing refrack technology issues

NCS Multistage has approached life-of-the-well issues with its MultiCycle frack sleeves. "When we started looking at the life of the well, that's when we came out with the MultiCycle sleeve, which frees

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Halliburton engineers monitor hydraulic fracturing operations on a job in West Texas. *(Photo courtesy of Halliburton)*

operators from having to frack from the toe to the heel in sequence. This gives operators several options during completion and also during production and refracks or recompletion," DeGeare said.

One completion option is called shift-frack-close, which deals with sand (proppant) management. The sleeve is closed immediately after fracturing. "This lets the fracture heal while the sand is held in place. After formation stresses equalize, we open all the sleeves with little or no sand flowback. We've taken some operators from producing 15 to 20 tons of sand per well after stimulation to basically producing no sand," he said.

Another completion option involves stress shadowing. When an operator moves from one stage to the next, at times there is difficulty in getting the next stage broken down. The sleeve allows the operator to skip over the next stage, which leaves enough time for the first fracture to heal and relieve the stress. They can then come back to that stage and fracture it.

During production the biggest advantage is zone-by-zone wellbore management. The MultiCycle sleeve allows the operator to use coiled tubing to shut off water zones and depleted zones. The sleeve has proven effective in managing horizontal waterflood operations in Canada.

The MultiCycle frack sleeve also offers options for future refracks or recompletions. Operators can close the sleeves to re-establish wellbore pressure integrity so that fracturing energy can be focused for maximum effectiveness.

"We had one operator that doubled the sleeve count for the initial completion then opened and fracked every other sleeve. When he gets ready to refrack, he plans to close all the original sleeves, and then open and frack the sleeves in between one at a time with the goal of contacting a lot of unstimulated rock," DeGeare continued.

More sand

Whiting Petroleum Corp. has been testing larger sand volume completions across its acreage in the Williston Basin. Production from enhanced completions in its Polar, Walleye and Pronghorn fields has outperformed wells completed with

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The PowerDrive ICE rotary steerable system is being prepared for running. The RSS enables standard drilling operations in reservoirs with extreme temperatures. *(Photo courtesy of Schlumberger)*

lower sand volumes, according to a July 17 operations update.

Sand volumes ranged from 4 MMlb to 6 MMlb, and well costs were from $6.5 million to $7.5 million.

In the Polar Field, the enhanced completions resulted in 40% productivity increase. Two wells were completed with slick water and higher sand volume in Williams County, N.D. On average, these wells had 60-day rates of 935 boe/d, which was higher than 12 offsetting wells.

A 50% increase in productivity was recorded from two enhanced completions in the Walleye Field, also in Williams County. On average, these wells had 60-day rates of 1,095 boe/d, which were more than three offsetting wells.

Finally, the enhanced completions at the Pronghorn Field also registered a 50% increase. Whiting completed nine of the high-volume sand, slickwater wells in Stark County, N.D., that have at least 120 days of production. On average, over that period these wells flowed 755 boe/d, outperforming 42 offsetting wells completed with lower sand volumes. Because of the increased productivity, the company moved a drilling rig back to the Pronghorn Field.

Earth model refines frack design

The first producing well in the Permian Basin was stimulated with nitroglycerin in July 1920. The thousands of wells that have been drilled since then provide a huge database of cores, well logs and production logs—just the kind of treasure trove of information that Laredo Petroleum thinks will pay off.

The company is applying some technology that is more than 25 years old—the earth model. The data collected from wells on the company's more than 140,000 acres will soon pay off.

"We think that the earth model has potential if you look at what we've done consistently to maybe have as much as a 15% to 20% production increase in EURs," Laredo Petroleum CEO Randy Foutch said July 8 during an Independent Petroleum Association of America luncheon. "A 10% increase in the EUR level translates into exactly a 10% increase in rate of return."

With about 70 inputs from various datasets, such as whole and sidewall cores, production tests, openhole and cased-hole logs, production logs, fluid quality, rock brittleness, fracturing network and lithology, Laredo is applying its earth model for the standard wellbore, landing-point selection, geosteering, frack design and spacing, frack barriers and lateral lengths.

Foutch said the company sees the earth model as a value catalyst. Laredo has drilled enough wells and gathered enough data to provide something that is economically meaningful. "We're really driving down our capital efficiency to where $50 to $60 is pretty nice," he said.

Early data were generated from about 900 vertical wells, he explained. "We decided early on to get high-quality logs on every one of those wells. We would drill a well, but instead of comingling and fracking it, we would perforate, frack and produce one zone. We did that dozens of times. I think we've got a lot of ways to increase our value."

Laredo Petroleum said it has identified about 4.3 Bbbl of resource potential at more than 7,700 locations.

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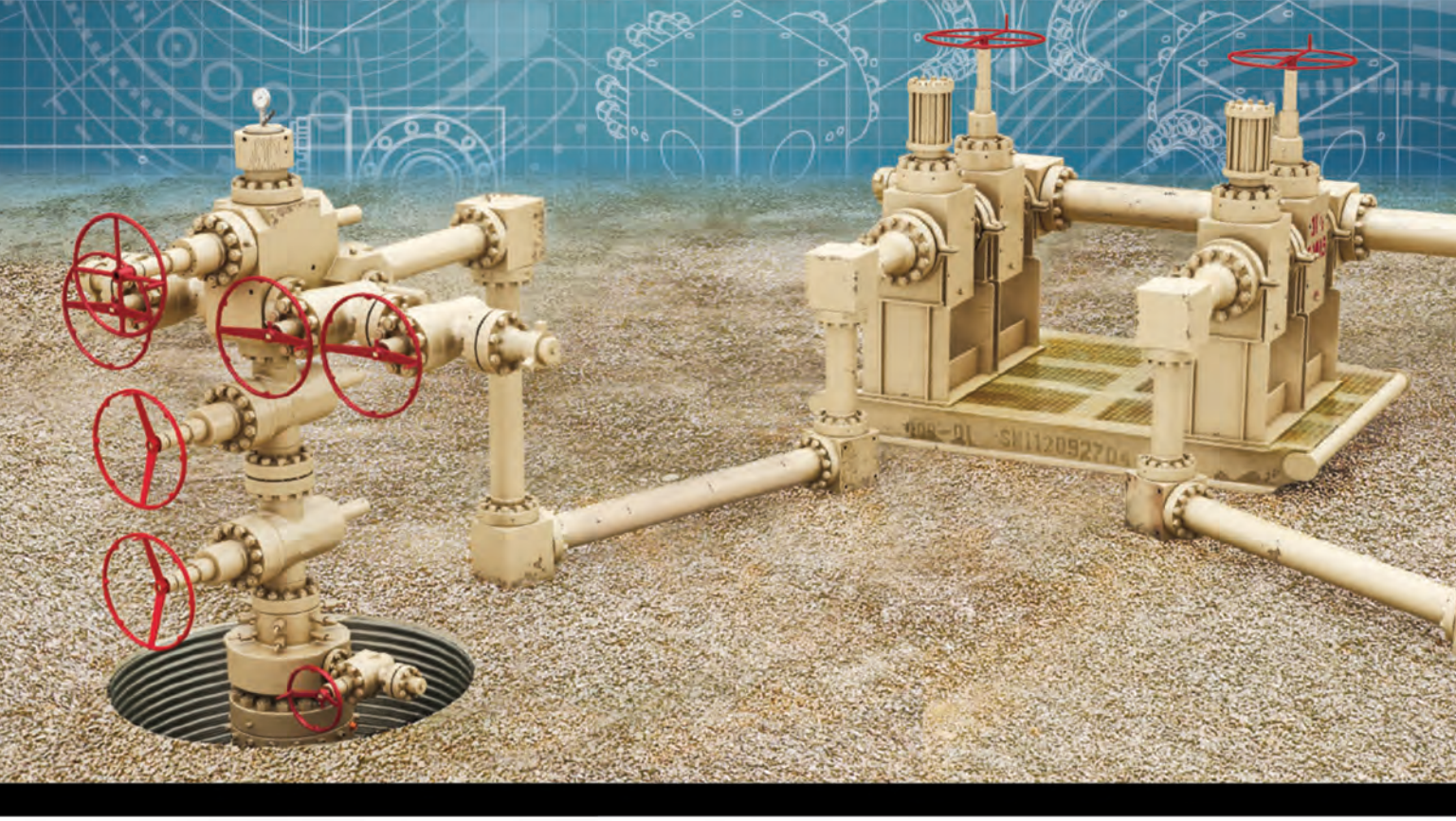

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Reducing well interventions

Magnum Oil Tools worked to develop a dissolvable plug for hydraulic fracturing. In 2012, the company brought its experience in zonal isolation to the table, partnering with Kureha Corp. and using the latter's unique material to develop a dissolvable line of completion tools. In March 2013, Magnum launched the first of these products, which was called the Fastball—a dissolvable frack ball for sliding-sleeve completions, explained Garrett Frazier, director of sales and marketing at Magnum Oil Tools.

On the heels of the Fastball's introduction, further R&D resulted in the release of the Magnum Vanishing Plug (MVP), a dissolvable frack plug used in plug-and-perf (PNP) completions. The MVP eliminated the plug drill-out process, enabling operators to save significant time, money and risks associated with well intervention.

The high-volume gravity-fed rapid sand deployment system, called Sand Storm, reduces particle emissions onsite. *(Photo courtesy of Calfrac Well Services)*

"Instead of waiting for coiled tubing [CT] to drill out the plugs, clean out the well and then take it to production, all an operator has to do is pump that last frack, change out the frack valve on location to a production tree and send the well straight to production," he explained.

"This is certainly a step-change technology. We just released it in October 2014. We're still in a hiring mode in that service department to satisfy all the demand," Frazier said.

"Thousands of stages per month are still being fracked even in this downturn, and operators are looking for significant ways to optimize their operations," he continued.

Other service companies also count on the reduction of CT milling operations. Baker Hughes combined its SHADOW series frack plug, a permanent millable plug that can be left downhole during production, with its IN-Tallic disintegrating frack balls.

These frack balls are made of controlled electrolytic metallic nanoconstructed material, which is a technology pioneered by Baker Hughes. The balls hold pressure during fracturing operations and then disintegrate when exposed to produced fluids.

Schlumberer introduced its dissolvable PNP system in February 2015. In this system both the frack balls and seats are fully degradable. Called the Infinity system, the company designed seats instead of plugs to isolate zones. Both dissolve once the ball and seat assemblies come in contact with completion fluids.

The technique eliminates lateral length restriction, which maximizes reservoir contact and EUR, and it greatly reduces intervention-related risks and costs, the company said.

Halliburton's Completion Tools introduced its Illusion dissolvable frack plug as the latest addition to Halliburton's Unconventional Completion portfolio. This frack plug provides zonal isolation for pumpdown applications during wellbore stimulation and combines Halliburton's frack plug designs with the dissolvable metal and rubber materials.

Forty stages in 24 hours

On the efficiency side, how quickly can the completion work be accomplished? NCS Multistage completed an 87-stage well in the Powder River Basin in Wyoming for Devon Energy Corp. in less than one

hour per stage. All the fracks were single-point injection, using NCS Multistage's CT frack system. The company set a record with 40 fractures in 24 hours with an average of 36 minutes per stage, DeGeare said.

Casing sleeves were run and cemented as part of the production casing string. The frack-isolation tool was run on CT to open each sleeve—in a single CT run.

"When compared with PNP, which was used on nearby wells, we saved them several days of work," he added.

With this technology, NCS Multistage also reduced the footprint of the frack spread by reducing the required horsepower on location by about two-thirds. "With our system, when we're done with the frack the well is ready to produce without any drillouts. We're saving operators several days by putting production online more quickly," he continued.

Fracture complexity with parallel laterals

In the Montney Shale in Canada, Painted Pony Petroleum Ltd. was the first Canadian operator to use openhole, multistage, ball-drop completions, which improved the company's productive capability by more than 40% compared to completion systems used earlier.

Painted Pony didn't stop there with applying innovations. Themig of Packers Plus asked, is it possible to generate complexity in the reservoir using methodologies that can cause the rock to fracture differently than from a single point of fracture?

Themig described one new technology being used by Painted Pony to produce complexity as rapid execution strategy, pointing out that Painted Pony improved its type curve from 5 Bcf to 13.5 Bcf in the Montney play. This process is just starting to develop and does have an influence on rock mechanics.

"It uses stress shadowing to influence the second well by what has been done in the first well. It only works if it can be rapidly deployed. This is an example of one of the basins where extensive work has been done on this. Painted Pony started with a baseline type curve of around 5 Bcf. The company had 40 wells completed with cemented plug and perforation, which is a pretty good baseline," he said.

The company has done a lot of microseismic and has some really good science behind the method. "Using this methodology, they have been able to develop three to four times the number of microseismic events during fracturing. They've had microseismic arrays on all their wells," he said.

The method involves drilling a pair of parallel horizontal wellbores. The area between the laterals is what Painted Pony calls the stressed area. "They rapidly do all the stages from one to 30 on the left-hand lateral, leave the well shut in with no flowback and try to fully stress the fairway between the laterals. They immediately begin to fracture the right-hand lateral. They are not trying to zipper frack these. They are trying to get the fractures to collide with each other," Themig continued.

Painted Pony has been using this methodology for one and a half years to two years. The improvement on the type curve has been significant to the changes in their reserves.

"This was used in one of the fields in the Montney Shale. Of all the wells in the area in 2014, 11 of the top 15 producing oil wells and 12 of the top 15 producing gas wells were openhole completions done by Packers Plus," he emphasized.

Part of the execution to make sure all stages were fractured includes a diagnostic system that provides real-time data during fracturing. Packers Plus called its system ePLUS Retina. "It is hooked up to a computer that does diagnostics on data we collect. We are able to detect downhole when seats are open, when balls land and even when we don't see the pressure signature. We've been able to detect nearly 100% of every event we've monitored," Themig said.

"One intriguing thing to me is being able to detect on-the-fly in real time where there is complex fracture development and where there is planar fracture development. That potentially means being able to adjust frack stages on-the-fly, focusing on better quality rock to deliver more new reserves," he explained.

This type of technology can impact the bottom line. "In an example of a field where the ePlus Retina was utilized along with some other methodologies, we were able to take their cost curve and move it from about $2 million per completion to $1.1 million per completion. In a fairly short time (2013 to 2015), we reduced their costs by almost 50% on this," Themig said. ■

Matching Drillbits to RSS Boosts Long, Single-run Laterals

Longer laterals, more stages and closer spacing tighten demand for pressure pumping services.

By Scott Weeden
Senior Editor, Drilling

Smooth lateral boreholes, lower torque and drag, higher build rates, greater exposure in pay zones—who wouldn't like rotary steerable systems (RSS)? As a matter of fact, a lot of operators prefer RSS to mud motors or RSS with mud motors. The market for RSS is steadily growing in a variety of applications both onshore and offshore.

Baker Hughes introduced RSS in 1997 and has drilled more than 100 million feet of hole since then. Schlumberger began its RSS service in 1998, and to date its total is more than 204 million feet. Weatherford has drilled 289 wells in U.S. shale plays in single runs (vertical/curve/lateral) totaling more than 2.5 million feet.

"It's been a steady increase for the last 10 to 15 years. RSS are taking over a bigger portion of the directional drilling market. Globally the share is over 50% of that market," said Jim Tilley, product manager for RSS, Sperry Drilling, a Halliburton business line.

"We can see the ratio of RSS to mud motors in general in the industry growing every year because at the end of the day we are showing time savings and better performance with RSS. The overall well construction cost is improving with this technology," explained Cesar Figueredo, product champion for RSS, drilling and measurements at Schlumberger.

"RSS is going toward a commodity rather than a luxury. One thing we haven't seen in the industry downturn is a downturn in the application of RSS. In fact, if anything, we've probably seen a bit of an upturn. Even though activity is down, if people are going to drill a well, they want to drill them as efficiently as possible. They are turning to RSS for that," said Daryl Stroud, research, development and engineering director for steerable systems at Weatherford.

Robert Osborne, sales manager at Double Barrel RSS, pointed out that RSS create efficiencies, depending on the rotary steerable packages available. "RSS get you true concentric holes, meaning less torque and drag, lower friction, less key seating and fewer wiper trips. You should be able to get all your casing and completion tools to bottom with less downtime and fewer issues."

At the same time RSS have been encroaching on the market for mud motors, the technology has continued to expand RSS capabilities. "Baker Hughes introduced its RSS in 1997 as a commercial product. Since then we've added multiple generations of services. Once such a technology is on hand, the applications follow as we find out what it can do," said Rene Ritter, product line director, directional drilling, with Baker Hughes.

One of the factors that has slowed the implementation of RSS is the higher cost than mud motors. All of the RSS manufacturers are addressing that challenge.

"There is a big driver out there for RSS companies to get the costs out of these tools. Ten years ago these tools were really seen as a high-end technology solution. Even though that is still true, our clients are demanding more and more efficiencies out of us," Stroud continued. "They're looking to us to get the costs out not just in terms of capital costs of the equipment but also repair and maintenance costs so we can be more competitive and make it more economic for more applications."

For a new RSS being introduced by APS Technology, "we tried to insure that it was a very simple design that is easy to operate, simple to use and simple to repair. We try to make sure we cover things with the RSS like good dogleg performance, high reliability and low-cost of ownership, which comes from simplicity," said John Clegg, vice president, drilling products, at APS Technology.

Osborne added, "I think the one barrier to entry for any rotary steerable company is the value proposition—making the economics favorable. It comes down to whether or not we can make them understand the true value that a RSS is providing."

RSS technology has yet to reach its limits. With the promise from real-time data from LWD/MWD suites, combined RSS and mud motors that can produce up to 400 rpm at the bit, 360-degree formation imaging and being able to look ahead of the bit, returns on drilling and production from RSS can be even greater.

OPERATORS ARE BEGINNING TO WANT TO COMBINE MUD MOTORS WITH RSS TOOLS. Weatherford's Revolution RSS would do the steering and the motors would provide the horsepower near the bit.

(Image courtesy of Weatherford)

Hole quality boosts completion

In terms of completion, hole quality is very important. With RSS there are a lot of benefits that impact hydraulic fracturing, including a smoother, better quality hole; higher build rates getting to the curve; drilling longer laterals; better log quality and LWD formation response; lower torque and drag; and better hole cleaning, said Tilley.

"We're able to go in and drill a high dogleg curve and drill the lateral in one run. It helps economically in these applications to do all that in one run. With a motor, you might drill the curve, then trip out and change the bend and motor to drill the lateral," he explained.

Sperry Drilling has several projects underway. One is to increase the dogleg capability on its current platform. The company currently is at 12 degrees per 100 ft, which covers the vast majority of work for RSS, he continued. The company will be pushing that higher with its current system and in the next generation RSS.

For a performance improvement, the company added gamma ray to its slim RSS. "You're able to have near-bit formation sensors that help with the geosteering. We've got a gamma ray that is 3 ft above the bit. It can enable you to respond more quickly and stay in the best zone. We also have near-bit inclination that can allow much faster response in terms of geosteering so the placement of the well is much more accurate," he continued.

For high-temperature areas like the Eagle Ford, the company's SOLAR services Geo-Pilot XL RSS has an electronics system that works in temperatures up to 347 F and 30,000 psi rating. "We have the Eagle Ford and most U.S. applications covered with that capability," he added.

One of the most important parts of optimizing the RSS is by matching the bit design to the RSS. The bit has an impact on directional performance, penetration and vibration. Matching the bit to the RSS is one of the key points in improving ROP, reducing vibration and improving steerability.

"We're moving toward next generation systems that improve reliability and simplify design for overall better performance and reduce the cost of the system," Tilley said.

Higher temperature RSS

Schlumberger's most recent tool is the PowerDrive ICE UltraHT RSS, which is the only tool available for temperatures up to 392 F, Figueredo said. "Under these conditions, we can do the same work previous generations did in non-ultra HT [high temperature]. We can do the work in high temperature without doing anything special like stopping drilling to cool down the BHA [bottomhole assembly]."

There are two main components to the design—the electronic controls and mechanical section, which is right on top of the bit. The electronics are a completely new design with all of the components mounted on a ceramic substrate and encapsulated in inert gas, which makes the ICE UltraHT Drilling services fully functional at 392 F, he said.

The mechanical design features metal-to-metal seals that are engineered to improve the reliability in extreme downhole environments. This part is very similar to what the company has used for almost two years commercially with the PowerDrive Orbit RSS, which was the most recent launch before PowerDrive ICE RSS.

For its future development, Schlumberger is focused on improving reliability since the industry is facing more challenges in going deeper in wells and further in laterals.

"We are focused also on automation in general. For example, using the multi-axis hole inclination and azimuth, which is very accurate. We're putting in the algorithms to drill precisely the tangent in automatic mode. The system works with a closed loop to drill the tangent, whether it's vertical, the deviated tangent or the lateral tangent," Figueredo said.

"We are looking for ways to continually incorporate more and more automation to make it more efficient," he added. "The RSS technology also allows customers to get the best from the LWD by being able to define good quality images needed for formation evaluation and well placement."

Drilling at 400 rpm

When it comes to RSS in shale plays in the last few years, the industry has completely changed the way those wells are drilled. "When we first got involved with some of these applications, we used to drill the 8½-in. hole for the curve and then used a 6-in. or 6⅛-in. hole size for the lateral. Since the advent of RSS

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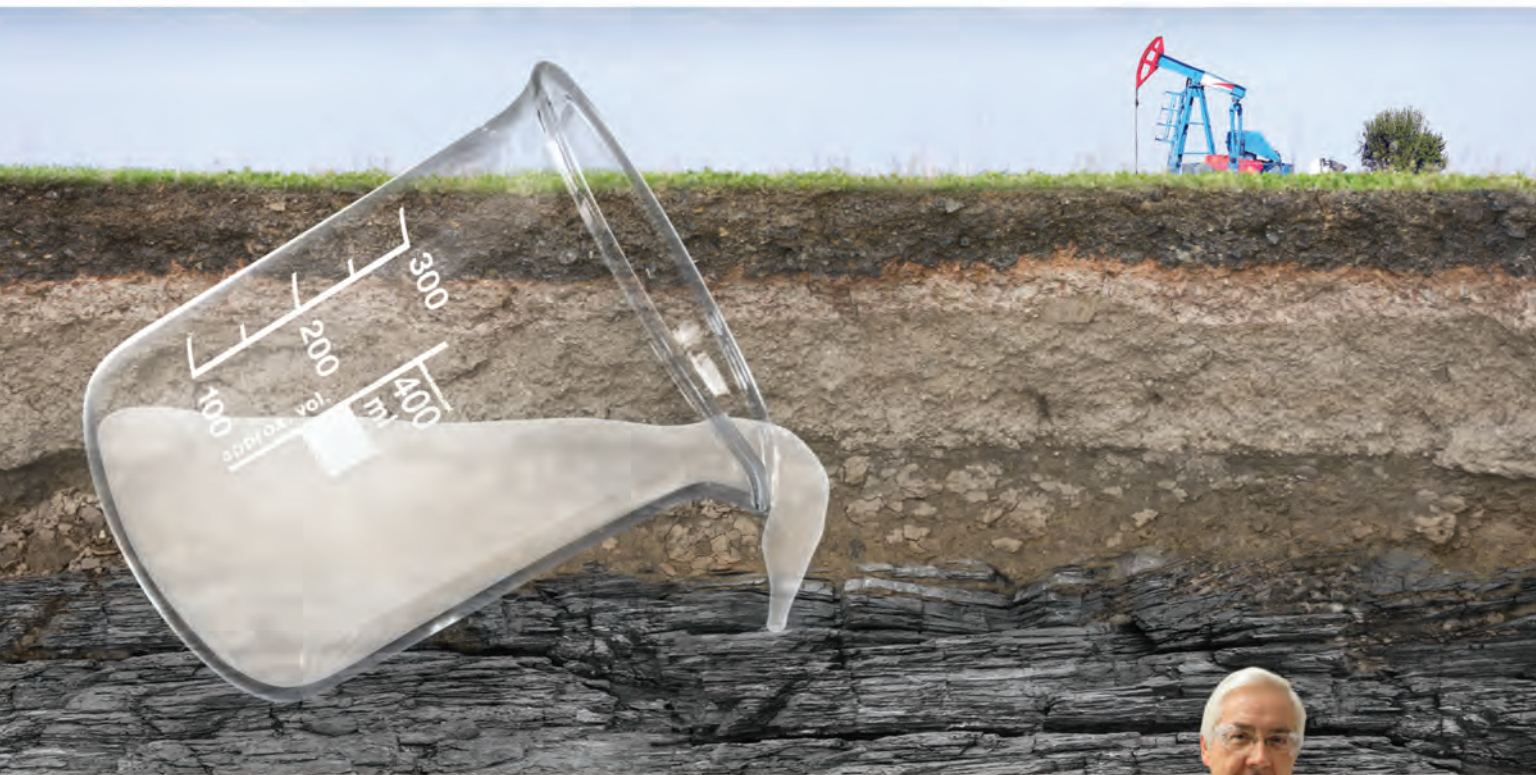

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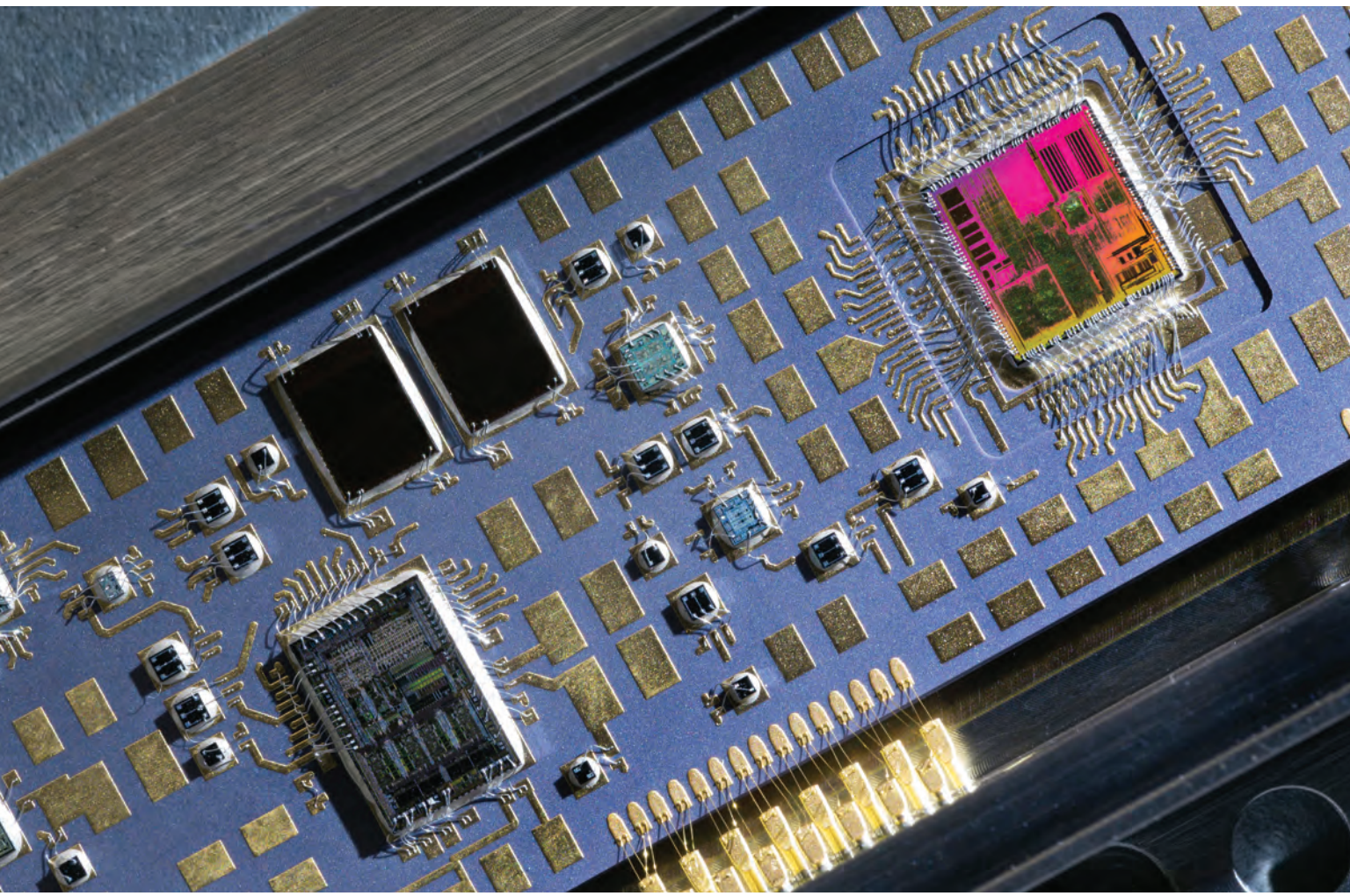

The ultraHT-rated electronics in the PowerDrive ICE RSS service were fully functional after 2,000 hours of testing at more than 392 F. *(Image courtesy of Schlumberger)*

in that application, we drill the whole vertical section, curve and lateral in the same hole size to complete the well in basically one run," Stroud said.

RSS also changed the way operators approach well planning. "Obviously while drilling such a high quality borehole, we're able to drill farther and farther laterally, giving the operators a bigger hole section in the pay zone. When you talk about fracking that wellbore, it really shows the importance of RSS in that market," he continued.

The limits for applications of RSS have yet to be reached, he said. For example, in drilling doglegs, "in some of the more shallow applications, we don't have RSS that can drill 15 degrees per 30 m [100 ft] and that has kept that part of the market firmly with mud motors," he said.

For deeper formations, "we've always had tools that could do 10 degrees [per] 30 m. We now have a tool that can reach 16 degrees [per] 30 m dogleg severity," he added.

Operators are beginning to want to combine mud motors with RSS tools to get the best of both worlds. The Revolution RSS would do the steering and the motors would provide the horsepower near the bit. One of the limitations before on RSS tools was how fast the tools could rotate since the rotation was being provided from the surface. Customers are continually pushing for higher performance in the tools. The string rotates at 120 rpm to 130 rpm, and the motor is adding another 100 rpm or more. "We've even had inquiries for rotating the RSS at 400 rpm," Stroud said.

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In drilling faster in one run, the drillbits have to keep up with the RSS technology. "We need to have bits that can cope with that kind of rpm and ROP. At the moment, I'd say the bits are a little bit ahead of RSS in terms of being able to cope with high rpm," he added.

Lateral is most technical section of hole

RSS technology is going to continue to push into the curve with higher build rates. Then the technology will go farther in the lateral, "which I think is by far the most technical section of the hole where you could potentially need resistivity as well as other forms of downhole measurements of the mechanical push that RSS provides," Osborne said. "I see technology pushing farther down the hole, but I think the lateral is where the most technology is needed and the most need exists."

Double Barrel's RSS tool is built in a single, 23-ft collar with integrated real-time direction and inclination, and bulk gamma. The tool is available in 6½-in. and 6¾-in. sizes, which accommodate 7⅞-in., 8½-in. and 8¾-in. drill sizes, respectively.

"We're launching a second-generation electronics package that will help with more reliability, which translates to increased battery life on the bottom that allows our customers to stay in the hole longer," he explained. "It's not necessarily a battery enhancement, it's more an electronics enhancement. The new electronics will run more efficiently and reliably, and therefore will take less battery power."

The new electronics also will increase the system's temperature capabilities. "We're currently rated at 150 C (302 F), which is the shutdown temperature. The new technology will increase the tool into the 160 C (320 F) range (operational)," he said.

The company has seen some vibration-related issues. Double Barrel has had success with a mud motor running on top of the tool to reduce string vibration.

The company has been active in southern Oklahoma and the Rockies. However, Osborne pointed out that operators in other areas are continuing to push the length of laterals. "The Eagle Ford will be the next basin that pushes the envelope to 2,134 m to 2,439 m (7,000 ft or 8,000 ft). I think that in the Permian, operators will be pushing farther and farther as the rigs gain more experience, and technology is introduced into the market."

The RSS market will continue to grow. He noted that Double Barrel's advantage is that it is a small, lean organization that has the expertise and adaptability to compete favorably.

Reducing borehole uncertainty

There are three main factors that involve RSS: wellbore placement, wellbore quality with real-time information, and drilling efficiency. Baker Hughes' Ritter explained that wellbore placement in a fast and accurate way comes with RSS. "Wellbore placement increases formation exposure for production after placing the wellbore in the sweet spots.

"Wellbore quality is very important because a smooth wellbore makes everyone's life easier later in the completion program," he said. Another benefit of RSS when it comes to quality in the unconventionals is being able to avoid induced fractures. Balanced drilling is beneficially done with RSS because of the wellbore quality related to subsequent production.

"Between the drilling and fracturing processes, you don't want to waste time. With RSS, you have the chance to do the logging in place, and the real-time telemetry is very sophisticated. When it comes to logging, we provide 360-degree, high-resolution images," he continued.

Drilling efficiency with RSS is faster and has multiple applications. The returned drilling responses and the ability to impact the steering ability in real time are added benefits. In the Utica Shale, the curve in a well was drilled at 17.56 degrees per 100-ft inclination. "Yes, that happened. But most of the demand from operators for the last two to three years is 15 degrees," he said.

With RSS, an operator can position the wellbore and overcome the "ellipses of uncertainty" in real time. "If I start drilling, I know where the wellbore will be over the next couple of hundred feet, but much less certain for the next 2,000 ft. Over longer distance, every degree of inaccuracy is a multiplier to uncertainty and thus to the apparent risk distribution," Ritter explained. "RSS has the ability to correct well paths and complete adjustments in real time, which is why RSS is so very essential for long laterals."

The SureSteer 475-rss can be operated from the surface top drive or the downhole SureSteer 675-rsm. *(Image courtesy of APS Technology)*

Bit selection is critical for RSS performance. When Baker Hughes started making RSS, it left the bit selection up to the operator. "For the last three systems we launched (AutoTrak X-treme, AutoTrak Curve and AutoTrak eXact), we saw that there was a fine and sensitive correlation where the bit must match the rest of the system. If the system is set up right, we can get another two-digit percentage of improvement in performance, whether it's placement, ROP or hole quality," he said.

Mud turbine provides downhole power

Steering pads, directional measurement, control electronics, and hydraulic and electrical power systems are all driven by an integrated turbine alternator system in APS Technology's SureSteer 475-rss, which was introduced at the 2015 SPE/IADC Drilling Conference in London. The system can be operated from the surface top drive or the downhole SureSteer 675-rsm (rotary steerable motor), Clegg explained.

"The turbine is driven by mud flow, which serves a number of functions. It drives the alternator. We can set up the turbine so the speed at which it drives the alternator is in the optimum range for generating electrical power for the sensors and communications with the MWD. Also it is an appropriate speed to drive a vane pump, which provides the hydraulic flow and pressure to extend the three steering blades that are around the outside of the tool," he continued.

"At the same time, we are able to make the RSS part of a modular string that will include a wide range of MWD and LWD products. It's a node on our bus, which allows many data and control integration options going forward," he said.

"There is also a simple package of accelerometers and magnetometers that will allow the tool to deduce its orientation and at what point in the rotation it should open and close the steering blades," he added. "This is the key to our ability to provide a controllable and reliable tool."

The company designed the two separate tools to share some common elements. Both tools use the same push-the-bit steering principle and steering blades to push the bit where it needs to go.

"The RSS is designed to maximize the drillstring speed. Because it is single-piece construction, the tool has a higher build rate capability. The RSM has a power section integrated into it. It can maximize the drillbit speed and the horsepower to the bit downhole so it doesn't get all of its power from the top drive," Clegg explained.

The steering head rotates (60 rpm to 80 rpm) more slowly than the bit (180 rpm). That significantly reduces the amount of reciprocating motion and therefore can reduce the amount of wear on operating parts and lower repair and maintenance costs, he said.

APS Technology provides its RSS and RSM to smaller directional drilling companies that are not one of the big four. Those companies can then provide the technology to their customers, he said. ■

Companies Strive to Remain Strong in Downturn

Acquisitions and new technologies can facilitate stability, survival and growth during challenging times.

By Ariana Benavidez
Associate Editor

Net petroleum imports have been decreasing more and more in the U.S. due to the use of hydraulic fracturing and horizontal drilling. This year, the U.S. surpassed Saudi Arabia as the largest oil producer, according to the U.S. Energy Information Administration. In addition, a $1.6 trillion increase in revenues to federal, state and local governments from 2012 to 2025 was predicted (due to fracking), according to a 2013 IHS article.

However, with the industry's downturn, half of the fracking companies operating in the U.S. are forecast to close or be sold by year-end because of loss of revenues from cost-cutting measures by oil companies, according to an April 2015 *Bloomberg Business* article.

Despite the economic woes, many service companies are aiming to address industry challenges through acquisitions or new technologies. The following is a sampling of key players that offer pressure pumping and other technologies and services for hydraulic fracturing operations, followed by a section for water management key players.

Key Players

Advanced Stimulation Technologies Inc.

Founded in 2007, Advanced Stimulation Technologies Inc. (AST) offers frack fluids; borate-, titanate- and zirconate-based fracturing systems; instant and delayed crosslinked systems; slickwater systems; and emulsified acid systems. Among those is the company's A-Light acid gel system, which has a corrosion inhibitor, iron control and surfactant built into one package. In addition, 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.

Equipment provided includes laboratory analysis devices, cementing units with remote monitoring systems available and fracturing equipment that includes a hydration unit that works at 120 bbl/min and has a 200-bbl holding capacity. The fracturing equipment also has 100,000-hhp capabilities.

Archer

Archer is an 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. 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.

Baker Hughes

Baker Hughes has a presence in North America, Latin America, Europe, Africa, Russia's Caspian Sea region, the Middle East and the Asia-Pacific region. The company's hydraulic fracturing services include hydraulic fracturing surface systems, fracturing fluid systems, proppant technology and completion tools as well as services that include multistage hydraulic fracturing systems and StimPlus services.

The company's multistage fracturing solutions include FracPoint ball-activated multistage fracturing systems; OptiPort and OptiFrac coiled-tubing-activated multistage fracturing systems; QUIK Drill composite plugs and intervention-less SHADOW fracture plugs for plug-and-perf applications; and hybrid solutions for extended-reach applications.

The StimPlus service aims to combine hydraulic fracturing and production chemistry to maximize post-fracturing production and reduce post-fracturing intervention cost related to scale, organic deposition, bacteria and corrosion. According to the company, this program eliminates a short-lived chemical squeeze or an expensive well remediation. When StimPlus chemical inhibitors are added during the fracturing job, organic and inorganic deposition is decreased, which improves well economics, the company said on its website. Baker Hughes' chemicals prevent scale, paraffin, asphaltenes and salt, and control bacteria and corrosion, according to the company. This results in reduced nonproductive time. With the StimPlus service, slow-release solid flow assurance chemicals are pumped into the reservoir as part of a fracture, gravel pack or other stimulation treatment to protect against production flow problems.

Baker Hughes offers SmartCare products and systems to minimize health and environmental hazards of oilfield chemicals. The company's Bifuel fracturing services allow operators to replace up to 70% of the diesel used to generate hydraulic horsepower with cleaner-burning natural gas. With the company's Rhino Bifuel pumps, air emissions are reduced and HSE risks are lowered, according to the Baker Hughes website.

Additionally, the Baker Hughes BrineCare fracturing fluid systems reuse produced water in hydraulic fracturing and are engineered for fast,

BrineCare fracturing fluid systems are engineered for fast, effective screening and application. *(Image courtesy of Baker Hughes)*

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.

Basic Energy Services

Basic Energy Services, headquartered in Fort Worth, Texas, provides a range of wellsite services in the U.S. to more than 2,000 drilling and producing companies, establishing and maintaining the flow of oil and natural gas throughout the productive life of a well. The company's operations are managed regionally and are concentrated in major U.S. onshore oil and natural gas-producing regions located in Texas, Louisiana, Oklahoma, New Mexico, Arkansas, Kansas, and the Rocky Mountain and Appalachian regions. Basic has a significant presence in the Permian Basin and Bakken, Eagle Ford, Haynesville and Marcellus shales.

The company's operations are focused on liquids-rich basins that have exhibited strong drilling and production economics as well as natural gas-focused shale plays characterized by prolific reserves, the company said. 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 fluid services segment uses a fleet of 1,047 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 421 well servicing rigs and related equipment encompassing a full range of services performed with a mobile well servicing rig, including the installation and removal of downhole equipment and elimination of obstructions in the wellbore.

The contract drilling segment operates 12 drilling rigs and related equipment that are used to initiate production from a well.

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

Hydraulic fracturing takes place in Kenedy, Texas. *(Photo courtesy of C&J Energy Services)*

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services to the oil and gas industry. The company's services include cementing, directional drilling, fracturing, coiled tubing, wireline, rig services and fluids management.

According to the company's website, its 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's fracturing services include pre-job testing, real-time monitoring and onsite maintenance of equipment, and field fluid tests conducted during the rigup process.

In addition, the company's fluids management services offer the largest fluids services fleet in the U.S. C&J's fleet of workover rigs makes the company the second largest well servicing provider in the U.S., according to its website. C&J manufactures and markets an assortment of fluids used in the drilling, completion and workover of oil and gas wells. The company also has thousands of portable tanks and a large fleet of truck and trailer combos for fluids storage and transportation. Full-service vacuum/kill trucks also are available for wastewater disposal and well-killing operations.

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 93% 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. In 2014, Calfrac performed more than 45,000 fracturing jobs across Western Canada, the U.S., Russia and Latin America.

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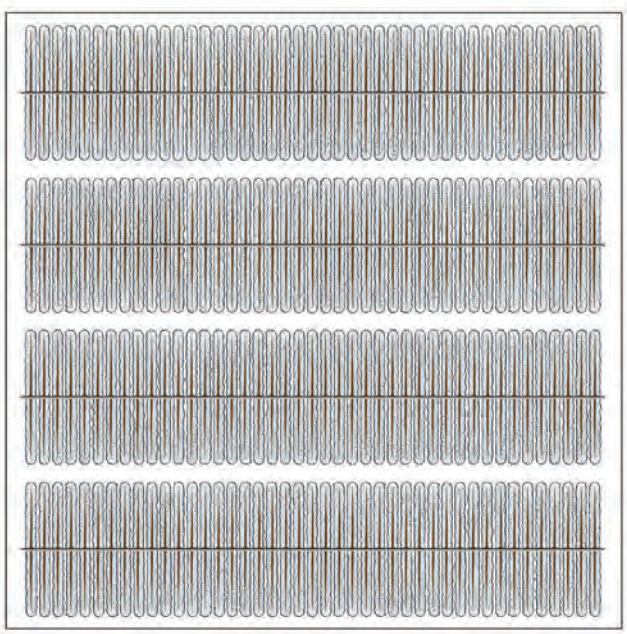
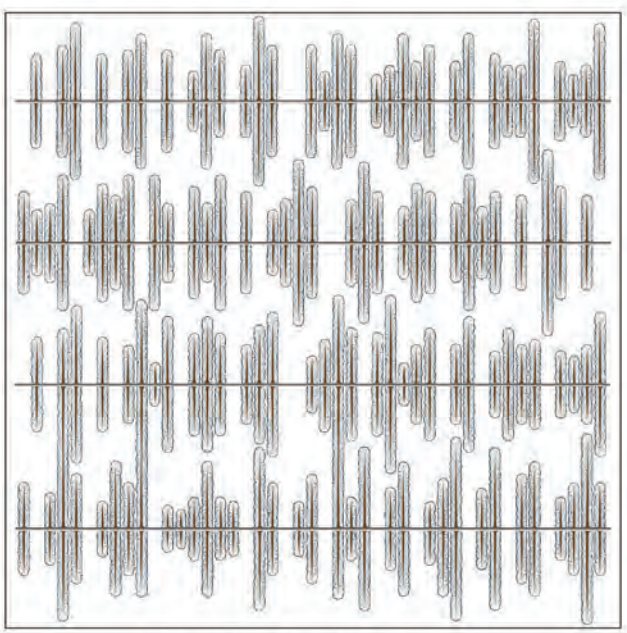


Predictable: Multistage Unlimited casing sleeves



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Calfrac's service line equipment ranges from high-capacity pumpers to combination frack pumpers/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 (QC) units that provide space for QC, testing and analysis.

Additionally, the company has a technical center in Calgary, Alberta, that focuses on developing new technologies, 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 trouble-shooting issues at the well site.

Calfrac operated in the Neuquén Basin in Argentina during December 2014. *(Photo courtesy of Calfrac Well Services)*

Compass Well Services

Specializing in cementing and fracturing jobs, Compass Well Services is an independent company with experience working in most of the major plays across the U.S.

Compass has a variety of trucks in its fleet. Compass Fracturing Services has about 80,000 hhp and associated equipment. The quintuplex pumping units have 2,250-hhp capabilities and offer remote control and monitoring. The company's blender units are designed to blend 120 bbl/min. Hydration units hold a 240-Bbbl hydration tank and also have electronic control and monitoring capabilities.

The Compass Cementing Services team can design and pump any blend. The company's twin-pump cementing equipment provides real-time data acquisition, micromotion monitoring and automatic density control. The company has 12 twin-pump cementing units as well as three bulk plants in Texas with the capability of blending and delivering bulk cement for full horizontal long strings, the company said on its website.

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, allows the company to provide CO_2 products, CO_2 transportation and field storage, CO_2 booster pumps and downhole pumping services to the Per-

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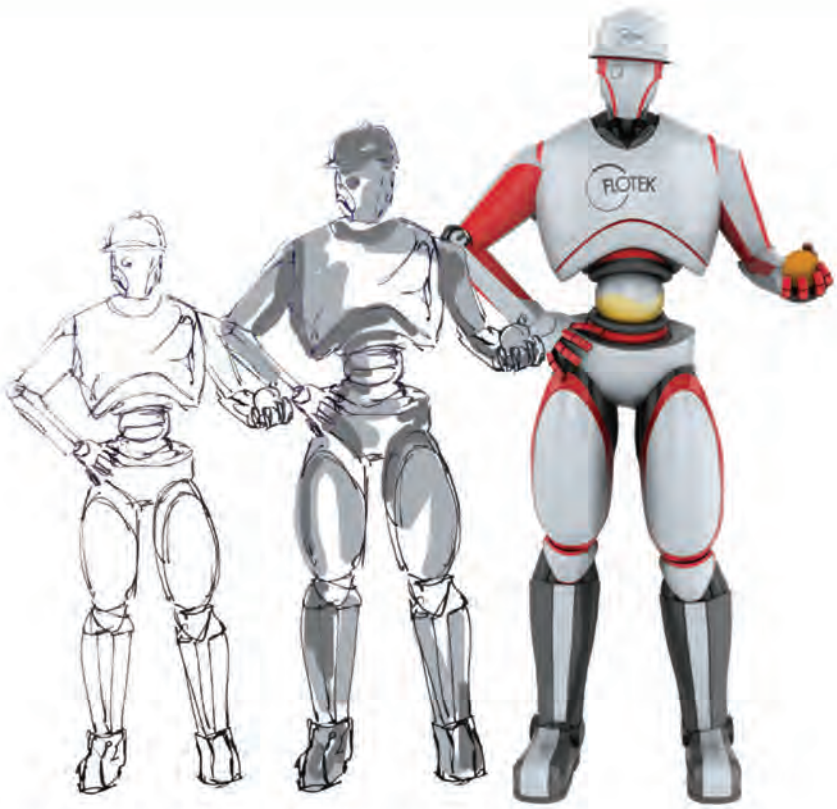

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mian Basin. Consolidated and Team CO2 also provide a full line of acidizing services in the Permian Basin.

Cudd Energy Services

Headquartered in The Woodlands, Texas, 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 fractures. 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 70 F to 400 F. Acidizing applications include matrix, coiled tubing, remedial and acid fracturing.

CES' stimulation services include additives and equipment that are custom-engineered for stimulations services. A key additive in the company's suite is Petro-Flo microbiocide, a safer, more effective biocide alternative than traditional biocides, according to the company. Petro-Flo microbiocide is designed to penetrate biofilm, break it down from within and prevent new biofilm from forming.

The company's stimulation equipment fleet includes about 900,000 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.

CES provides a variety of stimulation services. *(Photo courtesy of Cudd Energy Services)*

Economy Polymers and Chemicals

Founded in 1951, Economy Polymers and Chemicals (EPC) manufactures high-viscosity guar gum powder and oilfield stimulation chemicals. The company's range of chemical additives for hydraulic fracturing and oilfield stimulation include acidizing, cementing and coiled-tubing (CT) chemicals as well as guar gum slurries. EPC's hydraulic fracturing chemical offerings include clay control, crosslinkers, the Econo Buffer series, gel stabilizers, gelled hydrocarbon chemicals, gelling agents, pH buffers, scale inhibitors, surfactants, friction reducers, biocides and breakers.

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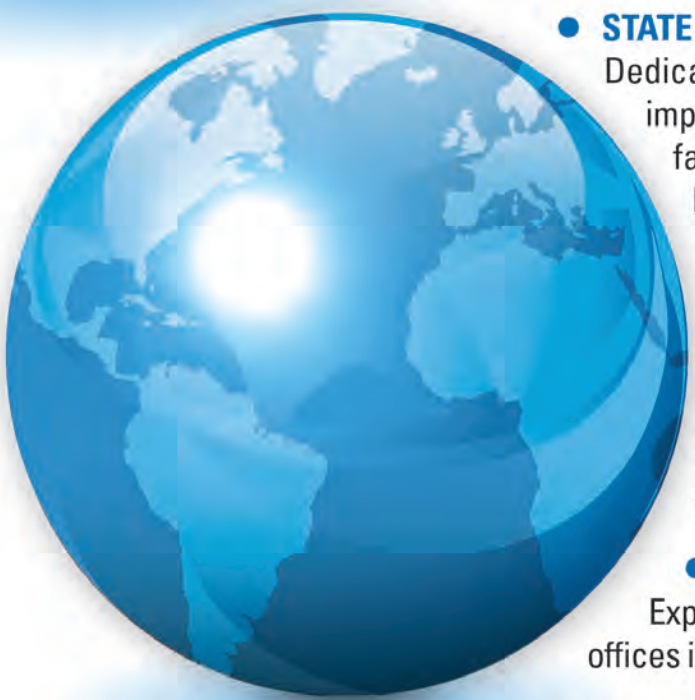

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The synthetic Econo-FR300 friction reducer can be used in fracturing, acidizing, CT and drilling applications. This friction reducer additive is designed to enhance the water displacement in oil wells by considerably reducing the friction pressure experiences at very high flow rates.

In addition, the Ecopol-SI2000 scale inhibitor, designed to prevent scale buildup, can be used in fracturing, drilling and CT applications. According to the company, the inhibitor can tolerate very high concentrations of salt, increases levels of metal impurities in a solution and has a high alkalinity level.

Another product offered by EPC is the ECONO-PS1 powdered breaker agent for use in guar and guar derivative-based fracturing fluids. The oxidizer is effective at temperatures above 120 F but should be used with the activator ECONO-TH100 at temperatures below 120 F, according to a company product data sheet.

Enerchem International Inc.

Canada-based Enerchem International Inc. is a producer and distributor of hydrocarbon drilling and fracturing fluids for the upstream oil and gas industry. Enerchem also provides fluid transportation and other related oilfield services through its wholly owned subsidiary Millard Trucking Ltd.

The company's Fracsol fracture fluid is a low-odor oil-based fluid with a high flash point and upgraded hydrocarbon, with the damaging paraffins and heavy ends eliminated. Other oil-based fluids are Enerchem's Drillsol and Drillsol Plus drilling fluids. These also offer a high flash point as well as a high analine point and low aromatic content, according to the company's website. The drilling fluid products are biodegradable, thus decreasing the costs for cuttings disposal.

In addition, Enerchem's solvent fluids offer solutions for wellbore cleanups, maintenance programs to control wax buildup, formation stimulation and


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squeezes, tank cleaning and dilution of heavy oil. The company's solvent products include Waxsol, Unisol, Xysol, EZsol and Envirosol.

One of Enerchem's Canada-based manufacturing facilities is shown. *(Photo by MT Actions Photography, courtesy of Enerchem)*

Flotek Industries Inc.

Houston-based Flotek develops and distributes specialty chemicals and downhole drilling and production equipment for the oilfield service industry. The company's products and services range from energy chemistry technologies to drilling and production technologies. Flotek's energy chemistry products include stimulation, cementing, coiled tubing and production chemicals as well as IOR, solvents and surfactants, and drilling fluid additives. The company also offers reservoir characterization, polymer conformance and logistics management services as well as remote monitoring, tool inspection services, and drilling tools rental and management.

Flotek's stimulation chemical products include the biodegradable Complex nano-Fluid technology suite as well as corrosion inhibitors and acid systems, buffers, clay control, fluid loss control, friction reducers, iron control, nonemulsifiers and surfactants.

In addition, the company offers drilling fluid additives that are designed to optimize the permeability of the reservoir to hydrocarbons, improve drilling system performance, control drillings solids, improve completion rates and reduce bit balling in water-sensitive formations, according to Flotek's website. Among the drilling fluid additives offered are Drill-In, Drill-In LO, Drill-In HO, Drill-In FMS, PCS and SS+, all of which are sold in North America and the Middle East.

Flotek's Drill-In HO, compatible with oil- and water-based drilling fluids, is designed to enhance drilling fluids by improving system performance, optimizing filter-cake lift-off and filtrate flowback from the reservoir, the company said.

The company's PCS and SS+ additives are cationic shale and clay stabilizers used in the Microsolution SS system. PCS also is environmentally safe and chloride-free.

Flotek purchased International Artificial Lift LLC (IAC), a provider of hydraulic lift systems and supporting equipment, in January. IAC has provided new opportunities for Flotek in both domestic and international markets, especially in Central and South America, according to Flotek's first-quarter 2015 report.

FTS International

FTS International (FTSI) offers hydraulic fracturing solutions primarily for unconventional plays. The company's well completion services include pressure pumping, wireline and perforating, and reservoir optimization technologies.

Regarding FTSI's pressure pumping services, the company develops and deploys its custom-manufactured solutions, such as its dual fuel-powered equipment. These pressure pumping units replace up to 65% of diesel fuel with natural gas, according to the company. This reduces the diesel traffic to and from the site and also benefits the environment. In addition, particulate matter and nitrous oxide are reduced by burning less diesel fuel.

To automate hydraulic fracturing manifold valves, the company offers a remote-actuated manifold system. This system allows remote control over hydraulic fracturing manifold valves via computer interface, removing the need for physical valve control, according to the company.

FTSI custom-manufactures and assembles hydraulic fracturing units and pumps in addition to many wireline components used in its fleets. FTSI also has a corporate technology center (CTC), based in Houston, which serves as the R&D and technical services hub for the company. This is where many of

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Employees in Pennsylvania operate one of FTS International's dual fuel-powered pressure pump units that run partially on natural gas. *(Photo courtesy of FTS International)*

the company's reservoir optimization solutions originate, including fracturing fluids, engineered fracture stimulation designs and customized solutions. The CTC is responsible for product development such as new diverting agents and products that facilitate water reuse in well completions.

Halliburton

Basin-specific knowledge, expertise and new technologies have established Halliburton as a North American leader in unconventional resources.

With the CYPHER Seismic-to-Stimulation Service, Halliburton helps its customers determine where to drill, how to drill, where to frack and how to frack. Specifically, the company uses the FracInsight service for new perforation placement and integrated sensor diagnostics for well and fracture spacing and stimulation design.

With the RockPerm service, Halliburton tests formation cuttings and reservoir fluids pre-stimu-

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lation to select the surfactant that will result in better well performance cost-effectively, the company said. For refracturing treatments, "ACTIVATE Refracturing Service enables recovery of bypassed reserves predictively and repeatedly at one-third the cost per barrel of oil equivalent compared to new drills," Halliburton said. As a main component of the ACTIVATE service, AccessFrac stimulation service uses diversion technology and optimized multicycle designs to ensure each cluster realizes its full potential.

The company said that Frac of the Future has improved the way that it runs fracture operations, resulting in time and cost savings, less capital, fewer personnel and reduced environmental impact. In addition, the newly added Q10 pump, the company's most versatile pump, is designed to cut nonproductive time by sustaining continuous pumping operations. The SandCastle vertical storage system can minimize footprint on site and can eliminate emissions with its solar-powered panels, the company said. The system is designed to tackle space constraints at wellsite locations.

The Frac of the Future is designed to increase surface efficiency with Q10 pumps and the SandCastle vertical proppant storage system. *(Photo courtesy of Halliburton)*

Halliburton recently released the Illusion frack plug, which is the industry's first dissolvable frack plug, according to a June press release. "With the Illusion dissolvable frack plug, operators are now able to eliminate risks and costs associated with conventional plug removal, resulting in quicker and more efficient hydraulic fracturing operations," the company said.

Independence Oilfield Chemicals

Texas-based Independence Oilfield Chemicals (IOC), an Innospec company, was founded in 2012. With locations near key U.S. basins in the Northeast, Rockies, Texas and New Mexico, IOC supplies services ranging from localized specialty blending and proprietary formulations to built-in private label blending and bulk-to-wellsite logistics.

In addition to its extensive lines of production, coiled tubing and cementing chemical offerings, IOC also provides a broad portfolio of proprietary and specialty stimulation chemical products and integrated fluid systems. These include acid and acid replacement, biocides, breakers, brines, buffers, clay control, cleaners, corrosion inhibitors, crosslinkers, diverting agents, flowback surfactants, friction reducers, gelling agents, gel stabilizers, iron control, lubricants and scale inhibitors.

One of the company's latest stimulation technologies is the VisLink system. Designed to crosslink ultralow guar-based polymer fluids to carry larger concentrations of proppant—while creating fracture networks that maximize reservoir contact in unconventional basins—VisLink combines the upsides of slickwater and gel systems, the company said. The visible lipping of this viscoelastic gel is easily observed with gel loadings as low as 8 parts per trillion (ppt) to 10 ppt.

VisLink also allows companies to use fewer chemicals while accomplishing the advantages obtained from conventional gel and slickwater treatments. To accommodate cold weather conditions, VisLink is designed to improve pumping while enhancing the viscoelastic nature of ultralow gel systems, IOC said.

IOC's main R&D technology center is located in The Woodlands, Texas. Focused on conducting

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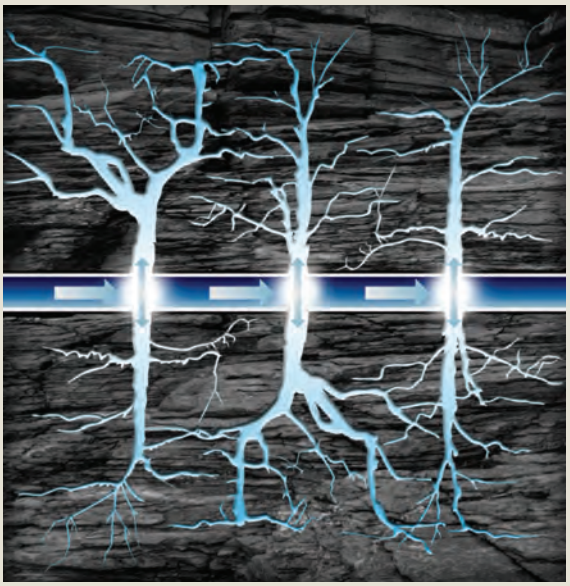
basic and applied research in stimulation and production chemistry, the center is equipped with HP/HT rheology equipment used to develop new stimulation systems and conduct product quality-control testing.



VisLink can maximize fracture complexity and ensure proper proppant placement using less chemicals. *(Image courtesy of Independence Oilfield Chemicals)*

Keane Group

Houston-based Keane Group offers hydraulic fracturing services, wireline technologies and top-hole air drilling in most U.S. shale basins.

Keane's hydraulic fracturing equipment includes high-efficiency fracturing pumps, blenders, hydration units, conveyors and mountain movers. The work-site equipment is backed up by an extensive logistics organization that has national sand contracts, more than 800 owned rail cars and a fleet of air-slide sand haulers. Field operations include real and remote data monitoring, advanced pump and blender controls, fracture performance analysis and real-time fracture modeling software. The pumping units are capable of adapting to varying pressures and rates for most applications. As part of ongoing efforts to lead environmental stewardship, Keane is converting the pumping units to Environmental Protection Agency-certified Tier 4 engines.

The company offers completions solutions with hydraulic fracturing and wireline in Pennsylvania, North Dakota and Texas. Keane Group offers wireline technology services, specializing in plug-and-perf operations as well as providing mechanical services, radial cement bond logging and casing image calipers. Radio-frequency safe and addressable switches are available to reinforce safety.

Marcellus offerings include the top-hole air drilling package, which is used to drill to depths of 10,000 ft.

Keane uses a fracture-simulating software that contains four fully integrated modules for fracture design, fracture analysis, economic optimization and reservoir performance. In addition, Keane uses software programs that offer a fully customizable display of the fracturing data. All jobs offer web-based, real-time streaming, which may be viewed from smartphones and PCs.

Keane has delivered tens of thousands of stages in vertical and horizontal wells and has experience in stack frack operations and multiwell zipper configurations. The stage sizes pumped routinely exceed 1 MMlb.

A Keane fracture truck is on location in the Marcellus Shale. *(Photo courtesy of Keane Group)*

Liberty Oilfield Services LLC

With a focus on the Rocky Mountain basins, Liberty Oilfield Services (LOS) specializes in stimulation services. The Denver-based frack company provides advanced designs, laboratory testing, fracture treatment analysis, fracture modeling, production data analysis, quality-control testing, diagnostic fracture injection test analysis and reservoir modeling.

LOS was formed in 2011 and began fracturing operations in the Williston Basin that same year. Liberty has camps in Henderson, Colo. (Denver-Julesburg Basin), Gillette, Wyo. (Powder River Basin), and Williston, N.D. (Williston Basin/Bakken Shale).

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LOS introduced portable sand storage containers to the Rockies, eliminating pneumatic transfer equipment and reducing dust, noise and truck traffic, while improving the storage, handling and site delivery of proppant to address HSE problems, the company said.

In December 2014, LOS signed an agreement with Energy Recovery to be the first hydraulic fracturing service provider to test the VorTeq fracturing manifold system. This system is the "first product engineered to increase run time and reduce maintenance cost by rerouting the proppant-laden fluid away from the high-pressure pumps," the company said in a press release.

A Liberty Oilfield Services truck is connected to a manifold on a well pad. *(Photo courtesy of Liberty Oilfield Services)*

Magnablend Inc.

Magnablend, a Univar company, supplies custom specialty chemical blending, manufacturing and packaging for the oil and gas industry. The company also has a technology laboratory for product development and technical support.

Formed in 1979, Magnablend offers chemical and logistics experience as well as facilities across the U.S. The company's oilfield chemicals and gas services include drilling and completion fluid additives, cementing additives, stimulation additives, production chemicals, EOR chemicals and traditional products, like calcium chloride and hydrochloric acid.

The drilling and completion fluid additives available consist of flocculants, deflocculants, viscosifiers, clay stabilizers, weighting agents, buffers, lost circulation control additives, defoamers, foamers, emulsifiers, shale stabilizers, surfactants, biocides, base oils, lubricants and filtration control additives.

In addition, stimulation additives available include acids, friction reducers, surfactants, nonemulsifiers, viscosifiers, polymer slurries, clay stabilizers, biocides, buffers, crosslinkers, breakers, foamers, defoamers, iron control agents, scavengers and flowback enhancers.

Magnablend's Specialty Services Complex in Waxahachie, Texas, can provide fluid system design, testing and customization. The laboratory can perform a variety of product and system tests, including HP/HT rheology testing for linear and crosslinked gels, fluid emulsions testing, cement fluid loss testing, and interfacial surface tension testing and wetting.

A Magnablend chemist tests crosslinked gel at the company's technology laboratory in Waxahachie, Texas. *(Photo courtesy of Magnablend)*

Millennium Stimulation Services Ltd.

Founded in 2012, Millennium Stimulation Services Ltd. provides fracturing services in the Williston Basin in Saskatchewan and Manitoba, Canada, and in the Western Canadian Sedimentary Basin region.

Millennium introduced a new technology to the oil field with its Energized Natural Gas (ENG) process. This process is designed to reduce or completely eliminate the amount of water needed to hydraulically fracture a well. This is done by replacing the water with LNG. The ENG process also completely eliminates post-completion flaring, reducing the environmental impact of greenhouse gasses, the company said.

Millennium offers a variety of fracturing equipment and technologies. Fracturing equipment includes frack pumps, blenders, chemical trailers, hydration trailers, iron trucks, data trailers, sand storage trailers and auxiliary units. Coiled-tubing and nitrogen equipment also are available, such as coiled-tubing units, a twin pumper and nitrogen pumpers.

Technologies offered by Millennium include BossFrac, CobraGel, ShelbyFR, CleanFlow and Cyclone. BossFrac is a water-based linear gel that uses ultralow residue carboxymethyl hydroxypropyl guar (CMHPG). Also in the BossFrac series is BossFrac-Z, foamed BossFrac and emulsified BossFrac, all of which use CMHPG. BossFrac-Z is a zirconium crosslinked water-based gel. Foamed BossFrac is a nitrogen internal phase foam with a water-based linear gel external phase, and emulsified BossFrac is a CO_2 internal phase emulsion with a water-based linear gel external phase.

CobraGel, CobraGel-B and CobraGel-DB all use low-residue guar. CobraGel is a water-based linear gel, CobraGel-B is a borate crosslinked water-based gel, and CobraGel-DB is a delayed borate crosslinked water-based gel.

ShelbyFR is friction-reduced water that uses polyacrylamide. CleanFlow is a water-based surfactant system with no residue.

Additionally, the Cyclone series consists of hydrocarbons with a range of gels, including phosphate ester gel and low-volatility phosphorus gel.

In August 2014, Millennium acquired ENFRAC Inc., an energized or foam frack completion technology company.

Nalco Champion

WellChem Technologies, a division of Nalco Champion, helps oilfield service companies drill, cement, complete and stimulate wells via development of chemistries based on specific challenges. WellChem creates high-performing products for drilling, cementing, completion and stimulation efforts. In addition, a growing focus of the company is to develop environmentally friendly chemistries and economical products. WellChem Technologies also has the ability to design and develop products that are tailored to meet specific needs. The company designs total fracturing fluid packages covering broad temperature ranges to meet the strictest of requirements.

WellChem has locations in the U.S., Europe and Asia. Among the drilling, stimulation and completions solutions offered by WellChem are its performance additives, which are specifically designed to handle challenging environments and conditions.

Oasis Well Services LLC

Oasis Well Services (OWS), part of Oasis Petroleum Inc., was formed in 2011 and completed its first frack job in March 2012. In 2014, OWS expanded to two fracturing fleets.

OWS provides well services and well completion products to Oasis Petroleum North America LLC a subsidiary of Oasis Petroleum.

Oasis Petroleum's 2015 capex is set at about $705 million, with about $678 million designated for E&P. About $565 million will be directed toward drilling and completions in the Williston Basin, where the company has about 506,000 net leasehold acres.

Capital invested in OWS in 2015 will be for additional pressure pumping capacity, according to the company's 2014 annual report.

As a result of the lower oil price environment, Oasis Petroleum is slowing the pace of development in 2015 and plans to reduce its well completions from 195 gross (147.4 net) operated wells in 2014 to 79 gross (63.3 net) operated wells in 2015, the company said in its annual report. The company planned to complete 100% of its wells with OWS beginning in February 2015 and has the ability to control the pace of

completions to allow for additional financial flexibility. In fourth-quarter 2014, Oasis Petroleum wrote off $2.9 million of leases that it did not expect to develop before its 2015 and 2016 contract expirations, according to the report.

ProPetro Services Inc.

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 Stimulation Services offers 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 250,000 hhp for vertical and horizontal work, reaching all plays in West Texas and southeastern New Mexico, according to ProPetro's website. 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.

The company's Permian drilling services include vertical drilling as well as turnkey and day work. The company has seven of the new 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.

The company also offers pump-downs, toe preps, foamed acid, CO_2, nitrogen, rock salt jobs, small frack jobs, bulk acid delivery and acid transfers among its stimulation services. ProPetro has 10,000-hhp acidizing equipment for acid 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 Gainesville and Wichita Falls, Texas, locations and its services range from small foam fracture jobs to 120-bbl/min multistage fracks.

Quasar has three hydraulic fracturing crews with pressure pumping capability of 39,000 hp. The company also has three crews for acidizing jobs and seven cementing crews. All of Quasar's cementing units are equipped with densometers and data acquisition.

Sanjel Corp.

Sanjel Corp., an international energy service company, provides cementing, coiled-tubing, fracturing, completions, resource and logistics solutions. Suretech, a Sanjel specialized energy service, offers multistage completions system solutions for unconventional reservoir development. Terracor operates transload facilities that service Sanjel's third-party sand logistics operations. Sanjel's Reservoir Solutions Group integrates statistics and reservoir modeling that are designed to result in a more efficient well design and planning process. All of the company's fracturing fluids and surfactant technologies are engineered in-house.

Sanjel provides in-house manufacturing, design and maintenance of its purpose-built equipment. "Total combined available hydraulic horsepower [of Sanjel's fracturing spreads] is more than 550,000, and all pumping units possess a high horsepower-to-weight ratio with minimized environmental emissions," the company said on its website.

Sanjel's BORAjel-D and BORAjel-HT are borate crosslinked fracturing fluids designed to reduce environmental impact. BORAjel-HT provides gel stability and custom control of break times at temperatures of up to 284 F, according to the company. BORAjel-LPE uses a low-viscosity, high-elasticity fluid system to reduce friction and stimulate natural fractures while maintaining proppant-transport capabilities. Sanjel also provides produced water solutions using fracturing fluids designed to reuse flowback water and reduce the dependency on freshwater sources.

The company's fracturing technologies and services include high-rate blenders, programmable logic

controller boxes, supervisory control and data acquisition, chemical addition and hydration units, and tubeless mixing systems. The company also operates bifuel hydraulic horsepower units that allow for 70% substitution of diesel with natural gas. The bifuel units are installed on both the quintuplex and triplex pumping units.

Schlumberger Ltd.

Schlumberger offers products and services from exploration through production. 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's multistage stimulations systems includes 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 released this year, the company's KickStart rupture disc valve eliminated the need for mechanical intervention 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.

Schlumberger continues to expand its multistage stimulation portfolio. *(Image courtesy of Schlumberger)*

Another Schlumberger product is the ELEMENTAL degradable alloy fracture ball, which 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.

This year, Schlumberger won Hart Energy's Meritorious Award for Engineering Innovation in four categories. The company was the exploration category winner for its Petrel 2014 user experience; the drillbits category winner for its StingBlade Conical Diamond Element Bit; the drilling systems category winner for its GeoSphere Reservoir Mapping-While-Drilling Service; and the water management category winner for its EPCON Dual Compact Flotation Unit.

Stingray Pressure Pumping LLC

Operating in the Utica Shale, Stingray Pressure Pumping LLC provides logistics, pressure pumping, energy and cementing services. The company was founded in 2012 and operates as a subsidiary of Gulfport Energy Corp.

For a variety of drilling needs, the Ohio-based company supplies rental equipment, such as telehandlers, manlifts, light plants and towers, generators, composite rig mats, steel rig mats and a 100-ton crane.

In addition, Stingray's water transfer crews can 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.

The company also provides laboratory testing of all slurries.

Superior Energy Services

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

Pressure pumping services include horizontal and vertical well hydraulic fracturing, cementing and stimulation services 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. If required, Superior has the ability to 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 (PNP) 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.

The company's OmniFrac MST Frac System is an openhole, multistage completion system designed for land-based completions in unconventional tight gas sands, gas and hydrate shales, and coalbed methane reservoirs. According to Superior, it's a lower-cost alternative to cemented PNP completions and allows operators more surface area to the reservoir, increased production, and faster stimulation times when compared to conventional completion methods. It uses packers

for zonal isolation and ball-drop-actuated sleeves for staged fracture treatments.

Torqued-Up Energy Services Inc.

Torqued-Up Energy Services Inc. offers coiled tubing (CT) and pressure pumping services. Founded in 2004, the company operates out of multiple Texas locations. The company offers conventional CT units, specializing in high pressure (HP) and well control. The units are designed to deliver any CT operation at shallow, medium and deep depths. The CT unit's services include underbalanced milling and drilling, cement and stimulation fluid placement, drilling and underbalanced drilling in vertical and horizontal wells, and HP well control location consulting and fracturing treatments. The remote BOP system provides for 15,000-psi wellhead working pressure and has a nitrogen-pressured accumulator for hydraulic backup supply.

The company's pressure pumping services include nitrogen, acid and solvent treatments, sand plugs, stimulation, pressure testing, frack and perforation breakdowns, and pumping support for CT, snubbing, electric line, slickline and drilling operations.

Trican

Trican, a global well service company, reaches all parts of the oil and gas spectrum with services in E&P, drilling, completions, midstream, downstream and R&D.

Trican's completions services include multistage fracturing tools, fracturing, coiled tubing (CT), reservoir solutions, acidizing and production enhancement, well intervention tools, and geological solutions. The company offers a vast amount of fracturing services, including horizontal well fracturing; CT, limited entry, acid, slickwater and foam fracturing; crosslinked water fracturing; hydrocarbon fracturing; proppant solutions; fracture design; remote monitoring; geological studies; and laboratory solutions.

Trican's horizontal well fracturing products and services consist of plug-and-perf methods, ball-activated systems, CT fracturing and diversion products, including BioBall ball sealers and the TriVert diverting agent.

Trican has a line of environmentally friendly hydraulic fracturing fluids that are designed to use less freshwater and/or minimize impact on the environment. These products include TriFrac-MLT, Eco-Clean, MVP-Frac, Stratum and V-Frac (Velocity Frac). TriFrac-MLT, Stratum-RW and V-Frac allow the reuse of produced and flowback water, therefore eliminating the cost associated with upfront freshwater acquisition. TriFrac-MLT is a crosslinked gelled water system that is highly tolerant of brine fluids, according to the company. This allows for the reuse of 100% untreated flowback or produced water. TriFrac-MLT allows operators to use water with total dissolved solids levels greater than 300,000 parts per million (ppm) and hardness greater than 30,000 ppm, the company said. MVP-Frac can reduce the amount of water required on a job by allowing more aggressive sand ramps and replacing some of the water with nitrogen.

A Trican fracturing spread in the Permian Basin is shown. *(Photo courtesy of Trican)*

Another development designed to reduce the need for freshwater comes in the form of salt-tolerant friction reducers. Trican's FR series

is part of the V-Frac system and is designed to give optimal friction-reduction performance in brine (saltwater), as do the environmentally friendly green friction reducer options, according to the company.

In the last five years, Trican has developed more than 160 new cementing and stimulation products and more than 45 CT innovations and has authored more than 60 technical publications on acidizing and fracturing fluids and techniques.

Last year, Trican broke a record for pumping efficiency on a large multiwell completion job in the Horn River Basin. The company established a record completing 27 stages within 24 hours in a single well in South Texas. Trican Completion Solutions' horizontal cemented completion system, i-Frac CEM, has completed more than 400 wells, with 12,500-plus sleeves and more than 4,200-plus stages, according to the company.

Trican began operations in Saudi Arabia and Colombia last year.

Tucker Energy Services

Privately owned Tucker Energy Services (TES) operates in seven countries and offers products and services that include 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 stimulation, 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. facility is in McAlester, Okla., and serves operators in the Mid-continent 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.

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. *(Photo courtesy of Tucker Energy Services)*

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 MMhp 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

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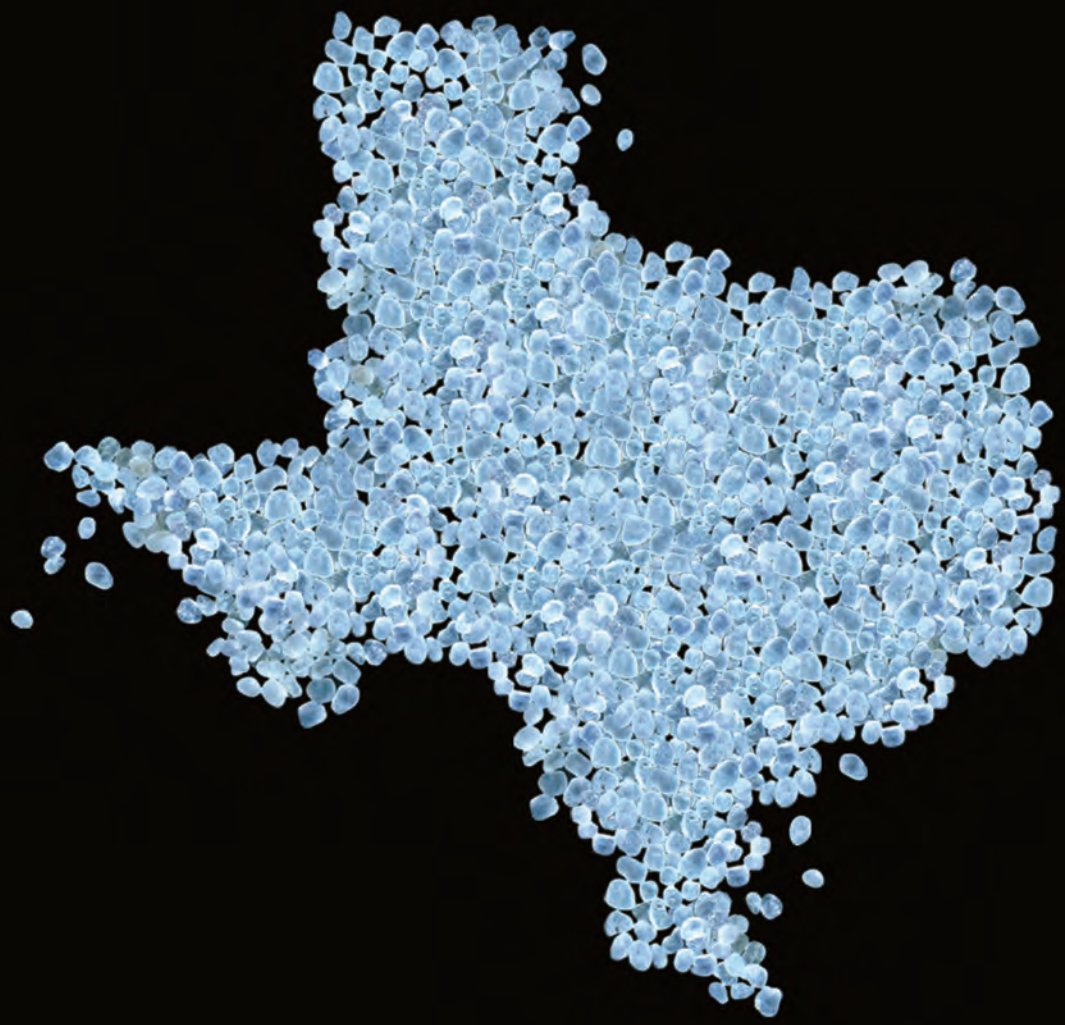

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and provides these multiple well services in Texas, New Mexico and Oklahoma, to serve the Permian Basin and Barnett, Woodbine/Eaglebine and Eagle Ford shales.

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.

A six-well pad operates in north-central Pennsylvania near the city of Williamsport, Pa. *(Photo courtesy of Patterson-UTI)*

U.S. Well Services LLC

Houston-based U.S. Well Services (USWS) is an oilfield services provider of well stimulation services to the upstream oil and gas industry operating in the Marcellus and Utica shales. The company is looking to expand its services to new areas in the U.S., including the Permian Basin, Granite Wash Formation and the Bakken, Haynesville, Niobrara and Eagle Ford shales.

The USWS Clean Fleet is on location in West Virginia. *(Photo courtesy of U.S. Well Services LLC)*

The company offers high-pressure hydraulic fracturing in unconventional oil and natural gas basins. USWS equipment consists of hydraulic fracturing fleets that are among the newest in the Northeast and are rated to handle pressures exceeding 10,000 psi, the company said on its website. The company also has triplex hydraulic horsepower units rated to 14,500 psi and 130-bbl/min blenders.

In July 2014, USWS deployed its Clean Fleet fracturing technology, the first fully electric, fully mobile well stimulation system powered by natural gas, according to the company's website. The fleet runs on electric power generated by natural gas-fueled turbine engine generators. The company said that Clean Fleet can reduce noise pollution, refueling traffic, site noise and emissions. According to a press release, Clean Fleet can mitigate environmental exposure by reducing NO_x and carbon monoxide emissions by 99%.

Weatherford International Plc

Operating in more than 100 countries, Weatherford International Plc is one of the largest oilfield service companies and operates internationally in every major oil and gas region. 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 company's new TBlockSure is a temporary diverting and fluid-loss-control agent for multistage fracturing, refracturing or workovers. Created from a dissolvable material, this technology provides zonal isolation and mechanical diversion while eliminating the need for bridge plugs, minimizing cleanup and reducing or eliminating plug mill-out time, the company said on its website.

Among the company's openhole isolation products are ZoneSelect and Fraxsis. The ZoneSelect openhole completion system includes hydraulic-set and swellable packers, sleeves, liners, plugs and balls. The system is designed to withstand challenging well conditions and the high pressures of fracturing operations. The Fraxsis annulus swellable packer is

designed for fracturing isolation. "The proprietary high-strength elastomers and extrusion-eliminating backup systems enable swellable elements to achieve high differential pressure ratings. The shorter element sets faster, which enables fracturing to begin sooner," the company said on its website.

In addition, the FracAdvisor service offers assistance to operators for optimizing completion designs, decreasing operational risks and increasing efficiency of hydraulic fracturing operations for increased reservoir drainage, the company said in its 2014 annual report.

In December 2014, Weatherford closed the sale of the company's engineered chemistry and integrity drilling fluids businesses to an affiliate of The Lubrizol Corp. for a purchase price of $750 million.

X-Chem LLC

Founded in 1982, X-Chem provides production and pipeline chemicals, water management and laboratory services. With locations across the U.S., X-Chem, a wholly owned subsidiary of NCH Corp., offers solutions for the maintenance, production, completion and stimulation of oil and gas wells and pipelines for onshore and offshore operations.

The company has a large line of chemical and additive products and has developed the Fraxtar line of environmentally friendly hydraulic fracturing fluids that offer improved safety. In addition, the company offers emulsion breakers, fluid additives, corrosion inhibitors, foaming additives, biocides, scale inhibitors, hydrogen sulfide scavengers, and paraffin and asphaltene inhibitors.

The company's AguaMax water treating products include surfactants, iron sulfide dissolvers, water clarifiers, anti-foulants, defoamers, friction reducers and oxygen scavengers. These products have numerous applications, including on oil and gas wells, gas lift, pipelines, flowlines, formation squeeze and water disposal. According to a company brochure, the AguaMax products are designed to increase production, reduce corrosion in the system and leave water clear with less suspended oil or solids.

Additionally, CorrNox assists in inhibiting corrosion, ScaleNox reduces and removes scale, and FOMax foaming additives are designed for a range of operating conditions such as high-temperature and cold climates.

WATER MANAGEMENT KEY PLAYERS

Altela Inc.

Headquartered in Denver, Altela Inc. was founded in 2005. The company designs and manufactures technology to desalinate and decontaminate highly challenged waste fluids. Altela's products and services include AltelaRain, fluid waste reduction, waste-to-asset conversion, water desalination and various integrated services that include regulatory and permitting services, water treatment process engineering and controls, systems integration and component sourcing, and project management.

AltelaRain is a modular water desalination and decontamination system that is designed to treat highly challenged fluids. The system recreates nature's process for purifying water—making rain—using low-energy and readily available materials. According to the company, AltelaRain provides lower operating costs and capital costs than other desalination technologies.

The system "reduces fluid waste volumes by concentrating waste fluid to 20% or less of the original volume and at the same time returns approximately 50% of the original volume to the customer as clean reusable water," the company said on its website. The system has been treating complex waste fluids for 10 years. Applications have included frack flowback and produced water, reconcentrating completion brines from oil and gas operations, landfill leachate and reverse-osmosis wastewater concentrate.

The company has had projects in Pennsylvania, Colorado, New Mexico, the Navajo Nation lands and Canada. Altela, with its joint venture partners, has built two centralized wastewater treatment facilities located within the Marcellus Shale in Pennsylvania focused on fluid waste reduction, water desalination and other integrated services for the treatment of oil and gas wastewater and landfill leachate. The company's South Platte River Basin project in Colorado launched in May 2015 and uses the AltelaRain treatment system for the fluid waste reduction of reverse osmosis concentrate brine waste for a water service provider in central Colorado.

Aquatech

With a wide range of water treatment and wastewater technologies and services, Aquatech has been serving oil and gas companies for more than 30 years. In addition to the company's integrated water treatment products, Aquatech provides global sourcing; engineering, procurement and construction; operation and maintenance; and onsite services. It also has the capability to deliver projects on a build-own-operate-transfer basis.

The company offers products for the following categories: pretreatment, ion exchange, membrane processes, wastewater recycle and reuse, zero liquid discharge, industrial concentration and desalination.

Aquatech's upstream water treatment applications include oil sands produced water treatment, coal seam methane and coalbed methane operations, and EOR for heavy oil. The company's technologies include its SmartMOD modular evaporation system for produced water in oil and gas exploration along with its HeVap high-efficiency evaporation system. SmartMOD is a water recycle solution for produced water treatment in the steam-assisted gravity drainage process. The "design transforms tall, thermal evaporator vessels into smaller modular sections that maintain vertical falling principles," the company said.

Aquatech's shale gas treatment consists of specific process units: MoTreat, MoMix, MoPress and MoVap. The MoSuite mobile water treatment line was designed by Aquatech for onsite and satellite coal seam methane gas recovery. "The various units work in tangent to optimize the water treatment process, yielding water that can be recycled and reused without the need for costly trucking to offsite facilities," the company said.

The Aquatech MoSuite is a mobile wastewater treatment solution for unconventional gas. *(Photo courtesy of Aquatech)*

Aquatech has offices throughout North America and a presence worldwide through subsidiaries in Europe, the Middle East, India and China.

Bosque Systems LLC

Bosque Systems, an independent oilfield water management company, has operations in Texas, Oklahoma, New Mexico, Arkansas, North Dakota, Wyoming and Colorado. The company offers reuse and recycle, pipeline, water treatment and saltwater disposal solutions.

As of August 13, Bosque has managed more than 821 MMbbl under its water solution services and is continuing to expand. The company's technology enables operators to reuse 100% of their flowback and produced water in the drought-prone Wolfcamp play, according to the company's website. This minimizes freshwater withdrawal and reduces truck traffic in the region by using pipeline across fields, Bosque said.

The company provides water treatment technologies and also offers bacteria sterilization, sulfate scale prevention, solids and iron removal, and scale inhibitor technologies. To sterilize water by removing bacteria before it gets injected for hydraulic fracturing, the company offers DIONIX Mobile. In addition, DIONIX Stationary is designed for EOR at saltwater disposal facilities. The technology also offers a biocide that is designed to kill 100% of microorganisms, and it protects facilities by oxidizing iron sulfide, the company said. ScaleStop is used to prevent scale from forming at saltwater disposal sites or before water is injected for hydraulic fracturing. The AnCat technologies are designed to reduce sulfate concentration when using brackish water and are fit-to-size no matter the volume to treat, the company said on its website.

Recently, Bosque added hydraulic fracturing fluids to its product line.

Bosque's DIONIXTM system is a mobile water treatment technology that serves the oil and gas industry. *(Photo courtesy of Bosque Systems LLC)*

DuPont

As a centuries-old chemical company, DuPont is focused on science and R&D with more than 10,000 scientists and engineers and more than 150 R&D locations worldwide. In 2013, the company had $2.2 billion invested in R&D and about $10 billion in sales from new products introduced in the last four years. The company also has three new innovation centers in Switzerland, Turkey and the U.S.

DuPont lists nearly 40 products and services specifically for oil and gas, which include asset productivity consulting, energy efficiency and environmental management consulting, Hytrel thermoplastic polyester elastomers, Viton fluoroelastomers with high heat resistance (400 F) and renewably sourced polymers.

The company also offers STRATCO sulfuric acid alkylation technology, which is designed to yield clean-burning gasoline with high octane, low-Reid vapor pressure, low sulfur and zero olefins. In addition, DuPont also provides Vespel custom parts and shapes made from polyimide resin that are used in demanding applications.

The company's oil and gas water treatments for upstream gas production include chlorine dioxide use, which according to DuPont's website, minimizes potential impact from undesired reactions with organics in the water. The company's Endimal deodorizing oxidant is designed to control noxious, irritating or pungent odors from many operations. Endimal also reduces hydrogen sulfide corrosion problems, the company said.

Fluid Technologies International Private Ltd.

Fluid Technologies International's (FTI) water treatment services range from filters, softeners and de-ionizers to chemicals for boiler and cooling circuits and ion-exchange resins.

The water and wastewater treatment company offers the Osmoflo-Series and Seaflo-Series reverse-osmosis (RO) desalination systems for brackish water and seawater. The Osmoflo-Series RO systems are designed to provide high-quality water under the harsh demands of continuous operation and challenging environments. The Seaflo-Series RO systems are designed to provide high-quality water while incorporating energy recovery turbines. The system also can perform under extreme seawater conditions, the company said in a brochure. Both systems have various applications, including drinking water, electronics production, automotive and chemical manufacturing.

In addition, FTI provides cooling water treatments to meet the demands of scale, corrosion and biofouling. CoolCare 4010, 4015, 4020 and 4030 are corrosion inhibitors for open circuits. CoolCare 4035 is a polymeric dispersant and antifoulant combination designed for use in industrial cooling water systems where iron oxide, silt, debris and particulate are contaminants. CoolCare 4050 and 4055 are corrosion inhibitors for closed circuits. E-Cool 652 is a corrosion inhibitor designed for use in engine-cooling circuits.

FTI also offers a range of microbiocides, including nonoxidizing biocides (BioCare 5010, 5020 and 5040) and oxidizing biocides (BioCare 5030 and 5050) as well as an algaecide (BioCare 5325).

The company's wastewater treatment technologies, servicing Pakistan, include Sequential Batch reactors (SBR) and Membrane Bio reactors (MBR). SBR is a fill-and-draw reactor system, and MBR is an activated sludge reactor system. Both systems use a

single complete mix reactor in which all steps of the activated sludge process occur.

Fountain Quail Water Management

Texas-based Fountain Quail Water Management is the oilfield-services subsidiary of Canada-based Aqua-Pure Ventures. Founded in 2004, Fountain Quail provides recycling products and services for unconventional oil and gas producers across North America.

According to the company, Fountain Quail pioneered unconventional water recycling and has many industry firsts, including the first recycling permit in the state of Texas, the first National Pollutant Discharge Elimination System discharge permit for treated shale water in the state of Arkansas, and the first recycler to meet Pennsylvania discharge criteria for treated distilled water.

The company has two primary treatment platforms. The mobile ROVER system generates clean brine for reuse (10,000 bbl/d). The modular and transportable NOMAD system generates freshwater for reuse or discharge (2,000 bbl/d distilled water).

Fountain Quail's NOMAD evaporator technology was developed by Aqua-Pure. The technology is designed to convert contaminated water back into distilled water and reduce freshwater supply volumes, water hauling volume and wastewater disposal by up to 90%, the company said on its website. The company said the NOMAD evaporator can reduce the cost of natural gas production, specifically in environments where freshwater is limited and/or disposal costs are high.

Fountain Quail's ROVER system operated in the Permian Basin this year. *(Photo courtesy of Fountain Quail Water Management)*

In the Marcellus Shale, Eureka Resources opened its water treatment facility in partnership with Fountain Quail in June 2010. Operating with three NOMAD units, the plant has recycled up to 200,000 gal/d of wastewater from Marcellus producers that include Range Resources, XTO Energy and Chesapeake Energy.

Fountain Quail's ROVER platform was developed based on more than a decade of pretreatment experience ahead of the NOMAD units. The ROVER system removes suspended solids, polymer, iron and other problem constituents as dry cake for disposal, the company said.

In Texas alone, the company has recycled more than 1 billion gal of flowback and produced water since 2004.

Hydrasep Inc.

Hydrasep specializes in fluid separation technologies. The company's products consist of ReCTangular (RCT) separators, ReCTangular with Oil-removal Chamber (RCTOC) separators, RCT dense nonaqueous phase liquid (DNAPL) separators, UnderGround separators (UG), Hydrasep separators (ASME Style) and BioDiesel separators (BD). Applications include process recovery and treatment, production water, fracking water recovery, groundwater, stormwater remediation, biodiesel and mobile separators.

Hydrasep can treat flowback water and produced water in-line and on site and also can recover pipeline-quality crude. The company offers several hydraulic separator products: the RCT model, RCT/DNAPL model, RCTOC model, Hydrasep model, UG model and BD model.

Hydrasep RCT oil-water separators are designed for flows with low oil concentrations. The RCT/DNAPL model is designed for liquids heavier than water and in concentrations less than 50%. This model is used for the treatment of process water where the oils and other contaminants are heavier than water or for the removal of water and solids from vegetable- or petroleum-based oils. The RCTOC model is designed for liquids lighter than water and also in

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concentrations less than 50% and is used in oil recovery and process wastewater treatment. Both models can be used for groundwater treatments. The Hydrasep model is designed for liquids where volatile organic compounds are present or where pressure and/or vacuum are required. All three models can be used for production water recovery as well.

According to the company, all separators offer easy access, low maintenance, sectional covers and solids retention and removal and are nonclogging.

The customized HS-1000-RCTOC-H (sloped bottom for sediment retention) is used in the recovery of oils from drilling muds. *(Photo courtesy of Hydrasep Inc.)*

Hydrozonix

Hydrozonix is a water management company that provides mobile, high-rate, environmentally friendly water treatment solutions to the oil and gas E&P industry. Services include storage solutions, water transfer solutions, consulting, water quality analysis, treatment and complete water management. The company is an alliance between Phillips and Jordan Inc., the Siboney Group and PBA Holdings. Hydrozonix operates in North Dakota, Pennsylvania, Texas and Wyoming and has treated more than 74.5 MMbbl of water as of June 24.

The company offers onsite and offsite treatments, impoundment treatment and customized solutions. Aerating systems provide pretreatment of bacteria, iron and sulfides as well as maintenance of treated water for bacterial control, allowing water to be stored for long periods of time without bacterial regrowth or odor concerns, the company said. The onsite treatment is designed to provide chemical-free pretreatment of frack fluid and treats bacteria and scale at rates up to 80 bbl/min (3,360 gal/min) per unit with the Hydrozonix EF80 systems. In June 2014, a 100-bbl/min system was introduced and currently is operating in Pennsylvania. The systems are designed to treat a blend of complex waters including high-salinity produced fluids. Offsite treatment provides a mobile, near-field, environmentally friendly way of treating flowback and produced fluid for reuse on fracks.

The company's field chemistry group provides real-time testing of water quality, including bacteria. The X-FRaC quality-assurance and quality-control program was developed for produced water recycling on crosslink gel fracks.

In addition to the EF80 system, chemical-free customized solutions also are available to treat bacteria, scale, organics (oil, grease and volatiles) and hydrogen sulfide. The company said its solutions are scalable and modular.

The Hydrozonix EF80 system operates on a fracturing operation in the Permian Basin. *(Photo courtesy of Hydrozonix)*

Kroff Well Services Inc.

Kroff Inc. provides water and wastewater treatment and recycling services as well as treatment programs and laboratory services. Kroff offers products and services through eight companies, each offering customized chemical, engineering and technology solutions. One of those subsidiaries is Kroff Well Services Inc. (KWS). KWS offers drilling fluids, fracturing and coiled-tubing chemicals, salt-

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water disposal well services, and water treatment and reuse services.

In January, KWS launched EnviroSTIM chemistries for drilling, stimulation, treatment of flowback and produced water as well as water destined for disposal at injection well sites, according to a press release. The products have been "successfully applied on hundreds of wells and thousands of stages in every major shale play," the company said. The EnviroSTIM product line includes friction reducers, scale, iron, microbiological control agents, acidizers, clay control chemistries, microemulsions, breakers, nonemulsifiers and boron-mitigation products. The EnviroSTIM products are designed for freshwater, blended water, treated flowback water and production brines.

KWS offers drilling fluid chemistries that are designed to protect the stability of the formation and to maximize recovery while also minimizing time invested, the company said on its website. Drilling fluid offerings include surfactants and soaps, mud and cuttings dewatering polymers, antifoams, super absorbents, delivery and application systems and drilling mud treatments.

In addition, the company provides water treatment and reuse services that include geochemical modeling, microbiological evaluations, sequential flowback reports and friction-reduction analysis. Geochemical modeling involves evaluating fluid design and sequential flowback data with software to create 3-D imaging and assessments specific to downhole applications. Microbiological testing provides rapid analysis of microbiological concentrations in water samples. Sequential flowback reports allow KWS to provide a basis for flowback reuse strategies, including blending plans and water remediation recommendations, the company said.

Magna Energy Services

Serving the Rocky Mountains region, Magna Energy Services specializes in plug-and-abandonment operations, 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 lay-flat hose, high-density polyethylene pipe, aluminum pipe, centrifugal pumps, 51,000-bbl above-ground storage tanks, pipe manifolds, in-line 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 has the capability of hauling heavy equipment such as low boys and pipes to be used in various fluid-handling operations, the company said. The company also has fast bay rights in the basins in which it operates that allow it to access multiple disposal outlets to get rid of fluids.

In addition, Magna's oilfield rig services include well completions, workovers, production and auxiliary equipment. 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 mastless trucks can operate at depths up to 20,000 ft.

Opus

Opus offers consultancy, technology and environmental expertise and services to the oil and gas industry. The company's consultancy services are based on more than 30 years of experience in oil and gas separation. Services include comprehensive studies, fluid characterization, process studies, computational fluid dynamics, physical modeling and test facilities.

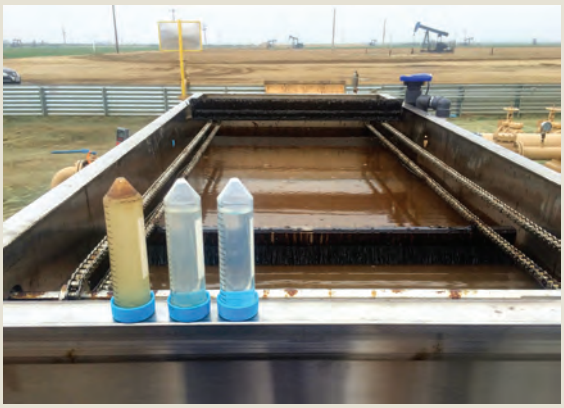
The company's technology is designed to meet the needs of each production facility, and Opus provides long-term solutions to the challenging demands of process efficiency and separation. Technologies offered include compact flotation units (CFU), coalescer and bespoke process vessel technologies and sand management solutions. The Opus CFU is a multiphase separator that is designed to achieve high oil removal resulting in a reduction of water content down to 10 parts per million. The CFU also offers high throughput relative to volume that allows it to be very effective on fixed and floating installations, the company said. The CFU handles high solids loading and provides stable operation with low operator

intervention and high flow capacity and is designed to be retrofitted onto existing platforms, according to a company brochure.

The Opus Mare's Tail coalescer is designed to increase the removal of oil from produced water. According to the company, it can be easily retrofitted into existing installations or installed as part of a water treatment package for a new installation.

The company also offers sand management technologies, including sand jetting systems and the Linear Coanda technology. The Linear Coanda technology is designed to transport solids continuously down the vessel, using the flow of the fluids in the vessel to reduce the amount of water required. Turbulence is reduced because the design drives accumulated sand in the same direction as the bulk fluids, the company said.

In 2013, Opus was aquired by international oil services provider Aker Solutions.



OriginClear's EWS removes contaminants from produced water for Vaquero Energy in Bakersfield, Calif. *(Photo courtesy of OriginClear)*

OriginClear Inc.

OriginClear, formerly OriginOil, is known for its Electro Water Separation (EWS) water cleanup technology. EWS removes oils, suspended solids, certain dissolved solids and pathogens from produced and frack water. EWS is designed to remove insoluble organics, particulates and prescribed contaminants across water-intensive industries. In a two-step process, EWS circulates wastewater through reactor tubes and applies electric-pulses to clump the organics and contaminants. Next, the organics and particulates are lifted to the surface by a cloud of microbubbles generated by a second surge of pulses in the flotation chamber and are then raked off for disposal. Simultaneously, oxidizing agents are generated that both disinfect bacteria and oxidize heavy metals and organic contaminants. According to the company, the process has removed 99.9% of turbidity and has reduced suspended solids and hydrocarbons to below detection limits on wastewater from Colorado gas wells, West Texas Intermediate wells and Monterrey Shale heavy oil reserves.

OriginClear has completed testing of EWS on disposal well water from the Permian Basin in Texas. The water quality during the test period varied widely on a daily basis. Despite this challenge, OriginClear's EWS process eliminated turbidity, according to a recent *E&P* article.

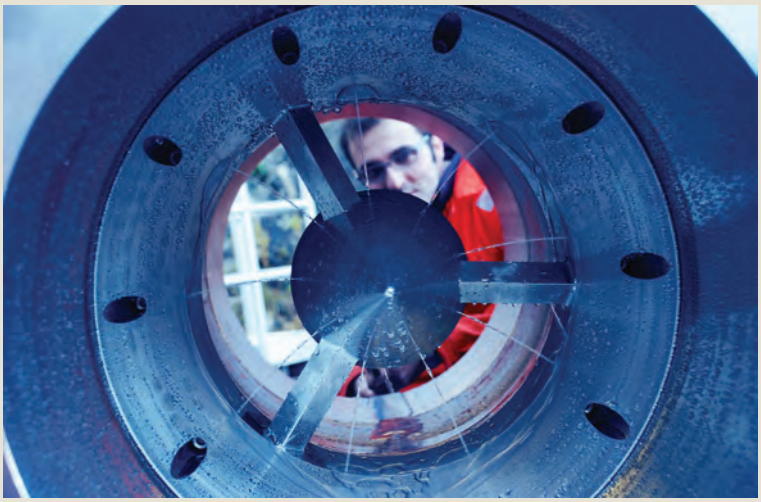
In June 2014, OriginClear successfully demonstrated a 1,000-bbl/d EWS system on produced and flowback water from western Colorado wells for ISI, a designer, manufacturer and seller of relocatable water tanks to fracking operators across the U.S. EWS technology was coupled with an ultrafiltration membrane system from TriSep Corp. Third-party tests from Lizard Analytical Laboratories confirmed removal of 99.8% of turbidity, 100% of suspended solids and 99.2% of oil from the water, according to OriginClear.

Additionally, OriginClear will acquire Progressive Water Treatment Inc., a designer and manufacturer of water treatment systems, by October, the company announced in an August press release.

ProSep

Houston-based ProSep provides products and services centered on oil, gas, produced water, R&D, energy services and manufacturing. The company's crude oil treatment technologies include primary separators, dehydrators and desalters. ProSep's proprietary mixing technologies, including ProMix, ProSalt and ProBlend for oil streams and ProScav and ProDry for gas streams, are in-line mixers. These mixers are designed to reduce chemical and washwater consumption for operators. Other gas treatment services provided by ProSep include gas treatment, dehydration and processing.

Among the company's produced water treatment services are primary, secondary and tertiary technologies as well as seawater treating. The company's



ProSep's mixing technologies include ProMix, ProSalt and ProBlend for oil streams and ProScav and ProDry for gas streams. *(Image courtesy of ProSep)*

proprietary technologies for produced water treatment include TORR, Osorb Media and CTour, which offer scalable solutions that reduce outlet discharge to below a 5-parts-per-million oil-in-water level, the company said. ProSep's produced water treatment options can be supplied as individual process units, integrated plug-and-play packages or complete produced water treatment solutions.

The TORR coalescing technology addresses future increases in water cut for offshore operators, and the CTour process equipment is designed to remove both dispersed oil and water-soluble organics through condensate injection into produced water streams.

Osorb Media is an organically modified silica adsorbent and absorbent used for the treatment of oilfield water and gas streams. The technology adsorbs free, dispersed and water-soluble hydrocarbons as well as many nonpolar oilfield chemicals from produced water, the company said. ProSep is the only company licensed to supply Osorb to oil and gas companies.

Additionally, ProSep offers customized seawater treatment and injection systems, using membrane technologies to meet specific water specifications, for onshore and offshore applications.

RecyClean Services

RecyClean Services, a division of The Mark Corp. group of companies, offers the Hydro-Pod water management solution, which uses a combination of ozone and electrocoagulation technologies to provide a sustainable water source suitable for reuse in the fracking process. According to the company, this product also reduces water acquisition and disposal costs.

The Hydro-Pod treats frack flowback and produced waters and is "the only technology that addresses nine-plus impurities in one treatment to mitigate the risks associated with reusing produced water," the company said on its website. The nine areas of concern the Hydro-Pod treats are total dissolved solids, suspended solids, hardness, iron, bacteria, total oil and grease, organics, dissolved gases and boron. The units process 2.5 bbl/min to 3 bbl/min and can be run in tandem for higher flow-rate requirements. The units also can serve as a centralized processing facility to serve multiple well locations. According to the company, liability from transporting and injection of disposal wastewater is nearly eliminated.

The Hydro-Pod addresses nine-plus areas of concern with a single system. *(Image courtesy of The Mark Corp.)*

Rockwater Energy Solutions

Rockwater Energy Solutions provides water management services and chemical technologies designed to optimize water treatment, stimulation, fracturing and production operations in the U.S. and Western Canada.

Rockwater's full life-cycle water management services include water treatment, transfer, flowback and well testing, and fluid logistics. Optimal storage during water transfer or treatment operations can be achieved with Rockwater's above-ground storage tanks (ASTs). With capacities ranging up to more

than 60,000 bbl, ASTs supplied by the company can replace more than 120 standard tanks used in hydraulic fracturing operations—tanks that, on average, can handle 500 bbl each, the company said.

Water treatment has been a focus of the company since its formation in 2011, with Rockwater treating more than 38 MMbbl of water to date. The company recently acquired Neohydro Corp. for its Pathocell technology, which employs electro-oxidation to reduce bacteria, suspended solids and metals in produced and flowback water for reuse in fracturing.

In addition, the company's completion and stimulation chemicals include biocides, breakers, corrosion inhibitors, crosslinkers, fluid-loss additives, foamers and defoamers, friction reducers, scale inhibitors and surfactants. The company also provides guar and guar additives to the oil and gas industry.

Select Energy Services

Houston-based Select Energy Services provides end-to-end water services to oilfield operators throughout the U.S. The company was founded in 2007 and has since grown to have more than $800 million in revenues. Select has three business units: water solutions, well testing and fluid handling.

The company's water transfer service line offers high-volume, high-rate water transfer services through a range of mobile piping systems including no-leak pipe systems to support hydraulic fracturing, the company said on its website. Select has more than 1,000 miles of overland transfer pipe and 1,200 water transfer pumps. Equipment offerings include the company's lay-flat EnviroHose, pumps, manifolds, floats, road crossings, support rentals, aluminum pipe and Yelomine pipe.

The company's AquaView water monitoring technology system is designed to retrieve volumetric analyses of water sources and provide real-time data. According to Select, the system can be rapidly deployed and can deliver map results and continuous monitoring immediately. The service provides total volumetric output of water in storage, estimation of usable storage, a contour map with depth measurements and 3-D bathymetric imagery.

Additionally, Select's water treatment services include a variety of biocontrol and recycling technologies to prepare source water to go downhole on the fly or to tie flowback water back into the frack supply for reuse, the company said. Select offers water disinfection and biocontrol treatments as well as reuse and recycle technologies, like chemical clarification, field distillation, electrocoagulation, chlorine dioxide and hydrogen peroxide.

In addition, the company's well testing and flowback services include site-by-site consulting, short-term testing, long-term testing, testing of formation fluids, coiled-tubing cleanout and snubbing operations. The equipment for these services includes plug catchers, manifolds, sand separators, test separators, flare stacks, line heaters and frack stacks.

In December 2014, the company launched the Pecan Hill Water Solutions Facility in southeast Grady County, Okla., to serve oil and gas operations, a company press release stated. The facility houses a saltwater disposal well, freshwater trucking depot and access to 25,000 bbl/d of freshwater from a buried pipeline.

Also, in November 2014, Select Energy Services and X-Chem/Terra launched three water treatment projects in the Permian Basin and are jointly pursuing several other projects across the U.S. ■

Josh Butler, project manager for Select Energy Services, provides a demonstration of the Pecan Hill Water Solutions pipeline automation system during the system's grand opening in 2014. *(Image courtesy of Select Energy Services)*

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Completion Tools at a Glance

Companies offer up a smorgasbord of new technologies.

Staff Report
Hart Energy

So many tools and techniques are required to complete today's challenging wells. Advances in horizontal drilling are causing operators to seek better production efficiency. Below are some of the tools that help them achieve that goal.

Diverters

Weatherford International has introduced the TBlockSure degradable mechanical diverter system, a tool that can be deployed on both new and refracturing well candidates in vertical and horizontal completions where traditional diversion and isolation methods are insufficient. The system requires a viscous water-based fracturing fluid able to pump the diverter pill at the time of diversion. The larger particle size materials will bridge and seal the area of interest: perforations, small fractures and ports on a sliding-sleeve system. The smaller particles of the system will fill in the void space of the larger particles and under compaction will create a tight seal capable of withstanding differential pressures greater than 4,000 psi.

FTS International's NuFlo Diverting Agent increases stimulated reservoir volume in refracture and new well applications. The diverting material temporarily blocks existing fractures to allow new fractures to develop, then dissolves completely over time and temperature. This gives operators the ability to tap into more clusters during initial fracturing or restimulation.

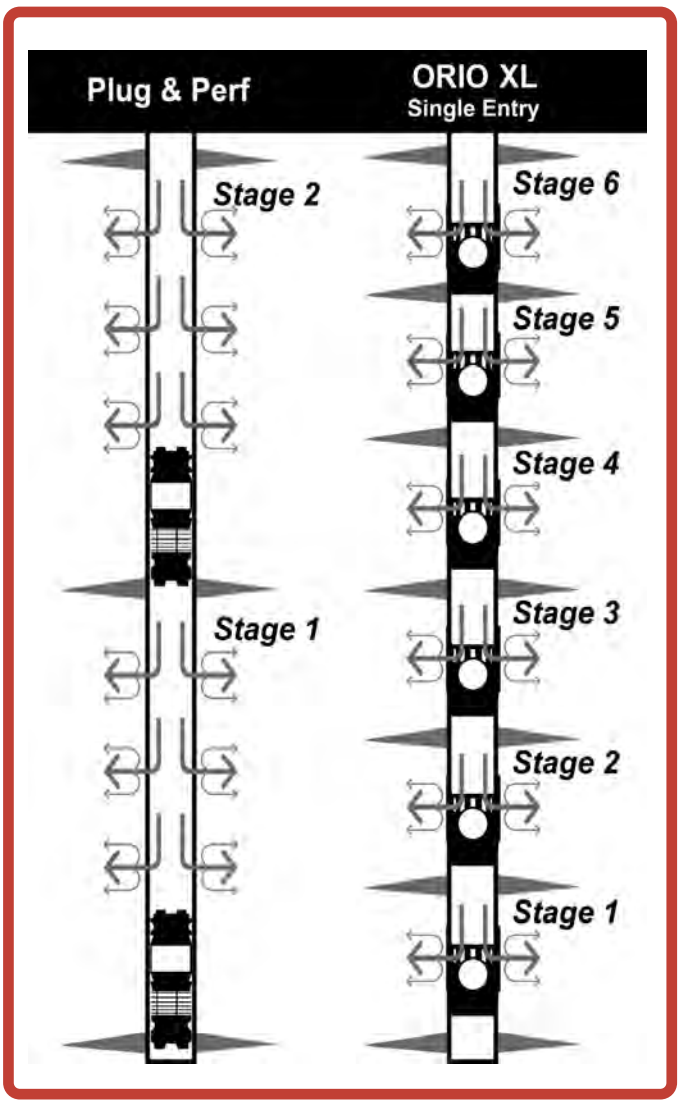
The NuFlo system can be used to divert fluid at the wellbore (NuFlo 1000) or in the fracture far field (NuFlo 1000FF). It is effective in new or depleted wellbores and can be used in many active shale plays.

The latest advance in diverter technology from Baker Hughes is a solid particulate diverter and ultralightweight proppant combination known as REAL Divert Complete that is engineered to deliver effective, efficient diversion without risking collapsed or choked hydrocarbon pathways in the near wellbore and far field. Conductivity is enabled by premixing an engineered solid particulate diverter with a specially engineered, strong-but-lightweight proppant and placing it into the fracture area.

Once the diverter particulates dissolve, the proppant particles remain in place to keep the fracture open and maintain a permanent connection in the near-wellbore and far-field areas of the fracture network, allowing unrestricted hydrocarbon flow throughout the life of the well.

Sliding sleeves

The Packers Plus Diffusor completion system brings the efficiency of ball-drop completion technology to cemented wells. A specially designed coating helps prevent cement from adhering to this system of sliding sleeves. When the system is cemented in place, a series of Diffusor sleeves are opened using increasingly larger actuation balls. Stimulation of the reservoir is completed in one continuous pumping operation, eliminating the time spent tripping in and out of the wellbore with conventional cemented liner completion methods. Once the stimulation operation is complete, the well can be immediately flowed back and put on production,



The ORIO XL Frac Sleeve increases the number of sleeves or sleeve clusters that can be employed in the completion design. *(Image courtesy of Team Oil Tools)*

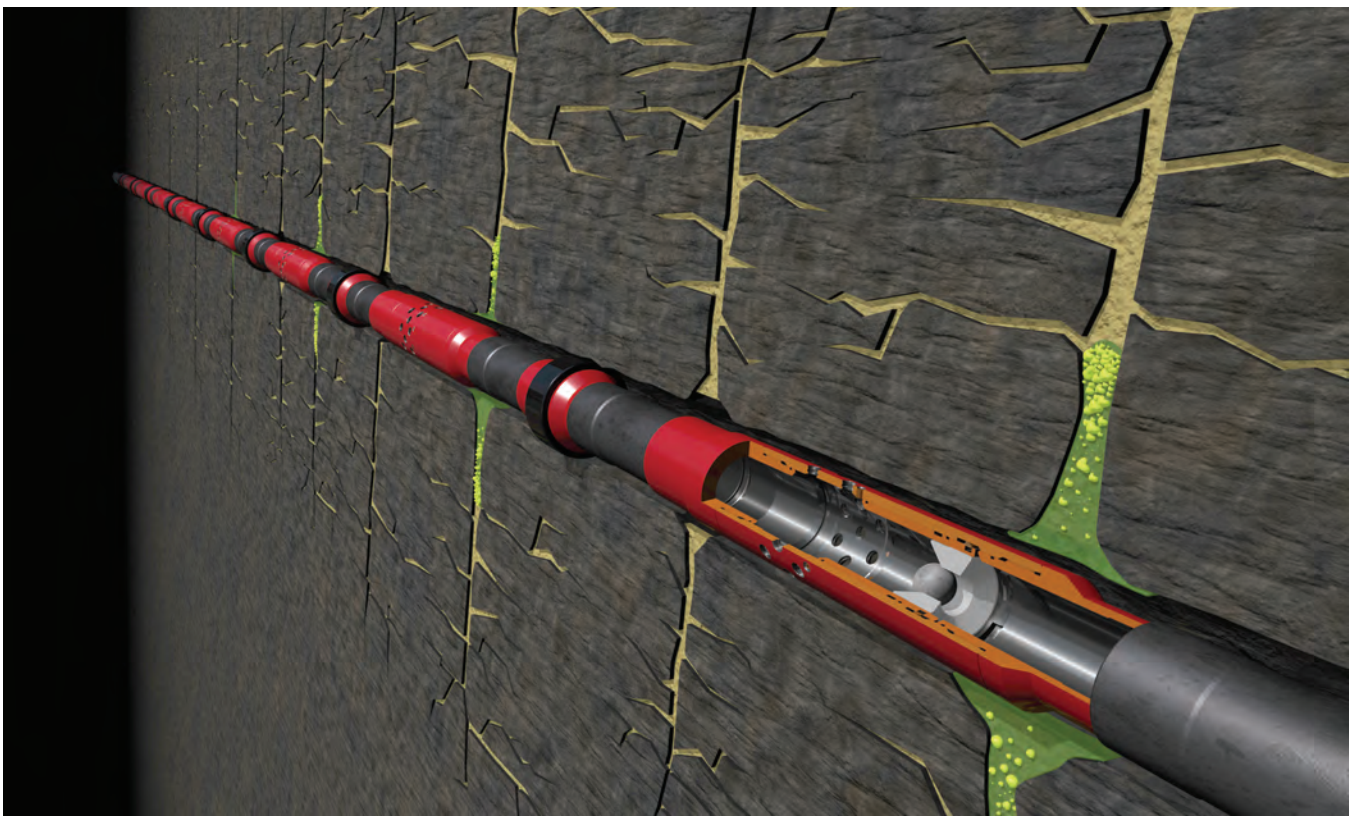
providing operators with an efficient and cost-effective method for completing cemented wells.

The Packers Plus QuickFRAC limited entry completion system is designed to enable operators to increase stage counts—with the possibility of achieving more than 100 stages—and maximize reservoir contact while maintaining the operational efficiency and favorable economics provided through a single completion technique. The QuickPORT IV sliding sleeves in this ball-drop completion system are installed in the wellbore as individually isolated stages, but only one actuation ball is required to open multiple sleeves, reducing operation time. The QuickPORT IV sleeves are specially designed to work in openhole and cemented wells, providing operators with the flexibility to design effective completions for their specific requirements.

Ball-activated sliding-sleeve technology developed by Team Oil Tools for multizone cemented lateral completions allows up to 90 individual sleeves to be opened as a single-point-of-entry completion without dropping a ball diameter smaller than 4 in. in 5.5-in. casing or a 3-in. ball in 4.5-in. casing. The ORIO XL Frac Sleeve allows an increase in wellbore internal diameter over the length of the completion and increases the total number of sleeves or sleeve clusters that can be employed in the completion design.

Halliburton's RapidStart Initiator coiled-tubing (CT) sleeve eliminates the need for an initial CT run to create a flow path for plug-and-perf (PNP) operations. This sleeve is run as part of the casing string and is cemented in place. When surface pressure is applied, the RapidStart Initiator CT sleeve begins to slowly meter open, allowing a casing pressure test. Once the metering process is finished, the sleeve opens, creating a fluid flow path.

Improving completion efficiency without compromising reservoir contact area is another method to improve the cost-effectiveness of a completion solution. The Halliburton RapidFrac ND (nondelay) system is a fracturing sleeve system that is ball-drop-operated for superior efficiency, enabling up to 54 individual target stages to be fractured with multiple entry points per target stage. When combined with Halliburton AccessFrac service, record reservoir contact levels can be achieved and production results elevated. The AccessFrac service consists of degradable diverting agents that optimize fracture stimulation of the reservoir by increasing the amount of the formation that is stimulated. The AccessFrac service also has been combined with the Halliburton RapidStage system to increase wellbore production



Halliburton's AccessFrac service's degradable diverting agents increase the amount of formation that is stimulated.
(Image courtesy of Halliburton)

by 30% or more. The RapidStage system is Halliburton's most cost-effective, ball-drop-operated frack sleeve solution that allows for the stimulation up to 54 single-target entry points in a wellbore. It can be run with Halliburton Swellpacker Slip-on isolation systems or ZoneGuard FP (frackpack) openhole packers for economic annular frack stage isolation.

Frack fluid

Cameron's Monoline Frac Fluid Delivery System uses controlled, bolted connections that promote a higher level of system integrity and safety. With the Monoline, a series of 5-in. high-pressure pipe segments are joined together with 90-degree elbows and swivel flanges. This configuration allows for the full 3 degrees of freedom needed to accommodate alignment between the frack tree and the frack manifold. Without the need for hammer unions, this new technology eliminates the potential for mismatched equipment, simplifies hookup and allows for up to a 75% reduction in required connectors. When compared with conventional systems, the Monoline reduces installation time by more than 60% as it eliminates more than 80 hammer unions, making the well site safer and operations more reliable, the company said.

Pumps

FTS International offers dual fuel-powered hydraulic pumps that allow the substitution of up to 65% of diesel fuel with clean-burning, lower-cost natural gas. With this solution, operators can streamline their supply chain and increase efficiency, which can lead to lower costs, the company said.

Frack balls and plugs

Dissolvable products such as Halliburton Illusion frack plugs and RapidBall DM (dissolvable metallic) self-removing frack balls eliminate the need for post-stimulation CT milling and cleanout trips. These balls and plugs stand up to harsh fracturing conditions and then dissolve with temperature and wellbore fluids.

SAINT-GOBAIN

The proof is in the data!

Average reported oil production for wells completed by a single service company in Dunn County, ND in 2013.

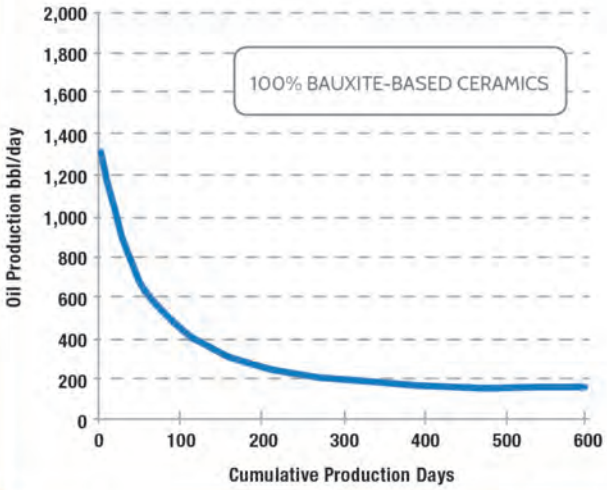
WTI@$55

Average revenue (3 years)

$10.2 M

Profit/lb of proppant

+$0.32/lb



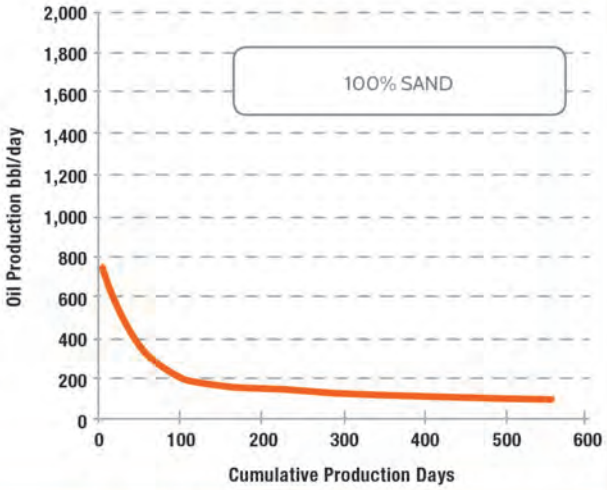
WTI@$55

Average revenue (3 years)

$4.07 M

Profit/lb of proppant

-$1.3/lb



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The Diamondback composite drillable plug is designed to minimize risks associated with presetting and the mill-out time lost due to spinning. *(Photo courtesy of Schlumberger)*

Schlumberger's Diamondback plug isolates stages during PNP operations and can be set using wireline, CT or jointed pipe. A one-way internal check valve is closed with a ball dropped from the surface while the zone above the plug is being fractured.

Magnum Oil Tools' Magnum Fastball is designed to eliminate the need for expensive, time-consuming drill-outs and well interventions to improve operators' well completion efficiency. Made of patented materials, the Magnum Fastball dissolves at a predictable rate in the presence of common wellbore temperatures. By bypassing the need for drill-outs, it also eliminates the risk of events that would require well interventions like stuck frack balls or loose frack ball fragments.

The Magnum Vanishing Plug (MVP) was developed to eliminate the cost and risks associated with well intervention, reducing total days to completion. Many early-adopter operating companies conducted trials of the MVP by starting with a "toe package" in which five to 10 MVP plugs were set in the end or "toe" of a horizontal wellbore. Several other operators implemented the MVP to isolate all stages in the horizontal wellbore with strong results.

CT

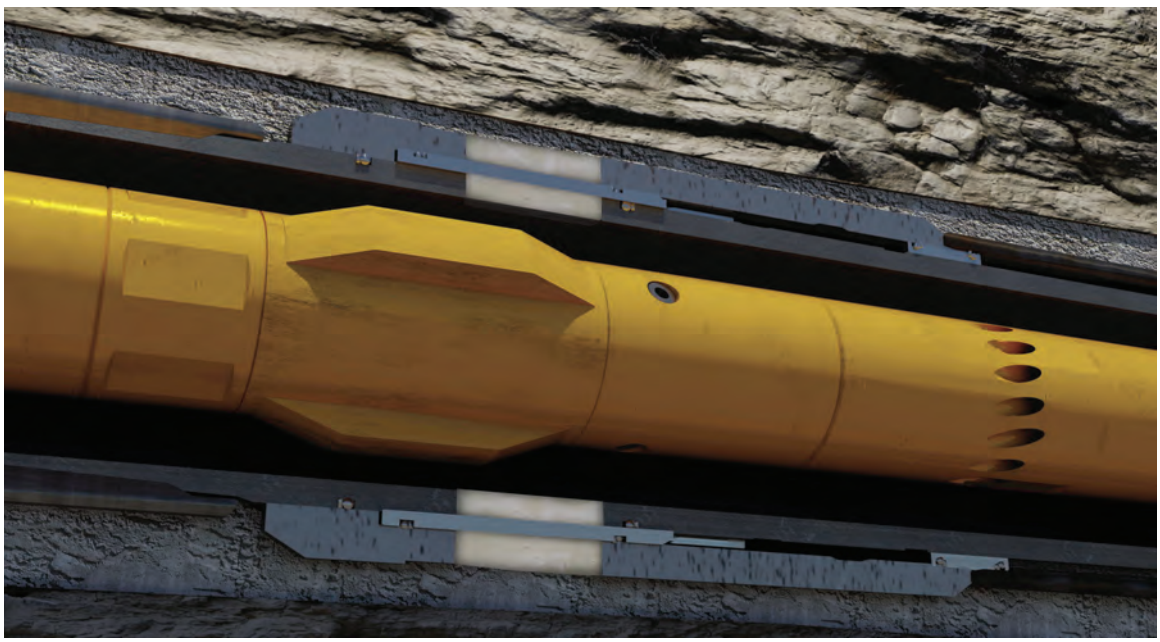
The Packers Plus Quadrant completion system is specially designed to complete an unlimited number of stages within reach of a CT unit. This multistage system combines the use of the Quadrant Isolation Tool and multiple Quadrant sliding sleeves to isolate and stimulate selected zones of the wellbore. The isolation tool remains static in the wellbore as the sliding sleeves shift open, ensuring isolation is maintained for stimulation and reducing issues related to CT movement in the well. The isolation tool can be set and unset multiple times in one trip, enabling stimulation of the reservoir in one continuous operation. The Quadrant system leaves the wellbore with a full inside diameter, and production can begin immediately following stimulation of the last stage since no intervention is required.

The Baker Hughes OptiPort CT-activated system enables rapid and aggressive stimulation treatments through targeted fracturing while using less fluid and less horsepower than completion methods such as PNP. The system also supports advanced data gathering during stimulation, allowing operators to optimize performance throughout fracturing operations as well as gain valuable reservoir insight.

On a recent job in the Eagle Ford, an operator wanted to get a better understanding of which stimulation techniques would be most effective for other wells in the same reservoir. The OptiPort system offered a solution that was flexible enough to efficiently treat a high number of stages while also delivering quality data for immediate analysis.

Well integrity

The Schlumberger MeshSlot premium sintered mesh screens have two, three or four layers of woven



Baker Hughes' OptiPort system uses targeted fracturing for rapid and aggressive stimulation. *(Image courtesy of Baker Hughes)*

wire mesh, forming a resilient filter and providing well integrity and mechanical stability. Mesh screens maintain their strength during installation without altering the filter pore openings.

Liner hanger systems provide multiple benefits in well construction ranging from enhancing well integrity to reducing costs. The complexity of each application depends on a number of factors such as well deviation, temperature and pressure. With a range of available features, the Schlumberger COLOSSUS liner hanger systems are suitable for the most straightforward to the most challenging environments.

Schlumberger's TRC-II tubing-retrievable charged safety valve is a surface-controlled subsurface valve that uses a gas-spring design with gas-powered actuators that allow installation at depths significantly deeper than conventional spring-type designs. Because these valves can be run at greater depths, they can be positioned below the hydrate- or paraffin-deposit regions to increase operating efficiency.

Baker Hughes recommended the application of its ScaleSorb 3 time-released solid scale inhibitor to an operator in Utah's Green River and Wasatch formations. The application placed the chemical at the tips of the fracture to offer maximum scale protection. To monitor the treatment's effectiveness, a residual monitoring program was implemented and, to date, 564 wells, including all of the new completions, have been treated in this manner. In wells with high water vol-

The Schlumberger COLOSSUS liner hanger systems can support both cemented and uncemented wells, including HP/HT environments. *(Photo courtesy of Schlumberger)*

umes, the solid scale inhibitor was complemented with the addition of liquid scale inhibitor.

Once the program was in place, well failures dropped from 20 wells per month to zero. The operator estimated that this program saved $35,000 per well per month by eliminating remediation and avoiding lost production.

Cameron's multibowl nested diverter snap ring wellhead system incorporates a rotating mandrel casing hanger designed to improve cement job integrity and wellbore stability for vertical and horizontal gas wells. The hanger enables the operator to rotate the production casing during installation, promoting better displacement efficiencies, effective zonal isolation and less eccentricity in the pipe during cementing jobs.

Isolation barriers

Magnum's Interventionless MagnumDisk (I-MAG) effectively isolates the production tubing from the wellbore reservoir pressure and eliminates the need for slickline intervention, the company said. The I-MAG is run as an isolation barrier on the bottom of the tubing and/or below a packer bottomhole assembly to isolate the tubing or to set hydraulic-set packers. After all tests are performed, a predetermined activation pressure is applied at surface to rupture the disk. Once the disks are ruptured, the wellbore fluids can then be produced up the production tubing and maintain full tubing inside diameter without restrictions.

Intelligent completions

Schlumberger's IntelliZone Compact modular multizonal management system is the first fully integrated flow control technology for multizone wells. According to the company, it brings together as one compact unit an advanced design and production modeling engine, a fully integrated completion module and a user-friendly, remote operating system. ■

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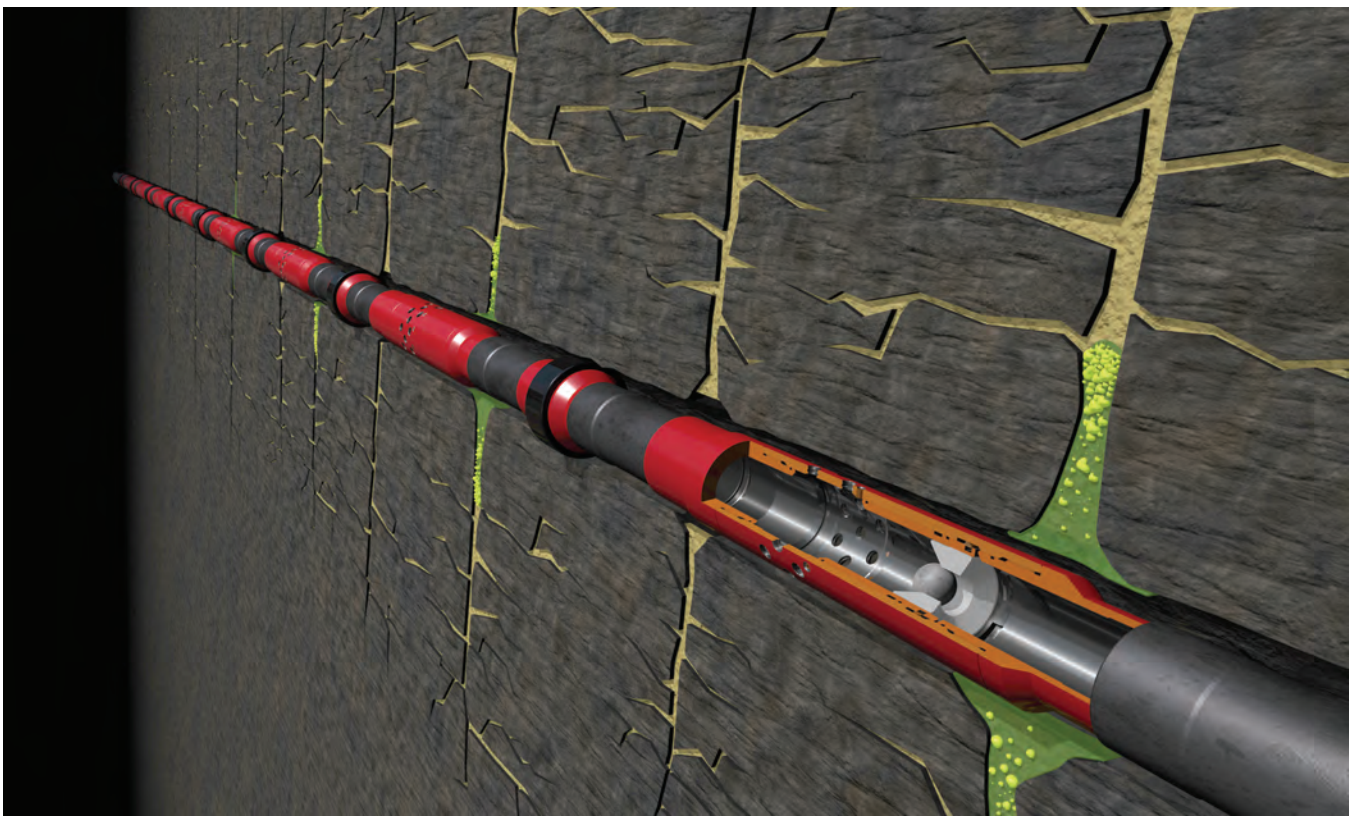

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(Image courtesy of Halliburton)

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Mr. Sandman, Bring Me a Dream

An increase in fracturing job sizes as well as a focus on reservoir contact and conductivity are driving operators to use higher volumes of proppants per well.

By Richard Mason
Hart Energy

Go pound sand!

That's not a pejorative in oil and gas; rather, it describes a completion process in hydrocarbon extraction that is becoming standard operating procedure for the top performing operators in tight formation plays.

Larger proppant loading—a significant boost in the use of bulk commodity sand—has become a standard technique in a well stimulation recipe that also involves individual stages spaced more tightly along the horizontal wellbore. The result is a production uplift, whether measured over 24 hours, 30 days, 90 days or six months. The technique has given birth to a variety of names, including high-intensity completions, enhanced completions, upsized fracks and engineered completions. In the very best reservoir rock, the result is the same regardless of terminology. Well productivity rises whether the target is oil, liquids or natural gas.

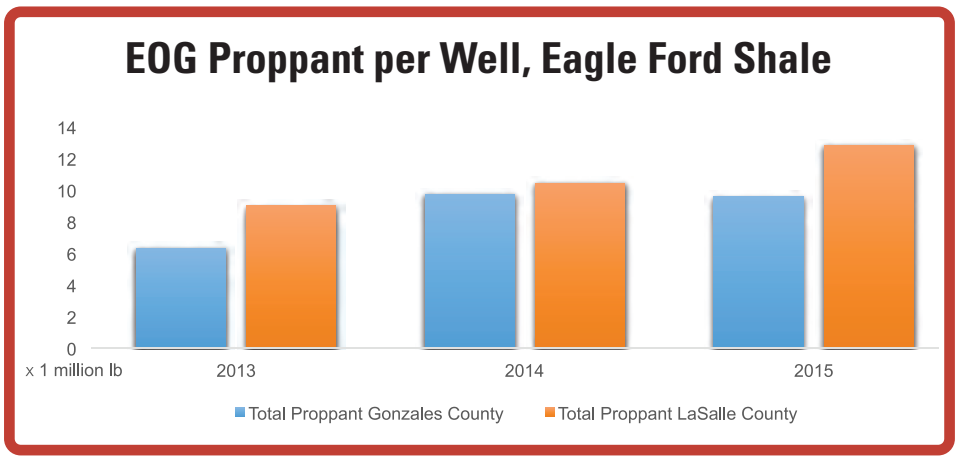
Bulk commodity sand represents up to 10% by volume of material pumped below ground during fracture stimulation operations. It is second only to water, which constitutes 90% of the downhole cocktail. Water, at high pressure, cracks the rock while sand keeps fractures open and allows hydrocarbons to escape their geologic prison. Operators prefer spherical particle shapes for greater strength, either in the form of Northern White from the upper Midwest or Texas brown in the southwest. Both have the ability to withstand heat and pressure. Finer-mesh sands exhibit greater strength and find application in dry gas production, while larger liquid molecules flow better when proppant involves larger mesh sizes. The propensity in dry gas markets like the Marcellus-Utica, Barnett and Haynesville shales is toward 40-70 mesh sand, while oil plays such as the Bakken, Niobrara and Eagle Ford shales display a preference for 30-40 mesh, though operators mix and match to meet completion goals.

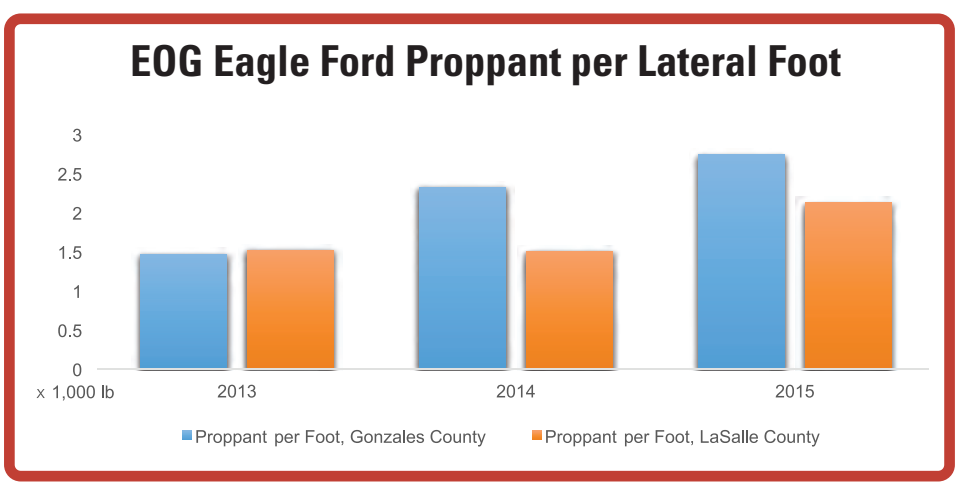
Proppant represents about 15% of horizontal well costs and has remained static as a cost center, even as the cost of proppant declined on a per-well basis to $1.08 million in first-half 2015 from $1.26 million in 2014, according to energy consulting firm Woods Mackenzie. Total completion cost declined from $3.8 million per well in 2014 to $3.4 million in 2015 according to the Woods Mackenzie study, although the rise of high-intensity completions is the major reason that the share of total well costs allocated to completions grew to 49% in first-half 2015 vs. 46% in 2014.

Multiple industry metrics illustrate the dramatic change underway in proppant loading. Whether measured in proppant per rig, per well, per stage or per lateral foot, sand volumes are marching exponentially higher. According to a report from investment banker Raymond James & Associates Inc., the number of frack stages per horizontal well grew

17% in three years to 21.3 in 2014 (and 22-plus during first-half 2015), while the volume of proppant per well climbed 29% from 1.75 metric tons per well to 2.25 metric tons in 2014.

To better understand the volumes involved in high-intensity completion practices, consider that it takes 36 rail cars to transport enough sand to meet the average 7.7 MMlb of sand pumped down horizontal laterals in the tight formation basins. On a four-well pad, which is common in liquids plays, operators are using the equivalent of 144 rail cars of sand. In a handful of cases, operators are using in excess of 10 million lb of sand per lateral, or essentially two 100-car unit trains of sand per four-well pad. Similarly, transporting sand from a regional transloading facility, where rail cars deposit sand from the mines, to the individual well site can require 430 truckloads for a single lateral.





High-intensity completions are evident in both the growing volume of proppant per well and in proppant volume per lateral foot. *(Source: Credit Suisse)*

That's a lot of sand. The expansion in per-well sand volumes is layered upon secular growth in the number of horizontal wells per rig. Both events—higher downhole intensity and more wells per rig—originated in the post-2012 move to pad drilling and batch completions as operators worked through a cycle of improved drilling efficiency, improved completion efficiency and now, thanks to larger loads of bulk commodity sand, completion effectiveness. Additionally, operators are pushing lateral length when land ownership allows. This results in more stages per well at the same time that operators are decreasing the spacing between stages and increasing the volume of proppant per stage. At the well level, all factors favor greater proppant use in the very best reservoir rock.

There may be fewer wells in the wake of a 56% decline in rig count since the October 2014 peak, but as operators focus on the core of the core in a low commodity price environment, a greater percentage of wells are employing high-intensity completions, skewing average numbers for proppant use higher.

Sand gets pounded

Despite the positive news on greater downhole intensity, the downturn in oil and gas activity is projected to drop annual demand for sand up to 30% in 2015. At press time, future sand consumption remained a guessing game. A Cowan and Co. analyst report estimated the industry would consume 36 million tons in 2015 before activity rises by 400 rigs—50%—in 2016 and sand consumption grows by more than one-third to 49 million tons.

Nonetheless, current metrics reflect tough times. Sales to the oil and gas industry among the four

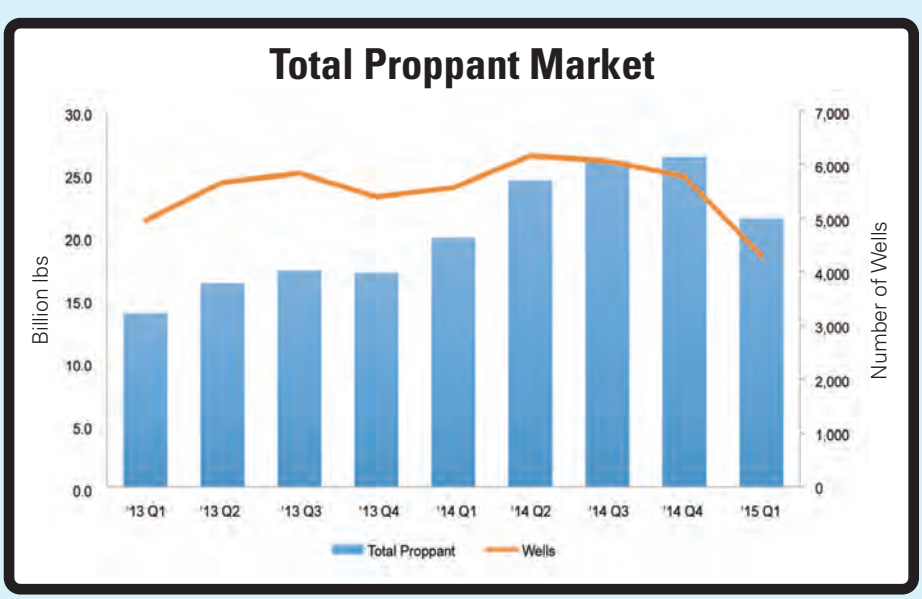
Proppant, Frack Sand Market Outlook Remains Strong

Despite decrease in drilling activity, proppant and frack sand usage continues to rise as operators work core areas.

By Todd Bush
Energent Group

The total proppant market doubled from the beginning of 2013 to year-end 2014. In all, the market grew from 13.9 billion lb of sand in first-quarter 2013 to 21.4 billion lb of sand in first-quarter 2015. Many operators tested high-intensity completions that used significantly more raw sand over resin-coated sand or ceramic proppant.

More than $22 billion in operator budgets was slashed in first-quarter 2015. As operators turned their capital and focus to the core acreage, many laid down rigs and cut longer-term drilling and servicing contracts. EOG Resources has deferred completions in core areas to ensure the return on new wells meet shareholder expectations.



(Source: Energent)

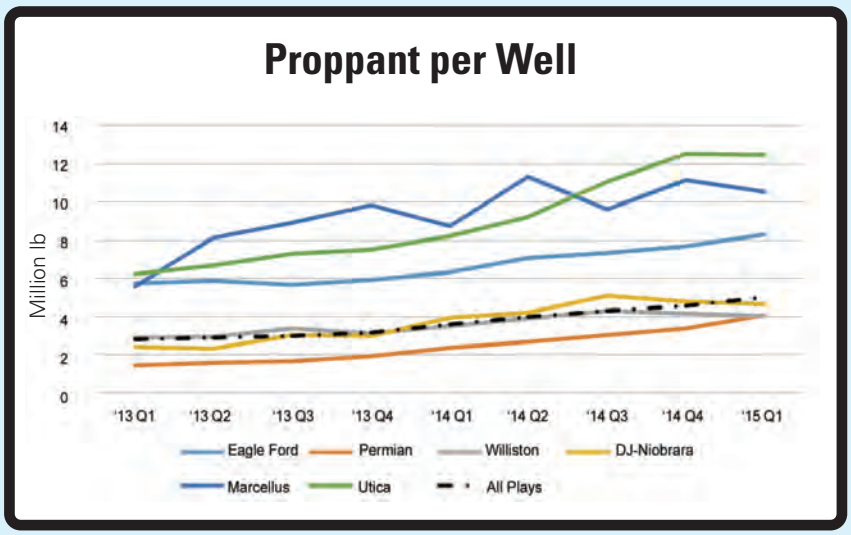
Proppant per well

There is no doubt the overall decrease in activity has impacted the frack sand market; however, the amount of sand per well continues to increase.

In each of the major shale plays, proppant per well continues to increase.

The average across all shale plays is about 4 million lb per well in first-quarter 2015 compared to 2.8 million lb in first-quarter 2013.

The Eagle Ford Shale is the top frack sand market based on volume with more than 5.6 billion lb of sand used in first-quarter 2015. Compared to the previous quarter, frack sand usage was down 27% from 7.6 billion lb of sand.



(Source: Energent)

Increase in Proppant per Well

	'14 Q1	'15 Q1
Eagle Ford	10%	32%
Permian	65%	74%
Williston	22%	14%
DJ-Niobrara	65%	18%
Marcellus	57%	21%
Utica	32%	52%
All Plays	28%	39%

EP Energy's enhanced completion program improved well performance by 14% in the Eagle Ford Shale, according to company presentations. The company's previous completion technique included 5.1 million lb of sand and resin-coated sand for most Eagle Ford wells in mid-2014. Based on the latest completions, EP Energy now uses 10.2 million lb of proppant per well. EP Energy relies on Weatherford and FTSI for pressure pumping in the Eagle Ford.

Expect the Permian to grow in importance as operators' capital is deployed in core areas with lower operating costs and higher returns. Permian operators used 4.5 billion lb of sand in first-quarter 2015 compared to 5.2 billion lb of sand in fourth-quarter 2014.

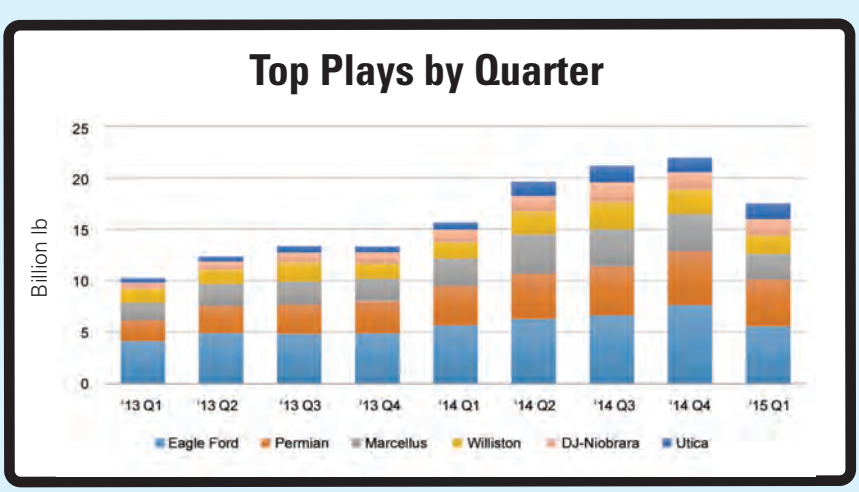
In the Permian Basin, Devon is another operator seeing success with enhanced completions. In first-half 2014 the company used 3.7 million lb of proppant but by the year-end was using 5.9 million lb of proppant per well. Baker Hughes and Halliburton pump the majority of jobs for Devon in the Permian Basin.

Not surprisingly, 82% of the proppant produced is used in the top six unconventional plays: the Eagle Ford Shale, Permian Basin, Marcellus Shale, Williston Basin, Niobrara Shale in the Denver-Julesburg Basin, and Utica Shale.

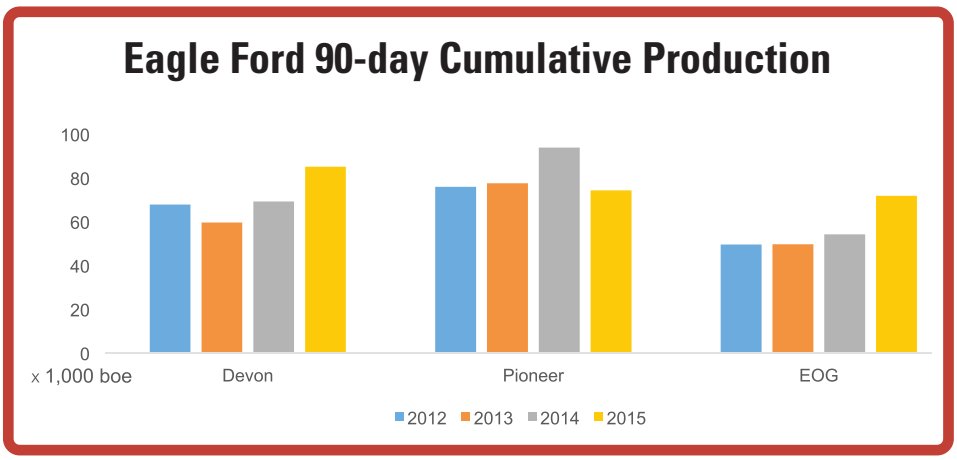
Big 3 lose market share

The Big 3 pressure pumpers, Halliburton, Schlumberger and Baker Hughes, totaled 46% of the market in first-quarter 2014. With the decline in oil prices and rig counts, the Big 3's market share declined to 42%.

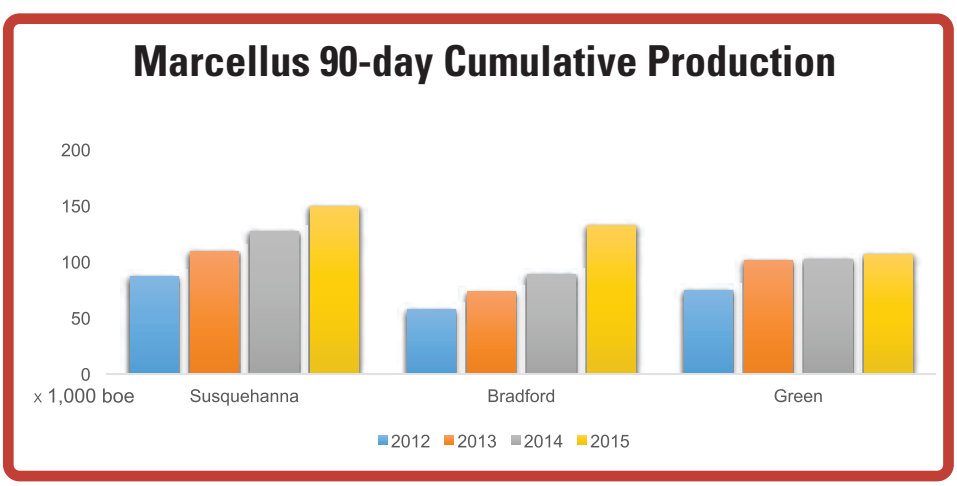
Several pressure pumpers including Weatherford, C&J Energy and FTSI defended their market share successfully through cost reductions and contract negotiations. ■



(Source: Energent)



The evolution to high-intensity completions produces higher cumulative production during the first 90 days. *(Source: Credit Suisse)*



Pennsylvania counties in both the dry gas and wet gas windows of the Marcellus Shale have seen uplift in 90-day cumulative production from high-intensity completions. *(Source: Credit Suisse)*

publicly held sand mining companies in first-quarter 2015 fell to 5.87 million tons, which is down 12% sequentially. While lower rig count and fewer well completions argue for less aggregate sand volume in 2015, the irony is that sand use per well continues to rise as operators focus drilling activity in the core of the core of the very best plays where larger volumes of sand are more effective.

Sand providers have been pursuing strategies to adjust to changing market dynamics, including price reductions, contract modifications, cancellation of capacity expansion, layoffs and reducing distributions for master limited partnership unitholders. In first-half 2015, U.S. Silica Holdings Inc. reduced shifts and laid off workers at its Sparta, Wis., facility and deferred startup of its 3-million-ton Fairchild, Wis., plant until 2016. FMSA Holdings idled the 1-million-ton Brewer, Mo., facility and closed a 300,000-ton Readfield, Wis., plant, while Emerge Energy Services LP suspended plans to open a 2.5-million-ton Independence, Wis., plant. Similarly, CARBO Ceramics Inc. is mothballing its McIntyre, Ga., ceramic proppant facility as oil and gas operators eschew expensive ceramics for cheaper bulk sand as a proppant. Meanwhile the scramble to obtain rail cars for sand transportation in 2014—as many as 12,500 additional cars for the four publicly held sand providers—is on hold as suppliers cancel or defer orders.

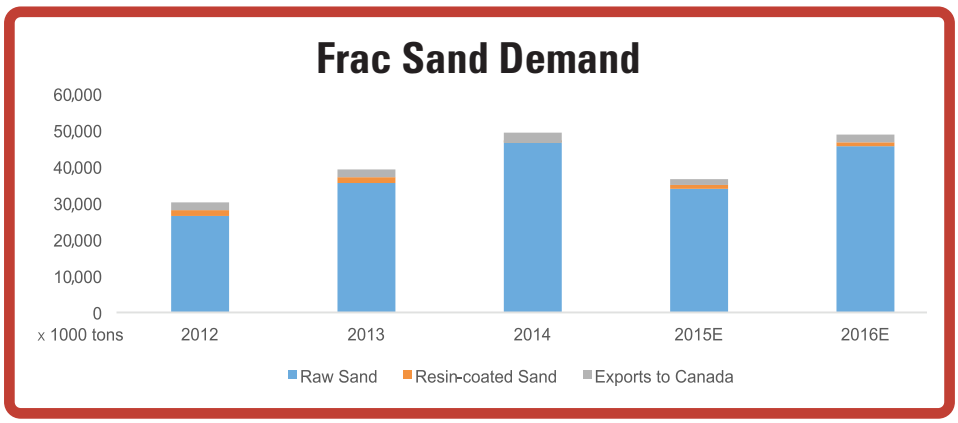
Sand revolution

The move toward greater proppant loading represents a re-polarization in industry well-development philosophy. In the early days of the Barnett Shale, operators modified slickwater techniques common in East Texas gas plays by increasing water volume while decreasing proppant loading. The method reduced completion cost and became known as a light sand frack.

But that tried-and-true technique was upended in summer 2012 when EOG Resources Inc. began touting monster wells in the Eagle Ford Shale during its earnings calls. Monster wells sported IP rates that were a step level higher when compared to neighboring activity with standard completion practices. Though EOG remained close-lipped, state records revealed the company was employing a significant increase in sand volumes for so-called monster wells. Other Eagle Ford operators began emulating the practice over the next two years. The technique soon spread to the Permian Basin, the Anadarko Basin, the Rockies, including the Bakken

Shale, and Appalachia, though the Eagle Ford remains the largest proppant consuming market in the U.S. on a volume basis and hence the center for high-intensity completions.

The evolution in pad drilling and batch completion techniques reduced cycle time per well and soon led to greater downhole intensity as operators employed zipper fracture stimulation techniques to multiple laterals on a single pad. According to Hart Energy market intelligence surveys, zipper fracks accounted for up to two-thirds of horizontal completions in 2014 in the major unconventional plays whether the laterals were parallel, or stacked and staggered. An accidental result was the discovery that the technique, initially implemented to improve wellsite equipment utilization, created greater stimulated rock volume. When operators turbocharged the technique with greater proppant loading, the result was reflected in a sudden bump in sand demand that collided in 2014 with the restricted ability to transport sand via rail from mines in the upper Midwest to tight formation plays in Canada, Texas and Appalachia.



Frack sand demand grew at a rate of about 30% annually during the most recent uptick in oil and gas activity but is expected to fall 30% in 2015. Future growth is predicated on fewer rigs but more sand use per well as operators concentrate on high-grading activity to core acreage. *(Source: Cowan and Co.)*

Although the sand revolution has been calibrated in bulk volumes, it also surfaced as a derivative financial play on Wall Street during the record level run in energy-related IPOs between May 2013 and May 2014. While several companies in the midstream sector saw enormous appreciation after their IPOs, along with a few specialized upstream regional operators, the one fact that stood out among the two dozen IPOs over the course of the 2013 to 2014 time period was that three of the top 10 performing IPOs—including the No. 1 performer—were mining firms that supplied sand in the form of proppant to the oil and gas industry. Fast forward one year, and the sand mining sector remains the most heavily shorted niche in oil services as investors bet demand will follow commodity prices lower.

Although the oil and gas downturn has altered the near-term narrative for proppant, it has not diminished its importance. As commodity prices declined in 2015, oil and gas operators began emphasizing net present value for wells, which meant accelerating production to maintain well economics.

A second trend is more subtle but involves the transition to completion efficiency in which effort is directed to reduced downtime at the well site through cycle improvement—usually in the form of zipper fracture stimulation. Zipper fracks alternate treatment by a stimulation crew across two or more laterals to eliminate expensive nonproductive time. Meanwhile the industry is shifting completion strategies from attempting to frack into hydrocarbon-bearing strata by extending induced fractures deep into the reservoir to targeting greater access to hydrocarbons close by the wellbore. This change in technique emphasizes placing the horizontal lateral in the very best part of the formation, reducing stage spacing from 300 ft or 400 ft previously to approximately 200 ft currently (less with coiled tubing-conveyed fracture stimulation), and placing horizontal laterals closer together, including stacking and staggering laterals from a single pad.

Operators also are targeting precision placement of perforations to overcome issues with suboptimal stage performance. Anecdotally, presentations by major service providers at Hart Energy conferences indicate the number of ineffective or suboptimal stages has decreased from 60% two years ago

Speaking of Completions

Industry experts offer insights about the role of sand and proppant.

In the Bakken

"That typical 4-million-lb completion, if it's using a crosslink fluid or hybrid-fluid system, would use about 60,000 bbl to 70,000 bbl of fluid. Shifting to slick water requires more fluid pumped at a higher rate. Those fluid volumes climb to 200,000 bbl to 250,000 bbl. When we track the impact of proppant intensity in the basin, we see in core rock a significant EUR and NPV [net present value] uplift to wells.

"In other words, in some of the core regions, we see as much as a doubling of EURs. Assuming the incremental well cost associated with that, we can see as much as three or four times uplift on the NPV.

—**Gibson Scott**, TG Investment Research Inc.
Hart Energy video interview, DUG Bakken Conference, April 1, 2015

In the Permian

"Five years ago, you couldn't do the size of fracks we're doing now. There just wasn't the capability for doing it. We've tested not just the amount of sand we use, but the spacing. We've tested the amount of water we use to move that. We've tested how quick you allow that well to start flowing back. We've tested ceramics. Where we are is that the more rock we can touch effectively—and make it stay touched, actually propagating the sand into the fracture—the better the wells we're going to have."

—**Randy Foutch**, Laredo Petroleum Inc.
Hart Energy video interview, DUG Permian Conference, May 21, 2015

In the Marcellus

"It used to be all about how much water can you pump, what is the frack height and how far can you reach. Then the industry began looking at sand, sand placement and getting better near-wellbore quality in terms of placement of sand.

"We're looking at a couple of things. One, we want to make sure that we're landing the well to begin with in the right place.

"Second, we are experimenting with different sand loading. We're up to 1 million lb of sand per stage in some of our Marcellus wells. I think that quality of placement and predictability of placement of proppant have become norms in the industry."

—**William J. Way**, Southwestern Energy Co.
Hart Energy video interview, Jan. 31, 2015

to about 40% currently. Operators also are fine-tuning stage placement to allow similar completion methods for similar reservoir rock and skipping or altering techniques in rock that may have poorer productive potential. Combined with greater proppant loading, these alterations in traditional practice have improved well productivity in the early stages of a well's life cycle.

Numerous public presentations by oil and gas operators credit high-intensity completions with as much as a 30% production uplift in the Permian's Delaware Basin, the Eagle Ford, the dry gas Marcellus and the Cana Woodford. A 2014 industry study on frack sand by investment banker Raymond James cited the example of SM Energy Co., which increased sand use from 1,128 lb per lateral foot initially to 2,025 lb per lateral foot as part of an enhanced completion program in the Eagle Ford Shale. While proppant loading grew 80% in the new technique, the rate of return moved up 40% per well, providing a $2 million increase in net present value per well. Those uplifts are becoming ever more important in a low commodity price environment.

The reality is that the best reservoir rocks respond favorably to high proppant loading. The challenge is extending that completion effectiveness to lower-quality rock where what works best in quality rock can torpedo well economics outside the play's core.

Meanwhile operators are placing renewed interest in high-volume, slickwater fracture stimulation with large proppant loading as a cost-saving measure in a low commodity-price environment. In some cases, such as the Bakken Shale, massive slickwater treatments with high proppant loading have extended the economics of wells to portions of the reservoir outside the central core. Bulk commodity sand now represents more than 90% of the market as ceramics lose share on the basis of price. Resin-coated sand has made some inroads as operators use it at the tail end of the well stimulation process to improve fracture integrity in the Marcellus and the Permian Basin.

High-intensity completions are all about sand. The sand revolution in oil and gas remains in the early innings despite challenges from a low commodity price environment. ■

Proppant Key Players

As operators seek to coax resources from plays that are more difficult to access, proppant providers continue to develop solutions for a variety of formation challenges.

Key Players

Badger Mining Corp.

Badger Mining Corp.'s focus on growing operations has included acquiring Atlas Resin Proppants, which merged with the company earlier this year. Due to the Atlas merger, Badger Mining's product offerings now also include resin-coated sand, according to the company's website. In April, Badger Mining also acquired the assets of Northern Frac Proppants II LLC, including a processing facility.

With corporate offices in Berlin and Taylor, Wis., the company operates three sand processing facilities in Fairwater, Taylor and Alma Center, Wis.; coating facilities in Taylor and Merrillan, Wis.; and a transloading facility in George West, Texas. In addition, the company has agreements in place with sub-contractors for several other transloading facilities in North America.

Badger Mining manufactures several mesh sizes of Badger Frac proppant, using Northern White sand from the Wonewoc and St. Peter sandstone formations, according to the company. The company also now offers the Atlas product line of resin-coated proppants, which use Badger Sand as a base. The product line includes pre-cured resin-coated proppant in several mesh sizes and with demonstrated compressive strength and crush resistance. The line also includes curable resin-coated proppants with economy and low-temperature variations. Curable resin-coated proppants can reduce fines migration and embedment while preventing proppant flowback, according to the company.

CARBO

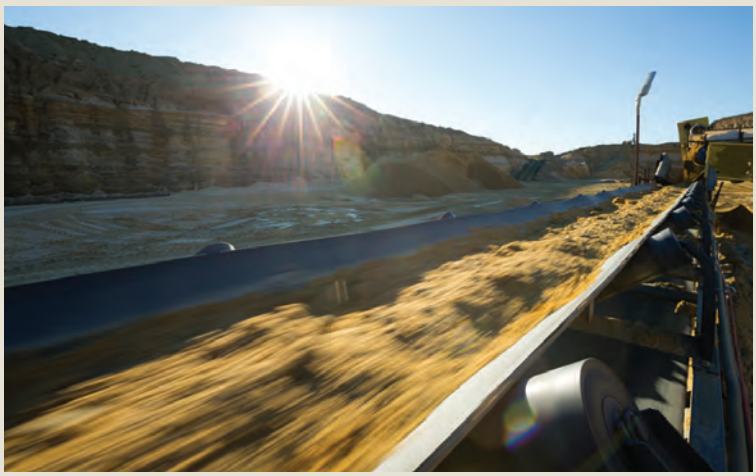
CARBO, an oilfield services technology company, provides production enhancement and environmental protection solutions, helps businesses build and optimize their frack, and offers spill prevention and containment solutions.

SCALEGUARD proppant-delivered scale-inhibiting technology from CARBO allows an engineered release of scale inhibitor, delivering long-term protection of scale from the fracture through the wellbore to the surface processing equipment.
(Image courtesy of CARBO Ceramics)

The company's production enhancement solutions include FRACPRO fracture design and analysis software, CARBO CERAMICS & TECHNOLOGIES (the company's fracture technologies business) and STRATAGEN fracture consulting services.

FRACPRO is designed to deliver the information necessary to achieve successful stimulations, regardless of formation type, permeability or location, the company said. "The software can effectively model any type of pressure stimulation job, including multitreatment horizontal completions, alternating wellbore treatments (zipper frack) and acid fracturing limited entry perforating designs and tip screenout projects. It can model fracture growth in any formation— shale, carbonate, sandstone and coal," the company said on its website. "FRACPRO software allows understanding of proppant placement, interference effects, conductivity improvements and fracture complexity." The software also can incorporate the effects of proppant damage due to crushing, embedment, stress cycling, and non-Darcy and multiphase flow. It models all the treatments of a multistage completion in a single file, the company said.

In addition, CARBO CERAMICS & TECHNOLOGIES, a global supplier of ceramic proppant, offers fracture technologies that include high-quality, high-performance proppant, proppant-delivered production assurance, proppant-delivered flow enhancement and proppant-delivered fracture evaluation services.



Fairmount Santrol has five Northern White mines. *(Image courtesy of Fairmount Santrol)*

According to the company, its proppant can achieve increased production and EUR with no increase in authority for expenditures. The company's proppant is designed to have a low internal pellet porosity, allowing it to withstand pressure cycling and avoid the creation of fines. "That means the proppant will maintain more space to flow for the life of the well," CARBO said on its website.

STRATAGEN, a CARBO fracture consulting services business, provides fracture design and evaluation services, well performance analysis, and onsite fracture supervision and advisory services. Additionally, WELLWORX well performance analysis is designed to offer operators an index of the completion success indicators to accelerate optimized completion and fracture designs for the reservoir, according to the company. "The service uses multiwell, data-driven linear and neural network analysis techniques to identify new recovery opportunities and the optimum field development strategy," CARBO said.

Diamond Proppant Inc.

Based out of Houston, Diamond Proppant Inc. is a wholly owned subsidiary of Jingang New Materials Co. Ltd., which manufactures the company's line proppants at its facilities in Shandong, China. Diamond's C-Flo high strength proppant consists of sintered bauxite sourced out of Jingang's mines.

Offered in mesh sizes of 20/40, 30/50 and 40/70, the proppant can enable maximum conductivity due to its uniformity in size and sphericity, according to the company's website. It has exhibited high crush resistance and can be used in high-temperature drilling environments and deep wells. Uniform sphericity allows the proppant to maintain high levels of conductivity and permeability and can decrease the risk of damage to production equipment.

Fairmount Santrol

Ohio-based Fairmount Santrol provides high-performance sand and sand-based products used by E&P companies to increase oil and gas production.

The oil and gas business segment includes Propel SSP proppant transport technology. This proppant and fluid system can increase hydraulic fracturing efficiency by reducing pumping time and water con-

sumption, in addition to eliminating extra frack fluid chemicals.

Other product lines include curable resin-coated sand, precured resin-coated sand, frack sand and biodegradable ball sealers. Curable resin-coated sand can prevent proppant flowback with effective bond strength or unconfined compressive strength, according to the company.

Precured resin-coated sand is designed to offer greater conductivity, crush resistance and proppant flowback control. The resin encapsulates fines, which can reduce flow capacity up to 60% for "superior conductivity," the company said.

Northern White sand, which is more than 99.8% high-purity quartz, is designed to have greater conductivity and crush strength. Texas Gold sand offers reliable hydraulic fracturing results, Fairmount said. In addition, BioBall biodegradable ball sealers are used as diverting agents and for zonal isolation.

The company has three R&D centers in Sugar Land, Texas; Ottawa, Ill.; and Detroit. Company research scientists are improving resin-coated sand performance by investigating proppant surface science and other structural features at the atomic and molecular level to optimize bonding between resin and the substrate, the company said.

Fineway Ceramics

Since 2008, FineWay Ceramics has been supplying bauxite-based ceramic proppants to the North American market and is headquartered in Windsor, Ontario, Canada.

The company offers low-, middle- and high-density ceramic proppants for a full range of well depths in standard mesh sizes of 20/40, 30/50 and 40/70 and in custom mesh sizes upon request, according to the company's website. In addition, FineWay offers resin-coated ceramic proppants.

The company's growth focus includes development of ultralow density, high-strength proppants and customer-specific solutions for last-mile logistics and inventory management.

FineWay's logistics network is built upon long-term commitments from railway operators and transloading partners for the major plays, with storage to minimize last-mile delivery costs.

Hexion's line of resin-coated proppants offer advanced technology for a variety of applications. *(Photo courtesy of Hexion Inc.)*

Hexion Inc. (formerly Momentive Specialty Chemicals Inc.)

As of Jan. 15, Momentive Specialty Chemicals Inc. became Hexion Inc. The company's oil and gas product offerings include resin-coated proppants, performance additives and production chemicals, which consist of hydrogen sulfide scavengers.

Hexion manufactures its own resins, with the company producing resin for a variety of industries such as aerospace and renewable energy, in addition to the oil and gas industry.

The company's OilPlus proppants, AquaBond proppants, Black Pro proppants, Prime Plus proppants and SB Prime proppants are resin-coated sands with Stress Bond technology that can be applied to typical closure stresses up to 10,000 psi or greater, according to the company.

The company's Black Ultra proppants, SiberProp proppants and SB Excel proppants also are resin-coated sands with Stress Bond technology that can be applied to typical closure stresses up to 8,000 psi. Black Ultra proppants are designed for low bottomhole static temperatures down to 90 F. The XRT Ceramax resin-coated proppant line is made from ceramic and bauxite for HP/HT well conditions. The Stress Bond technology "provides improved fracture flow capacity and flowback control," according to the company's website.

The company's performance additives consist of solutions for well stimulation, drilling and cementing. Hexion's hydrogen sulfide scavengers are designed for crude oil, natural gas, LPG and steam-

assisted gravity drainage. These scavengers are designed for the oil and gas industry, and the company offers custom blends.

Hi-Crush Partners LP

With corporate offices in both Sheffield, Pa., and Houston, Hi-Crush Proppants owns and operates frack sand reserves and processing and transportation facilities. The company specializes in monocrystalline sand, producing from its reserves of Northern White frack sand, found mainly throughout Wisconsin and parts of the Midwest. The company serves tier one and smaller pressure pumping companies, according to its website.

Hi-Crush's facilities in Wyeville and Augusta, Wis., each process about 1.6 million tons of frack sand per year in multiple mesh sizes. Both locations also include onsite rail facilities with rail spurs connecting to Union Pacific Railroad mainlines.

In June 2013, Hi-Crush acquired D&I Silica LLC, which supplies frack sand, terminal storage and railcar storage and handling to operators in the Marcellus and Utica shales. In addition to these two plays, Hi-Crush also reported access to all major oil and gas basins in the U.S. in a June 2015 presentation.

The company reported first-quarter 2015 revenue of $102,111, down from fourth-quarter 2014 revenue of $130,929 but up from first-quarter 2014 revenue of $70,578. In its June 2015 presentation the company attributed the decline in frack sand demand quarter-to-quarter to the decline in rig count also experienced during late 2014 and early 2015. Despite this drop, the company predicts strong long-term fundamentals for frack sand.

Imerys Oilfield Solutions

Imerys uses South Georgia kaolin clay to manufacture its lightweight ceramic proppants at its facilities in Andersonville and Wrens, Ga. The company's range of ceramic proppants includes ProLite, an economic lightweight proppant that can be used in a variety of wells, according to the Imerys website. The company manufactures the proppant in 20/40, 30/50 and 40/70 mesh sizes. In an API/ISO crush test, the 20/40 mesh showed 5% fines generated by weight, the 30/50 mesh showed 4% fines generated by weight and the 40/70 mesh showed 3.5% fines generated by weight.

The company also offers ShaleProp lightweight ceramic proppant, which was designed to improve productivity in water fracks, according to the company. ShaleProp comes in mesh sizes of 20/40 and 30/50. In an API/ISO crush test the 20/40 mesh showed fines generation of 7% by weight, and the 30/50 mesh showed fines generation of 5% by weight. Along with ProLite, ShaleProp was shown to have long-term conductivity and long-term permeability.

For HP/HT wells with closure stress levels in excess of 15,000 psi, the company's Propynite proppant allows high well productivity, according to Imerys. The proppant can improve residue transport, reducing slurry friction losses by 10%.

Preferred Sands LLC

A private company with corporate offices in Radnor, Pa., Preferred Sands operates proppant facilities in Blair and Bloomer, Wis.; Genoa, Neb; Hanson Lake, Saskatoon, Saskatchewan; Sanders, Ariz.; and Woodbury, Minn.

The company developed its RCS resin-coated sand proppant line for a range of well conditions, including HP/HT, using Dow Chemical Co.'s Teraforce technology. Also in partnership with Dow, Preferred Sands designed its DustPro treated proppant to reduce airborne silica dust particles. The DustPro proppant also uses Teraforce technology, which can minimize proppant flowback by allowing formation of particle-to-particle bonds, according to Preferred Sands' website. Both proppant types also rely on Dow's Tersus technology to reduce proppant dust while maintaining substrate sieve characteristics. In addition, Preferred Sands also offers silica sands in every gradation.

In September 2014, Preferred Sands and Dow Chemical were recognized for Teraforce technology with the 2014 Polyurethane Innovation Award from the Center for the Polyurethanes Industry of the American Chemistry Council, according to a press release.

Rainbow Ceramics

Prop Supply & Service LLC is doing business as Rainbow Ceramics, which manufactures and sup-

Rainbow's ultralightweight ceramic proppant ReaLite is well suited for slickwater fracturing. *(Image courtesy of Rainbow Ceramics)*

plies ultralightweight, lightweight, intermediate- and high-strength ceramic proppants. The company's proppants include ReaLite, PropLight, PropMaster and PropRaider. The ReaLite ultralightweight ceramic proppant is Rainbow's most cost-effective proppant and is well suited for slickwater fracturing, according to the company. ReaLite is created from naturally occurring clay and can provide 50% higher strength, improved conductivity, more thermal stability and better placement than premium resin-coated sand, the company said.

In addition, the PropLight lightweight ceramic proppant provides high fracturing conductivity for applications in wells with moderate depths and offers chemical inertness and thermal stability.

The PropMaster intermediate-strength sintered bauxite is designed for high performance under closure stresses of up to 14,000 psi. According to the company, the proppant's roundness and sphere form minimize friction and wear on fluid-carrying and pumping equipment.

PropRaider sintered bauxite is Rainbow Ceramic's highest-strength proppant and is designed for applications in deep wells with high closure stresses and temperatures. PropRaider offers "maximum conductivity, high crush resistance and excellent thermal stability in hot downhole conditions," according to the company.

Saint-Gobain

With more than 265 locations in North America, Saint-Gobain manufactures four major types of proppants including lightweight, intermediate strength, high-strength and ultrahigh strength. Saint-Gobain's lightweight proppants, BauxLite and Versalite, are engineered to offer crush resistance and come in sieve distributions of 16/30, 20/40, 30/50 and 40/80.

The company's intermediate-strength proppants comprise InterProp and VersaProp, both of which are made of bauxite. VersaProp seeks to maximize conductivity through a proprietary sieve distribution. InterProp can also deliver improved conductivity, with a focus on wells with low to moderate permeability, according to the company.

Saint-Gobain's UltraProp high-strength proppant uses the VersaProp sieve distribution and offers a larger median particle diameter for improved conductivity. The company's second high-strength proppant, Sintered Bauxite, can withstand HP/HT conditions in deep wells, while maintaining conductivity, according to the company. For even harsher environments, such as the Gulf of Mexico's deepwater and continental shelf formations, the company engineered Titan ultrahigh strength proppant, which is capable of withstanding high closure stresses and temperatures.

Shamrock Proppants

With its corporate headquarters located in Mexico, Mo., Shamrock Proppants specializes in manufacturing lightweight ceramic proppant. In 2013, the company purchased the facilities, which formerly were owned by Mid America Brick. The facility includes access to both rail transportation and trucking routes.

On its website, Shamrock notes that its facilities for both raw mining and processing are ISO 9001 certified. The company offers proppants in a variety of mesh sizes, ranging from 20/40 to 40/80. Results from an API crush test showed 3.8% fines generated by weight for 20/40 mesh proppant and 1.6% fines generated by weight for 40/80 mesh proppant, both of which meet ISO specification 13503-2. The company noted its proppants have roundness of 0.9, sphericity of 0.9, bulk density of 98 lb/cu. ft, apparent specific gravity of 2.63 and solubility in 12/3 HCL/HF acid of 4%.

Superior Silica Sands LLC

With headquarters in Fort Worth, Texas, Superior Silica Sands owns proppant facilities in Kosse, Texas, and in Clinton, New Auburn and Arland, Wis. The company is owned by Emerge Energy, which itself is owned by Insight Equity.

The company's proppant plants are well-connected to major modes of transportation, with the Clinton plant located alongside the Canadian National Railroad; the New Auburn plant located along the Progressive Rail Short Line, which connects to the Union Pacific Railroad; and the Arland plant designed for truck to rail transport. Additionally, Superior connects to U.S. transload terminals in Bainville, Mont.; Canton and Mingo Junction, Ohio; Elmira, N.Y.; Maidsville, W.Va.; Odessa, San Angelo and San Antonio, Texas; and Shattuck, Okla. The company also makes use of Canada transload terminals in Rocky Mountain House and Sexsmith, Alberta.

The company specializes in several different gradations of white, Northern/Ottawa sand from its quarries in Wisconsin, according to Superior's website. This type of sand is known for its sphericity, conductivity, structural integrity and crush strength. In addition, at its Kosse facility, Superior processes a native Texas sand, known as Native Star sand, in 40/70 and 100 mesh sizes.

Unimin Energy Solutions

Unimin Energy Solutions is headquartered in The Woodlands, Texas, and is the global oilfield minerals business unit within the Sibelco Group, a privately held miner and processor of industrial materials that has been in business for 140 years. Unimin Energy Solutions' product portfolio encompasses MudStar brand barites and Trugel brand bentonites for drilling muds, Silverbond brand silica flour for well cementing, Unifrac brand northern white and Texas brown frack sand proppants, PropStar brand resin-coated sand proppants and flowback control agents covering the full range of reservoir conditions, and AccuPack brand gravel pack sands used for sand control in offshore oilfields.

The company has a global frack sand production capacity of more than 15 million tons per year and a network of 20-plus plants across the U.S., Europe and Australia. Unimin also has a fleet of more than 35 transload terminals in the U.S. and Canada.

U.S. Silica Holdings Inc.

With operations spanning the U.S., the company has proppant facilities located in Voca, Texas; Mill Creek, Okla; Pacific, Mo.; Ottawa and Rochelle, Ill.; Sparta, Wis.; and Rockwood, Mich. U.S. Silica's corporate offices are located in Frederick, Md.; Chicago; and Houston.

Adhering to ISO and API guidelines, the company's proppants are manufactured to meet specifications relating to crush resistance, acid solubility, turbidity, particle distribution and sphericity, according to U.S. Silica's website. The company's offerings include U.S. Silica White proppant, made from Northern White sand in a range of mesh sizes. Known for its durability and strength, the Ottawa type fracturing sand uses monocrystalline alpha quartz mineral from the St. Peter and Sylvania formations, the company said.

The company draws on the Hickory Sandstone Formation, located in Central Texas near the Permian Basin and Eagle Ford Shale, to manufacture its Premium Hickory quartz proppant. Naturally coarse, the proppant can be used in operations requiring high relative conductivity, according to the company.

The company's Coated Sand Solutions division also recently designed a resin-coated proppant for HP/HT conditions. Known as InnoProp, the proppant uses Ottawa type sands coated with a thermoset resin that allows improved conductivity and strength, according to the company. ■

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Shifting Sources

Water management continues to evolve as operators look to make more with less in drought-prone areas.

By Jennifer Presley
Senior Editor, Production

Water is a simple chemical compound made up of two parts hydrogen to one part oxygen. Through its simplicity, water's versatility is fully realized as a key building block for life and all things that make life possible. Water is both friend and foe; it is a currency with a value that grows and declines based on market supply and demand.

For the oil and gas industry, management of a resource so simple yet so valuable has grown in its complexity over the past few years as the shale gale blew west from Pennsylvania's Marcellus to California's Monterey, touching down in several points along the way.

Along with advancements made in directional drilling and hydraulic fracturing—the two technologies largely credited for shale's success—water management also has evolved to meet the changing demands of the environmental, financial and political landscapes.

But technology is not the only area of evolution. As operators and service companies moved into different formations, so did the knowledge of what did or did not work in one area move and with a little tinkering, find success. This increase in the industry's understanding of the science behind the process is helping to solve some lingering questions and challenges, like water sourcing and transportation.

How much?

With every drop of water under increased scrutiny, especially in drought-prone areas, a common question that crops up in debates on hydraulic fracturing is how much water is required to fracture a well?

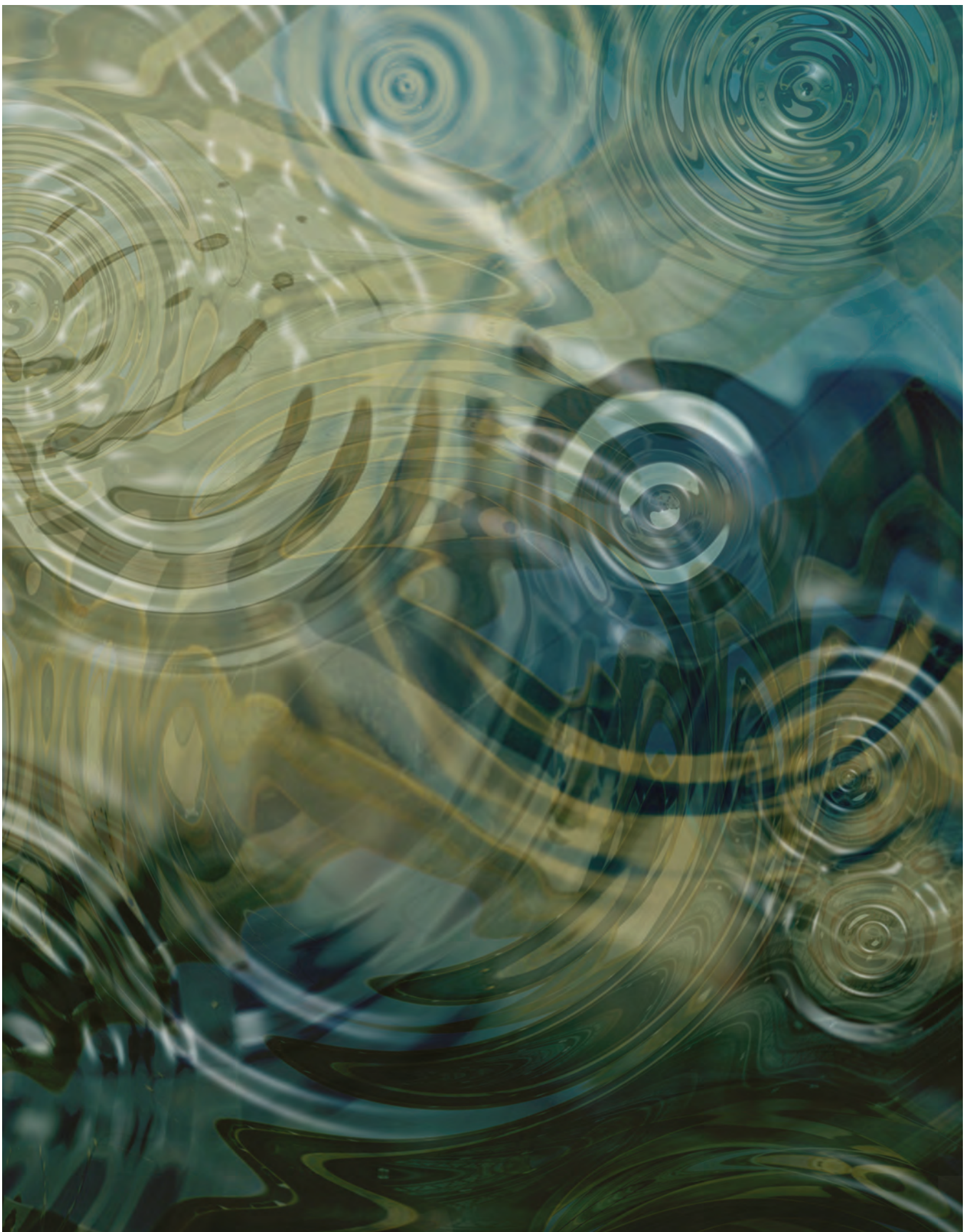
The answer is not as cut and dried as many seem to think it to be. It depends on a number of factors that prevent a definitive answer. However, the U.S. Geological Survey (USGS) weighed in on it when it conducted the first national-scale analysis of hydraulic fracturing water usage and found that "it depends" can be the most accurate answer possible.

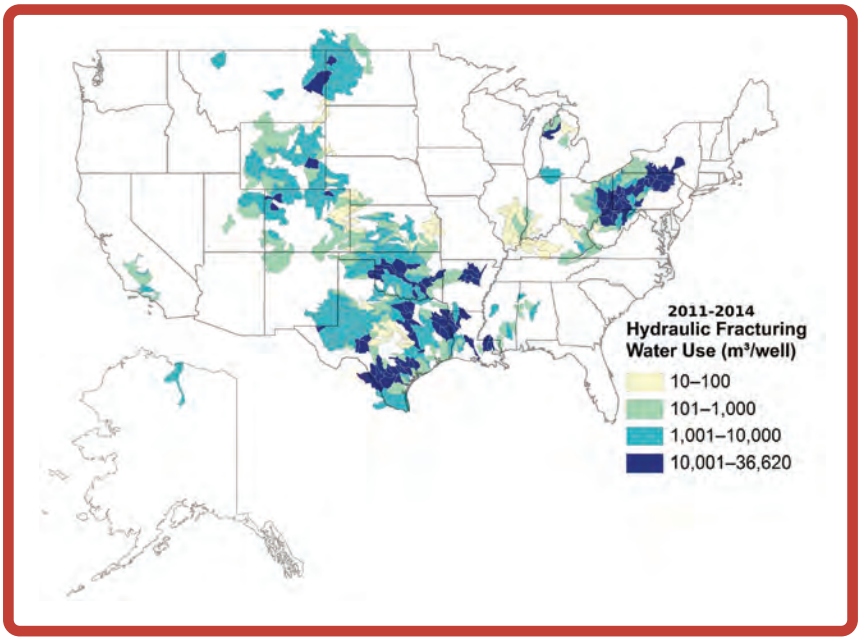
"One of the most important things we found was that the amount of water used per well varies quite a bit, even within a single oil and gas basin," said Tanya Gallegos, a USGS scientist and the study's lead author, in a joint American Geophysical Union (AGU) and USGS-issued press release. "This is important for land and resource managers because a better understanding of the volumes of water injected for hydraulic fracturing could be a key to understanding the potential for some environmental impacts."

The findings—announced in June 2015—show that water volumes for hydraulic fracturing averaged within U.S. watersheds range from 2,600 gal to as high as 9.7 million gal per well, the release said. These numbers come from the analysis and compilation of the water volumes used to fracture more than 263,000 oil and gas wells drilled between 2000 and 2014.

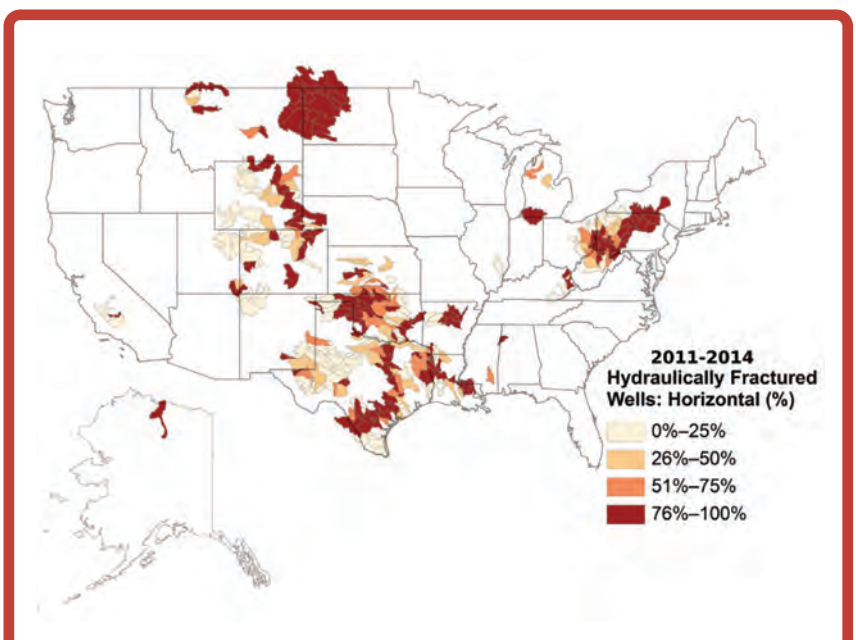
In 52 of the 57 watersheds with the highest average water use for hydraulic fracturing, more than 90% of the wells were horizontally drilled, the release said. The watersheds with the highest water use coincided with parts of the Eagle Ford, Haynesville-Bossier, Barnett, Fayetteville, Woodford, Tuscaloosa, Marcellus and Utica shales.

The study—featured in a paper accepted for publication with the AGU's *Water Resources Research*—





This map shows the average water use in hydraulic fracturing per oil and gas well in watersheds across the U.S. *(Source: USGS)*



This map shows the percentage of oil and gas wells that use horizontal drilling in watersheds across the U.S. *(Source: USGS)*

found that the median annual water volume estimates for fracturing horizontal wells increased from 177,000 gal per oil and gas well to more than 4 million gal per oil well and 5.1 million gal per gas well, according to the release.

Drought's impact

While the increased water volumes delivered increased production, Mother Nature has made it more difficult for operators in some areas with decreased rainfalls. Take California for example. The state has endured the past four years through a drought categorized as "exceptional" by The National Drought Mitigation Center.

So significant is the drought that in April 2015, California's Gov. Jerry Brown ordered the state's first mandatory 25% reduction in urban water usage. The restrictions require water suppliers to the state's cities and towns to reduce usage as compared to the amount used in 2013. While California has been hit hardest by the drought, it has not thirsted alone.

Severe and exceptional drought conditions have plagued most of the southwestern U.S. for several years. The heavy spring and summer rains that fell this year helped to erase water deficits in Oklahoma, Texas and elsewhere. However, the water surplus is likely temporary as record-setting summer temperatures settled in for the year, just as the rain clouds moved out.

In times of drought, the question of how much water is left is commonly asked, and surprisingly, it was not until recently that a group had the tools

to divine an answer. In two studies led by the University of California, Irvine, researchers found that human consumption is rapidly draining about a third of its largest groundwater basins, despite having little to no accurate data about how much water remains in them, according to an AGU press release.

The findings, using data from NASA's Gravity Recovery and Climate Experiment satellites, show that of the 37 largest aquifer systems studied between 2003 and 2013, California's Central Valley Aquifer System—a system heavily used for agriculture—is suffering rapid depletion and labeled highly stressed by the research team, the release said.

In addition to being the state's vegetable and fruit basket, the Central Valley is home to the San Joaquin Basin with its many oil and gas fields—including Kern River, Kettleman North Dome and Kettle Middle Dome—and portions of the Monterey and Kreyenhagen shales that have seen increased exploration activity in recent years.

Shifting sources

While oil and gas is not the largest consumer of surface water or groundwater—that would be agriculture—it does get a fair amount of attention for its water use. However, over the past few years there has been a gradual shift to the recycling/reuse of produced and flowback water in hydraulic fracturing operations, bringing the usage amount even lower.

For example, in its Fayetteville and Marcellus shale operating divisions, Southwestern Energy (SWN) is reusing or recycling 100% of flowback and produced water from its wells there, according to Rowlan Greaves, et. al in "The Fresh Water Neutral Challenge: The Need for Protection, Reduction, Innovation and Conservation" (SPE 173324). The paper, delivered at the 2015 SPE Hydraulic Fracturing Conference, sheds light on the company's Energy Conserving Water or "ECH$_2$0" initiative launched in 2013.

In the company's Fayetteville operations, 41% of the approximate 50 MMbbl water used in 2013 was reuse, according to the paper. The successful and consistent reuse and recycling of all flowback and produced water requires three elements to work in sync: the design of fracture treatments with significant reuse volume percentages, the facilities necessary to store and recycle these water types, and logistical and planning support to efficiently store, transfer and plan the use of these water types in concert with operations, the paper said.

An example of the company's efforts is its Judsonia Water Reuse and Recycling Facility, located north of Searcy, Ark. The facility covers 160 acres and is permitted as a centralized waste treatment facility for hazardous and nonhazardous industrial waste and wastewater.

Similar facilities are starting to sprout up in places like the Permian Basin. Laredo Petroleum and Approach Resources are two of many operators in the region to use water recycling and reuse.

One focus for Laredo Petroleum when it entered the Permian Basin was to acquire high-quality, contiguous acreage in the right basin, the company's Chairman and CEO Randy Foutch said in his presentation at the Hart Energy DUG Permian Conference in May.

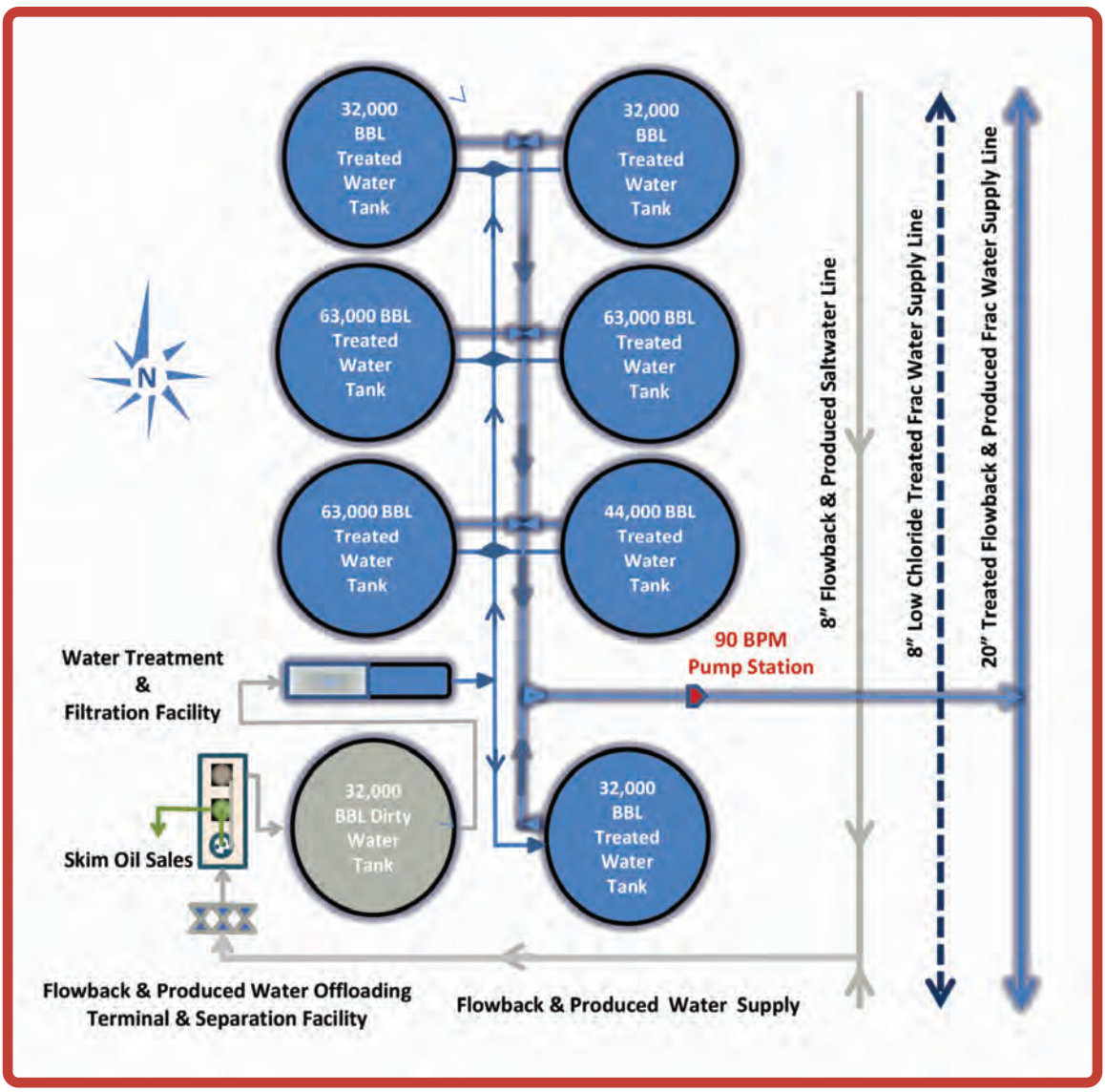
"Our contiguous or blocked up acreage is something that is pretty important to us and provides huge advantages," he said.

The company holds 179,722 gross (149,141 net) acres with about 4.3 Bboe of resource potential on more than 7,700 identified locations in the eastern portion of Glasscock and Reagan counties and portions of Irion and Howard counties, targeting formations like the Cline and Wolfcamp.

According to Foutch, this contiguous acreage enables the company to achieve operational efficiencies by leveraging data and infrastructure. Production infrastructure and facilities are aligned in corridors, and there are currently four in different phases of development, he said.

"Very important are the water recycling and handling facilities we have," he said. "They allow us to complete multiple wells and zipper fracks."

Approach holds 143,000 gross (130,000 net) acres with about 1-plus Bboe of gross, unrisked resource potential within the Southern Midland Basin that dips into northern Crockett County. There, the company is pursuing the Wolfcamp Formation from its Pangea development.



Approach Resources' Flowback and Produced Water Recycle Facility has a capacity of 329,000 bbl and is located in the company's Pangea development. *(Source: Approach Resources)*

"In 2012, we made a big investment in infrastructure with six pipelines to every future location, gas lift, oil and gas lines and three water pipelines. It has allowed us to drive down our costs. We spent $100 million on this infrastructure and it's paid out," J. Ross Craft, Approach Resources chairman, CEO and president, said in his presentation at the Hart Energy DUG Permian Conference held in May.

"Our infrastructure is laid in the core of our properties," he said. "We started a pilot program in 2014 to recycle water. We're fully in agreement that recycled water is the way to go."

The company completed what Craft dubbed its "super recycling center" in March and in the time since, has seen great returns.

"We completed the super recycling center, we can hold on surface about 300,000 bbl of fluid, we produce 25,000 bwd [bbl/d of water] to 30,000 bwd. Since we put this system in place, we've processed over one million barrels and we've used it all on fracturing operations."

According to the company, as of August 2015, more than two million barrels of water have been processed since the facility opened. ■

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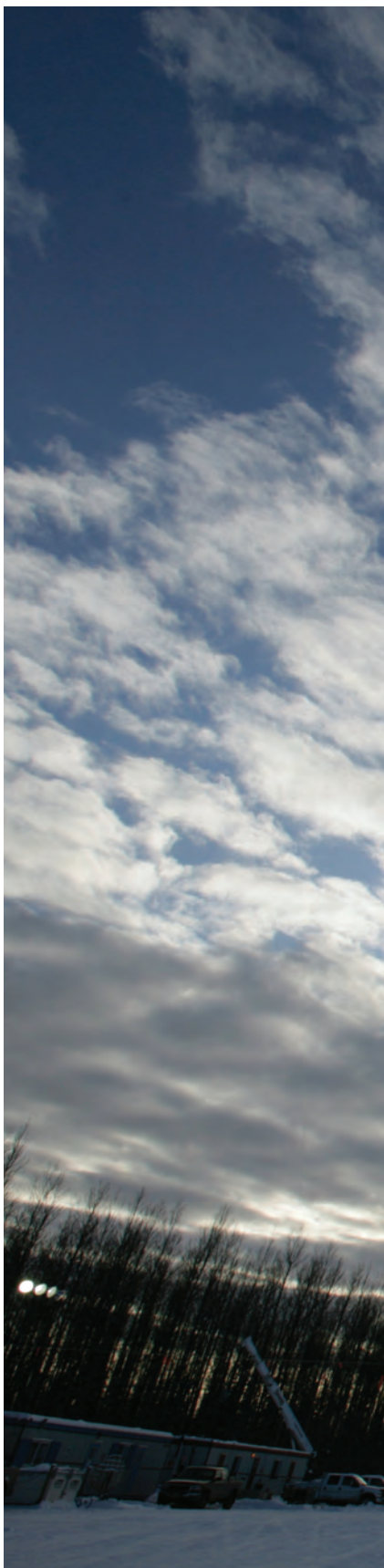
Induced Seismicity in Oil and Gas Operations

It's likely that certain oilfield activities can cause earthquakes, but more research needs to be done.



By Julie Shemeta
MEQ Geo Inc.

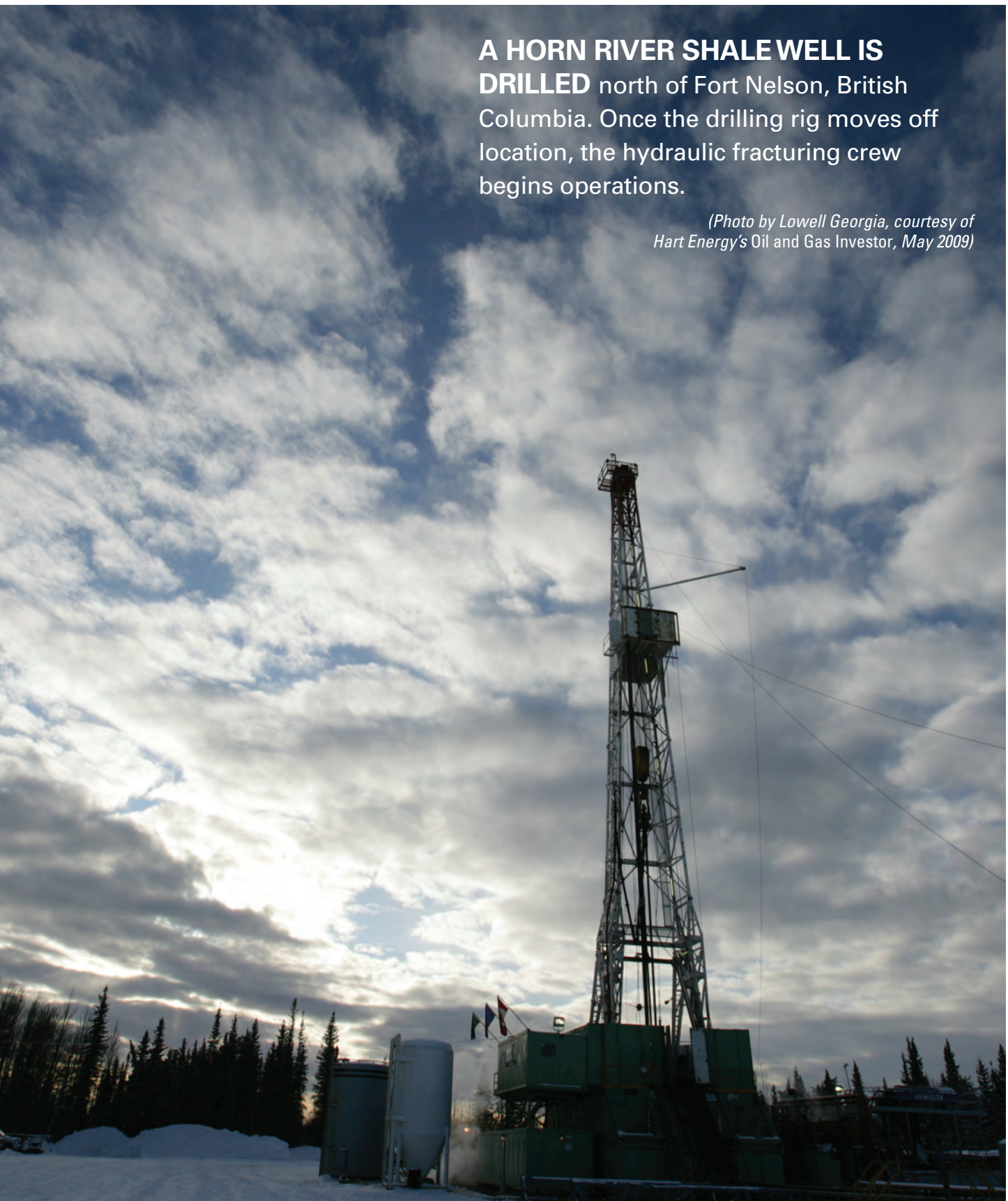
Induced seismicity, once an obscure phenomenon, is currently a red-hot environmental issue in North America, in particular due to increased events in Oklahoma, Ohio, Texas, Colorado, and British Columbia and Alberta, Canada. Many news media reports suggest hydraulic fracturing is the cause, but the occurrence of induced events is complex, and the cause and size of the induced earthquakes vary from area to area.

Induced seismicity refers to earthquakes caused by human activity. A thorough review of the topic is presented by the National Academy of Science study, "Induced Seismicity Potential in Energy Technologies," published in 2013 and available for download at *nap.edu/catalog/13355/induced-seismicity-potential-in-energy-technologies*.

Earthquakes induced by oil and gas operations can occur when changes in the subsurface occur near pre-existing faults due to activities such as wastewater injection (Oklahoma), hydraulic fracturing (British Columbia and Alberta, Canada; Oklahoma and Ohio) or when large volumes of material are extracted or compacted (Groeningen Field in the Netherlands). The orientation of a fault with respect to the surrounding stresses in the earth and the extent of subsurface changes due to human activity, such as pore pressure, may prompt a pre-existing fault to slip and cause an earthquake. Wastewater disposal wells and hydraulic fracturing have both been suspected to have induced seismic events as large as magnitude (M) 4.4 (hydraulic fracturing) and M 5.6 (wastewater disposal).

Disposal wells

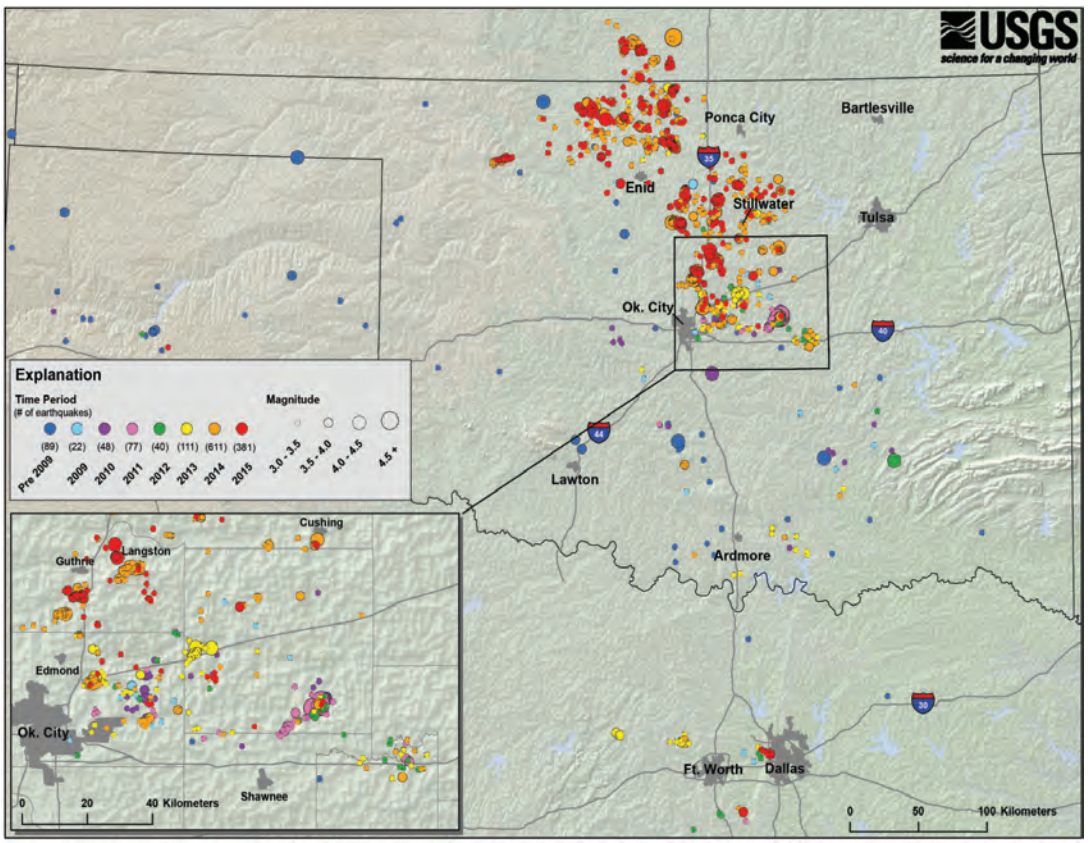
Induced earthquakes related to wastewater injection are relatively rare. The U.S. has about 150,000 Environmental Protection Agency Class II injec-



A HORN RIVER SHALE WELL IS DRILLED north of Fort Nelson, British Columbia. Once the drilling rig moves off location, the hydraulic fracturing crew begins operations.

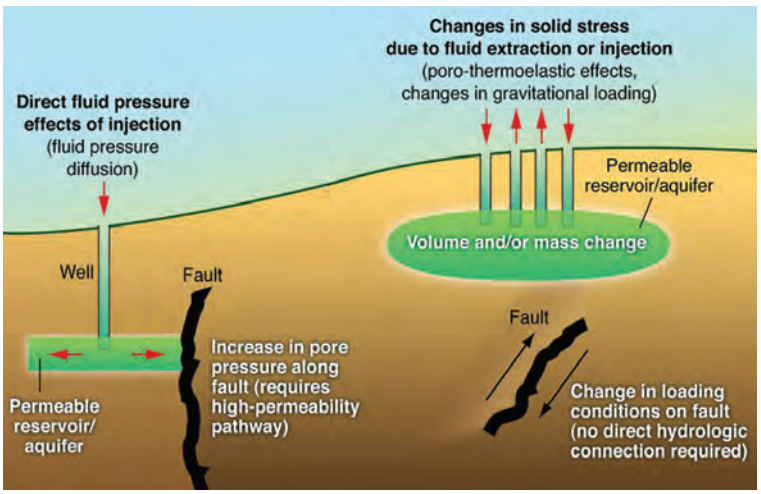
(Photo by Lowell Georgia, courtesy of Hart Energy's Oil and Gas Investor*, May 2009)*

Seismicity Map 1970-May 27, 2015



Seismic events have been on the rise in Oklahoma in recent years. *(Image courtesy of USGS)*

tion wells, of which about 30,000 are disposal wells. The disposal wells vary in injection rate and injection target. An injection well is specially drilled to target a rock formation with high permeability. The disposal is typically performed under "vacuum"—disposing of water without additional pressure, where the weight of the wastewater column in the wellbore is enough to drive the water into the disposal interval. Wastewater injection wells are designed to be used for years and years of safe disposal, and very few of these wells have been associated with any seismic activity. The recent and dramatic increase in seismicity in the Oklahoma area since 2009 is unprecedented in rate and size of the suspected number of potentially induced events. Several dewatering plays in Oklahoma and southern Kansas, which produced as much as 50% to 90% produced water with the hydrocarbons, are suspected to have played a major role in the seismicity increase but are not the only cause for the increase. Long-term wastewater injection near a fault zone near Prague, Okla., has been cited as the possible cause of a series of earthquakes in late 2011, with the largest being an M 5.6 that caused damage to nearby structures. The Oklahoma Geological Survey issued a statement April 21, 2015, saying, "The rates and trends in seismicity in Oklahoma are very unlikely to represent a naturally occurring process" and published a new website dedicated to earthquakes in Oklahoma (*earthquakes.ok.gov/*). In particular, central and north-central Oklahoma were identified as potentially having triggered earthquakes from the injection of produced water into disposal wells. A recent U.S. Geological Survey (USGS) study in Oklahoma suggests the majority of the recent earthquakes in central



Induced seismicity can come from a variety of sources. *(Image courtesy of USGS)*

Oklahoma are occurring on optimally oriented reactivated ancient faults that extend from the Arbuckle Group (the injection formation for many waste disposal wells in the area) into the crystalline basement rocks.

Hydraulic fracturing

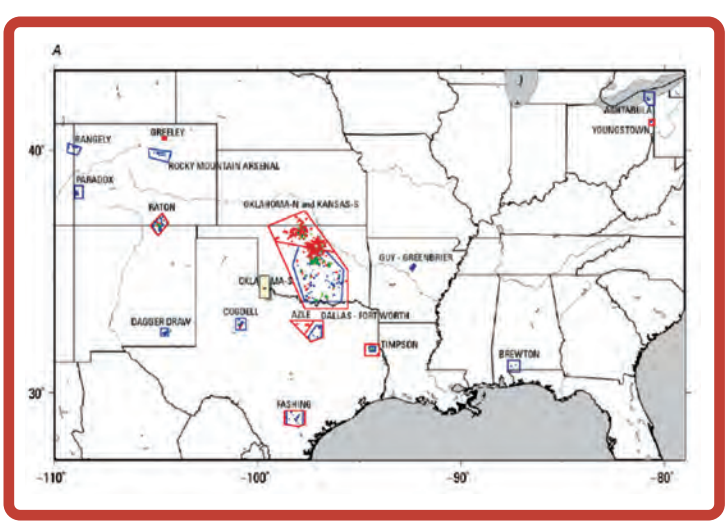
The hydraulic fracturing process is brief, typically taking a few days to perform in separate frack stages systematically along the wellbore. Just a handful of hydraulically fractured wells in the U.S. have documented felt seismic events. However, several cases of suspected induced seismicity during hydraulic fracturing operations have recently been reported in Canada in the Horn River Basin in British Columbia and the Duvernay Shale in Alberta, where the largest suspected frack event was measured at M 4.4. The event occurred in the Fox Creek area of northern Alberta on Jan. 22, 2015. In 2012, the British Columbia Oil and Gas Commission issued a report documenting a variety of suspected induced earthquakes ranging in size from M 2 to M 3.8, also suspected to be related to hydraulic fracturing operations in the Horn River Basin.

Detection and location of induced seismicity can be problematic. Induced seismicity often is occurring in seismically "quiet" areas; therefore, instrumentation typically used to collect earthquake data might not be present. If arrays exist, they are often sparse, and it is difficult to get an accurate earthquake location; thus, linking a particular disposal or fracture operation to an earthquake sequence is problematic. Operators have installed proprietary seismic networks in special areas of concern for recording and locating potentially induced earthquakes but have, for the most part, kept these data proprietary. Regulations requiring the collection of earthquake data under the conditions of the permit, such as in Ohio and parts of Canada, might lead to better understanding of the issue; however, it is not clear if the earthquake data required by permit will be available to the public research community.

Ground shaking

Is there an increase in seismic hazard from induced seismicity? The USGS recently published a report that attempts to quantify the associated hazard from potentially induced seismic events from oil and gas activity in the U.S.

The potentially induced earthquakes were removed from the catalog of tectonic events used to assess the hazards from naturally occurring earthquakes. USGS seismic hazard maps, created from the analysis of naturally occurring earthquakes, are



This 2015 figure from Petersen and others shows the earthquake locations and areas of potentially induced earthquakes in the central and eastern U.S. *(Image courtesy of MEQ Geo Inc.)*

used to help determine seismic hazards for purposes such as building codes. The hazard from induced earthquakes is different than "normal" tectonic activity as it is nonstationary and will depend on industry activity; therefore, the time-independent statistical methods normally applied to assess earthquake hazards cannot be used. Based on a variety of models to assess the induced seismicity catalog, the USGS study suggests recent induced seismic activity in Oklahoma contributes significantly to the ground-shaking hazard. The preliminary modeling results show nearly a 100 higher annual rate of ground motion exceedance from induced seismicity near Oklahoma City, compared to the hazard from naturally occurring events. However, a recent study suggests ground shaking from induced seismic events might be less than tectonic earthquakes due to the shallow depths and lower stress drop when the earthquakes occur.

Reaction by regulators

The reaction to induced seismicity by U.S. state and Canadian province regulators is mixed. Induced earthquakes potentially caused from wastewater injection in the Guy-Greenbrier area of Arkansas in 2010 and 2011 prompted state regulators to create an injection "moratorium zone" in the vicinity of the earthquake activity. Permission to inject in the special area requires a hearing by the Arkansas Oil and Gas Commission. Ohio rewrote permits for hydraulic fracturing after activity was observed in Utica hydraulic fracturing operations. The new regulations call for special earthquake monitoring if drilling near a known fault or any mapped seismicity activity greater than M 2, with a special map to indicate the areas of the increased regulations.

Hydraulic fracturing operations in Ohio that fall within the mapped special areas are required to install a seismic network in areas within 3 miles of a known active fault, and the network must be capable of detecting and locating an M 1 event. If a seismic event greater than M 1 occurs during well operations, the work is suspended while the cause of the seismicity is investigated. Seismic activity occurring in March 2014 in Mahoning County, Ohio, near a hydraulic fracturing operation in the Utica Shale caused the operations in the well to be suspended by orders of the Ohio Department of Natural Resources.

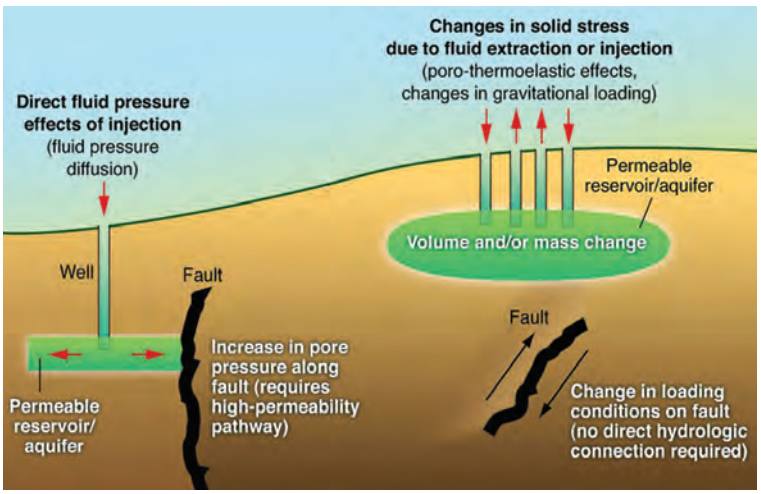
In Canada, the Alberta Energy Regulator released new guidelines in February 2015 for hydraulic fracturing operations in the Duvernay zone in the Fox Creek area of Alberta. The guidelines require operators to comply with a "traffic light" seismic protocol where operations are varied depending on the level of seismicity activity observed.

Industry response

Oil and gas operators have had a reserved public response to the induced seismicity issue so far. Many companies have internal induced seismicity working groups and have actively participated in special work groups and oil and gas industry trade groups to help develop guidelines and mitigation plans for companies in the event of an induced seismic event.

Very little publicly released scientific research related to induced seismicity has been published by oil and gas companies, with the Blackpool hydraulic fracturing earthquake being an exception. Cuadrilla Resources made all the technical reports available for the public by its consultants following the M 2.3 earthquake that was recorded in 2011 during a hydraulic fracturing operation.

The technical issues surrounding the issue are complex, and the subsurface data to characterize the areas are often sparse and expensive to obtain. Even in well-understood subsurface areas, the faults that slip are below the active injection zones or hydrocarbon-bearing zones and are located in the crystalline basement rocks, where even less subsurface information is known or understood. The timing of induced seismicity can vary as well: Induced seismic events can occur contemporaneously with injection or might be delayed by days, months or even years in cases of wastewater injection. Pinpointing a particular well to a series of earthquakes can be problematic as in many areas the pathway for the fluid and/or pore pressure perturbations is poorly understood. The USGS and many universities in Canada, the U.S. and worldwide have active research groups and consortia examining the issue. Increased interest by the public, operators, regulators and researchers will continue to drive forward increased understanding of this hot-button issue. ■



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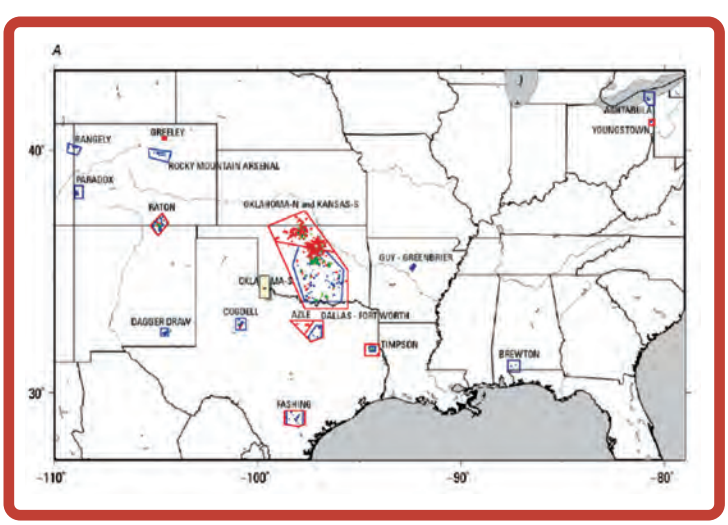

This 2015 figure from Petersen and others shows the earthquake locations and areas of potentially induced earthquakes in the central and eastern U.S. *(Image courtesy of MEQ Geo Inc.)*

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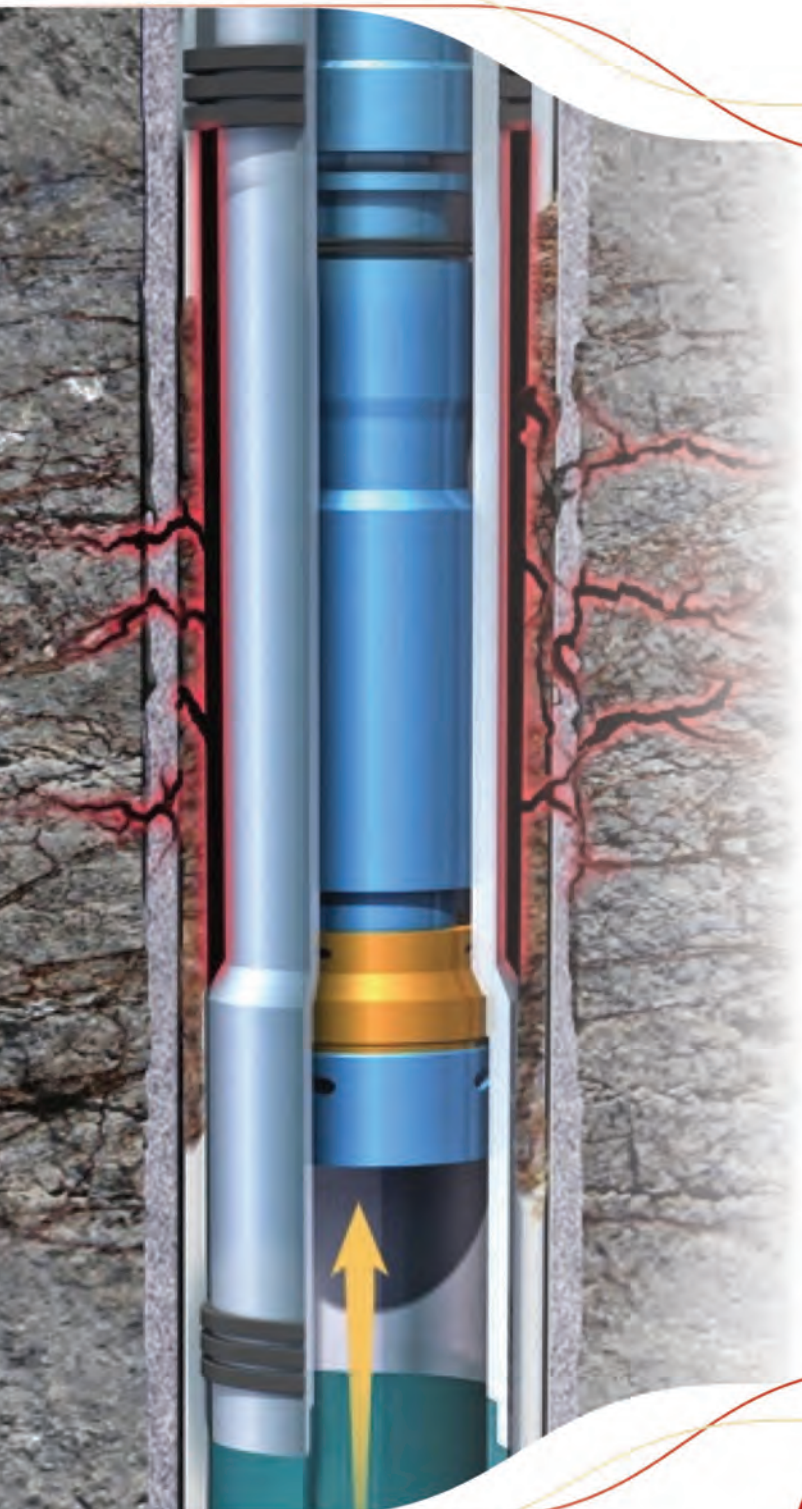

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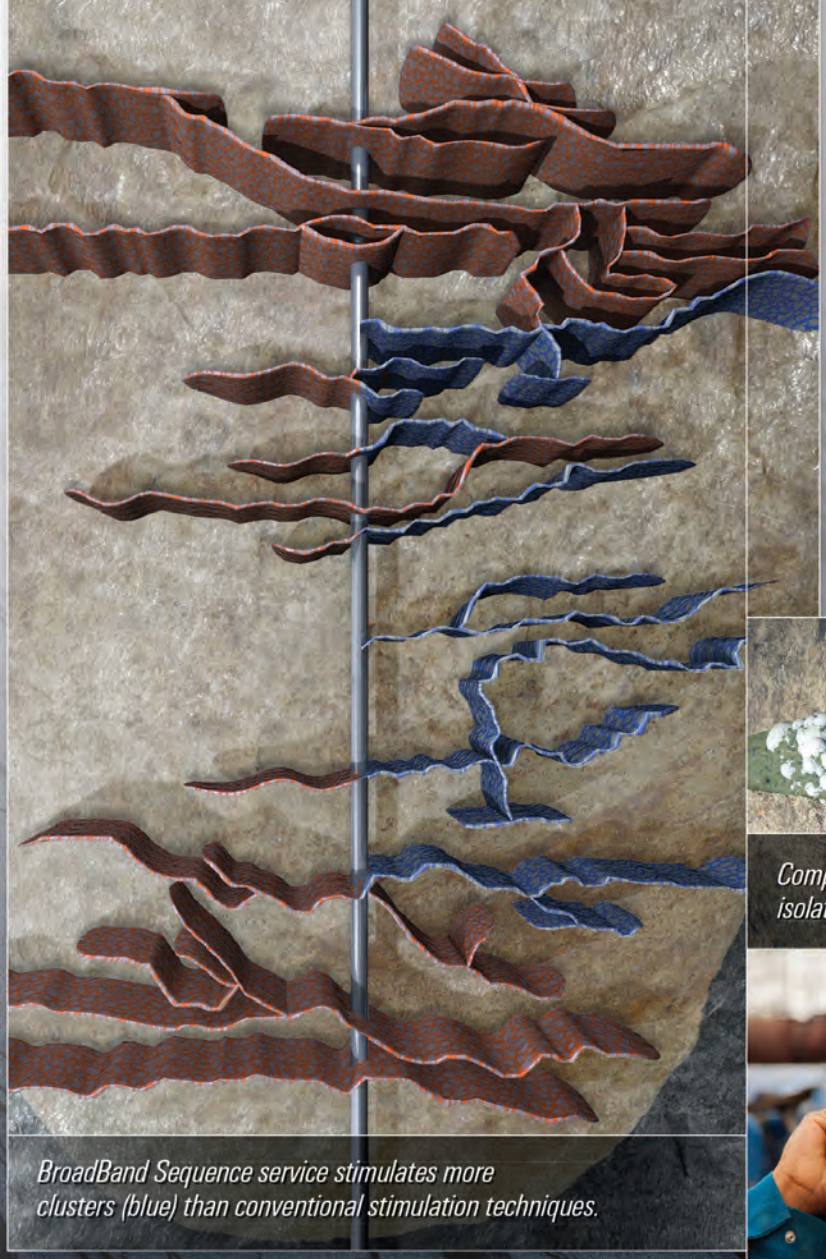

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