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A supplement to *E&P*

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The 2014 Hydraulic Fracturing Techbook is the sixth 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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BHP Billiton Petroleum zipper fractures its Crozier A wells, a five-well pad targeting the upper Eagle Ford Shale in DeWitt County, Texas. *(Photo by Dan Young, courtesy of* Oil and Gas Investor*)*

One Size Does Not Fit All in Hydraulic Fracturing

Even within the same shale play, the 'cookie-cutter' approach to hydraulic fracturing and well completion does not provide the maximum effectiveness along the entire length of the lateral.

By Scott Weeden
Senior Editor, Drilling

How does the industry deal with the randomness that is inherent in shale plays? At Hart Energy's DUG conferences—whether in Australia or the U.S.—the emphasis is the same, focusing on understanding rock quality to enhance completion effectiveness and maximize production.

With an estimated 40% to 50% of the laterals in horizontal wells not contributing to production, operators are faced with designing and engineering hydraulic fracturing and well completion to reduce the number of noncontributing stages. Variability in rock quality along the lateral should be addressed in designing the stimulations to boost EURs and improve economics.

There are a lot of opportunities for experimenting to find the optimum stimulation and completion. For example, hydraulic fracturing activity is rising dramatically. According to the latest release of Well IQ from PacWest Consulting Partners, the number of wells hydraulically stimulated in North America is forecast to increase by 9% in 2014, 14% in 2015 and 11% in 2016. The number of horizontal stages also is predicted to rise by 19% in 2014, 19% in 2015 and 16% in 2016.

According to Hart Energy market intelligence telephone surveys, operators in the Niobrara are moving to pad drilling. Service providers cited the average number of wells per pad at five with as many as 12 or 13 planned for new deep Niobrara wells in the Piceance

Basin. Zipper fracks now account for 71% of completed horizontal wells on multiwell pads in the Niobrara. Operators are using an estimated 1.9 MMlb of sand per well on average with straight sand accounting for 82% of proppant consumed in the region.

Four plays in the U.S.—Bakken, Denver-Julesburg, Eagle Ford and Permian—are forecast to represent 77% (66,685 stages) of the growth in horizontal frack stages in 2014. In Canada, the Cardium, Duvernay, Montney and Viking plays should provide 13,274 frack stages in 2014, which would be 92% of the total, noted PacWest.

Out of those numbers, no two plays are the same, and no two wells are exactly the same. Given the variations in rock quality over short distances, the cookie-cutter approach to "manufacturing" leaves a lot of oil and gas in the ground.

"In shale plays, reaching manufacturing mode is not really good enough. To obtain the really high performance, we need to customize our manufacturing," emphasized Bob Banks, executive vice president and COO at Swift Energy Co. "We have to optimize each area, accepting that conditions can change over very short distances. We need to learn quickly and gain an understanding of results as fast as possible."

Kevin Schepel, chief geoscience and technology officer at ZaZa Energy, spoke with E&P at the DUG Australia Conference. "There is a lot of technology recently that is designed toward being able to target the frack in the reservoir and control where the frack goes. There is a need for more control as we move into the Eagle Ford in East Texas. We are looking at designing fracks

NINE WELLS—THREE WELLS EACH ON THREE PADS—are simultaneously hydraulically fractured on the Three Sisters lease in the Eagle Ford.

(Image courtesy of Pioneer Resources)

more precisely to target quality reservoir and eliminate potential fracture growth into nonproductive strata or into deeper water-bearing intervals."

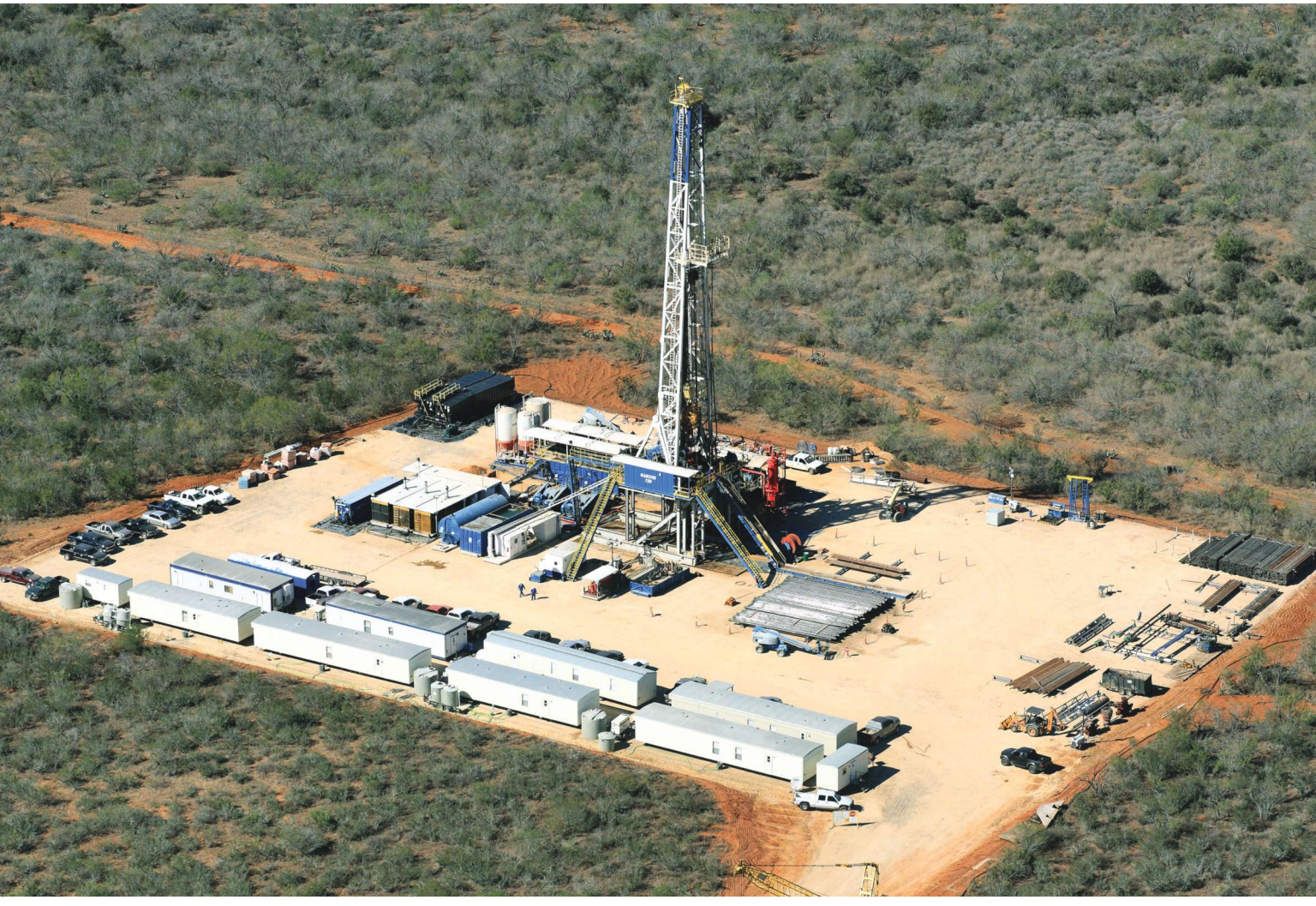
He said he has been able to see most of what is emerging in the unconventional environment in the world. "There are two things we need to keep in focus. The rocks aren't all the same, and the petrophysical properties, kerogens and fluids aren't all the same. You've got to get that data up front to understand the reservoir characteristics."

Pioneer Resources in the Permian Basin is looking at frack design by interval. "We are not at this point trying to adjust by stage within an interval. We're very careful on how we land our wells. We want to be in specific landing zones that provide us with an in-gauge wellbore and allow good fracture initiation," said Tom Spalding, vice president, subsurface, for the Permian Asset Team for Pioneer.

"As long as we can meet those metrics and keep the well in the zone, we will make slight adjustments to our frack recipe based on the rock properties and geomechanics that we see in that particular interval," he added.

Aaron Reyna, senior vice president of development for the Kansas Business Unit at SandRidge, said, "We have some ongoing and exciting completion initiatives that are showing some significant positive results. We have an implementation of a multilateral sectional development that we see will lower capex and really improve our returns going forward."

SandRidge sees additional opportunities for



ZaZa Energy drills from a single-pad location in La Salle County, Texas. *(Image courtesy of ZaZa Energy)*

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A Sidewinder walking rig drills on a Swift Energy location in the Eagle Ford in McMullen County in South Texas. *(Image courtesy of Swift Energy Co.)*

enhancing its program economics in the Mississippi Lime in Kansas through its downhole mechanical design changes. The company is using two different mechanical configurations—an openhole packer system and a chemical-packer/sleeve-tool system—to reduce completion costs and allow use of natural fractures that are necessary for production.

Regardless of a company's focus on hydraulic fracturing and well completion, the name of the game is experimenting with the optimum way to produce those shale plays.

Swift's Eagle Ford strategy

In its development approach in the Eagle Ford, the company attacked its subsurface modeling by acquiring 3-D seismic and preparing a geological and reservoir model that is further calibrated to actual reservoir performance.

"On the drilling and evaluation side, we really put a large effort into working the rig efficiencies, establishing technical limits criteria for each part of the operation and enhancing our supply—chain management alliances, transportation and cost structures. On the completion and stimulation side, we captured lessons learned for optimizing lateral lengths, orientations, stages, spacing and overall frack recipe," Banks explained. "Lastly, we had to optimize on the common water management systems, facilities and infrastructure."

In moving its Eagle Ford development into the manufacturing phase, Swift had to ask itself a number of questions to further drive and capture performance gains. First, what major performance drivers have been identified? Second, how should it deal with the randomness that is inherent to shale plays? Next, is the company organized to quickly adapt to different areas? Then, what is Swift doing to ensure it is learning and improving fast enough? Lastly, is manufacturing mode really what it should strive for?

Often the manufacturing mode is referred to as a cookie-cutter, assembly-line approach. "I believe that you need to be careful of the division of labor tendency in a cookie-cutter approach. A lot of times the drilling guys will work their metrics, the geoscientists will work their metrics and the production team will chase their metrics, but things fall through the cracks leading to the potential for underperformance," Banks said.

The speed of the manufacturing pace can "cause operators to outrun their headlights," he continued. Operators have to work as a team in a collaborative way to make progress in the Eagle Ford and squeeze efficiencies. Swift has learned a lot of lessons about performance drivers and gains.

"Once an area is commercially viable, we need to test the technical limits as soon as possible to understand its true potential," Banks emphasized.

"We believe longer laterals are cost effective. The extra drilling time is minimal. The extra frack stages

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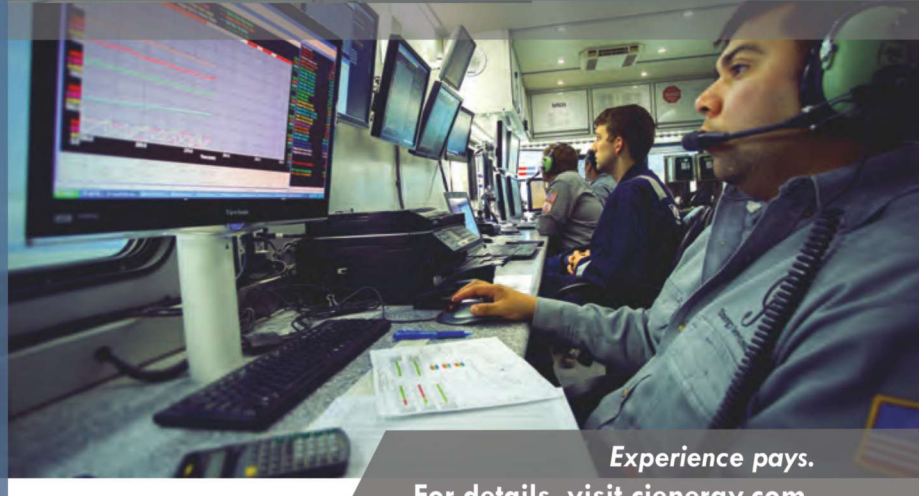

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if properly designed are worth the investment. Our team has done a great job in improving completion processes and have focused on some new techniques in toe preparation operations that save about $180,000 per well," he continued.

"Our improved coiled-tubing drill-out time and process are saving about $150,000 per well. These gains, along with the drilling efficiency gains, all roll up into more producing days per year," he added.

A Weatherford fleet performs hydraulic fracturing on Swift Energy's Fasken No. 9-H and No. 10-H in Webb County, Texas. *(Image courtesy of Swift Energy Co.)*

Customized manufacturing

Swift has renamed its "manufacturing" phase to "customized manufacturing." "We need to treat each well as an individual investment that deserves its own engineering rigor. Just like Carroll Shelby took a basic assembly-line Ford Mustang and customized it into a Shelby Mustang, that's how we think about what we're doing in manufacturing mode," he said.

A large part of Swift's customized manufacturing includes logging the laterals. "We do see significant variability in rock quality along the laterals. By logging the wellbores laterally, we can selectively group and perforate high- and like-quality rock and that allows us to be more aggressive with the frack job.

"As a result, we can often times eliminate a frack stage or two without suffering any detrimental effect," Banks explained. "It allows us to obtain a more effective, robust fracture stimulation when we're pumping into like-quality rocks."

This also allows the company to increase sand concentration that helps improve the complexity of the fracture stimulation, thus increasing the overall stimulated reservoir volume accessed by our individual wells. In 2011, Swift was routinely fracturing an average of 15 stages with 790 lb of proppant per lateral foot. Today, the company is fracturing an average of 20 stages with 1,240 lb of proppant per lateral foot. "All the while we're doing that, the team has driven down the cost from about $5.3 million per well completion to $4 million per completion," he continued.

What are the benefits of customization? In the Fasken Field in Webb County, Texas, where Swift is partnering with PT Saka Energi Indonesia, its original well design delivered 1 Bcf of production over the first 150 days. An enhanced design increased the production to about 1.5 Bcf for the first 150 days. Now, the company is producing about 2 Bcf in the first 150 days in customized design wells, Banks said.

"That translates into some pretty good economics. We've improved our economics from 40% to 80% in the dry-gas window to over 100%. We have had 10 wells in a row each with an IP over 20 MMcf/d," he added.

In the oil window in McMullen County, Texas, the results have been similar. In the AWP Field, wells were originally completed with 5,700-ft laterals with 16 stages and 7.2 MMlb of sand. Cumulative production over 90 days was nearly 80,000 boe. The enhanced design consisted of 6,000-ft laterals with 20 stages and 7.9 MMlb of sand. These wells added another 4,000 boe over the 90-day period.

Using the customized completion approach, Swift has taken wells with shorter laterals of 5,600 ft and similar sand loadings and increased production by another 5,000 boe in the first 90 days.

"That translates into improved economics, moving those early economics from a 20% rate of return [ROR] to a 60% to 90% ROR. In both the Fasken and AWP areas, we are seeing flatter decline profiles from the customized program," he said.

Maximizing fracture systems

An operator and its service providers have the ability to evolve the frack design and tweak it as it goes, ZaZa's Schepel said. "I think one of the big things

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we will see going forward is the ability to directionally control fracture propagation. I think that is going to be a big plus in the next few years. That will be either through diversion, oriented perforations or some type of isolation."

Operators know what is happening with fracture propagation through microseismic data. "It is the microseismic data that is telling us where the fractures are going. Without that, you would never know. You would just frack and hope for the best," he continued.

"Getting microseismic early will help you determine the preferred orientation and direction of the frack. If it is not going in the direction you want it to, maybe there is some intervention and remedial work you can do to fix it. That is going to be my focus for the next year or so, working with the service companies to evaluate and integrate the rock mechanics and refine our frack design," he added.

In the East Texas extension of the Eagle Ford, a different methodology is used compared to the traditional Eagle Ford. "We use massive hydraulic frack jobs in the carbonate rich portions of the core Eagle Ford to induce fracturing because there are not a lot of natural fractures or anisotropy in the reservoir. As you move into areas like the eastern extension of the Eagle Ford, you end up with more clastic and layering in the reservoir," he explained.

Two wells are completed simultaneously with a zipper frack in La Salle County, Texas. *(Image courtesy of ZaZa Energy)*

Below the Eagle Ford you have the carbonates of the Lower Cretaceous. "When you start getting into the natural fracturing in the carbonates, you have more issues with controlling where the frack goes. Where you have naturally occurring fractures, the frack will tend to propagate to those more quickly. There is a need for more control," he said.

"If you are dealing with a formation that has a high-carbonate content, you can run diagnostic tools in the lateral to know where the naturally occurring fracture system is. You can run a tool that will give you a 360-degree view of the lateral. You can determine the magnitude and orientation of the natural fractures and design the completion accordingly. You can then decide whether you want to avoid the natural fractures or frack what is there for optimal growth and connectivity," Schepel said.

For example, if there are deeper targets or zones that have aquifers, fracks need to be designed to eliminate potential growth into those zones. "Once you frack into an aquifer and you start producing water up a fracture network, you can change the near-bore wettability from oil-wet to water-wet and risk a preferential dominance of water flow. You want to avoid getting into those zones. It may take a couple of wells to diagnose the reservoir and fluid characteristics and determine if there is a problem, but then you have options to modify the frack for that design," Schepel explained.

One thing operators need is more production logging tools. "Running tools in laterals after the frack to tell us where the fluids are coming from can be important. A lot of operators don't do production logging. Do you really want to jeopardize a potential high-producing well by running a production log? It could be disruptive. But it may be helpful getting the log early after the frack and before you install all the production facilities," he added.

Connections between formations

Shales are most often present as seals for structural or stratigraphic traps in the hydrocarbon system. Hydrocarbons can sometimes migrate into the overlying seal layers, or the seals can be source rocks for

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This dual wellhead configuration includes a microseismic monitoring well on this Eagle Ford pad in La Salle County, Texas. *(Image courtesy of ZaZa Energy)*

the adjacent reservoirs. These seals are also often under pressure because they are holding back larger hydrocarbon columns with sometimes gaseous, lighter hydrocarbons from below. That differential pressure at the seal can cause natural fracturing at the shale and reservoir interface and result in a favorable vertical and horizontal target.

"That's an important aspect. The horizontal Buda and the Eagle Ford are examples of this. The Buda is taking off from the heart of the Eagle Ford all the way into the Austin Chalk trend and into East Texas. The Buda and the Eagle Ford and the Eagle Ford and the overlying Chalk are in a uniform hydrocarbon system, which means the formations are connected," he said.

There is a whole phase of redevelopment in the Eagle Ford in new reservoir tiers in the Eagle Ford organic and upper and lower Eagle Ford. "These are all in communication but are isolated enough to be separate targets. There are similar geologic and physical rock processes going on in the Buda, which is just below the Eagle Ford," he continued.

"Anytime you have carbonates and organic shales that interact over time you have digenetic and physical processes that preserve the organics in the shales but also cause porosity in carbonates. As oxygen is used to mature the shales and convert organics to hydrocarbons, it's the oxygen deprivation in the formation that leads to carbonic acid dissolving the carbonates. All of that interacts. As you're forming organic-rich potential shale resources, you are improving the ability to form porosity in the carbonates," he explained.

If the Eagle Ford or Buda is fractured, there could be communication between the two regardless of which formation is fractured. "You are potentially getting contribution or connection between those reservoirs. I think there are several companies now in the eastern extension of the Eagle Ford in the Karnes Trough that are experimenting with drilling horizontal Buda wells, knowing that the Eagle Ford and Buda are almost in a combined hydrocarbon system," he continued.

"Because of all these things, you are going to have to learn that it takes several wells to understand the production performance. You've got to have the ability to evolve the frack design and tweak it as you go," Schepel said.

The latest industry estimate on recovery from unconventional reservoirs ranges from 5% to 10%. There are basically two ways to improve the recovery—increased pay exposure with better connectivity to what is there, or higher gas-oil ratio (GOR), fluid mobility, and reservoir energy that are going to improve recovery, he said.

"How do you maximize pay exposure or conductivity? Fracks can do that," he continued. "The better the frack design, the more connectivity. That is the whole principle. Pretty much everyone who is experimenting with higher proppant concentrations is trying to do that."

However, when an operator increases the frack size, screenouts start to occur. A lot of companies are going back to smaller proppant—100-mesh sand—because the proppant concentration can be increased without a concern for screenouts.

"I don't know if that is good or not. From what I've seen from the companies doing that, yes, they are getting huge concentrations out, and they tend to get pretty high rates initially. They are getting that initial flush production, and then they seem to be dropping off more rapidly," he added.

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Pioneer Resources drills four wells on the DL Hutt lease south of Midland, Texas. *(Image courtesy of Pioneer Resources)*

"What's really going to dominate production at a later date is how quickly you can recharge that existing network with new hydrocarbons. That's why every play has a hyperbolic production decline curve because you get a lot of production up front. In the first six months, you may get 50% of your production. It basically tails off after that.

"How do you control that recharge? Some shale reservoirs have what I call kerogen-release porosity. That is the heavier hydrocarbons that are stored with the kerogens. As the pressure drops in the reservoir either while drilling or during production, the kerogen releases new hydrocarbons into the system. That is what makes the Eagle Ford a great play. Kerogens in that rock are very strong hydrocarbon absorbers, so you see a lot of storage of heavier hydrocarbons and potential recharge as you deplete the higher GOR, higher energy portions of the play. That is why you are getting a lot of big EURs in the Eagle Ford," he said.

Rock properties determine landing zone

The Permian Basin, specifically the Midland Basin, is a huge growth area for Pioneer Resources. At this point, most people realize that the deeper part of the Midland Basin is where the pressures are higher and maturities are greater, making it the most prolific part of the basin, Spalding said.

"That would probably be true for all the intervals as you go out into the axis of the basin. A majority of our acreage is out in the deeper portion of the basin where the Spraberry Trend Field is," he continued.

To develop those resources, Pioneer focuses on variations in rock properties by landing zone. Whether the wellbore is landing in one of the three Spraberry shales or one the three Wolfcamp shales, the company has a full geosteering team to make sure the well lands where the rock properties are best.

The company has access to more than 16,000 ft of core samples through the Spraberry and Wolfcamp across the basin. "We've got about 1,300 wells with full suites of logs. We have mapped these zones in great detail across the entire basin. Based on the rock properties from one area to the next, we determine what we think is the optimum landing zone," he continued.

"We generally are drilling off pads with three to four wells on a pad. We're doing spacing tests in several of our areas where we have lease density. We've also tested areas where we drilled all three Wolfcamp zones [Wolfcamp A, B and D] and staggered those wells. We have a couple of spacing tests where we've done 11 wells and looked at the interaction between wells," he explained.

Pioneer covers all of the areas where it is drilling with 3-D seismic. "We spent a lot on collecting microseismic as well as radioactive proppant and chemical fluid tracer data. We're really working hard to understand correct spacing from one lease area to the next. We are very focused on that. Our next step is moving to full development across the field and spacing is really critical," Spalding said.

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Understanding the rock properties is key to designing the frack jobs. For the most part, the company performs some variation of hybrid frack. All of its wells are cased, so the company uses plug-and-perf (PNP) completions. The company does not adjust its fracks stage to stage within a particular interval.

"Most of the variations that we have tried have been things like the stage width. We vary it from 240 ft to 300 ft stages with four instead of five perforation clusters. We varied the size of the proppants lately, trying 30-to-50 and 40-to-70 mesh. We've used some 100-mesh sand for initiation. We recently did some experiments with up to 1,100 lb/ft of proppant.

"We've tried various amounts of gel vs. slick water and different pump rates. We pretty consistently pump at 80 bbl/min. That may vary slightly depending on the number of perforations that we are trying to pump. We have varied recipes like that, but these are variations on the same theme," Spalding said.

The company is vertically integrated with its own pumping services company and its own sand mine in central Texas. This also saves costs for the company.

"We've moved almost completely to walking rigs, where we can move quickly from wellhead to wellhead on three- to four-well pads. If we can zipper frack two or three wells together, we are going to be saving costs just due to time. Wherever we can shave days off our schedule, we can improve costs and get production onstream more quickly," he said.

Redesigning mechanical completions

"We've continued to maximize the efficiency of our completions. We're now running openhole packer systems that allow production from the entire section, which is not [obstructed] by cement, which is what we typically see in older designs," SandRidge's Reyna said. "We're also running electric submersible pumps [ESPs] at 90 degrees. These provide the lowest possible pressure for the life cycle of the well."

Stimulation is an integral part of the success of the program. There are two generalized methods for initiating fractures. The one generally accepted by the industry is planar. This completion included a cemented 4½-in. production liner, standard 10-stage stimulation and 52-degree ESP installation. The cost to drill and complete the well was $3.12 million. The 180-day cumulative production was 62,200 boe.

With the openhole packer system, SandRidge uses dendritic stimulation, which involves cycling the pump to create additional fracture networks near the wellbore. This included a 10-stage stimulation with a 90-degree ESP installation. The cost for drilling and completing the well was $2.93 million. The 180-day cumulative production was 62,200 boe.

"The dendritic design is the one we're physically employing at the present time. It is the result of cyclical pumping during each individual stage. What this means is that we're actually contacting more surface area, which is beneficial to the performance of a well," he said. "What we're doing right now has been cost-neutral relative to stimulation costs from what we did in the past."

To date, the company has completed 19 wells with the new design. "We're seeing a conservative uplift in EUR of about 15% relative to the offset planar design wells," he added. "With the 180-day performance, there has been a 68% performance gain with the dendritic design."

The second system being used by SandRidge involves a chemical packer, which is a temporary gel system for hydraulic isolation, and a sleeve-tool system. This design allows the company to access the wellbore through the liner that is being run. It is a sleeve and PNP combination that is extremely fast. This system saves about $60,000 per well and takes less than two days to stimulate vs. an original design of six days, Reyna explained.

"I am very excited about the chemical-packer and sleeve-tool system. We believe this can really be a gamechanger under the correct applications. A well savings of $250,000 can be expected and projected with this system. It uses polymer gel instead of permanent cement. It also uses a fully retractable liner," he said.

"It has already been employed in a well in Oklahoma with operational, mechanical and economical success," he continued. "Our stretch goal is to get to $2.3 million per well. One of the things we're excited about moving forward is to continue to drive costs down." ■

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Pressure, Proppants and Profits

Company innovation in fracturing factors is driving improved shale operations.

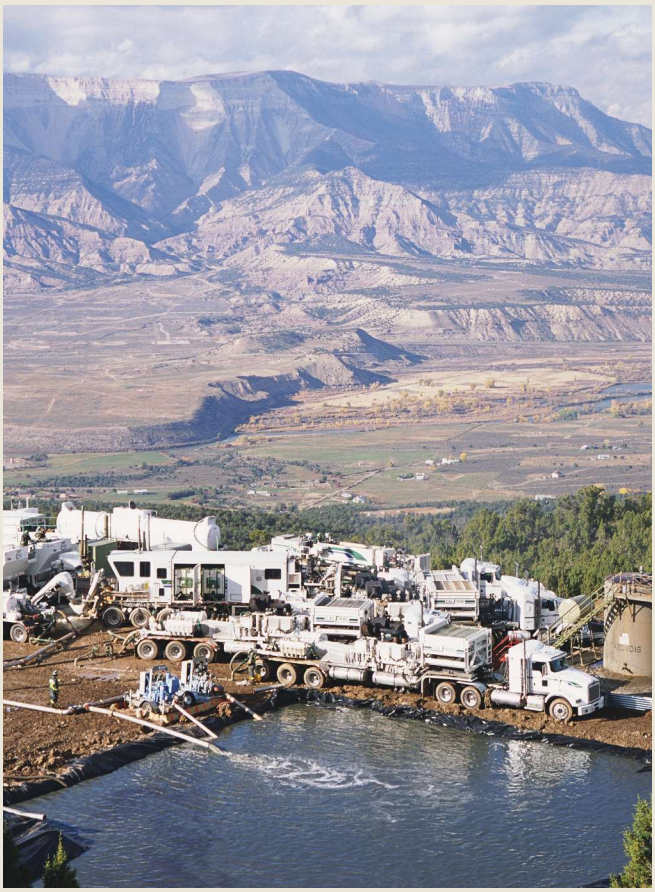
By Travis E. Poling
Contributing Editor

The hydraulic fracturing equipment, treatments and remote technology of today would likely be an odd sight to those in Kansas who first employed the concept of fracking on the Klepper #1 in 1947. Accounts of the time say it didn't help that well much, but by the time Halliburton acquired a license to the technology 10 years later, the idea had proved to be a sound one, at least some of the time.

Innovation by the players in the industry improved the process. Fracturing techniques now used in unconventional shale oil and gas plays worldwide have made improving technology and outcomes a major competitive advantage as the number of well service and supplier companies increases to get a piece of the pie.

Innovation, efficiency and environment have been the watchwords in all aspects of the hydraulic fracturing industry this year.

The stakes are high as the Permian Basin, Bakken Shale, Eagle Ford Shale and several smaller plays are poised to produce an estimated 2.8 MMbbl/d of oil by 2020. Production is at about 2 MMbbl/d, according to the U.S. Energy Information Administration (EIA).



The Rocky Mountains of western Colorado serve as a backdrop to this Calfrac site. *(Image courtesy of Calfrac Well Services)*

Well stimulation technologies, along with better tools to find reserves, have played a role in increasing the success rate of wildcat wells. Wildcat wells drilled in 2012 were 61% successful compared to only 26.6% 20 years earlier, according to statistics from the Independent Petroleum Association of America.

Now with the massive number of wells being drilled across unconventional plays and even the revival of old basins, well services companies are trying to help producers improve production by doing it cheaper, safer and right the first time.

For example, improved drilling efficiencies in one of the biggest shale plays, the Eagle Ford of South Texas, "have led to significant crude oil production increases in the Eagle Ford," according to an analysis of data released in September

by the EIA. It found that natural declines in well production have been offset by bigger IP. "By offsetting the natural declines through the use of new recovery techniques, further production increases are possible," the EIA reported.

Even sand and other specialized proppants are playing a greater role in production than ever before. The EIA report said that producers, since 2013, "are using significantly more proppant when hydraulically fracturing new wells." That seems to have improved IP rates, but the later drops were steeper.

Increasing demands for proppants have meant suppliers are ramping up their operations. Gary Kolstad, CEO of specialty proppants maker CARBO Ceramics, said in a Sept. 22 news release that an oversupply had created competitive price pressures and that sand, particularly in the Bakken nearer the supply, was being used more as an inexpensive alternative to sometimes higher-performing ceramic and other engineered proppants.

Water and the treatment of water also have played a major role in innovation by the well services and chemicals industry involved in fracking, not just because of government pressures to protect a clean water supply for people and animals but also due to the scarcity of potable water in general in many of the shale plays. Treatments using 100% oil-based fluids to technologies allow used water to be used again without the scale buildup that can damage a wellbore. In general, billions of dollars are being spent on innovation not just for a competitive edge but also to stay ahead of regulations that might otherwise put a halt to some fracturing methods.

The following key players have demonstrated leadership with advanced technologies and services for hydraulic fracturing operators.

Key Players

Advanced Stimulation Technologies Inc.

The Midland, Texas-headquartered Advanced Stimulation Technologies (AST) has been operating since 2007, with its first treatment in the Wolfberry Shale of the Permian Basin in 2008. The company's three lines of business focus on products, services and equipment for the oil field.

The frack fluid and other systems provided by the company undergo laboratory testing including a miniaturized fracturing analysis before being administered at the wellhead. Systems include the use of emulsified acid, nitrogen, CO_2, slick water for faster pumping down the bore, and additions such as borate, titanate and ziconate.

Where water-based systems are impractical, such as when oil-bearing formations might be sensitive to fracturing fluids containing water, AST offers the O-Light gel oil system that is mixed with a base fluid such as kerosene, diesel or other condensate. The advantage, according to the company, is that it can be mixed on the fly as needed and is stable up to 300 F.

Services from AST include fracturing for vertical and horizontal well treatments, acidizing, and cementing services including everything from long-string production casing to lightweight cement slurries. Equipment provided includes laboratory analysis devices, cementing units with remote monitoring capabilities available and fracturing equipment that includes a hydration unit that works at 120 bbl/min.

Archer Ltd.

Part of the global Archer Ltd., the pumping services unit provides everything from drilling fluids to specialized pumps used in the fracturing process.

Its AWC Frac Valves use a ball-screw technology first commercialized by the company for safe gate valves more than a decade ago. The Torque Master and Hydro Master valves need fewer turns for opening and closing to improve efficiency.

In shale plays, Archer specializes in vertical and horizontal wellbore stimulation including high-pressure (HP) and high-rate hydraulic fracturing, pressurized fluid pumping, coiled tubing (CT) and wireline, and nitrogen services. The company also provides rig assist snubbing for improved results from the well.

The cased-hold wireline services include a fleet of 100 trucks in the U.S. and have a full slate of diagnostics tools for more successful repairs.

With its pressure pumping and CT services, the company quickly has grown throughout the unconventional plays in the U.S. Pressure pumping solutions for hydraulic fracturing include conventional slickwater treatments, crosslinked fluids, energized fluids, linear gel and acid fracturing. The equipment includes HP, high-rate fracturing pumps, articulating arm discharge manifolds for safety and efficiency, and a 130-bbl/min trailer-mounted blender for the fieldwork.

Atlas Resin Proppants

Founded in 2005 a few years before the widespread expansion of unconventional plays across the U.S. and Canada, Atlas Resin Proppants supplies resin-coated proppants offered to the oil and gas industry.

In 2007, the company was wholly acquired by one of its limited partners, Badger Mining Co., a supplier of raw silica sand proppants to the industry. Atlas headquarters moved in 2009 from Tulsa, Okla. to Taylor, Wis. to be closer to the comany's key treatment facility in that area. Since then, Atlas has built two more production facilities in Wisconsin to keep up with the demand for proppants used in hydraulic fracturing.

The company uses Northern White frack sand as its base for an economical curable resin proppant and a premium version. Both provide flowback prevention, strength and conductivity, but the premium variety gives additional strength when needed in hydraulic fracturing treatments. Precured proppants from Atlas are a less expensive option when flowback isn't an issue. The premium version is a less expensive alternative to low-density and medium-density ceramic materials. A low-temperature resin propant was designed for use in reservoirs with lower temperatures.

Atlas and its partners have transload locations for products in all the major U.S. shale plays, including the Eagle Ford, Permian, Utica, Marcellus and Bakken.

Baker Hughes

Houston-based Baker Hughes, with its size and range of services, boasts that it has participated in 97% of the wells drilled in the Eagle Ford Shale alone and is a major player in the Marcellus, Bakken, Woodford and Barnett plays.

While the company has found that demand for fracturing services and new ways to do it have increased, rig counts haven't necessarily increased due to greater efficiencies in drilling performance.

The company is taking fracturing innovations from U.S. shale plays and deploying them globally, including markets in Russia and China.

Among its technological advances going global is the S3 FracHook Multilateral Fracturing System, which allows operators to gain access to more of a formation from a single-well hole. Also, in second-quarter 2014, Baker Hughes reported customer success with Shadow frack plugs set as deep as 25,000 ft for horizontal well construction that allowed greater access to reserves.

The water management services business H2prO is gaining momentum in the Eagle Ford, Marcellus and Permian basins and treats millions of barrels of water a month, according to the company.

To deal with the special challenges involved in unconventional plays, the company formed the Center of Reservoir Excellence that combines knowledge resources worldwide to further develop technology solutions for the shale gas and oil industry, including fracturing. The company also introduced a more environmentally sustainable fracturing fluid system dubbed BrineCare. It allows operations to take untreated, produced and brackish water-based fluids and use them in the fracturing process. Baker Hughes reported that tests of the system in the potable-water challenged Delaware Basin in New Mexico resulted in production rates similar to fracturing techniques using freshwater.

Basic Energy Services

Basic Energy Services, based in Fort Worth, Texas, has about 2,000 customers with a heavy concentration in liquids-rich basins including the Eagle Ford, Permian and Midcontinent.

From 157 offices in 15 states, the company offers well completion and remedial services, fluid services, rental tools and fishing tools, well servicing and contract drilling. Completions and remedial services made up 40% of the revenue mix in 2013, according to Basic's annual financial statement filed with the U.S. Securities and Exchange Commission.

There Is Nothing Absurd About Making The Transition From Diesel To Electric Power

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Most of the 2013 capex went into new saltwater disposal facilities, executives said at a December 2013 presentation at the Capital One Securities Energy Conference.

Revenue in the specialized completion and remedial services segment in first-quarter 2014 was more than $160 million. That came from focusing on markets the company considered traditionally underserved by larger companies in the oil field with services such as workover and pumping services for fracturing and refracturing, coiled tubing and nitrogen for completions, and various remedial services.

In 2014, Basic expanded and redeployed its pumping services to go from 222,300 hhp dedicated to fracturing efforts in 2013 to an estimated 324,900 hhp by year-end 2014, according to a company presentation at Imperial Capital's Annual Global Opportunities Conference. The company also grew in every region, most notably in the Permian Basin, where pumping services nearly doubled to an estimated 130,700 hhp by year-end 2014.

Bayou Well Services LLC

The wellsite support services company Bayou focuses on well services, pressure pumping, rental tools and fluid logistics from its headquarters in Houston. A bright purple is a hallmark of its pumping equipment.

The company operates in every major U.S. shale play and has the ability to do remote fracturing in tight well-spacing situations on unconventional surfaces from up to thousands of feet away using wireless devices.

Bayou said its dual-fuel pressure pumping means high efficiency at any depth or reservoir temperature as more fleets are converted to natural gas to aid in the production of oil and gas.

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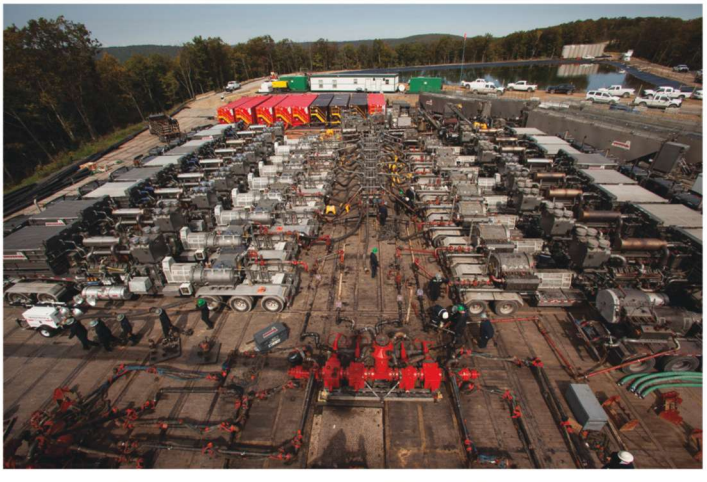

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Founded in late 2009, the company is registered to do business in several states with one or more shale plays including Colorado, Louisiana, Michigan, Mississippi, North Dakota, Oklahoma and Texas. Bayou has been aggressively hiring in several states.

C&J Energy Services

Founded in 1997 as a hydraulic fracturing and coiled-tubing services provider, C&J has diversified with several acquisitions since its IPO in 2011.

The company acquired Total Equipment and Service, an equipment supplier and manufacturer. That was followed in 2012 with the acquisition of Casedhole Solutions Inc., which specializes in several oilfield services including pressure pumping, pipe recovery, perforating and wireline logging.

An acquisition of Tiger Cased Hole Services Inc. was completed in second-quarter 2014 for greater reach on the West Coast and an acquisition of Nabors' Completion and Production Services businesses is pending. The Nabors buy would make C&J the fifth largest hydraulic fracturing services company in North America and woud add cementing to its range of well completion services.

The company has expanded capacity in existing business and has entered new business such as data control manufacturing and directional drilling in 2013 while expanding service areas geographically. In April, C&J added 20,000 more hhp and another 40,000 hhp in July to meet demand. The firm is on pace to add another 40,000 hhp by year-end 2014, according to C&J's second-quarter earnings release.

The company has sites in numerous liquids-rich basins and shale plays around the country. Through Total Equipment, the company is working to bring even more manufacturing functions in-house and hired 30 new engineers last year to help achieve that, according to a December 2013 presentation at the Cowen Oil Service and E&P Conference.

Calfrac Well Services Ltd.

Calfrac made its move into the Eagle Ford Shale in fourth-quarter 2013 with the $147 million acquisition of hydraulic fracturing and coiled-tubing (CT) firm Mission Well Services LLC. The company already was active in other major shale plays in the U.S., Russia and Latin America.

The company tests fracturing chemical solutions in simulated conditions at its technology and training center in Calgary, Alberta, Canada, where the firm is headquartered. Calfrac laboratories are working on additions to the lines of fluids designed to work best in unconventional formations, according to the company website. That has made it a major player in some of the most active shale plays in the U.S., including the Bakken and Marcellus Shale, according to the company's 2013 earnings report. The company is now introducing that expertise to the Eagle Ford, including customized well completion simulation programs for clients.

With the acquisition of Mission, Calfrac gains 157,500 hp of pumping capacity. It also comes with high-rate blenders, sand handling and three deep-capacity CT units along with the fluid and nitrogen pumping equipment, according to the company release announcing the purchase agreement. As of June 30, 2014, the company had U.S. pumping

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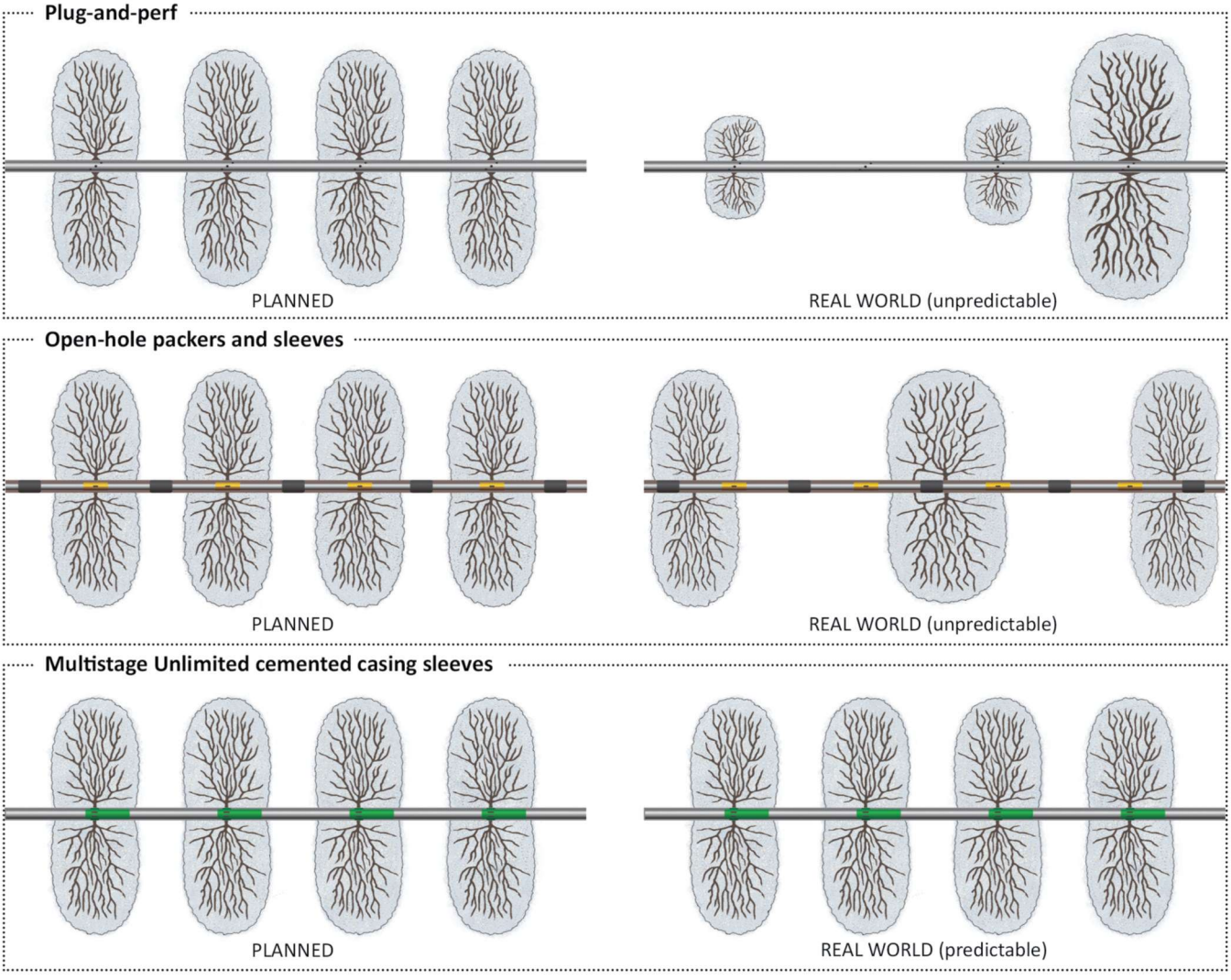

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power totaling 660,000 hhp along with 18 cementing units and eight CT units.

In second-quarter 2014, Calfrac increased revenue by 75% when compared to the same quarter last year. That is largely thanks to a 93% increase in the number of fracturing jobs the company performed in the period.

CARBO Ceramics

CARBO Ceramics has become the largest supplier of ceramic proppants used in fracturing treatments and also sells resin-coated and uncoated white sand proppants.

Among its technical achievements in the last year was maximized well production for a Permian Basin operator using low-density ceramic proppants as part of CARBO's technologies to design, build and optimize the fracturing experience.

CARBOECONOPROP, a low-density ceramic product, was blended with resin-coated proppants by a Bone Springs Formation operator for better production from the well.

CARBONRT, a nonradioactive tracking technology, has been rolled out into new markets across North America and showed in a case study where it has been used to verify that the well casing stayed isolated from a water treatment center in the area.

The company's SCALEGUARD is being used in several plays, including the Rocky Mountains, to provide protection in the long term against scale buildup in fracturing fluids, which can damage the well over time.

CARBO also now has an application. The iPhone version of the Fracpro Remote application lets operators log into frack jobs from a remote location and get real-time data.

A Calfrac Well Services crew works the Lone Mountain frack site along the mesas in western Colorado at high altitude and sometimes in harsh conditions. *(Image courtesy of Calfrac Well Services)*

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In September, the company advised investors and the financial community that it expected sales volumes in third-quarter 2014 to be about the same as the first quarter because more operators were using less expensive fracturing proppants such as plentiful sand.

Circle Z Pressure Pumping LLC

Energy production servicing company Circle Z Pressure Pumping was founded in 2009 and works primarily around South Texas and the area where Arkansas, Louisiana and Texas come together.

Circle Z trucks can generate more than 2,250 hp for servicing wells up to 15,000 lb of pressure, according to the company website. The company also does acidizing and remedial work using smaller pump trucks. Work in unconventional plays is focused on the Eagle Ford and Haynesville shales. The company has 16 pump trucks, according to Circle Z's website. The truck design allows for well-bore pressure testing, pumping plugs, perforation guns and additional tools used in well completion.

Other work performed by the company includes bucket and foam fracks, sand plugs and acidizing, which comes with Circle Z's ability to mix acid blends on site as needed.

Compass Well Services

Based in Fort Worth, Texas, Compass Well Services specializes in cementing and fracturing jobs throughout the Texas shale plays and several more around the country including the Barnett, Marcellus, Woodford, Fayetteville, Lewis and Eagle Ford. Compass also works in prominent basins where hydraulic fracturing is being employed including the Permian, Granite Wash, Colony Wash, Piceance, San Juan and Deep Hunton/Morrow basins.

The pumping fleet can pump 100 bbl/min of fluid with double tanks. The company also has

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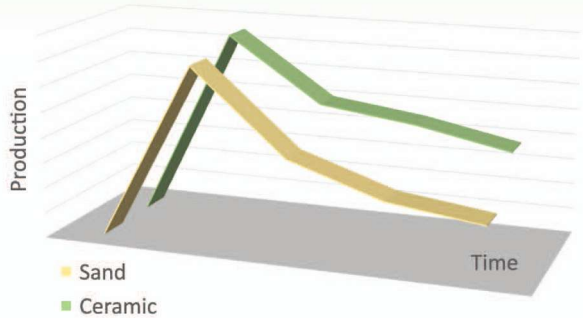

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remote data transmission to customers so the fracturing projects can be monitored.

The fleet includes Quintuplex pumping units with remote control and monitoring and can produce 2,250 hhp. The blender truck can do 1,500 hp. The Sandking holds proppants, and load-sensing pads detect how much sand or other proppant is in the 4,000-cf bin.

Compass has a cement plant for new wells, reworks and plugging that can make 8,500 sack batches for many small jobs or large ones quickly. The five twin-pump cementing units have the ability to capture real-time data, automatic density control and micromotion monitoring. Compass employees are trained to do design and pump complex acid-soluble slurries into 4,000-ft-long laterals.

Consolidated Oil Well Services LLC

With services in Kansas, Oklahoma and Wyoming, Consolidated Oil Well Services has been around since 1956.

The pressure pumping company does fracturing, cementing and acidizing in the Midcontinent and Rocky Mountain regions.

A subsidiary, Team CO2 Holdings, provides CO_2 products, transportation and storage to Permian Basin operators in Texas and New Mexico. Team CO2 also includes CO_2 booster pumps and downhole pumping services.

In the fracture-pumping arena, Consolidated has experience in areas such as single-pump scour fracks for the higher-rate, high-pressure pumping necessary to do horizontal wells. The company uses 3-D modeling to help design the process for each well and determines which fluid system will work best, including crosslinked, gelled diesel or a more environmentally friendly liquid guar system.

On the cementing services side of the business, Consolidated uses design software to consider the right cement additives needed for even the most challenging wells that range from high temperature to low-fluid-loss cement slurries.

Quintana Energy Partners is the owner of Q Consolidated, which owns both Consolidated and Team CO2.

Cudd Energy Services

Cudd Energy Services has its beginnings fighting well fires in Oklahoma but grew into a diversified oil services company through numerous acquisitions and an eventual merging of Cudd and Patterson Rental Tools into RPC Inc. The Woodlands, Texas-based company now operates Cudd Pressure Control and Cudd Pumping Services as one unit with more than 2,000 workers in 60 markets, including a heavy concentration in unconventional shale plays.

Cudd's services include well control, water management, well stimulation, coiled tubing, e-coil, nitrogen, hydraulic workovers, slickline, braided line and electric line, according to the company website.

Cudd, which is active in most major U.S. shale plays, opened a regional office in San Antonio in 2011 and began hiring about 200 drivers, logistics and inventory control personnel to support its growing hydraulic fracturing business in the Eagle Ford Shale.

Cudd is working to make its processes as environmentally friendly as possible by seeking out low-toxicity additives, silica sand dust control and the use of Petro-Flo Microbiocide in the fracturing process.

The company's e-coil technology gives operators images, logs and data immediately from all downhole operations.

Cudd is now taking the knowledge gained from working in the U.S. shales to Australia, where early this year, the company opened a Toowoomba office in Queensland, Australia.

Economy Polymers and Chemicals

With the business going back to 1951, Economy Polymers and Chemicals (EP&C) in Houston might be old school with tried-and-true oilfield stimulation compounds like guar gum slurries, but it has invested for years in R&D that is paying off as fracturing has become an expanding and dynamic business.

The subsidiary of Economy Mud Products has found a niche with a subsidiary of its own called Economy Liquid Inventory Management System (ELIMS). ELIMS specifically deals with management technology for hydraulic fracturing and related industries.

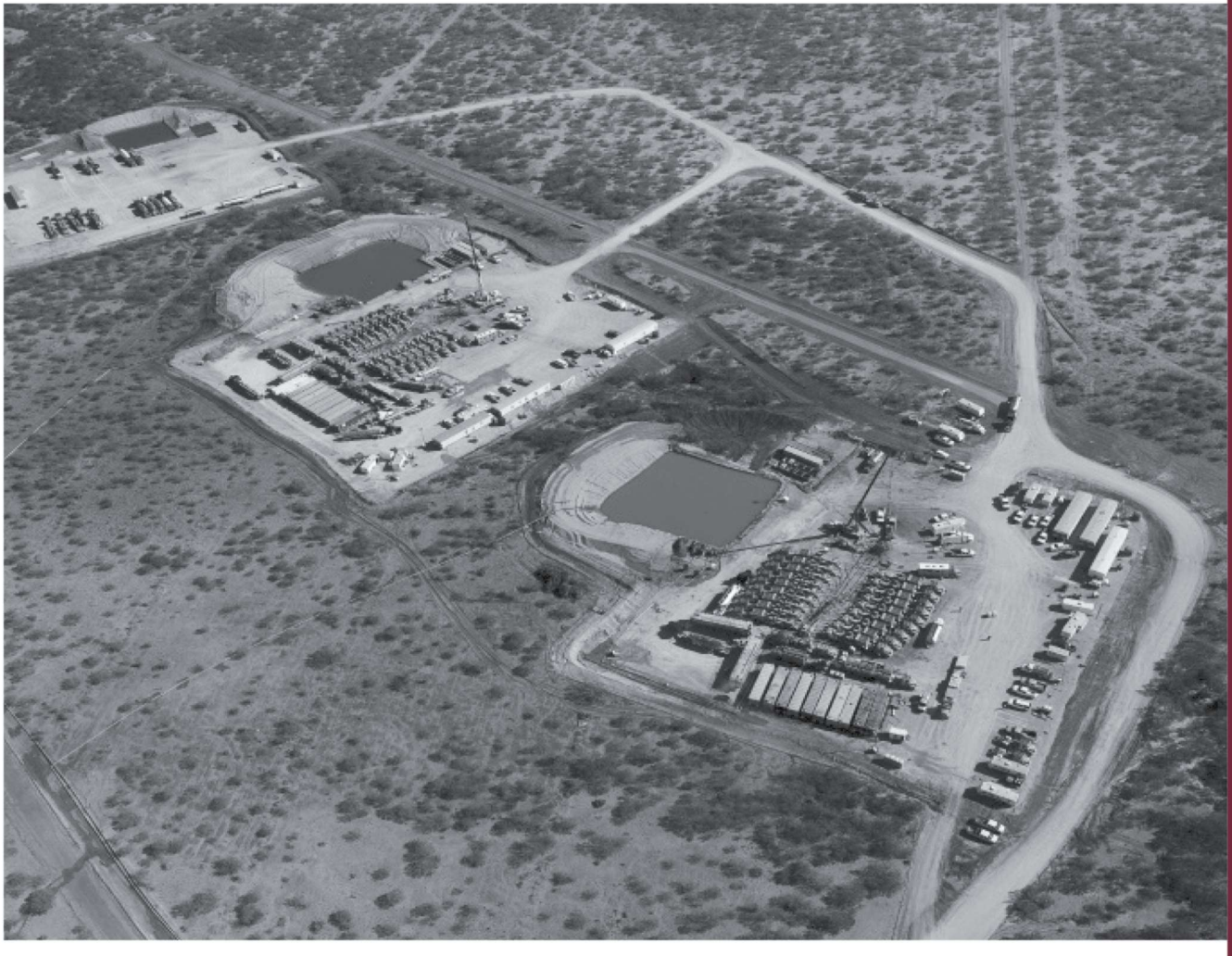
The company said its guar gum is used in every shale play in the country. R&D has led to the development of new types of guar that could better

THINK

In our extensive experience with thousands of unconventional wells, the best time to save money is long before the on-site work begins. When we partner up early in the stimulation design, we can better understand the scope of the challenges, and we can build cost savings right into every stage of the program.

SAVING MONEY ON UNCONVENTIONAL RESERVOIRS CALLS FOR UNCONVENTIONAL THINKING

Think first, save always. That's just one more example of how we deliver solutions to tough problems, saving you time and money. So if you're as tenacious as we are about thinking, we need to talk. Expect the Unconventional.



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serve the oil and gas industry. The company gave away a new variety of guar seeds to farmers in 2010 and began an expansion of its warehouse space the following year to deal with an increase in production. In 2012, EP&C gave away $18 million in guar seed to Indian farmers to encourage the crop.

Other Economy products used in the oil field include chemicals used in fracturing, acidizing, cementing and coiled-tubing systems. A variety of gels and stabilizers for the oil field come from parent company Economy Mud.

Element Technical Services

With its main focus on pressure pumping services in the Williston Basin, Element Technical Services territory ranges from Southeast Saskatchewan to Southwest Manitoba in Canada and from Montana to North Dakota in the U.S.

The company is based in Calgary, Alberta, Canada and was founded on the idea of serving the fracturing market with equipment, fluid technology and engineering services.

The fleet includes a blender unit, six pump trucks, chemical addition trucks and pumps, hydration units, a data van, iron trucks with a crane and sand transporters.

Fluid technologies include water-based fluids, produced water, slick water, and oil-based and foamed or energized gels that combine with engineering services and stimulation modeling.

Elite Well Services

Formed in 2012, Elite Well Services provides equipment and fluids for well stimulation primarily in southeast New Mexico.

The Artesia, N.M.-based company has a fleet of 18 fracturing pump units including 2,500-hhp Quintuplex pumps with up to 10,000 psi. The fluid blenders offer full control of the wet and dry chemicals and provide fluid at 125 bbl/min.

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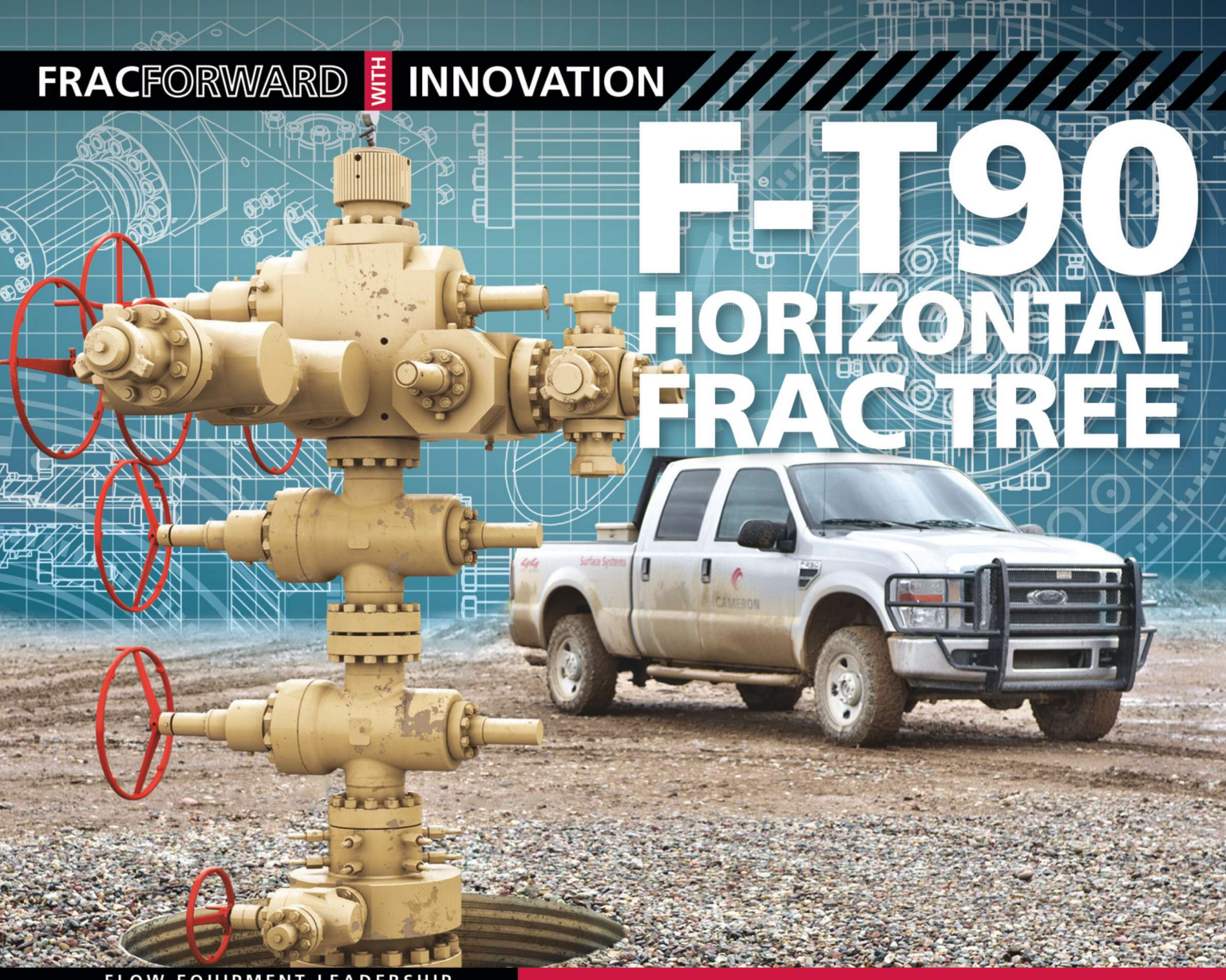

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Six Sand Dragon haulers can deliver up 20,000 lb/min of proppant, and the double-belt Sand Conveyers can pull proppant, materials out of several sand boxes and supply up to 18,000 lb/min.

To accommodate its acidization services, the company has three 5,000-gal acid transports and an acid van known as the ProphetDV Data Van System, which provides monitoring of stimulation operations.

Equipment totaling 25,000 hhp comes from NOV Enerflow Industries and chemicals through a partnership with Chemplex Chemicals in Synder, Texas.

EnerChem International Inc.

Based in Calgary, Alberta, Canada, EnerChem International sells fluids to the oil and gas industry, including an array of products used in hydraulic fracturing.

The list of chemical products includes Fracsol, Drillsol, EZSolPlus, Xysol and produced water. Fracsol is a completely oil-based frack fluid with little odor, a high flash point and fluid consistency. It comes in plus-sized versions and light.

EnerChem's drilling fluids such as Drillsol were formulated for the safety of the environment and the workers on the rig with a high flash point.

The company also has a transportation fleet for the oil field with tank trucks, pressure trucks, steamers, vacuum trucks and trailers through subsidiary Millard Trucking Ltd.

Evolution Well Services

Using natural gas-driven electric power on site, Evolution's Electrically Powered Frac Spread system is designed for better operational and control efficiencies, according to The Woodlands, Texas-based company.

The system can be used with the conventional fracturing treatments and the latest standard of Quintuplex 2500 pumps. The hybrid system was first introduced in February 2013 to demonstrate how it saved fuel in the fracturing process, had lower emissions—about two-thirds of normal fracturing methods—and provided a reduced environmental footprint.

The unit also powers the blenders and auxiliary equipment. Traditionally, fracturing operations are driven by diesel-fueled equipment instead of electricity from a gas turbine generator. Evolution executives also said the mobile technology can cut down on maintenance by about 60% with a 50,000-hr service life.

The units are quieter at about 76 dB and take up smaller patches of land for the drilling pad site. The company also provides data vans with remote controls and monitoring.

Fairmount Santrol

The proppants business is one of the largest providers of sands for hydraulic fracturing and changed its name earlier this year to Fairmount Santrol from Santrol. The company also filed in late August with the U.S. Securities and Exchange Commission to explore a possible IPO worth up to $1 billion, reported *Crain's Cleveland Business* and *Reuters* news service.

The 38-year-old company, based in Chesterland, Ohio, produced more than 7.5 MMlb of sand and related products last year from several plants across the country.

Fairmount Santrol has developed a hydrogel-coated sand that creates suspension in water, the Propel SSP, so it can flow evenly and deeper into the new fractures off the wellbore. The company said it makes the chemistry of working downhole simpler and maintains suspension even after pumping shutdowns.

Other products include resin-coated proppants, curable and precured proppants and a proppant for complex fracture networks. Northern White and Texas Gold sand form the basis of the frack sand program for the company. Activators and water-soluble ball sealers also are part of the product mix.

In early August, the company opened its seventh proppant terminal in the Midcontinent area of the U.S. in Ada, Okla. The location has easy access to the railroad and a state highway for truck transportation of proppant coming off the train. Fairmount Santrol now has more than 50 terminals across the U.S.

Flotek Industries Inc.

Flotek drilling and production products are the culmination of several mergers and acquisitions since the company was formed in 1985.

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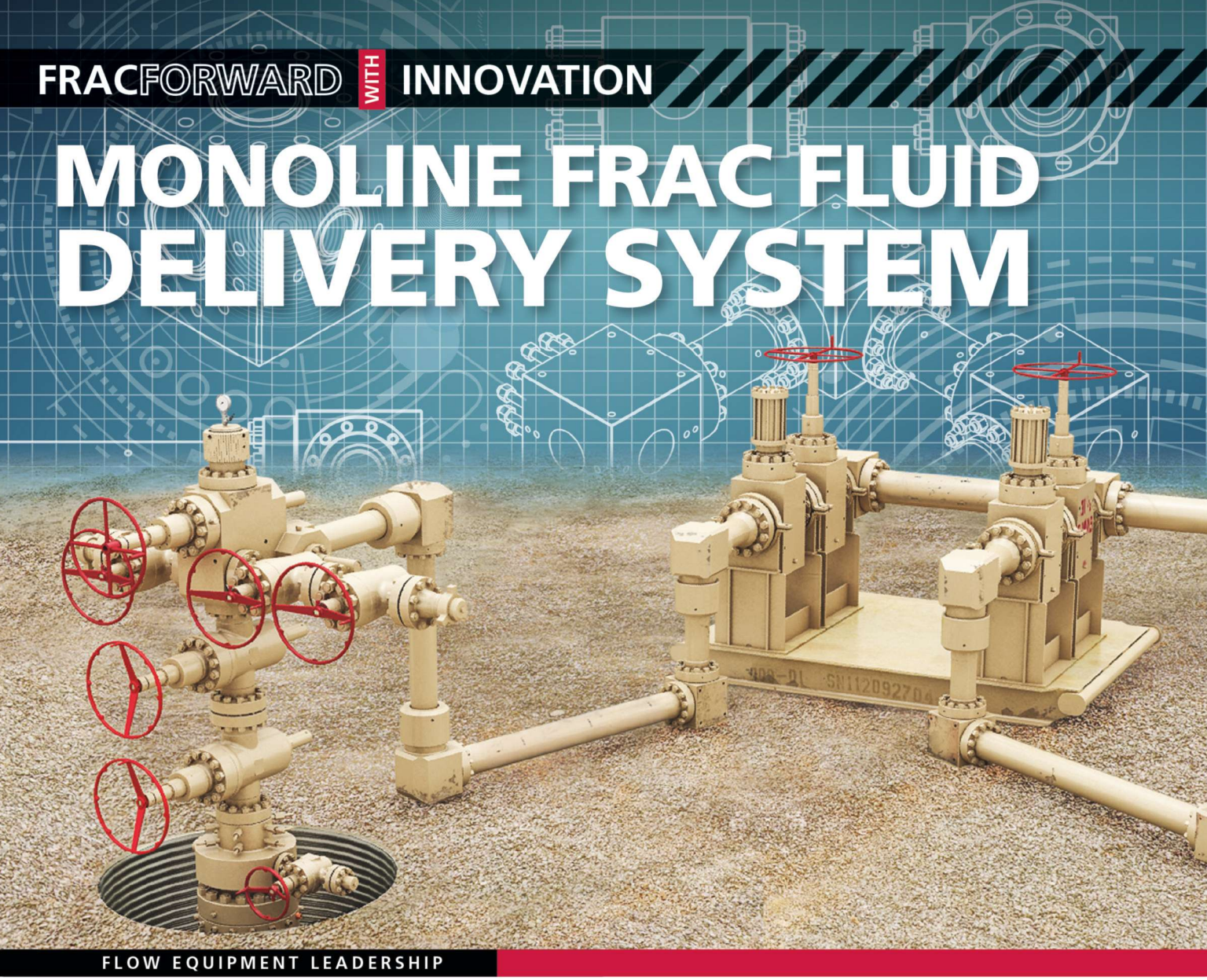

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- Quicker installation
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CAMERON

Now based in Houston, the firm did a reverse merger with CESI Chemical Inc. in 2001; acquired IBS 2000 Inc., a Denver company making environmentally neutral chemicals for the oil and gas industry, in 2002; and picked up the rights and assets to make oilfield shale shaker screens from Phoenix E&P Technology in 2005.

Also in 2005, Flotek bought downhole tool manufacturing and rental company Spidle Sales and Services Inc.; acquired Harmon's Machine Works Inc. in Midland, Texas; and picked up the assets of South Texas service tool rental and inspection company Precision-LOR Ltd.

The buying spree continued with the purchase of Can-Ok Oil Field Services, Stabilizer Technology Inc., assets from Total Well Solutions, Triumph Drilling Tools, CAVO Drilling Motors, Sooner Energy Services and Teledrift.

In more recent years, the company has positioned itself to become more deeply embedded in fracturing and shale technologies with the 2013 purchase of Florida Chemical Co. and its citrus-based solvents and the acquisition of Eclipse IOR Services LLC, a firm specializing in enhanced recovery technology.

In April 2014, Flotek bought SiteLark LLC to gain software solutions for the industy, including technologies that assist engineers with reservoir simulation, engineering and waterflood optimization.

Frac Specialists LLC

The Midland, Texas, business is a regional firm focused on hydraulic fracturing, acidizing and cement-pumping services across the Permian Basin, New Mexico and the Texas Panhandle.

Fracturing specialty work includes energized fluid services, slick water, crosslinked and gelled water fracks. Frac Specialists (FS) works with hydrochloric and acetic acidizing, toluene and xylene solvent hydrochloric acid systems, rock salt and ball seater diversion options. Services also include gelled and crosslinked hydrochloric acid and CO_2 foamed acid.

FS keeps two fracturing crews busy with the 100-bbl/min blenders, 2,500-hp Triplex and Quintuplex pumps, hydration units, 300,000 sand storage bins and computerized treatment vans.

There are five acid specialist crews with trailer-mounted pumps up to 2,000-hp and 5,000-gal acid transports. Five cement crews also are in the field with the single- and double-pump mixers on trailers.

All three business units are run from an 11-acre yard on Midland's east side with 35,000 gal of raw acid storage, a cement storage and mixing facility, sand storage and handling, and a 20,000-sq-ft office, shop and laboratory.

FTS International

The need for well stimulation with the development of the Barnett Shale led to the formation of FTS International in 2002. The founders sold the company to an investor group in 2011, and it has developed into a significant supplier for well completion services.

With a focus on unconventional gas and oil, the Fort Worth, Texas, company does pressure pumping, wireline and pressure control, and water management. FTS has developed a pressure-pumping unit that can run on traditional fuel or cleaner-burning natural gas.

The company's R&D unit also is working on new fluids and blending to do effective well stimulation that is more economical and environmentally friendly.

FTS operates 34 fleets of pressure pumping equipment in the U.S. in major shale formations, according to the company website. That represents about 1.5 MMhp of pumping capability.

The company sold its proppant assets to Fairmount Minerals in 2013 but signed a long-term contract with Fairmount to provide the proppant FTS needs for mixing with the fracturing fluids.

In June 2014, FTS and Sinopec Group formed the joint venture SinoFTS Petroleum Services Ltd. to provide hydraulic stimulation technologies honed in North American unconventional plays to shale drilling in China. Initially, FTS will help build out the pressure pumping fleet in China with custom-made equipment made in the U.S. The first focus will be on the Sichuan Basin, considered the shale play with the most potential in China.

GoFrac LLC

GoFrac was founded in 2011 as a joint effort of The Crawford Group, Soave Enterprises and Frank Autry, who until September 2014 served as COO.

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CAMERON

GoFrac now has 500 employees and 250,000 hhp operating in major shale plays across the country. The Fort Worth, Texas-based company also has offices in East, North and West Texas and Ohio.

Stimulation services include slick water, acid and gel jobs. CO_2 and nitrogen well stimulation jobs also are in the works for GoFrac, according to the company website. It also expects to add core tubing and wireline services to the mix.

Halliburton Obsidian and Fas Drill composite bridge and frack plugs offer dependable isolation as well as quick and easy removal for a full range of applications. *(Image courtesy of Halliburton)*

Besides designing well stimulation solutions for its own jobs, the engineering services team at GoFrac also provides field consulting services for clients. The group performs prefracture design and interpretation of the data and post-fracture production data analysis and future projections.

Frack pumps and blenders used in the field by GoFrac are made by Cummins as part of the customized fleet.

Halliburton

In September 2012, Halliburton introduced the commercialization of PermStim hydraulic fracturing fluid in the Eagle Ford Shale, and its use has since spread to other shale formations as it is more efficient than guar-based fluids. The company's new CleanStim formulation is designed to save on the use of freshwater when stimulating wells.

Another case study on the Halliburton website reported that it saved a customer $1 million using its RapidStage completion systems to stimulate a tricky well that presented numerous challenges. Various Halliburton frac sleeve systems under the RapidSuite line of products reduce the time it takes to stimulate a well, according to the company.

SoluCem cement, which can be dissolved with acid, also has proven to be effective in dealing with challenges presented by the Eagle Ford and other formations while fracturing in multiple stages.

In February, Pinnacle, a Halliburton service, introduced FracHeight, a fiber-optics-based tool to better diagnose and map fracturing.

In late 2013, Halliburton built a $70 million regional headquarters on 150 acres for its Eagle Ford Shale operations and to support the business lines of production enhancement, cementing, Baroid, the well pressure-control and intervention Boots & Coots division, wireline and perforation services.

The Eagle Ford has been a testing ground for many Halliburton products and services it is developing for the unconventional plays worldwide.

The company's CYPHER service provides everything from basin modeling to production analysis

for a more economical experience in getting shale and tight reservoirs to give up their oil and gas.

Hi-Crush

Hi-Crush Proppants LLC produces, stores and loads sand for transportation to shale plays where it is used in the hydraulic fracturing process. The Houston-based company, founded in 2010, acquires and develops Northern White sand, mostly from Wisconsin and other areas of the Midwest U.S.

The company also is 49.7% owner of Hi-Crush Partners LP, a publicly traded company that also develops frack sand reserves.

Hi-Crush Partners acquired D&I Silica in June 2013 to become a significant player in supplying sand to the Marcellus and Utica shales. The company also picked up 12 sand terminal storage, railcar storage and transloading sites in the deal.

Most of the sales are to pressure pumping subsidiaries of major oilfield service companies in shale plays throughout North America. A silo-based storage system helps maintain the quality of the sand as it awaits transportation by train to the service company.

The Wyeville, Wis., facility processes about 1.6 MMtons/year of fracking sand from the 651-acre mining site. It produces several sizes of mesh to provide different sizes of sand crystals to meet various fracturing needs. The facility in Augusta, Wis., mines a course grade of Northern White sand from 1,187 acres and also processes about 1.6 MMtons/year of fracking sand.

Imerys

The mineral conglomerate based in Paris, produces proppants for fracturing through its Oilfield Solutions company.

In April 2013, the company purchased PyraMax Ceramics, which was building a manufacturing facility in Wren, Ga., for ceramic proppants expected

to reach an annual capacity of 225,000 tons by year-end 2014.

To take advantage of the growing minerals market for hydraulic fracturing, the company has been focused on developing its oilfield minerals unit since 2010 through research. This has resulted in the filing of several proppant-related patents and its first ceramic proppant production line in Andersonville, Ga., in 2012.

The ceramic proppants, an alternative to processed silica sand in the fracking process, are made from kaolin clay found in South Georgia and come in different sizes, depending on the level of conductivity needed for treatment of an operator's particular well. ProLite is the most economical line for Imerys, while ShaleProp is in the middle of the product line.

In 2010, the company introduced Propynite, which is rod-shaped instead of sphere-shaped like most proppants. According to Imerys, the products provide better conductivity and greater porosity and can be transported with more ease downhole with a reduction in slurry friction of 10%.

Imerys has two terminals at its Georgia plants and six others scattered in several U.S. shale plays.

Independence Oilfield Chemicals

In 2012, a group of oilfield services veterans from stimulation, production chemicals and cementing formed Independence Oilfield Chemicals in The Woodlands, Texas. The firm has more than 100 employees throughout the U.S., including two chemists holding more than 65 patents for processes and chemicals used in stimulation and production.

ParaFrac, the most recent system commercially released by the company with a March 2014 launch, allows for a well stimulation treatment that goes deep into the reservoir and preemptively treats buildup of wax and asphaltene, which can cause the need for expensive well interventions.

Also in March, Independence introduced a crosslinking system that combines slickwater and guar-based systems into one for hydraulic fracturing with better proppant transport and less polymer damage. The VisLink-100 crosslinking system requires fewer chemicals and results in less cost and damage, according to the company.

Other well stimulation-related chemicals and systems from Independence include acids, biocides to control bacteria, breakers, brines, corrosion inhibitors, crosslinkers, flowback agents, friction reducers, guar slurries, gel stabilizers, lubricants and scale inhibitors.

Keane Group

Keane has worked in the drilling and fracturing service field in Appalachia and northeast Pennsylvania for decades and in recent years has made a series of company and asset acquisitions to expand into additional unconventional plays.

In December 2013, Houston-based Keane purchased the asset of Midland's Ultra Tech Frac Services LLC for a fracturing foothold in the Permian. The acquisition added 22,500 hhp to bring Keane to 136,000 hhp. The move sets the stage for additional expansion in the Permian as well as extending its wireline technologies services to the area.

Wireline services for the fracturing process were added to Keane when it acquired Calmena Wireline Technologies in April 2013. The Canadian company put Keane into the shale plays in Alberta, Canada and allowed it faster growth in the Marcellus Shale.

Keane uses the latest Triplex and Quintiplex frack pumps, blenders and other equipment and satellite-equipped data communications, fracture analysis and modeling software.

Wireline capabilities include pressure-controlled equipment with a rating of 15,000 psi and up to 7 in. of diameter for completions involving pump-down plug and perf.

Liberty Oilfield Services LLC

Denver-based Liberty Oilfield Services, which specializes in wells involving hydraulic fracturing, works largely in the Williston and Denver-Julesburg basins.

Liberty can bring up to 12 pumps to a well site for a total of 27,500 hhp for the well stimulation job if needed and can handle treating pressures up to 10,000 psi. High-rate blenders have a 120-bbl/min pumping rate per unit. Automated hydration units can blend two dry additives and as many as 10 gel, liquid and proppant additives.

The Iron Truck custom manifold, or missile, allows for easy setup and takedown from the rig to move from one well to the next in just a few hours for greater efficiency, according to the company.

Engineering services provide a variety of analyses to help determine how to stimulate the well and what will happen in the aftermath.

On the equipment side of Liberty's business, the company leases out wellbore valve rentals, flowback skid rentals and water manifold rentals. The company said it prides itself on adequately scaling the equipment for the size of the job, including having backup equipment, tools and parts on site to prevent delays from breakdowns or other unforeseen circumstances.

Magnablend Inc.

The 35-year-old Magnablend has significantly expanded the energy services portion of its chemical manufacturing and blending business as hydraulic fracturing activity booms.

The Waxahachie, Texas-based company also has offices in the Williston Basin area. In 2013, the company completed renovation in Ellis County, Texas, of the former 135-acre site of the Superconducting Super Collider. The government pulled the plug on the science project in 1993. Magnablend employs nearly 100 people at the facility where it manufactures products for well stimulation including guar slurries in every major shale play in the U.S.

The company blends many of its products in regional facilities to reduce prices and ship at a lower cost. It also produces well stimulation and drilling fluids, cement additives for the well, fast-hydrating guar and acidizing additives.

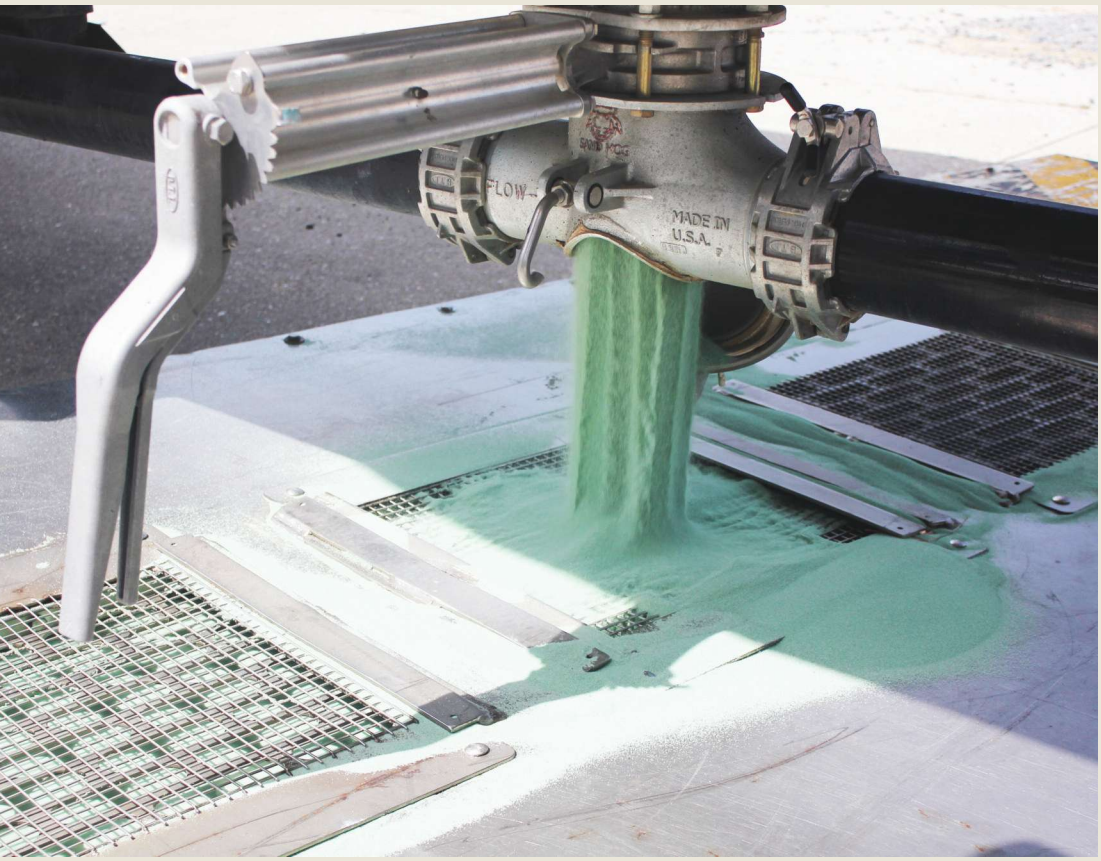
Guar slurry locations regionally include Waxahachie, close to the Barnett Shale; Alice, Texas in the Eagle Ford Shale area; and Casper, Wyo., central to the Bakken, Niobrara, Baxter and other plays. The company is opening a fourth site in Everson, Pa., near the Utica Shale.

Magnablend has operated as a wholly owned subsidiary since year-end 2012 when it was acquired by Univar, a global distributor of industrial and specialty chemicals.

Millennium Stimulation Services Ltd.

Based in Calgary, Alberta, Canada, Millennium Stimulation Services financed a major equipment expansion and an acquisition of another hydraulic fracturing specialty company in August 2014.

Millennium, in its first major acquisition, purchased ENFRAC Inc. for $12 million to gain expertise in another route to well stimulation. ENFRAC specializes in energized or foam frack well completions using LNG. ENFRAC's efficient pumping method for LNG in foam and energized fracking processes made it attractive to Millennium because of zero emissions, reduced needs for water and safe handling in the field.



The curable, resin-coated sand Prime Plus, a proppant used in the hydraulic fracturing process, is uploaded at one of Momentive Specialty Chemicals' transload facilities. *(Image courtesy of Momentive)*

The company spent an additional $38 million on newly built equipment to allow for more jobs and keep up with demand. The addition of an 18,000-brake-horsepower coil frack spread puts another fleet in the field and has cryogenic gas capabilities, which take advantage of the company's LNG service picked up in the ENFRAC acquisition.

The company expects that the fleet expansion should allow it to grow organically into 2016 in the plains, including Alberta, Saskatchewan and Manitoba in Canada, and Montana, North Dakota and South Dakota in the U.S.

Momentive Specialty Chemicals Inc.

Resin-coated proppants are the bread and butter of Momentive's oil and gas service business. Dating back to the 1980s, the company originated the use of resin to cover proppants for better fracturing in certain wells and is now one of the largest suppliers of specialty proppants in the world.

The OilPlus proppants are designed for best results in fracturing processes for oil and liquids-rich reservoirs. Curable sands and curable ceramics better prevent flowback, maximize the fracture flow capacity and cut down on the generation and migration of fines created in the process. Precured sands provide more strength in the sand grains so they produce fewer fines, while the resin coating captures the fines that are generated.

Momentive also does fracture diagnostics and provides sand management technology for operators. The company has found solutions for various types of reservoirs and has experienced success in East Texas, northern Louisiana, the Permian Basin, Eagle Ford and Rocky Mountains, according to case studies.

Its PropTrac diagnostics service measures propped fracture height using resin-coated proppants with tagging materials built in for better results from additional fracturing. The environmentally friendly product doesn't use radioactive materials for tracing in the process.

Nalco Champion

The EcoLab subsidiary Nalco Champion provides specialty chemicals and support throughout all three stages of the oil and gas business, but it starts with the solutions for recovering liquids at the wellhead.

The company's shale oil and gas segment includes flow management, integrity management, water treatment, phase separation, drilling and well stimulation treatments.

Drilling completion and stimulation solutions include acidizing additives, cementing additives such as chemical washers and defoamers, and

fracturing additives such as friction reducers and biocides.

EOR R&D available for the field includes residual oil recovery, sweep improvement, clay stabilization and dealing with high-temperature reservoirs. The company's flow assurance product line provides hydrate, paraffin and asphaltine inhibitors, along with hydrogen sulfide scavengers, foamers, foam control and surfactants.

In 2013, the R&D team fielded and completed more than 3,000 technical support requests worldwide, mostly related to oilfield chemicals and the downstream aspect of the business.

Nalco Champion employs more than 450 engineers, scientists and others with technical expertise in its R&D centers, including at its Houston headquarters. The company is building a new campus on its Sugar Land, Texas, property to open in first-quarter 2016.

Northern Frac Proppants

With mining and manufacturing of proppants in Wisconsin, Northern Frac Proppants (NFP) has become a larger player in supplying shale plays in the U.S. and Canada.

The Houston-based company began processing sand on a 1,800-acre site in Alma Center, Wis., in fall 2014, with an estimated 40 MMtons of proven Northern White sand reserves and an output of about 800,000 tons/year. The company said Phase I of production is fully spoken for by a backlog of operators, and the plant employs about 35 people.

The proppants are loaded directly to cars on Class I railroads without the extra expense of trucking the products to a rail terminal. Canadian National Railway recently expanded its track network in the area of the new proppant plant in two projects worth about $71 million to give proppant companies in the area direct access to the Bakken, Marcellus Shale and Canadian oil and gas plays.

NFP also is planning a wet sand plant with a dry processing facility in Jackson, Wis. That facility is on 604 acres and has 60 MMtons of proven sand reserves.

While most transportation is by rail, the company uses river barges to move proppant to operators in the southern states.

Oasis Well Services

Oasis Well Service (OWS) of Oasis Petroleum is poised to become a much larger part of the firm's business mix of $35 million in 2014 capex spent by the company. Most of the fracturing services work is in the Williston Basin, including the Bakken Shale, where Oasis Petroleum is a significant E&P force.

According to an investor presentation by the company, OWS was slated to have its second fracturing spread in full swing by late summer 2014, and the two spreads would perform 30% to 40% of the well completions for Oasis Petroleum. The company reported that the first unit already has returned 2.8 times the cash invested into OWS since it was launched.

The company touted that OWS saved $400,000 per well drilled by the parent in 2013.

Oxane Materials Inc.

Armed with patents for its advance ceramic proppants, Oxane Materials was spun out of Houston's Rice University. The company said its strong proppants improve the quality of wells in shale and other tight rocks while cutting down on the impact hydraulic fracturing can have on the environment.

Oxane R&D on its ceramic proppants is done in Houston, while manufacturing is done at its plant in Van Buren, Ark.

Ceramic proppants include the OxBall for intermediate to deep wells and OxSteel for intermediate to even deeper wells. The proppants are made with nanotechnology. Oxane claims its product is stronger and smoother than other proppants and will go farther, which, in practice, leads to higher oil and gas flow from a stimulated well.

Investors in the 12-year-old company include Chevron, Energy Ventures, Total, BP and ConocoPhillips, according to the *Journal of Petroleum Technology*. In 2013, the company raised another $12 million in capital and expanded its Arkansas plant.

Platinum Energy Solutions Inc.

Platinum Energy Solutions (PES) specializes in hydraulic fracturing, coiled-tubing (CT), nitrogen and cementing services, which has given it a presence in every shale play in the country and numerous unconventional plays emerging globally.

The fleet of hydraulic fracturing units are all rated at 15,000 psi or higher and can deal with difficult projects involving long laterals and several fracturing stages in high-pressure formations, like those found in the Eagle Ford Shale.

After a balance sheet restructuring completed in October 2013, the company continued to invest in the latest pressure pumping equipment and increased from two to four fleets in the field to keep up with demand in the sector.

PES has its headquarters in Houston; maintains operations facilities in San Antonio and Waskom, Texas, near the Louisiana border; and has an operation and research laboratory in Scott, La., not far from Lafayette.

With the addition of the two fleets, pressure pumping capabilities are close to 200,000 hhp. CT services complement the hydraulic fracturing operation because they let operators continue production without shutting down the well and possibly damaging the formation.

PES also provides nitrogen services where nitrogen from the air is liquefied and then used for various applications down the well or on the surface.

Preferred Sands

The Radnor, Pa.-based company specializing in Northern White sands for the oil and gas industry is expanding with a new plant in 2015 that will allow it to produce more than 7 Blb/year of sand, up from the current 3 Blb.

The move will allow Preferred Sands to service all the major basins in North America with deliveries from the new plant beginning in second-or third-quarter 2015, according to Preferred Sands CEO Michael O'Neill.

Preferred Sands and Dow Chemical were awarded the 2014 Polyurethane Innovation Award for the jointly created Preferred RCS, which is resin-coated sand with Dow's Teraforce technology. The technology saves energy in the process of making the proppant, reduces the risk of proppant flowback and doesn't require additional chemicals or activators when used in well stimulation. Preferred Sands also worked with Dow on DustPRO, a silica-dust preventer.

In September 2014, the company introduced NavPort, a database that can track wells from completion to production. That includes being able to track trends in proppant use by specific wells, the basin, operator or well service company. At the time of its introduction, the database included information from 70,000 wells, 900 operators and more than 50 well service firms in 500 counties from 25 states and Canada.

ProPetro Services Inc.

With a focus on the Permian, Uinta-Piceance and Anadarko basins, ProPetro Services specializes in fracturing, cementing, acidizing, coiled tubing, nitrogen and flowback services. The Midland, Texas-based company also offers drilling services at 8,000 ft to 12,000 ft and air drilling services from the surface to 4,000 ft.

The company, founded in 2005, also has division offices in Elk City, Okla., and Vernal, Utah.

ProPetro Stimulation Services has more than 250,000 hhp for vertical and horizontal pressure pumping in West Texas and southeastern New Mexico plays. Blenders in the fleets can mix up to 120 bbl/min with liquid and dry additives. The fleets also include data vans, onsite testing capabilities for fluids, crosslink and break schedule and sand-sieve analysis for proppants.

Flowback services include a full range of pumping services for nitrogen and methanol and equipment including hydraulic chokes, double-plug catchers and sand separators.

Acidizing services for well stimulation include pump-downs, toe preps and foamed acid. The unit also can do small fracture jobs and those involving rock salt. The company can transport up to 30,000 gal of acid and has 10,000 hhp available for jobs in the Permian Basin.

Python Pressure Pumping

Based in Ada, Okla., Python Pressure Pumping launched in July 2012 and has quickly filled to capacity with one fleet and will expand to a second fleet beginning in January 2015.

The company now has 31,000 hhp for pumping with 12 pumps in the fleet. Python recently retooled and replaced some parts of its fracturing spread, which also includes two blenders, five bulk sand trucks, three line missiles and three different types of transport.

The firm is focused mostly on the lower Permian Basin near Ozona, Texas, but also does work in eastern Oklahoma, several plays in Texas, New Mexico and a stretch from western Louisiana to Arkansas.

The new spread coming online next year will allow Python to sign contracts with at least three major operators wanting to contract with it, said Python sales manager Frankie Tomblin. The new fleet includes some redundancy, including an extra two pumps compared to the spread now in service.

Quasar Energy Services Inc.

The 36-year-old Quasar Energy Services operates out of Gainsville and Wichita Falls, Texas, with a satellite office near Fox, Okla.

Quasar has three hydraulic fracturing crews with a total pressure pumping capability of 39,000 hhp. The company can do small foam fracturing jobs and big multistage operations requiring 120 bbl/min of fracking fluids.

The company specializes in oil gel and diesel gel systems as part of its process. Quasar also has three crews for acidizing jobs and seven cementing crews. Although turnover in the industry can be high, the company boasts that the cementers on the crew average 10 years of experience.

Rainbow Ceramics (dba of Prop Supply & Service LLC)

Rainbow Ceramics, based in Houston, supplies a range of ceramic proppants to the energy industry from ultralightweight to high-strength designed for better conductivity, crush and chemical resistance, sphere quality and thermal stability.

Prop Supply & Service, which is better known as Rainbow, is increasing its manufacturing capacity at more than 12 production lines at five plants located in China. The firm also is expanding its distribution network to meet demand with transloading facilities throughout major shale

plays such as the Green River Basin, Bakken, Eagle Ford and Haynesville.

Two production kiln lines recently were added to accommodate the demand for Rainbow's ultra-lightweight ceramic proppant, and plans to build additional production lines are being made.

The company's most notable R&D effort was creating the ReaLite ultralightweight proppant made from natural clays such as porcelain and kaolin clays, a less expensive alternative to bauxite. The proppant doesn't sacrifice strength and puts less stress on the equipment carrying the fluids and the pumping equipment, according to the company.

The strongest in the line is PropRaider, made from high-strength sintered bauxite for deep oil and gas wells where others don't stand up as well because of crushing pressure and high temperatures.

RockPile Energy Services LLC

Triangle Petroleum subsidiary RockPile Energy Services was founded in Denver in 2011, with a focus on the Williston Basin plays in Montana and North Dakota.

RockPile started operating a second spread for fracturing services last year. In 2014, the company added a third around-the-clock pressure pumping spread and is planning a fourth, each with 27,000 hhp.

The company also has expertise in cased-hole wireline with two crews, pump-down services, hydraulic pressure pumping and workover rigs. According to RockPile, managing the services between wireline and pump-down can reduce methanol costs by 90%.

RockPile's proppant transportation services do away with silica dust using gravity instead of transferring the sand with pneumatic blowers. The company also moves the proppant in closed "sandboxes" each holding 46,000 lb instead of in semitrucks. Loading and unloading also is shortened from about an hour to five minutes. The company said loading the boxes at the mine and then taking them directly to the well site is more efficient and reduces the need for sand hauling equipment as part of the fracturing spread.

At its field operations unit in Dickinson, N.D., RockPile has a housing complex for employees with 20 units each containing two to three bedrooms. The site also contains the maintenance shop and the proppant terminal.

Saint-Gobain

One of the many lines of business in North America for French company Saint-Gobain is in ceramics. That business segment includes growing activity in ceramic proppants for hydraulic fracturing.

Saint-Gobain Proppants has operations in several locations in Arkansas, Kentucky, Massachusetts, California, New York, New Jersey, New Hampshire, Pennsylvania, Ohio, Tennessee, Texas and West Virginia.

In July 2013, Saint-Gobain Proppants opened a new 100,000-sq-ft plant that can produce 330 MMlb/year of proppants. The Saline County, Ark., facility increased production of Strong & Light-branded ceramic proppants.

Other proppant product lines include customized BauxLite and VersaLite along with more established proppants such as VersaProp, InterProp, UltraProp and Sintered Bauxite, made strong with high temperatures.

Sanjel Corp.

Sanjel's international energy services business is based in Calgary, Alberta, Canada, and includes a presence in several unconventional shale plays in the U.S. including the Williston Basin, Permian Basin and Eagle Ford Shale.

The company's pressure pumping business is the umbrella for its fracturing operations including acidizing, cementing, coiled tubing and nitrogen. For efficiency, Sanjel said it refurbishes its spread equipment every four years and replaces it every decade. The combined fleets have 531,000 hhp after two major hhp expansions in 2014.

In August, Sanjel said it would add 120,000 hhp to its operations in North America by May 2015 to meet demand for well stimulation services. The new pumps added in 2014 and the planned expansion will be used on horizontal well projects in Canada, the Bakken, Eagle Ford and Permian Basin plays.

Fracturing fluids that were developed at one of the company's 11 laboratories and field tested are designed for economy and to reduce any potentially

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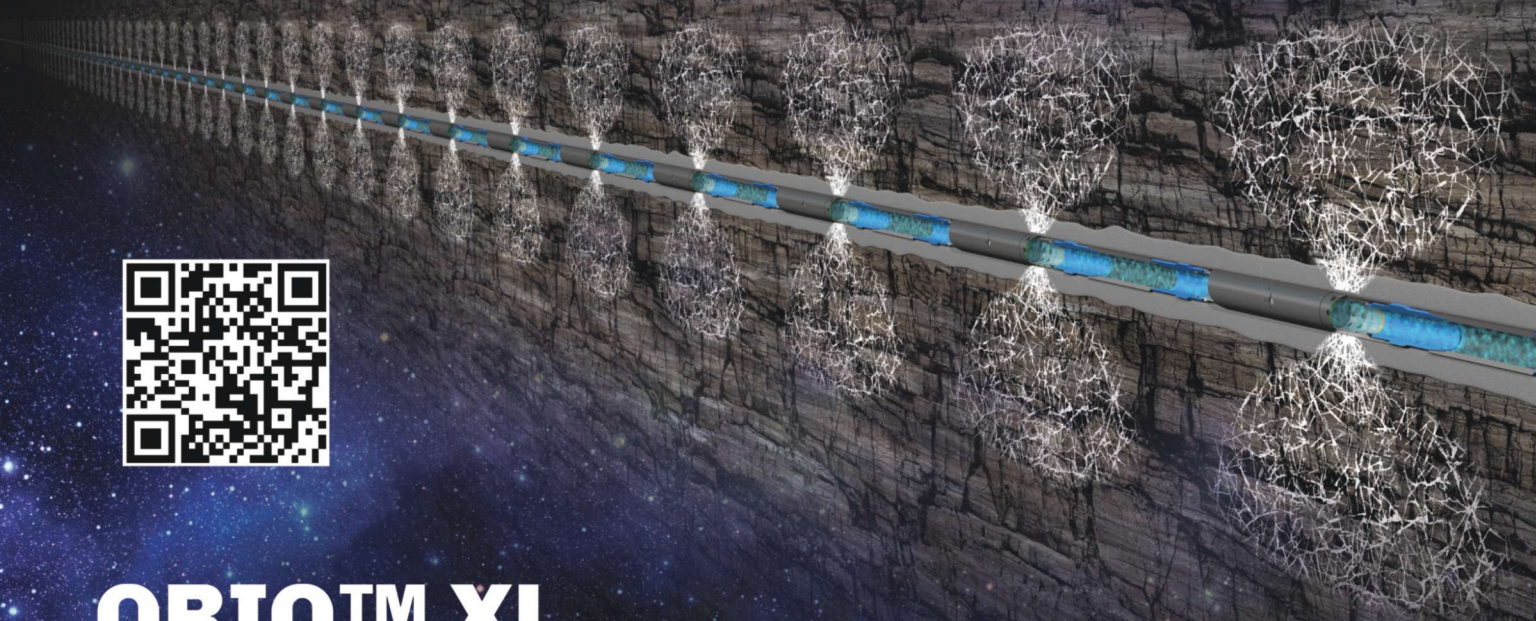

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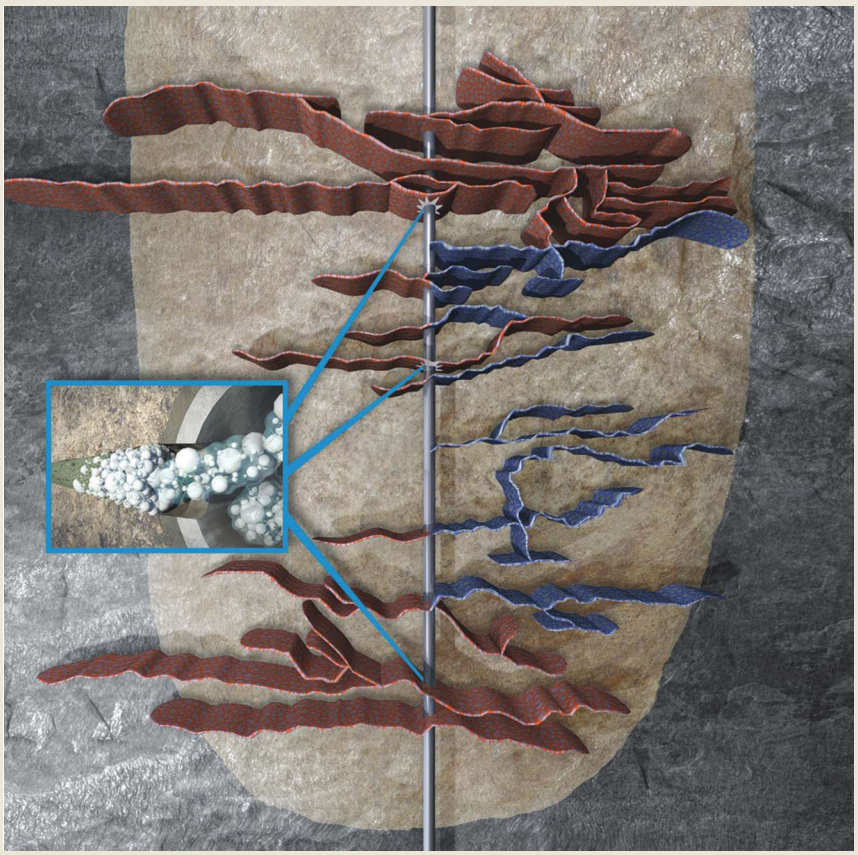

When the BroadBand Sequence fracturing service is used to stimulate additional clusters (blue), it provides more accurate results than the highly variable ones produced by conventional stimulation techniques. *(Image courtesy of Schlumberger)*

adverse environmental impact. The systems also can use nonpotable water and recovered load fluid. Gels used include crosslinked gels such as BORAjel-HT to deal with special conditions faced in well completions in certain formations.

Sanjel also has begun using Caterpillar's Dynamic Gas Blending technology as part of its fleets. That means the company can run its equipment on the job site with natural gas fuel blended with diesel to take advantage of inexpensive natural gas often available in the field.

Schlumberger Ltd.

Schlumberger is expanding its presence in the unconventional plays with new technologies such as the Petrel Shale offering, introduced in late August.

The software offers an end-to-end workflow with a shale-specific toolset to integrate well processes from exploration through production. It allows multidisciplinary teams to identify sweet spots, plan, drill and evaluate wells, and analyze production data from thousands of wells within a basin.

Schlumberger reported that its ThruBit through-the-bit-logging services helped improve perforation efficiency by 28% in one unconventional well, by providing data along the laterals that operators normally do not log due to efficiency concerns.

The well intervention's slickline conveyed OPTICall thermal profile and investigation service provides thermal profiling surveillance of the wellbore before, during and after hydraulic fracturing treatments. In Western Oklahoma, a fit-for-purpose, integrated drilling solution was used to reduce rig time and eliminate planned trips while drilling horizontal wells in the abrasive sandstone of the Granite Wash Formation. The Neyrfor Delta high-performance directional turbodrill combined with the Smith Bits Kinetic diamond-impregnated bits were selected, and the challenging curve and lateral were drilled in a single run, resulting in significant time savings.

Schlumberger has been involved in several major U.S. shale plays including the Eagle Ford Shale from the first discovery, and provides services such as production management, directional drilling, drilling fluids, formation evaluation, cementing and pump-down perforating, stimulation, coiled tubing, completions equipment, and testing.

The company employs a new fracture sequencing technology worldwide to improve production by

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allowing fracture initiation in multiple stages, while reducing over flushing in the process.

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The Central Missouri-based Shamrock Proppants mines the raw materials for its ceramic proppants and manufactures the spheres with easy access to rail lines and trucking routes to move the product to the well site.

The company is hiring for numerous positions including a director of sales in Houston and a process engineer for vice president of research to build a quality control laboratory, develop the next generation of well stimulation technology and quadruple productivity.

The fledgling company is aiming for $30 million in revenue in 2015.

Stingray Pressure Pumping LLC

Based in St. Clairsville, Ohio, Stingray Pressure Pumping operates primarily in the Utica Shale in the Appalachian Basin. The company recently has expanded into the Eagle Ford Shale of South Texas and has been actively recruiting for pressure pumping workers through the company's Facebook page.

Stingray also provides cementing services for safe well stimulation, equipment rental for the oil field and water transfer. Stingray Logistics does hauling jobs in the field, particularly dry bulk and heavy hauling for the well site.

Stingray is made up of four separate companies: Stingray Pressure Pumping LLC, Stingray Cementing LLC, Stingray Logistics LLC and Stingray Energy Services LLC. All are partly owned by an investment partnership of oilfield operator Gulfport Energy and Wexford.

Superior Energy Services

Superior Energy Services made its first major expansion into onshore services in 2006 with the purchase of Warrior Energy Services, a company that specialized in wireline and well intervention service.

It took a bigger position in land well services in a February 2012 merger with Complete Production Services, which was combined with existing Superior subsidiary Pumpco Energy Services. The company now has a global reach and is active in most major shale plays in North America.

Services related to hydraulic fracturing include pressure pumping, fluid handling and workover services.

"We posted strong incremental operating margins in three of our four segments, primarily due to ongoing increases in U.S. land activity," said Superior CEO David Dunlap in the company's second-quarter earnings report at the end of July. "These include improvements seen in horizontal well fracturing and well service rigs in the onshore completion and workover services segment as well as in coiled tubing, pressure control, wireline and remedial pumping in the production services segment."

Superior management said in an investor presentation that it would use the expected cash flow from U.S. operations in the shale plays to use in the international markets it is trying to open, including applying U.S. expertise to unconventional oil and gas operations in other countries.

TOPS Well Services

The Sealy, Texas-based TOPS Well Services primarily operates in the Bakken Shale of North Dakota and Montana with hydraulic fracturing-related services. The menu includes pressure pumping simul-fracks, as well as slickwater, crosslinked and gelled water fracturing.

The company said it is expanding its fleet to handle more jobs while demand is high. Currently, TOPS has control and data vans, 12 Stewart & Stevenson pumping units totaling more than 250,000 hhp and two blending units that can process up to 100 bbl/min. Acidizing services also are a part of the mix.

TOPS also has expanded into the Mississippi Lime of Northern Oklahoma and Southern Kansas.

TOPS' parent company Landy Energy Services was founded in 2000. Landy, also based in Sealy, has a Middle East branch in the United Arab Emirates and a Middle Asia branch in Turkmenistan.

Torqued-Up Energy Services Inc.

The decade-old Torqued-Up Energy Services is based in Tyler, Texas, and specializes in coiled-tub-

ing (CT) units for high-pressure (HP) and conventional well control, pressure pumping and hydraulic wrenching and testing.

The company is focused on work in East Texas, South Texas and West Texas plays.

The CT units' services include cement and well stimulation fluid placement, drilling and underbalance drilling in vertical and horizontal wells, HP well control location consulting and fracturing treatments. The remote BOP control system gives 15,000 psi of wellhead working pressure and has a nitrogen-pressured accumulator for hydraulic backup supply.

Pressure pumping services include nitrogen, CO_2, acid and solvent treatments, on-the-fly mixing and pumping of rock salt and viscous spacer used as diverting agents, and frack and perforation breakdowns. It also can be applied by Torqued-Up for sand plugs, well stimulation, pressure testing and support for snubbing, electric line and slickline. The company has about 3,200 hhp in four pumping units.

Applications for the wrenching and testing services unit of Torqued-Up can be used on frack stacks, flowback rigups, pipelines and even trees. The flexibility and ease of use make for quick time in putting up rigs to save the user time and money, according to the company.

Trican

Canada's Trican has U.S. headquarters in Houston, where it oversees completion solutions for multistage fracturing for both openhole and cemented installations with pressure pumping and other services in the Barnett, Fayetteville, Haynesville, Woodford, Eagle Ford, East Texas, Permian, Marcellus, Northwest Oklahoma and Bakken regions. The company also does business in Russia, Kazakhstan, Algeria, Saudi Arabia, Colombia and Australia.

Geological solutions from Trican include analysis and evaluation of unconventional reservoirs. For comparison and basing analysis on past experiences, the company has evaluated rock from most of the world's major basins, according to the company website. Its microseismic services produce a representation of fractures by monitoring microseismic events.

The company has been active in the U.S. for many years. But it was in 2007, with the acquisition of Liberty Pressure Pumping LP, that it began solidifying its toehold in the U.S. market. That was followed in 2010 with the buyout of a private stimulation services company in Shawnee, Okla., which added not only pumping horsepower to the portfolio but also acidizing service assets.

Strong demand for Trican's services in the Marcellus and Permian Basin regions in the first six months of 2014 led to increased U.S. revenues for the company, and price increases were put in play in both regions in second-quarter 2014, according to Trican's public financial filing on July 29.

Demand also was high in the Bakken region around North Dakota and Montana, which prompted the service company to add a second crew in that region in third-quarter 2014. Meanwhile, the fracturing crew in the Woodward region of Oklahoma was moved to the Permian Basin to meet demand there. Performance was below expectations in the Barnett, Oklahoma and Haynesville regions in first-half 2014, but contracts with operators there are expected to improve matters for revenue from those units, according to the second-quarter earnings release.

Tucker Energy Services

With decades of history in the oil fields of South America, including Trinidad, Venezuela and Colombia, Tucker Energy Services made forays into the U.S. dating back to 1986. However, in 2012, Tucker expanded the full range of its product lines, including hydraulic fracturing, to the country with a large operations center in Denton, Texas.

The company's U.S. operations are based in Houston, and it now has offices across Texas, Oklahoma and Kansas to serve the Midcontinent and Texas oil play with fracturing services. Services include openhole logging, cased-hole logging and perforating, coiled tubing (CT) and well stimulation.

Pumping equipment includes fleets with 2,500-hhp Triplex and Quintuplex frack pumps and 130-bbl/min frack blenders.

Tucker recently said that it had initiated a long-term contract with a major operator in the Wood-

ford Shale of Oklahoma for stimulation, cased-hole wireline and CT services.

Unimin Corp.

Unimin is one of the largest producers of sand used in hydraulic fracturing in North America. Based in New Canaan, Conn., the company has a diversified portfolio of nonmetallic mining assets including frack sand.

The PropZone line of oil industry sand products produced and distributed by the company includes UNIFRAC hydraulic fracturing sands, PROPSTAR resin-coated proppants and cementing additives. UNIFRAC can keep the frack open under pressures up to 10,000 psi.

The company has 18 plants including 14 stretching down the center of the U.S. from Minnesota to Texas, one in New Jersey and three in the Mexican states of Coahuila, Nuevo Leon and Veracruz.

The company added a new proppant distribution terminal in Lubbock, Texas, to serve the northern Permian Basin and the northern parts of the Cline Shale play. Two Class 1 railroads serve the terminal by way of the Plainsman Short Line Railroad. Unimin has six additional terminals in Texas and Oklahoma to serve the region, but the newest addition will make delivery to north Permian and Cline areas more efficient and cost effective, according to the company.

The company has multiple terminals in most major shale plays in the U.S.

Universal Pressure Pumping Inc. / Universal Well Services Inc.

Universal Pressure Pumping has provided hydraulic fracturing, cementing and acidizing services in the southwestern U.S. since 2003. It operates in the Barnett Shale, the Eagle Ford Shale and the Permian Basin, all in Texas.

The company is a subsidiary of Patterson-UTI Energy, which also owns Universal Well Services (UWS). UWS primarily serves the Appalachian Basin, including the Utica and Marcellus shale plays.

The services of both include pressure pumping spreads, cementing and acidizing.

In September, Universal agreed to acquire the pressure pumping assets of an undisclosed private company based in Texas. The deal includes 143,250 hhp of fracturing equipment made in 2011 and 2012, according to a statement from the company. That will give Patterson, through its subsidiaries, more than 1 MMhhp. With the acquisition, the company will grow in its existing Texas markets and grow into the Haynesville Shale of East Texas and Louisiana.

"This equipment has not been heavily operated since it was introduced to the market at a time of reduced demand for pressure pumping services," said Patterson CEO Andy Hendricks. "We believe the assets to be well maintained, in very good condition and in line with our high standards."

U.S. Silica Holdings Inc.

The commercial silica producer U.S. Silica is responding to greater demand of its sand for oil and gas well fracturing throughout the country and is adding two new expansions to supply greater volumes of Northern White frack sand to the industry.

The Frederick, Md.-based company announced in early September that it would add about 3.8 MMtons of new capacity. The effort includes a $33 million, 800,000-ton/year expansion of the Pacific, Mo., plant, which also will include a new transload facility. The company said the Missouri plant is closer to the Eagle Ford and Permian shale basins where there is heavy hydraulic fracturing activity expected for years to come. It also has access to Union Pacific and BNSF rail lines and river barges for transportation.

The company also is developing, at a cost of $150 million, a new 3-MMton/year frack sand mine and processing facility in Wisconsin. The expected completion date is mid-2016.

"These new capacity expansions will enable us to keep pace with the market and ensure that [operators] have ample products to satisfy their needs, said U.S. Silica CEO Bryan Shinn in a news release.

In July, the company acquired regional sand mining company Cadre Services Inc. in a $98 million deal. Based in Voca, Texas, Cadre recently expanded the capacity of its plant to handle up to 800,000 tons/year of its Premium Hickory sand,

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which also can be used as a proppant in some fracturing operations.

U.S. Well Services LLC

Houston-based U.S. Well Services brings well stimulation to numerous operators who need hydraulic fracturing in the unconventional plays and natural gas basins. The company is under contract for services in the Marcellus and Utica shale regions in Ohio, Pennsylvania and West Virginia.

The company added a third and fourth fleet in 2013 and is looking at additional expansion geographically. Potential new and existing customers also might cause the company to expand into the Bakken, Haynesville and Eagle Ford shales. The Permian Basin, Granite Wash and Niobrara shale also are under consideration.

In September 2014, U.S. Well Services said it had demonstrated operational costs of up to $40,000 a day for customer Antero Resources in trials with the new patented Clean Fleet technology for hydraulic fracturing. The system, used in the Marcellus Shale in West Virginia at Antero well sites, showed a 99% reduction in emissions, less sound pollution and cost savings.

In a news release, the company said Antero has made a commitment to continue using the technology with long-term contracts. "Its adoption and results further validate the importance of conducting hydraulic fracturing in a more environmentally responsible manner," said U.S. Well Services' CEO Brian Stewart in a written statement. The system runs on mobile, electric generators powered by natural gas produced in the field instead of diesel or other fuels.

Weatherford International

Through a series of more than 250 acquisitions in 13 years, Weatherford has become one of the world's largest suppliers of oil and gas well service companies. The company also is growing internally through new product development for the oil field, including technology for the specific conditions of big U.S. shale plays.

With headquarters in Switzerland and Houston, the company has been a key player in the unconventional plays in the U.S. Weatherford brought its pumping and stimulation services to the first Eagle Ford well completion in South Texas and now has about 1,300 employees in that region.

The company is using 2,500-hhp pumping units driven by dual-fuel conversions so the engines can run on diesel, natural gas, liquid propane or CNG, or a combination. The result is a stable technique that can save time and money during a hydraulic fracturing operation.

The company plans to equip as many fleets as needed for its shale oil and gas users with CAT-powered pumping units and is continuing regular deliveries to the field.

When it comes to fracturing-related well services, the company has a dominant position, with 28% of the casing and tubing services market and 16% of the openhole completion systems and related completion technology market (Halliburton and Baker Hughes each have 25%). The company lags behind its largest competitors in overall U.S. well services market share at 3% and 7% of reservoir evaluation service, which are areas the company sees an upside in, according to a September presentation at the Barclays Capital CEO Energy-Power Conference.

X-Chem LLC

Irving, Texas-based X-Chem provides production, pipeline, hydraulic fracturing and laboratory services to the oil and gas business, including unconventional plays across the U.S.

The company has developed the environmentally friendly FracStar treatment method for hydraulic fracturing and boasts low costs of fluids and solutions for the field.

AguaMax water-treating products are designed to prepare water for use in fracturing. The Aguanox line is an emulsion breaker for oil and water in oil emulsion. CorrNox assists in inhibiting corrosion, while CoilMax is added to fluids to save operators time and money when drilling downhole.

The 32-year-old company is a subsidiary of NCH Corp. and has more than 40 locations serving the shale oil and shale gas plays including in the Eagle Ford, Bakken, Louisiana, Permian and Marcellus, Oklahoma and the Mississippi basins. ■

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Data Integration Aids Effective Development

Shale plays will never be accused of being 'easy.' But a multidisciplinary approach can make them less challenging.

By Rhonda Duey
Executive Editor

Shale exploitation would not be possible without hydraulic fracturing. But the qualities of shale reservoirs also have forced the industry to rethink some of its assumptions about fracturing. Shales don't behave like sandstones. Due to the presence of organic matter, they don't always frack in a predictable manner. This leads to wells that are unable to meet their EURs.

Operators are responding by acquiring a smorgasbord of data, everything from high-resolution 3-D seismic to microseismic to cuttings to well logs, all with the intention of better understanding these inscrutable formations. But they're also going a step farther and integrating these data to enable the most effective completions.

At the recent Unconventional Resources Technology Conference, several companies presented findings consistent with a multidisciplinary approach to the characterization of unconventional reservoirs. These studies indicate, as one paper concludes, that "integration of disciplines is a key element in efforts to improve drilling and completion strategies by examining how multiple measurements from different sources relate to well production."

Haynesville integration

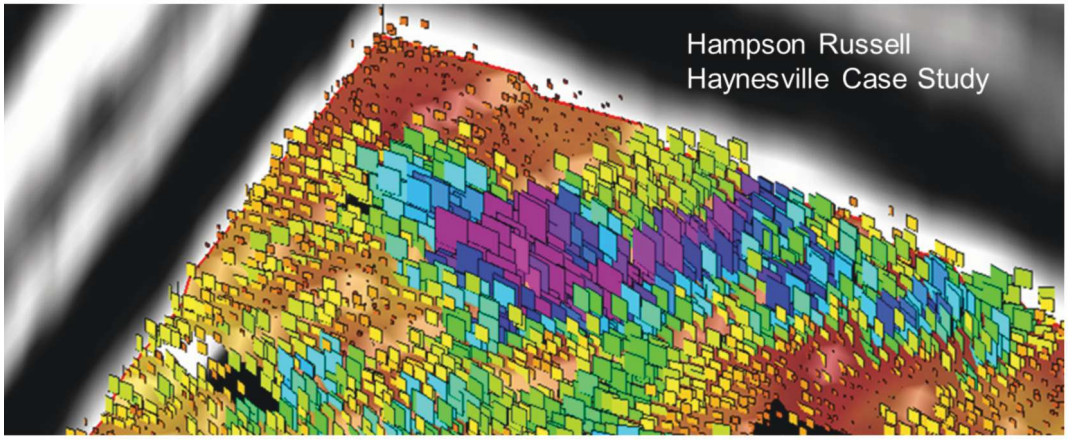
In one example, surface seismic was integrated with microseismic, mineralogy and rock properties to explain well variability and better home in on sweet spots. The paper, authored by CGG and Exco Resources, described the process of building "an accurate, robust and reproducible predictive model," never an easy task in shale plays. "Lacking this model, drilling and completion decisions are often made on nongeologic criteria," the authors wrote. "As these plays mature, it is becoming clear that many wells will not reach their production targets."

The study relied on improvements in prestack simultaneous inversion that in turn have caused operators to adopt integrated seismic reservoir studies to predict reservoir properties. However, seismic inversion alone is not enough to characterize unconventional reservoirs completely.

"Estimations of reservoir properties such as TOC [total organic carbon], rock strength and stress require careful analysis and a high degree of seismic fidelity," they wrote. "No single attribute appears to accurately predict production. A combination of attributes related to reservoir quality, rock strength and stress is needed to understand the quality of the reservoir in terms of hydrocarbon potential and optimization of well orientation and completion strategy."

The workflow that was applied to the Haynesville Shale included integrated reservoir and geomehcanical properties derived from prestack inversion as well as stress and fracture information derived from azimuthal analysis of the seismic data. Mineralogy from cuttings and stimulated reservoir vol-

Azimuthal Inversion to Infer Stress Regimes



This surface shows the DHSR overlaying Young's modulus, an indicator of how easily the fractures can be maintained. Plate orientation represents the direction of maximum horizontal stress, and height represents DHSR. *(Image courtesy of CGG GeoSoftware)*

ume (SRV) from microseismic also were employed. Eight wells were used to calibrate the surface seismic measurements.

To determine rock properties, prestack inversion was applied to angle gathers to derive compressional (P) impedance, shear (S) impedance and density. It was determined that the P impedance was inversely related to porosity while density and TOC had a similar relationship. Lambda-Rho values were related to high gas saturation through well log calibration.

Young's modulus and Poisson's ratio volumes also were created as these provide clues to the rock's brittleness and frackability. Mineral values also were estimated from the prestack inversion volumes to calibrate the brittleness estimates.

Fractures were analyzed through studying the amount of horizontal transverse isotropy in the data along with using azimuthal elastic inversion techniques. This led to the determination that the differential horizontal stress ratio (DHSR) was favorable for the Haynesville as it leads to more random fracture patterns, ideal in a formation with little natural fracturing.

Attributes were studied through the use of multi-attribute analysis, a process wherein multi-attribute linear regression finds a relationship between attributes in multidimensional space. This provides a "best fit" volume for a target attribute. These tend to be volumetric measurements and provide a link between geophysics and petrophysics and ultimately can be used to generate a sweet spot map.

Ultimately, the measurements were calibrated with microseismic and scanning electron microscope (SEM) cuttings analysis. The authors wrote that "physically meaningful statistical correlations" were observed between microseismic event density and the geomechanical and fracture estimates derived from the azimuthal analysis. The SRV and stimulated reservoir area are directly proportional to the Young's modulus and inversely proportional to DHSR.

Overall, the authors concluded that the integration of these disparate data sources led to estimates that were clearly related to lithology, TOC and rock texture, which are all key factors in finding the sweet spots in shales.

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Geology and geochemistry

Another integrated study titled "Sequence Stratigraphy, Geomechanics, Microseismicity and Geochemistry Relationships in Unconventional Resource Shales" studied the effects of sedimentation patterns on resulting brittle/ductile zones in shales. Co-authored by representatives from the University of Oklahoma, ConocoPhillips, Hilcorp Energy Co. and Noble Energy Co., the study described the building of a sequence stratigraphic framework from multiple datasets to map brittle and ductile strata as well as hydrocarbon-rich zones and frackable stratigraphic intervals.

Cyclical sea level fluctuations have led, in many shales, to the preservation of organic matter as well as the rise of lithofacies variations, the authors wrote. This can lead to alternating layers of ductile and brittle zones. Fluctuations in mineralogy can be measured by gamma-ray logs, and these fluctuations can in turn impact geomechanical properties in the reservoir. These fluctuations often occur at numerous scales.

Microseismic enters the picture because there is a stratigraphic component to event distribution. When properly acquired and processed, microseismic data can reveal these cyclical sedimentation patterns. Since microseismic events tend to be more evident in brittle sections, these data can be quite useful.

Chemistry came into play in this study through the use of biomarkers and their relationship to sequence stratigraphy. Biomarkers, defined by the authors as geochemical fingerprints, are used to interpret geological parameters. In the case of unconventional reservoirs, biomarkers are useful for typing organic matter and depositional environment, evaluating organic matter source and maturity, and evaluating oxygen availability during source rock deposition.

Based on their research, the authors concluded that the best landing zone for a horizontal well is a brittle zone bounded by ductile zones. "Initial fracturing will open the horizons, allowing hydrocarbons in the ductile beds to migrate to the brittle beds, which will remain open after proppant emplacement," they wrote.

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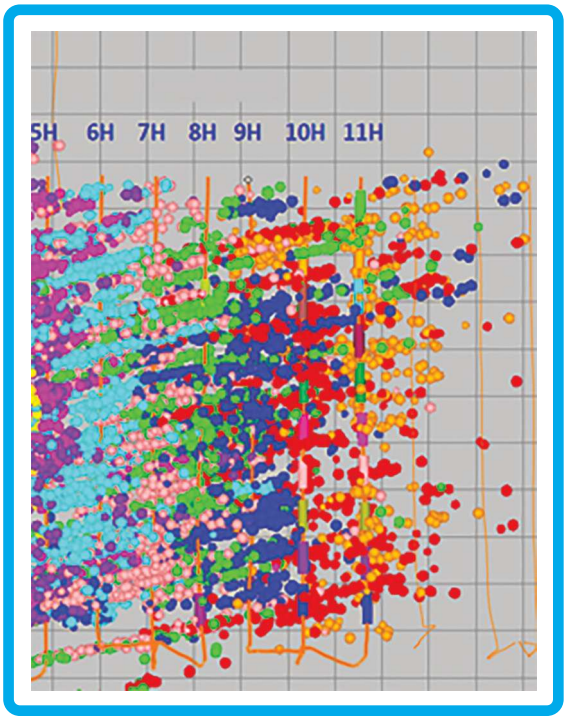

Microseismic fracture monitoring results from a group of wells completed in the study area are shown. The planar nature of the events supports a difference between minimum and maximum principle stress and confirms that the general direction of maximum stress is slightly north of west/east. *(Image courtesy of Schlumberger)*

Data acquisition in the Utica

A data acquisition program was planned for a four-well pad in the Utica to enhance the development of the Point Pleasant zone. Several authors from Hess outlined the parameters of the study, noting that this holistic data acquisition program was critical to planning the development and production phases of a liquids-rich shale reservoir.

The program began with LWD, enabling the geosteering of the four horizontal wells to maintain well spacing and trajectories. This was followed by pressure coring, speed coring and conventional coring to obtain virgin reservoir fluid characteristics and pressure-volume-temperature properties.

Microseismic monitoring enabled the understanding of stress redistribution around the wellbores, and the team is confident that it also can use the data to estimate effective fracture length. Tracer tests were done in conjunction with injected frack fluid to establish hydraulic communications along the pad wells, and downhole gauges and surface production data were used to measure production performance and well interference evaluations.

"It is recommended for shale wells that a diligent data acquisition program and effective use of these data are required for efficient and effective drilling, completion, rock-fluid characterization, production performance and well interference evaluation," the authors wrote. "This is the most critical task for the successful development and production of liquids-rich shale wells and maximizing their EUR potential."

Fracture interference in the Woodford

A paper co-authored by Schlumberger and Devon Energy described an integrated workflow designed to enable understanding of the mechanics of hydraulic fracturing interference and its impact on gas production, gas production drivers, well performance and recovery in horizontal wells in the Woodford Shale. The two companies collaborated on the approach, which integrated geology, geophysics, petrophysics, geomechanics, stimulation, completion, production and reservoir engineering.

Many of these integrations were performed in tandem. Petrophysical data were correlated with core data while the geomechanical interpretation was begun and the geological model was being developed. Once the petrophysical data were calibrated, they were added to the 3-D model.

At this point fracture simulation began. "Several iterations were necessary to refine and construct an accurate representative mechanical earth model with consistent and repeatable agreement with downhole pressure interference measurements, diagnostic injection tests, fracture stimulation treatment data and microseismic data," the authors wrote. "Based on the results from hydraulic fracture geometry and geomechanical iterations, production history-matching using analytical and numerical reservoir simulators was performed."

They noted that this process then proved repeatable in wells on both sides of a major geologic feature.

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"Once satisfied with single-well results, multiple well situations were modeled to explain existing production and well interference conditions and provide a basis for developing operational solutions," the authors wrote.

The use of this integrated modeling process resulted in several conclusions about the play:

- Mechanics of hydraulic fracture well interference include excessive fracture half-lengths, large frack heights and asymmetric frack fluid distribution in frack wings that are biased toward existing producing wells; and
- Drivers of fracture interference have a negative gas production impact.

Based on these conclusions, the authors suggested the stimulation of offset wells with CO_2 foam, injecting CO_2 in the laterals to provide flowback energy, refracturing the existing producing well with an energized fluid, improving infill well perforation efficiency, improving the propped to unpropped ratio and managing reservoir depletion.

Data management in the Bakken

Another example from Hess comes from the Bakken, where the authors used geomodeling to advance development of the company's North Dakota acreage. Using geomodels helped Hess organize, track and incorporate large amounts of data into a single model to make more informed decisions about well spacing, perforation locations and target interval selection.

The authors started with a ramp model of a possible depositional environment in an unconventional formation. "If we have a detailed understanding of the depositional environment and our position within it, then we should be able to make predictions about the physical properties away from known well locations," they wrote. "This information is important for resource planning and well allocation."

The next step was to upscale the information from the nano scale to a geomodel. The company acquired four samples of focused ion-beam SEM imaging. Two of these were from the upper Bakken taken only a few feet apart, but the images are quite different. A sequence stratigraphy model explained the difference—the samples were taken from two different sequences. The information can now be saved within the model.

Taking a 2-D slice through the 3-D model aided in well planning. "A good geomodel with properly distributed physical properties can give valuable insights into the well planning process, such as hazards to avoid (e.g. shale strikes), which facies to expect along the wellbore and whether or not large changes should be expected amongst any of the physical properties," the authors wrote. "If a full log suite is taken in the horizontal well, the geomodel can then be upsated with the new information and the difference (or estimation error) can be analyzed and understood."

Having this "look-back" capability enables the correlation of engineering data with physical properties, they added.

It also enabled a better allocation of wells within lease boundaries, which is based on determining the estimated depletion volume of each well. Correctly modeling the fracture system, whether hydraulic or natural, aids in this determination and is one of the many results of a well-constructed geomodel.

Overall, the integration of new data with preexisting data in this study demonstrates the value that a geomodel can bring to understanding key reservoir parameters, the authors said. The existing petrophysical and geological models were updated with core analysis data, geosteering information and log data from vertical and horizontal wells. "This process not only aids in creating better interpretations, but this living geomodel now also serves as a repository for field knowledge," the authors wrote.

As shale development becomes more mature, operators are benefitting from the skills they've applied to conventional fields for years—reservoir characterization aided by data integration. With the rush to hold acreage giving way to the need to maximize production, creative minds are yet again taking advantage of the vast measurement portfolio available to them. ■

Editor's note: This paper was based on URTeC papers 1923397,1920885, 1934195, 1923095 and 1933577.

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They Feel the Earth Move Under Their Feet

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

By Richard Mason
Chief Technical Director, Upstream, Hart Energy

Think of well stimulation as the Lazarus of oil service sectors. Like Lazarus, the sector has risen from the dead—once again—thanks to a beneficial convergence of factors. That buzz you're hearing in the background is not just from the earthy bass rumble of 10 or more 2,500 pump trucks revving up on well sites across the domestic market. Rather, there is a renewed lightness-in-step for well stimulation firms, a sense that trends are pushing the sector to the forefront of the industry.

Consolidation is underway as larger firms scramble for people, equipment and market share. Recent deals include the innovative $2.86 billion merger between the Nabors Industries Ltd. well stimulation segment and C&J Energy Services Inc. in June 2014, and Patterson-UTI Energy Inc.'s September acquisition of 143,000 hhp for an undisclosed price in South Texas.

Newbuild capacity is on the way, a shock to industry observers who six months ago expected the equipment oversupply that punished the industry after 2012 to continue into next year. It's not just capacity dribs or drabs either. More than 2 MMhhp is on the books for the domestic market, which amounts to fleet expansion of nearly 12%, according to a Simmons & Co. International report. Houston-based PacWest Consulting Partners expects additions of 3 MMhhp split almost evenly between 2014 and 2015.

This newbuild phase both offsets attrition and adds to industry capacity—the latter still worrisome for Wall Street. New orders have come sooner than expected, filling available slots among equipment and component manufacturers and pushing delivery into 2015.

Structural change in service delivery

But the main factor in the industry's Lazarus-like rise from the dead stems from the transformation brought about as oil and gas operators move into the resource harvest phase of the tight formation cycle. Four years ago operators vowed to go "liquids rich" after the natural gas price collapse. That hope now has turned into change.

Changes in the service sector reflect how the move to resource harvest has altered the structural nature of the industry. One example is found in the drilling sector, which is building 165 higher specification rigs, many with self-mobilization packages, higher capacity fluid systems and greater pipe-racking capabilities to meet operator needs to push lateral length.

A similar transformation is underway in the well stimulation sector. Efficiency gains in well stimulation are real and revolve around process or the ability to aggregate wellsite tasks into a batch approach. While ball drop sliding sleeves might have been the big "gee-whiz" factor three years ago, today's narrative of innovation focuses more on zipper manifolds and the ability to alternate processes and large vol-

A MANIFOLD TRAILER FEEDS SURROUNDING PUMP TRUCKS WITH FLUID THAT is pressurized and sent down into four wells at this North Central Pennsylvania shale job by Universal Pressure Pumping as part of a process known as "zipper fracturing." *(Image courtesy of Universal Pressure Pumping)*

umes of proppant between lateral wellbores, two, three or more times sequentially, shaving nonproductive downtime for expensive equipment and crews during the completion cycle.

The well stimulation sector is now front and center for oil and gas capital spending. While incremental development dollars are rising overall, well stimulation is capturing more of those dollars percentage-wise as rig count remains static in most plays, save the Permian.

To understand the scope of transformation impacting the service sector, it helps to review the trend-line Golden Oldies over the last three years. In 2012, the industry narrative was all about drilling efficiency as spud-to-rig release times dropped for horizontal drilling. Drilling days plummeted across multiple markets as operators moved from capturing acreage through single-well drilling to optimizing how best to drill.

In 2013, the narrative evolved to pad drilling and batch completions as the industry migrated from less than 20% of wells on pads at year-end 2012 to more than 65% of wells on pads one year later. That ranks as one of the most rapid transformations in any industry, let alone oil and gas. In some cases, it meant an evolution to rig specialization or using a spudder rig to drill top holes and set casing, while a bigger rig drilled the intermediate sections and built the curve for the hor-

Major Basin Well Stimulation Market Estimates, 2014

Basin	Wells/Year	Cost/ Well	Total Market	Stages/ Well	Stages Per Year	Well Stimulation
Bakken	1,970	$8,500,000	$16,745,000,000	44	86,680	$7,575,832,000
Marcellus/Utica	2,600	$5,500,000	$14,300,000,000	35	91,000	$7,953,400,000
Eagle Ford	4,720	$7,000,000	$33,040,000,000	26	122,720	$10,725,728,000
Permian Wolfberry	3,186	$3,300,000	$10,513,800,000	9	28,674	$1,577,070,000
Permian Horizontal	2,740	$8,500,000	$23,290,000,000	31	84,940	$7,423,756,000

Table illustrates approximate annual market size for drilling and completion in the major domestic markets, including an estimate of well stimulation expenditures. The Permian horizontal market is expected to nearly double in the next two years. *(Source: Hart Energy Market Intelligence Surveys)*

izontal lateral across multiple wells on the pad. Finally, a higher tech rig, usually with a self-mobilization package, came in and drilled horizontal laterals sequentially before the rig moved to the next pad.

The process created a second productivity enhancement wave, allowing operators to generate the same number of wells with fewer rigs. Pioneer Natural Resources Co. is a case in point. The company has been drilling 130 wells annually in the Eagle Ford. But Pioneer's rig count dropped from 12 two years ago to eight in 2014. Pioneer's 33% Eagle Ford performance improvement is not an isolated incident. That said, wells per rig, as measured by Baker Hughes Inc., has plateaued at roughly 5.3 quarterly since mid-2013, suggesting the industry has captured the vast majority of productivity gains on the drilling cycle.

Now the productivity revolution has moved to the completion phase. Initially, the focus centered on the ability to reduce completion cycle times once the drilling rig left the site. In some manifestations, cycle compression was characterized by the steady progression to 24-hour work schedules across the sector that allowed operators to double the number of stages completed daily. Currently, completed stages reside at a decimal point somewhere between 5 and 6 stages daily, depending on the basin. Meanwhile, operators moved to capture efficiency by employing zipper fracks, or alternating stage completion, usually along parallel wells (though sometimes in opposing laterals) in an attempt to eat away at a growing backlog of drilled but uncompleted wells that originated from the pad drilling phenomenon.

Toward completion effectiveness

However, completion efficiency is evolving to completion effectiveness, or the ability to boost recovery rates from a single-digit percentage of original oil in place to higher levels, whether an incremental 1% or 2%, which would have enormous impacts on the domestic production profile and revenue generation, or eventually up to double-digit percentages.

Thus, productivity processes like zipper fracks are transitioning from a method to reduce the backlog of drilled but uncompleted wells into a form of well enhancement. In theory, zipper fracks generate greater stimulated rock volume downhole when coupled with downspacing, particularly in less favorable rock. During 2014, the industry moved rapidly toward enhanced fractures, first starting two years ago in the Eagle Ford Shale and now spreading to the Bakken, Permian and Niobrara.

At the most elementary level, enhanced fractures register as greater volumes of proppant per lateral (plus closer spacing and engineered perforation clusters). Proppant use per stage in the Eagle Ford, for example, grew from less than 100,000 lb in fourth-quarter 2013 to nearly 400,000 lb in third-quarter 2014, according to Hart Energy market intelligence surveys.

A Morgan Stanley Research study found proppant use of 6 MMlb or more per well increasing from 22% of wells in April 2013 to 30% in June 2014. At the same time, proppant use of less than 2 MMlb per well dropped from 42% of wells in April 2013 to 31% in June 2014. Clearly, the era of the light sand frack, which used the bare minimum of

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proppant and was responsible for the large increase in unconventional shale production, has given way to massive slickwater assaults on naturally fractured tight oil reservoirs. Furthermore, slick water is making a comeback in the Bakken Shale and the Eagle Ford, although hybrid fractures and crosslink gels also are present in large numbers in the Eagle Ford and in the Permian Basin, sometimes because the technique requires less water.

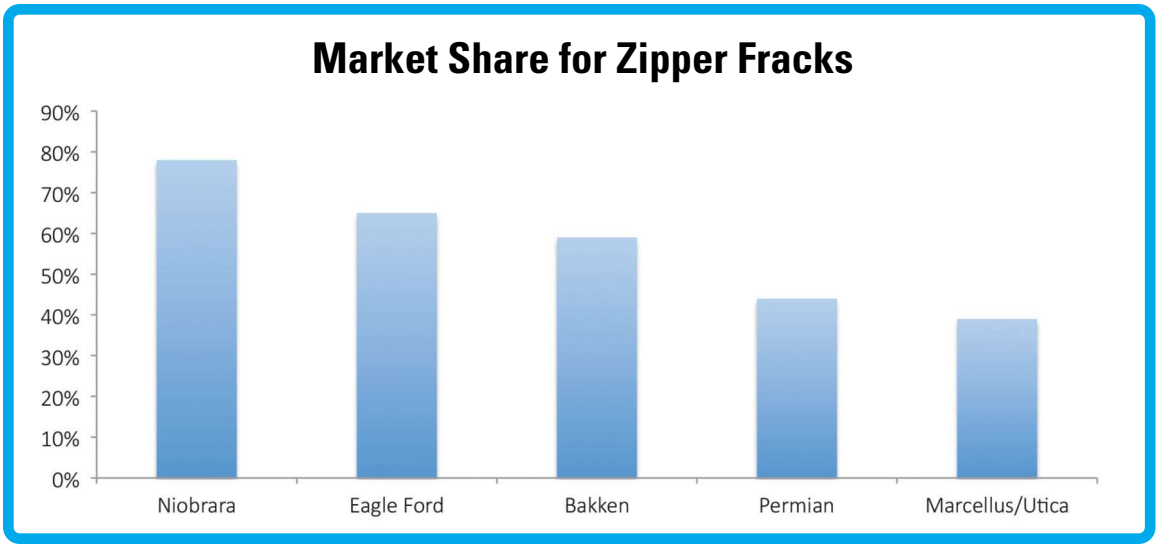
For perspective, operators are injecting the equivalent of two trainloads of sand—more than 200 hopper cars—into each four-well pad. That's a lot of bulk and it brings greater wear and tear on pressure pumping equipment, especially fluid ends, which are now in tight supply.

Longer term, operators theorize about recovery factors in tight formation oil that reflect the 40% or more found in conventional oil. A development of that nature—and such improvement is nowhere near industry grasp—would further postpone the steadily receding horizon of doom that has been the coin-in-trade for peak oil enthusiasts.

Certainly it can happen. Recoveries of shale gas rose from the low double digits midway through the last decade to nearly 40% in several plays within a half decade thanks to completion effectiveness, swamping the natural gas market with a tsunami of new production—and knocking the legs from beneath natural gas prices. The peculiar physics of liquids create a higher technological barrier to making the same thing happen in tight-formation oil. At Hart Energy's DUG Eagle Ford Conference and Exhibition in San Antonio, the operative statistic is that as many as 60% of stages perform sub-optimally in horizontal laterals. That leaves a lot of room for improvement, though that improvement is not as easy as it looks.

The future will take care of itself. In the meantime, there are many tasks at hand facing the well stimulation sector. The first is adjusting to the new normal. The well stimulation sector was characterized by roughly a 20% oversupply in equipment, according to the publicly held well stimulation providers on their various earnings conference calls in early 2014. Yet less than six months later, the industry is edging past the utilization threshold necessary to grant service providers pricing power. Wall Street also was caught flat-footed when the change occurred.

How could so many informed observers have been so unaware? The answer points back to the structural change underway in how the industry conducts business. Consider how the evolution to pad drilling and batch completions—the harvest mode of the unconventional cycle—impacts the industry. Eighteen months ago, service providers fracture stimulated a single lateral, usually involving 17 or 18 stages, and then moved to the next well in five to



The graph illustrates the percentage of zipper fracks reported for completions in select domestic markets. *(Source: Hart Energy Market Intelligence Surveys)*

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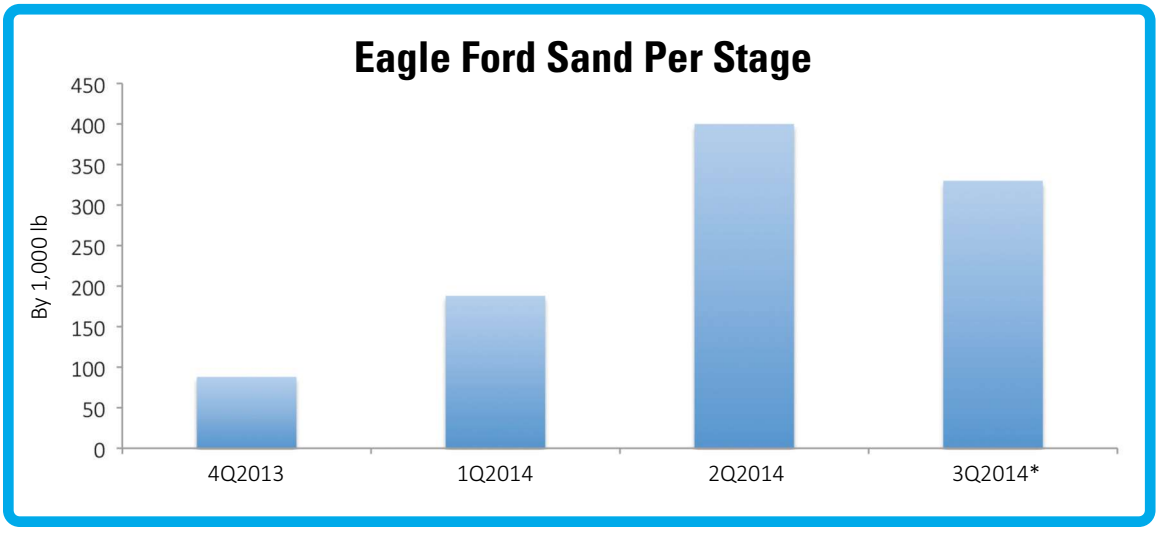

Sand use has grown dramatically over the last 9 months in the Eagle Ford as operators move to enhanced completions. The practice is now spreading to other domestic markets. (*Includes East Texas Eaglebine) *(Source: Hart Energy Market Intelligence Surveys)*

seven days. Now, well stimulation crews are spending 20 to 30 days on a multiwell pad, completing more than 100 aggregate stages. The evolution to pad drilling and batch completions removes well stimulation equipment from the market for a month or more. Hence, last spring's pressure pumping oversupply has turned into this year's tight market.

Furthermore, that tightness is expected to extend into the future as the Permian Basin begins its evolutionary arc from delineation and optimization in a stacked formation tight oil play toward the Holy Grail of resource harvest. Indeed, rising demand in the Permian, during first-half 2014, essentially attracted surplus equipment out of existing markets, helping to tighten the sector nationwide.

Meanwhile, organic demand is rising as operators push lateral lengths, add stages and pack them more closely together while dramatically increasing sand volumes. Those trends require greater sustained use of pressure pumping equipment at high-performance thresholds, prompting faster wear and tear.

This productivity transformation has created a market with high-contract coverage and tightened demand for well stimulation equipment on the spot market. In the Eagle Ford Shale, spot market fleets were booked 60 days out in third-quarter 2014. Lead time and scheduling issues are becoming a growing part of the conversation between service providers and operators. Eagle Ford service providers are adding hydraulic horsepower—and would add more—except for occasional tightness in components like fluid ends.

Prices rise—but so does fleet capacity

Industrywide, new fleets are arriving, with more expected through first-quarter 2015. Some multiregional providers are splitting equipment between plays such as the Eagle Ford and Permian Basin.

Pricing has risen 13% sequentially in plays like the Eagle Ford. Price increases started earlier in 2014 as demand grew for larger volumes of proppant. Labor and equipment attrition costs also factored in during first-half 2014. But service providers have been able to push pricing in a way that will have a positive impact on margin, which had virtually been at breakeven one year ago. As old contracts roll off, new ones now include an organic increase in margins for well stimulation providers.

Pricing domestically averaged about $104,000 per stage in late 2012 on an estimated 350,000 stages annually, according to Hart Energy market intelligence surveys of the well stimulation market. Nearly 18 months into the transition to pad drilling and batch completions, annual stage counts are estimated at 560,000. That rapid growth has cannibalized any excess capacity in the industry. Various sell

side analysts are estimating utilization rates at 85% of the domestic fleet. But that number might be a false positive. In fact, equipment is out all the time for repair and maintenance, or is rotating around job site, either as backup equipment or replacement for pieces that go down under heavy use. Consequently, effective utilization might be above the 90% threshold—closing in on full "effective" utilization, which is supporting contractor efforts to increase pricing.

PacWest Consulting Partners has developed most comprehensive metrics on the well stimulation sector. The company's second-quarter 2014 update pointed to a 9% increase in domestic horizontal well count in 2014, accompanied by a 19% increase in stage count—and a 30% increase in sand volumes. Clearly, downhole intensity is the fastest growing portion of oil and gas field services.

Hart Energy estimates, based on recurring quarterly surveys of domestic unconventional markets, peg average pricing domestically at $87,000 per stage in third-quarter 2014, down from $104,000 in late 2012. Pricing is up nearly 10% from the trough, however. Meanwhile, an increase in stage count per lateral has turned an industry totaling $36.4 billion in operator capex at year-end 2012 into a $49.5 billion industry, based on annual run rates in third-quarter 2014, implying a 36% increase in capital spending on the pressure pumping side of the business.

Indeed, the top four domestic markets were nearing 450,000 stages on an annual run rate in third-quarter 2014. Annual run rates for stages are estimated at 122,720 in the Eagle Ford, 118,800 in the Bakken and 117,000 in the Marcellus/Utica. The Permian Basin hosts 84,000 stages on the horizontal front currently (not counting vertical Wolfberry drilling) but should add another 65,000 stages annually over the next two years, assuming the region grows to the projected 200 additional horizontal rigs some expect, oil prices stay above $90, and the creeks (and Pecos River) don't rise.

So who benefits in the current market? Wall Street is always quick to clamber aboard the band-

wagon for the multinational service providers. The argument is that the large integrated companies provide proprietary services to operators and can bundle everything from microseismic to coil tubing, capturing market share. Besides, it is generally assumed that the margin-less environment in 2012 to 2013 prevented smaller firms from repairing and maintaining equipment, crippling their ability to provide services consistently.

But market concentration has yet to manifest in any measurable way. The top five pressure pumpers marketed 5.8 MMhhp in 2010 and represented 58% of the market. Pressure pumping capacity between the top five grew to 9.58 MMhhp in 2012, according to various sources including Credit Suisse and Simmons and Co. International. However, market share remained at 58% of industry capacity. Over the last two years, during a time of general oversupply for the pressure pumping sector, capacity for the top five grew once again to 10.13 MMhhp. As for top five market share, it remained unchanged at 58%. In other words, capacity rose for the top five service providers over the last half decade, but the pie grew at the same rate for everyone in the sector.

Part of the reason might be found in the tight formation cycle. From an equipment perspective, pressure pumping and land drilling are on opposite sides of the spectrum. Operators start with commodity drilling rigs as they seek to capture acreage or optimize drilling. However, as a play moves into the resource harvest phase, interest turns to specialized drilling rigs with self-mobilization packages, larger capacity top drives and upgraded fluid systems—hence the newbuild cycle currently underway. Operators are backing newbuilds with multiyear contracts for drilling in 2015 and beyond.

The opposite appears to be true for well stimulation. Early on, operators might want the specialty services that the multinational well stimulation companies provide. Well results are crucial as operators delineate a play and zero in on the best rocks, then work on optimization to better exploit the rock. However, in the resource harvest phase, operators get closer to a playbook for exploitation. At that point, the emphasis is on cost and efficiency, and pressure pumping devolves from proprietary early in the tight formation cycle to commoditization as the resource harvest phase takes hold.

Theoretically, the mid-tier well stimulation providers are likely to benefit from the coming cyclical uptake, partly by cannibalization of undercapitalized smaller tier players and the exit of private-equity-backed startups. Market concentration by the top five did not change during the build-out in 2010 to 2011 and the subsequent sector collapse in 2012 to 2013 as a result of overcapacity. It is not likely to change meaningfully going forward.

Anecdotally, the evolution from specialization to commoditization in well stimulation appears to be playing out in the field. It is echoed in wide performance variations among operators in a given play, even when operators are exploiting similar rocks. The best operators in a play might generate well results that exceed average by 30% or more, according to public presentations by Austin, TX-based DrillingInfo, while poor performing companies generate well performance that is 15% or more below average. If service companies were the primary source of performance improvements, those disparities among operators would be narrower.

At this stage in the tight formation cycle, completion effectiveness remains as much art as science. Witness the debate on sand volumes. Sand volume has increased, and so have well IPs. All eyes are watching. No doubt greater sand use boosts IPs. But is the industry getting the same volume out of the well faster, or actually increasing the total recovery out of the well? Time will tell. Meanwhile, the debate over sand reflects a trade-off depending on whether a company's strategy is to maximize IP or to maximize EUR. It might not be possible to maximize both.

Operators develop playbooks for exploiting the best rocks in a basin. However, those optimized completion techniques add cost. In good rocks, the extra cost boosts rates of return. At the same time, expensive well-completion techniques provide diminishing returns in lower quality rock. Completion recipes that incorporate lower inputs—and lower cost—might still produce higher quartile wells in lesser quality rock and achieve excellent economics. One size certainly does not fit all when it comes to completions. Viva la difference. It means more work for an expanding well stimulation market. ■

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Unconventional Activity Fuels Proppant Market Growth

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 Mary Hogan
Associate Managing Editor, Special Projects

As activity in unconventional oil and gas plays continues to ramp up—fueling the U.S. energy renaissance—the proppant market has experienced much growth and expansion. According to PacWest Consulting's recent *Proppant IQ Market Outlook*, published in September 2014, "North American proppant consumption is expected to increase at 23% per annum through 2016, from 80 billion pounds in 2013 to 153 billion pounds in 2016, with much of the growth occurring in frack sand consumption." Growth of 2% and 9% per year is expected for the resin-coated sand and ceramic markets, respectively, according to PacWest.

An increasing number of fracked horizontal wells and proppant intensity are driving the growth in proppant consumption, according to the outlook.

"The increase in stage counts per well and job size per stage has resulted in higher volumes of proppant per well and is gaining more popularity with regard to completion designs," said Joe Wong, president of Rainbow Ceramics.

Logistical challenges

The PacWest outlook predicted that the logistics of transporting increased amounts of proppant could prove to be a major challenge, "causing significant price increases at the well pad. This is due to shortages in rail cars, built-for-purpose frack sand truck trailers and other factors," Wong said.

John Lassek, director of production enhancement for CARBO, foresees two major challenges with regard to proppant supply and demand. First, since proppant manufacturing sites are generally not located near emerging and established oil fields, getting the proppant to the well site on time can pose a significant challenge. "Rail capacity is scarce, and the oil field competes with other industries for space on the rail lines to transport proppant around the country," he explained.

Second, as demand outstrips supply, the industry has started accepting lower- and lower-quality materials for proppant. "This can have a dramatic impact on long-term productivity and recovery of the wells," Lassek said.

Various regions have experienced shortages of sand as demand continues to rise, and even if product is available, logistics remain a big concern, Cameron Powell, senior business analyst at Rainbow Ceramics, said. "The railroads are investing billions of dollars in infrastructure throughout North America. Rail cars are being leased faster than they are

UNIVERSAL WELL SERVICES USES ITS NEW SAND TRUCKS in a hydraulic fracturing operation in the Northeastern U.S. oil fields.

(Image courtesy of Universal Well Services)

being built, thus leaving most proppant companies exhausting all resources to deliver product to customers on time."

Each type of proppant—including raw sand, resin-coated sand, curable resin-coated sand and ceramic—has experienced increased demand over the last several years, according to Lassek. "As the development of unconventional plays increases, so will the demand for all proppant types," he said.

That demand has brought a renewed focus on proppant innovation, which for several years centered on better materials and manufacturing processes to create stronger proppant. "There has been a shift in innovation recently that is focused on enhancing proppant to do more than hold the fracture open," Lassek explained. "Proppant is being used as a carrier to efficiently deliver long-lasting downhole chemistry, enhance flow through the proppant pack and provide understanding on the completion."

Most importantly, the geology of the reservoir and characteristics like expected well pressures, possible proppant flowback and embedment concerns dictate the size, type and amount of proppant used.

Boosting production with curable resin-coated sand

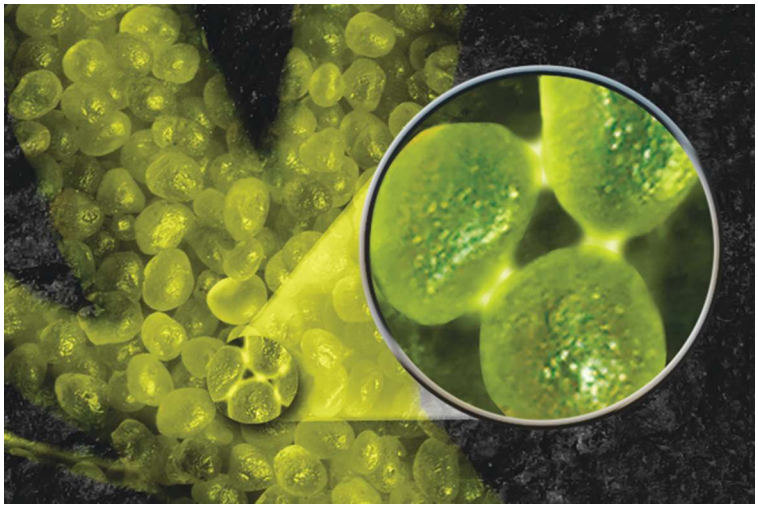
An Eagle Ford case study by Momentive Specialty Chemicals Inc. examined production levels of two operators over a three-year period, correlating those levels to specific completion details such as proppant type and volume. The study, titled "Statistical Analysis of Proppant Type and Additional Factors Impacting Production," chose the operators based on their location to one another and their selection of different proppant types.

Operator A used curable resin-coated sand, and Operator B used uncoated frack sand when fracturing the play's oil and condensate window. According to Andrea Hersey, the case study author and Momentive's technical sales manager, "One of the highest costs incurred in the fracturing treatment is the proppant, which also has a significant impact on well performance. This emphasizes the need to find the optimal proppant type, design and volume based on well conditions and budget."

The study compared wells based on length of production time, with six months and 24 months serving as "goal posts to represent short- and long-term production," according to the study. Results of the study found the benefits of curable resin-coated sand on production of Operator A's wells to be greater than the benefits of uncoated frack sand on Operator B's wells.

Proppant volume also played an important role in production results. Operator B used twice as much proppant as Operator A and saw 32% higher average production of barrels of oil equivalent for wells with six months or less production. However, according to the study, when the production time frame per well was increased to 24 months or longer, Operator A saw "28% higher boe production with around half the proppant volume." In addition, Operator A experienced cumulative barrels of oil equivalent per pound of proppant that was almost twice as high as that of Operator B.

Momentive concluded in the study that higher proppant volume might have contributed to the higher IP levels seen by Operator B. "In order to maximize production and decrease decline rates,



Momentive Specialty Chemicals' Prime Plus resin-coated proppants include Stress Bond technology. *(Image courtesy of Momentive Specialty Chemicals)*

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30-day cum. avg. rate: 605 boe/d

3

Green River Basin / Wyoming
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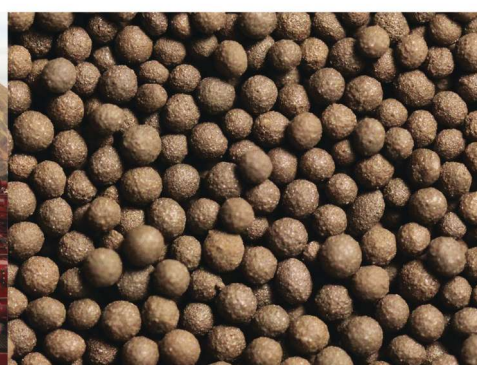

International Frac Sand Association Launches

The International Frac Sand Association launched in October 2014 in Houston, with membership open to frack sand producers, equipment providers, frack sand buyers and users, well service companies, logistics solution providers, technology companies, ceramic proppant manufacturers, E&P companies, import/export companies and others serving the industry.

The association's goal is "to provide the growing proppant industry with a trade association where [members] can network with others involved with frack sand and ceramic proppants, discuss best practices and work to meet their business and career goals," according to its website, *fracsands.org*. Members will be able to attend both national and regional events that focus on professional learning, career advancement, networking and the development of best practices. The association is offering three member levels: sponsor, corporate and individual.

increased volumes of [curable resin-coated sand] should be utilized," Hersey wrote in the Momentive study. "Although [curable resin-coated sand] has a higher cost than [uncoated frack sand], further analysis shows that the return on investment by doubling the proppant volume of Operator A would be two months with only a 20% production increase."

In laboratory tests, when uncoated frack sand was exposed to conditions similar to those found in the Eagle Ford Shale, the proppant "generated 16 times more fines than [curable resin-coated sand].

"This will significantly decrease the effective conductivity, which is evident in the long-term production results of [uncoated frack sand], compared to [curable resin-coated sand]," Hersey wrote in the company's case study.

Focus on reservoir contact, conductivity

As unconventional resource plays continue to be a growth area for the oil and gas industry, the focus on reservoir contact and conductivity—two key completion attributes—could drive an increase in higher volumes of proppants being used by operators per well.

Reservoir contact can drive early time production, according to CARBO's Lassek. Many operators focus on increasing reservoir contact through a combination of increasing the amount of fluid, proppant, number of stages or number of clusters or by drilling longer laterals. "From this perspective, proppant volumes should continue to rise," Lassek said.

Long-term productivity and EUR are governed by conductivity or the durability of the fracture over time. Increased conductivity can be achieved with higher proppant concentrations, coarser proppant or more conductive ceramic proppant. "Many operators focus on either increased contact or increased conductivity, whereas the optimal completion will be achieved through a combination of increased reservoir contact with increased conductivity," Lassek explained.

When it comes to finer vs. coarser proppants, many operators are choosing to use a combination of both. In early stages, hybrid designs with finer proppant can achieve farther transport into the fracture prior to settling. This is often followed by tailing in with coarser, more conductive proppant in the near wellbore area where it is needed most.

"Due to their higher conductivity, coarser proppant is particularly important in the liquids-rich plays," Lassek said. "These hybrid designs lead to demand for finer and coarser proppant."

Low-density ceramics have become some of CARBO's most sought-after proppants. Due to the low density of the material, companies can achieve 20% to 30% additional volume in their fractures. "In addition, for those in the industry moving to lower-viscosity fluids [such as slick water] the lower density ceramic transports farther than intermediate- and high-density ceramics," Lassek added.

The company has developed several new proppants including their newest technology, SCALEGUARD, a scale inhibitor that has been infused into ceramic proppant, allowing effective scale inhibition downhole. "We are targeting an 18- to 24-month effectiveness period, and our field tests have confirmed that we are on track to achieve this," Lassek said. The proppant has been used in the Rockies and Texas, with planned jobs in the Delaware Basin, Bakken and Utica.

RPM technology incorporates a proprietary surface coating, which can achieve neutral wettability on the proppant. This can eliminate capillary pressures, facilitate fracture cleanup and allow more oil

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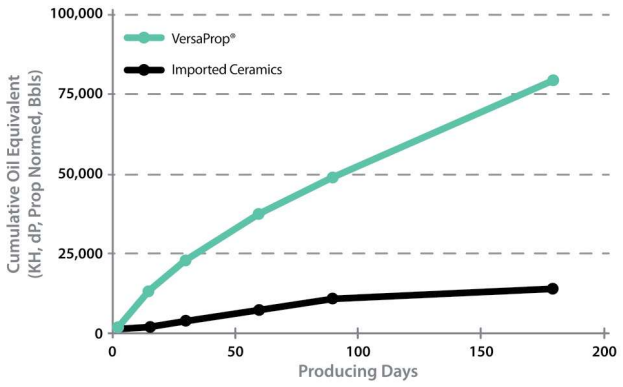

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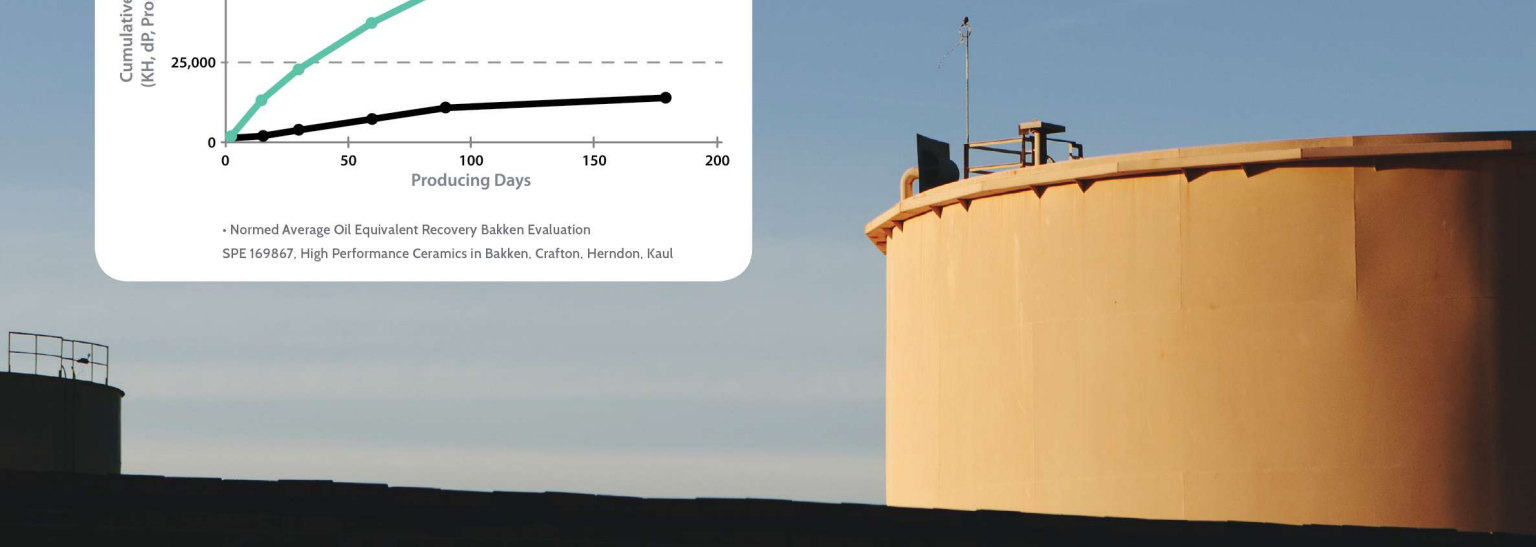

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and gas to flow through the proppant pack and into the wellbore. The technology has been field tested in several North American basins, including most recently the Permian.

The company's CARBONRT technology incorporates an environmentally benign taggant into the ore used to create the ceramic for proppants. This taggant can be measured after the fracture operation using a standard neutron log to understand where the proppant has been placed and to make design changes for greater effectiveness on future frack treatments.

KRYPTOSPHERE, which combines a new manufacturing process and new materials, is a strong proppant targeted for use in deep, offshore completions where closure pressure can reach above 20,000 psi," Lassek said. The new manufacturing process creates a smooth surface that reduces erosivity and lowers beta factors.

Selecting the right proppant

As fracturing jobs grow in size, E&P companies are using more and more proppant in fracturing operations. As such, they are continually searching for the optimal mix of lower-cost raw sand and higher-cost, high-conductivity resin-coated sand and ceramics to best address the geology of a well, according to Nick Johnson, Fairmount Santrol's vice president of marketing.

"Over the last year, we've seen a few emerging basins like the Delaware Wolfcamp in the Permian, the South Central Oklahoma Oil Province and the Eaglebine where operators are looking for proppants that are going to withstand higher closure stresses, reduce proppant flowback and reduce embedment," he explained. In these deeper, hotter formations, operators are looking for either precured or curable resin-coated sand that can withstand the pressures and temperatures.

The company's PowerProp precured resin-coated proppant has high conductivity and oftentimes competes in a space where companies typically would be using a lightweight ceramic proppant.

As companies work with more complex fractures, they are trying to create more complex fracture networks by connecting all of the microfractures with the naturally occurring fractures. To address this need, many companies are using slickwater designs vs. more viscous gel designs. "Generally, gel fracturing fluids are going to create these wider, shorter fractures, whereas slick water is going to create longer, thinner fractures," Johnson said. "So operators are experimenting a lot more with slickwater fractures because they want to just create a lot of thin fractures that are going to connect everything. By doing that, it's harder to transport the proppant, so they're using a lot of finer-mesh proppants—40/70 and 100 mesh. So we've seen a lot of that this year."

The company is still seeing strong demand for coarser proppants, but finer-mesh proppants have experienced a higher rate of growth due to their recent application in oil plays. In the past, for the most part, natural gas plays used fine-mesh products, and oil plays used coarser products. "Now, they're using fine-mesh products in oil plays as well," Johnson said.

The company's new Propel SSP proppant transport technology bonds a typical grain of proppant to hydrogel that can grow up to three times its original size when it comes in contact with water. "So the proppant particles will actually suspend themselves in the fracturing fluid," Johnson explained. "This allows the proppant to be transported farther out into the fractures and higher up into the fractures so you get better placement of the proppant. It expands the hydrocarbon drainage radius with a maximized propped frack area to increase the ultimate recovery of the well."

Recently, Chesapeake Energy used the proppant transport technology in seven field trials across the Eagle Ford, Marcellus, Mississippi Lime and Utica formations. Josh Jackson, manager of completions technology for Chesapeake, discussed the benefits of the proppant during the Society of Petroleum Engineers Horizontal Well Completions in North American Unconventionals workshop. "The suspended proppant, which performed with reduced or eliminated gel and friction reducer, was a technical success," he said.

Fairmount Santrol's CoolSet resin-coated proppant was designed to be able to bond in well temperatures down to 38 C (100 F) without the need for an outside chemical activator. In the past, the company's Super LC curable resin-coated proppant

could be used at temperatures below 66 C (150 F) in combination with a chemical activator to get the proppant to bond. Because CoolSet does not require the extra step of an activator, it can save an operator money as well as time, according to Johnson.

Advances in proppant technology

There have been multiple advances in the proppant world within the past few years, and advances will continue as the industry realizes the importance and versatility of proppants, according to Rainbow Ceramics' Wong. Two examples of advances include enhancing proppant performance characteristics by incorporating tracers and scale inhibitors into proppants.

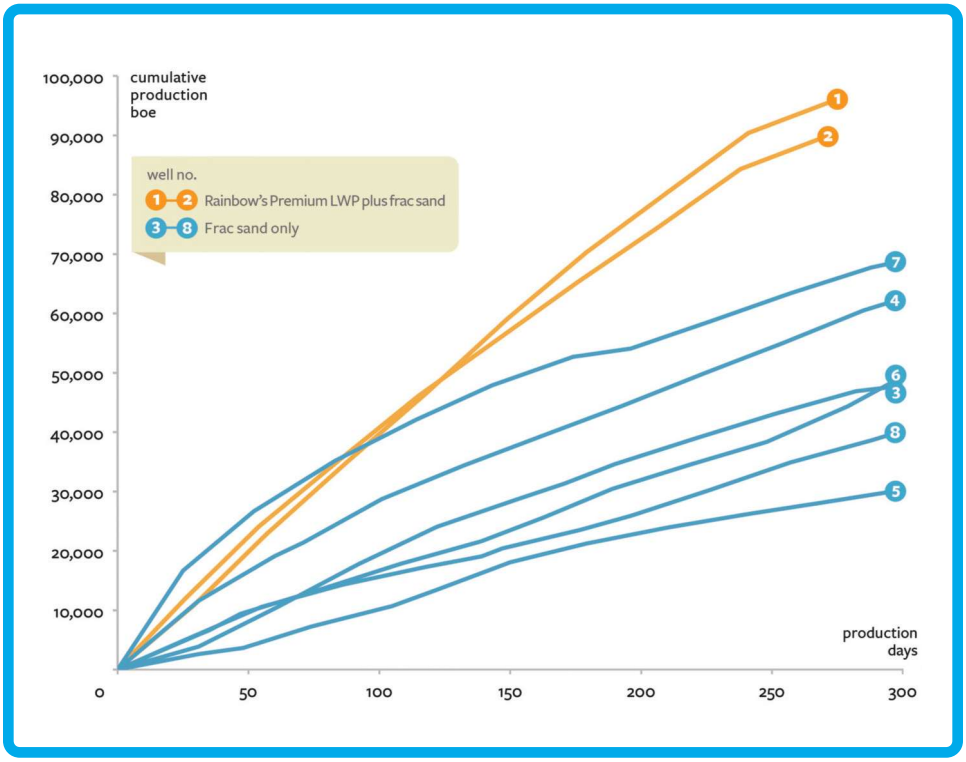
"Traceable proppants allow service companies to detect and effectively monitor proppant placement," he said. "Scale inhibitors can be used with the proppant pack throughout the entire fracturing process without any loss of conductivity while reducing chemical consumption and eliminating scale-inhibiting treatments."

Proppant selection including size, type and volume depends on the target formation and the completion design of each operator in each shale play, Wong said. "For example, slickwater fracks tend to use smaller mesh size proppant. Although slickwater fracks have gained popularity in some shale plays, they have not proven to be successful in all plays."

The choice in proppant type between natural sand, resin-coated sand and ceramics can vary dramatically by region and formation as well as by operator objectives and standard practices. Intermediate-strength proppant is the company's most popular product, especially in the Bakken Shale play. In the Permian Basin, the company has had much success with its lightweight ceramic proppant. Ultralightweight proppant is lighter than sand but possesses much higher strength than sand.

Many operators are focused on cutting completion costs and maximizing IP rates. "These operators generally look at well performance over the first 90 days of production and then move on to the next well," said Rainbow Ceramic's Powell. "Such cases favor using natural sand due to its lower cost per pound."

Other operators might take a longer-term approach and are focused on EUR rates to maximize overall well production and profits. Long-term production analysis supports the use of ceramic proppants. In the IP stage, proppants generally tend to perform the same. "However, looking past 270 days or so, production from wells fracked with sand tends to flatten or drop off," Powell explained. "Conversely, wells fracked with ceramic proppants result in much higher long-term well production under a broad spectrum of reservoir conditions. This is largely due to increased effective conductivity obtained from employing ceramics, which are stronger and more



The average cumulative production of the two wells fractured using a combination of Rainbow's 20/40 premium lightweight proppant and sand more than doubled the average cumulative production of six wells fractured using only frack sand. *(Chart courtesy of Rainbow Ceramics)*

uniform in size and shape and have greater chemical and thermal stability."

In a Williston Basin case study, an operator was able to double production using Rainbow's 20/40 lightweight ceramic proppant. In 2011 and 2012, the operator initially drilled and completed six Three Forks Shale wells using 100% frack sand but was not satisfied with the production performance of the wells.

In January 2013, the operator drilled and completed two additional Three Forks Shale wells in the same field, deciding to alter the frack design by replacing 30% of the frack sand with 800,000 lb of Rainbow's 20/40 lightweight ceramic proppant in each well. After 270 days of production, the average cumulative of the wells fractured with the lightweight proppant was 92,764 boe, which is 46,810 boe higher than the average cumulative production of the first six wells. "The wells are still performing, and the wells fractured with Rainbow's premium lightweight proppant are still outperforming the others," according to production data from Rainbow's case study.

The Quickstand Proppant Silo can be rapidly deployed on site and facilitates large storage of proppant on a smaller footprint. *(Image courtesy of Quickthree Solutions)*

Onsite storage solutions

With millions of tons of proppant being used in oil and gas operations every year, onsite storage has become a critical logistical factor. Quickthree Solutions Inc. has designed the Quickstand Proppant Silo to be rapidly deployable on site by the company's detachable trailer design and ready to use in minutes rather than hours. The vertical storage allows much larger storage of proppant on a smaller footprint. The Quickstand system is modular, can be rapidly deployed and configured into an 11-silo system capable of storing 3.9 MMlb of sand from a single T-belt in under an hour.

The solar-powered portable vertical storage system comes with built-in dust control. In addition, the Quickload Silos are fully automated and in some cases do not require direct operator supervision to operate. The silo's onboard load cells and management software linked through wireless give highly accurate and real-time monitoring of the proppant delivery during the frack job.

The company's silos and trailers are designed to offer improved economics and performance as well as ease of use for proppant storage and delivery at the well site, according to Alvin Herman, president and director of Quickthree Solutions. ■

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Water Reuse Gaining Momentum Across US Shales

Drilling boom prompts operators to evolve on the fly when it comes to the sourcing, recycling and logistics of water.

By Blake Wright
Contributing Editor

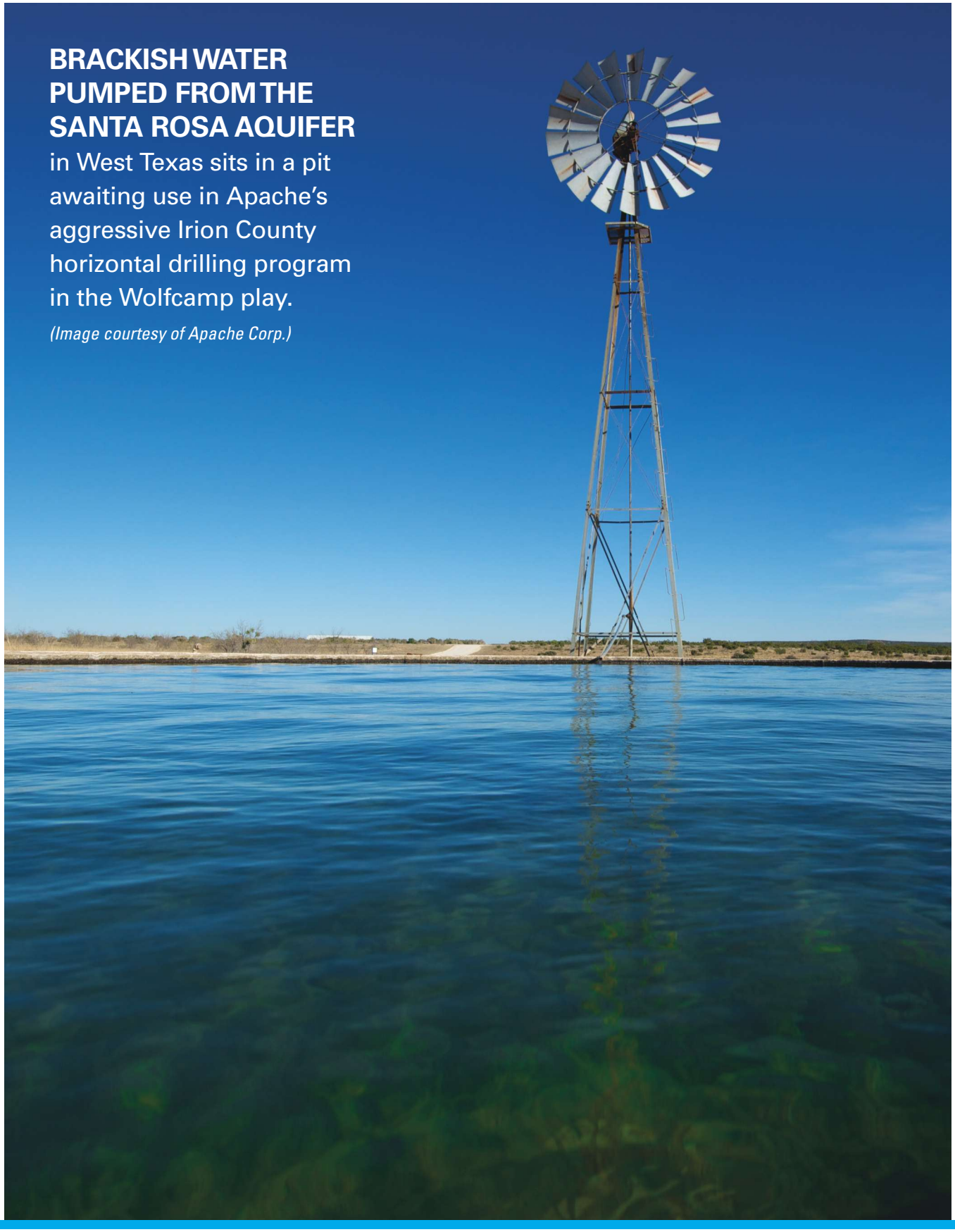
The oil and gas industry has long had a love-hate relationship with water. It can be the first sign of the end of the road for hydrocarbon-producing wells. It can stand thousands of feet deep between an operator and a multibillion-dollar payday in the challenging offshore. It can be the source of environmental upheaval and a rally cry for those seeking to halt oil and gas development in a given area. However, water also can be a valuable asset, even a tradable commodity for producers, and arguably, at no time in its history has water become more important to the industry as it has over the past half-decade, since the onset of the U.S. shale boom.

In 2009, drilling activity skyrocketed onshore as the use of hydraulic fracturing to simulation natural gas production from shale formations was commercialized in scale. Soon, the method was used to unlock unconventional oil reserves as well, and the industry was off and running.

Water is a key element to creating a usable frack fluid, and thus a successful frack job. As much as 5 MMgal of water is used per well on a multistage frack in some areas. Over the past five years, the boom spread across the U.S. from basin to basin—the Barnett, Haynesville, Marcellus, Eagle Ford, Utica and Permian. As activity swelled, the term "water management" became a common thread woven through operators' development programs. Aimed at equal parts efficient use and environmental stewardship, water management sprung up as a cottage industry—a subset of the oil services business that would cater to needs such as sourcing, recycle and reuse, logistics and disposal. For example, look no farther than companies like Texas-based Shalewater Solutions, Nuverra Environmental Solutions of Scottsdale, Arizona, Houston-based Select Energy Services or Canada's Aqua-Pure Ventures.

The challenges facing effective water management can be numerous. Portions of the U.S. are currently experiencing a severe drought as a lack of cumulative rainfall continues to take its toll on rivers, lakes and streams in areas of California and the Southwest. In Texas alone, climatologists have suggested that the current drought could end up being one of the top three worst in the past 500 years. The drought complicates water management from both the availability and sociological sides of the equation. Sourcing surface water becomes more difficult and much more of a public relations issue than before.

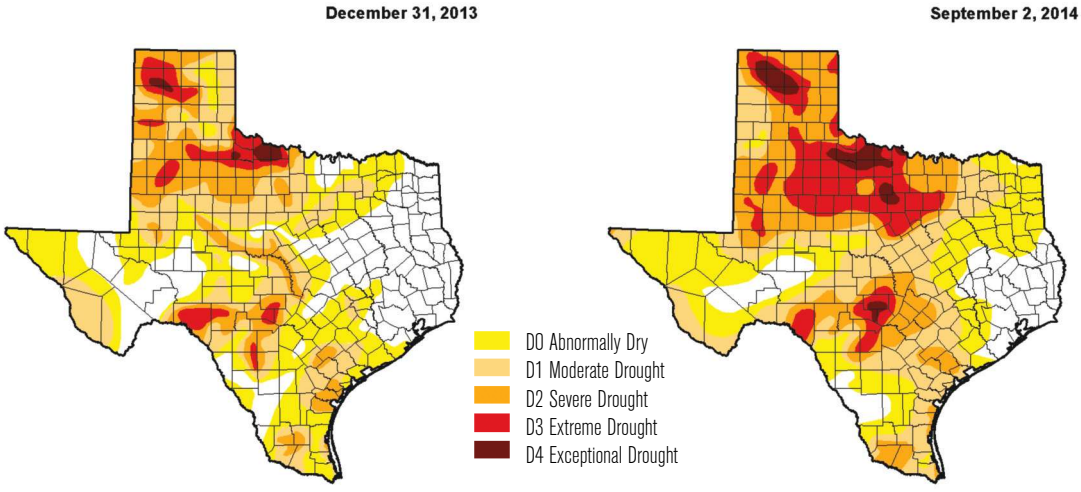
Texas and the U.S. are just the tip of the iceberg when it comes to water concerns for shale development. A report released earlier this year by the World Resources Institute concluded that almost 40% of



BRACKISH WATER PUMPED FROM THE SANTA ROSA AQUIFER in West Texas sits in a pit awaiting use in Apache's aggressive Irion County horizontal drilling program in the Wolfcamp play.

(Image courtesy of Apache Corp.)

Texas Drought Maps



(Source: Office of the State Climatologist)

global shale resources are located in areas with high water stress. Regions like Mexico, China and South Africa, which have some of the largest technically recoverable shale gas resources based on U.S. Energy Information Administration estimates, will face water availability issues due in part to competition for the resource from agricultural, municipal and industrial players.

Coming at the problem from both ends

Where possible, the industry has begun a concerted effort to move away from the use of freshwater for fracturing wells. Early concerns over the use of brackish, flowback, effluent or other nonfreshwater sources have centered on the potential substandard well performance due to reactivity of that water with the formation itself. When Halliburton kicked off its water management offerings a few years ago, it too concentrated on how to get the best water for the frack fluid being produced. Over time, the contractor's focus has swung 180 degrees, and now it is promoting how to get the best frack fluid from the water that is available. Today, fluid adjustment is the company's mantra.

"When I first got here at Halliburton, we had a customer that had 20,000 TDS [total dissolved solids] water," said Walter Dale, strategic business manager for Halliburton Water Solutions. "They were running it through a heat exchanger, and a UF [ultrafiltration] and a RO [reverse osmosis] system and basically making drinking water, then turning and using that water for hydraulic fracturing. That customer today has since gotten rid of all of that technology [and] just changed their frack fluids in order to be able to use that water. What we did is look at what was in the frack fluid that was keeping it from working with these waters. We know that we make frack fluid in the ocean at about 35,000 TDS every day with saltwater. We looked at the chemistries we do that with, and we ended up developing what we call UniStim, which is a universal, high TDS, crosslink fluid that can be used in any impaired water up to 300,000 TDS." The trend over the last four to five years has been to reduce the water treatment cost using fewer technologies and go more toward fluid adjustment, both with Halliburton and other organizations, Dale continued.

Halliburton has taken UniStim and its other product offerings and formed a suite of services it dubbed H2O Forward. H2O Forward is a service that is designed to use recycled or other alternative, nonfreshwater for hydraulic fracturing purposes. Tweaking the chemistry of the fluid itself, the company is able to reduce the waste and cost associated with removing contaminants from the water that can impact conventional fluids. The solution

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CleanWave destabilizes and coagulates the suspended colloidal matter in water. When contaminated water passes through electrocoagulation cells, the anodic process releases positively charged ions, which bind onto the negatively charged colloidal particles in water resulting in coagulation. *(Image courtesy of Halliburton)*

includes products that initially made up Halliburton's CleanSuite offering: CleanWave, a water treatment technology; CleanStream, a biocide reduction technology; and CleanStim, a food-grade frack fluid.

"What we realized is that while those three products are great, you couldn't apply every product in every instance and actually make it work for the customer," Dale said. "We launched H2O Forward this year as a service offering, and we added a lot of products. It includes those original products, but we've added UniStim and high TDS friction reducers for those customers that use slickwater fracks. We've added basic filtration, because sometimes CleanWave is overkill. We've added chlorine dioxide... the entire suite of MultiChem chemicals that are needed. The one thing that I've learned doing this is that there is no 'black box' approach. The one-size-fits-all solution really isn't out there. If it is, customers are having to spend a very high price point in water treatment, which usually kills potential recycle projects."

Much like the consistency and gravity of oil can change from well to well, the variability in water quality is equally as dynamic. Using the same frack fluid chemistry region to region becomes an economic challenge as treating, engineering and designing for all of that variability drives up cost. The H2O Forward process aims to lower the water quality required so that producers do not need to make water safe for drinking just to create a workable frack fluid.

Tale of two basins (Permian vs. Eagle Ford)

West Texas' Permian Basin has been a powerhouse of oil production since the first wells were drilled in the region during the 1920s. According to Texas Railroad Commission data, the basin has produced more than 29 Bbbl of oil and 75 Tcf of gas over its 90-plus year life and shows little signs of slowing down. As little ago as 2009, more than 3,300 new well permits were issued for the basin. In 2012, fueled by unconventional oil and gas development, that number ballooned to more than 9,300. Along with its robust oil production, the mature province produces a lot of water, via the drilled formations and flowback, making the area a prime spot for recycling efforts.

The Eagle Ford Shale, located about 300 miles southeast of the Permian as the crow flies, is a relatively new patch by comparison. The Texas Railroad Commission estimated that oil production from the region has grown from just 352 bbl/d in 2008 to almost 900,000 bbl/d during first-half 2014. Natural gas production also has grown exponentially from the play. With a limited number of wells in the ground, producers in the Eagle Ford are not seeing the produced water volumes that the Permian operators are experiencing, which makes the area's prevalent water use cycle the more classic method of freshwater-to-disposal. It is also classified by the industry as a "thirsty" basin—one that doesn't offer much flowback volume.

"They are two completely different basins even though they are both in Texas and both have water availability concerns because of the drought," Dale said. "When you look at it from a water recycling perspective, they are vastly different. In the Permian you have a high, impaired water supply in proximity to a high water demand for fracturing. When you look at the Eagle Ford, it's a thirsty basin, which means it doesn't give a lot of water back. The percent of flowback water in the Permian is somewhere between 15% and 30%. In the Eagle Ford, you very rarely get 10% of flowback volume."

In the Permian, Halliburton and other water service specialists use mobile recycling systems that can be moved from field to field to provide treated water for creating frack fluid. In a 2013 case study, Halliburton's recycling methods saved a Permian operator more than $500,000 and 8 MMgal of water via use of its H2O Forward suite and allowing for a functioning frack fluid to be made from impaired water containing up to 285,000 ppm TDS.

Eagle Ford operators simply do not yet produce enough water to make larger-scale recycling economical. For the South Texas play, water usually is obtained via freshwater wells drilled into regional aquifers. That water is then used in the fracturing process and whatever flows back is discarded via a saltwater disposal well.

> **"…THERE IS NO 'BLACK BOX' APPROACH.** The one-size-fits-all solution really isn't out there. If it is, customers are having to spend a very high price point in water treatment, which usually kills potential recycle projects."
>
> *—Walter Dale, Halliburton Water Solutions*

An April 2014 report conducted by Texas A&M University's Bush School of Government and Public Service found that during a recent four-year window fresh groundwater in the Eagle Ford was being consumed at about 2.5 times the groundwater recharge rates, with irrigation and not oil and gas, using more water than all other water-consuming categories combined. As competition for freshwater sources escalate, the report recommended, among other things, that incentivizing the oil industry use of brackish water in the area could arrest the growing rate of freshwater use.

Pioneering a recycling/reuse effort

While recycling is a way of life for operators in Pennsylvania's Marcellus Shale play due to restrictions on the number of disposal wells allowed in the region,

the practice of reuse of both produced and flowback water has been slower to catch on in other areas. Lack of produced water in more immature regions or abundant availability of other water sources play key roles in the decisions on whether or not to implement recycling and reuse strategies.

In West Texas, where produced water and flowback is more robust and the effects of a historic drought has taken its toll, recycling has become more important to the drilling equation, as has innovative sourcing of other usable waters. Operators and service companies even have a cooperative of sorts in place—the Energy Water Initiative—where they come together and share best practices and fresh concepts for dealing with water management issues.

Dallas-based Pioneer Natural Resources is one of the most active players in the region's Permian Basin, with a hefty acreage position in the Spraberry and Wolfcamp formations. Pioneer's total acreage position is about 900,000 gross acres (640,000 net acres).

As the producer's horizontal drilling program expanded and its need for current and future sources of water grew, it began to explore new avenues for securing new water volumes. Earlier this year, the operator secured a long-term deal with the city of Odessa, Texas, for access to its sewage water. This effluent source could be treated to a suitable level for use in making frack fluid. The deal with Odessa is a straight purchase agreement. Pioneer will lay a pipeline to the tailgate of the city's

Pioneer's recycled water ponds in West Texas are a bit bigger than a standard American football field.
(Image courtesy of Pioneer Natural Resources)

waste water facility, which will move the water to storage closer to its operations. The deal with Odessa is a 10-year purchase pact with an option to extend. According to Pioneer, the quantity will exceed 100,000 bbl/d.

Pioneer is closing in on a deal that would gain it access to nearby Midland's waste water as well. Under terms of the Midland, Texas, proposal, Pioneer will put up the funds for the city to build a secondary treatment plant—needed to get the water to a desired grade—and also upgrade the city's existing primary treatment plant in return for an initial term of 20 years of water rights from the township.

"It is a really attractive private/public partnership in that Midland would rather not spend a large amount of money to install the required secondary plant," said Stephen McNair, president of Pioneer Water Management LLC. "We need the water to be treated to a secondary plant level for our utilization, so we're putting up the money and we're building the plant. There will also be some upgrades to the existing plant including capacity increases to meet Midland's growth plans. So it helps them out financially and it secures water for us. Right now, it is structured as a 20-year deal with opportunities for extending. To be clear, the Midland deal has been agreed to regarding basic terms and conditions. We're now in the midst of negotiations with Midland on the definitive agreement."

Waste water is just one source the company is exploring. Today it purchases brackish water from service companies that are developing that resource via specialty wells but plans to move soon to developing its own brackish volumes. The company recently hired a subsurface specialist tasked specifically with the development of brackish water in the Permian Basin. Brackish water is present in deeper aquifers in the region such as the Santa Rosa.

Pioneer aims to marry the effluent sources from the region municipality deals with its own brackish production and recycle/reuse of produced and flowback water to supply its water needs going forward. Pioneer is working with service companies like Fountain Quail on a series of pilot recycling projects. These mobile recycling plants are being used to study the technology as well as the cost and effectiveness of the process prior to the future decisions regarding permanent recycling solutions for the area.

Pioneer is planning a new hire to act as a recycle program manager for the Permian, who will be tasked with putting together an implementation plan regarding recycling plants, including which technologies to pursue, ultimate location and sizing/throughput. The company has forecast a "healthy" capital budget over the next two to three years earmarked for growth of its recycling business.

"Our strategy is sustainability," McNair said. "We recognize the strain that would be on the area if the industry maintained its current practice of drilling local freshwater wells... and when I say local I'm talking about the old tried-and-true method of drilling a water well right there on the lease and then providing water for drilling and completions. We believe that is not sustainable. It's not the right thing to do from an environmental stewardship standpoint, and we definitely have a plan to reduce our reliance on underground freshwater. When you look at our development plan for the Permian, it's a healthy growth plan. We need to put the water infrastructure in place that can reduce the reliance on freshwater but also source, transport and store water for these wells to be completed. The plan is to stay away from potable water."

For peer operator Apache Corp., an aggressive drilling program in Irion County's Barnhart area called for a similarly aggressive water reuse system that would source brackish and produced water. The Barnhart area is in the heart of the Permian's Wolfcamp play. During 2013, the producer used 10 MMbbl of brackish water and another 3.1 MMbbl of produced water at Barnhart. The company currently is developing a similar produced water recycling project in Reagan County and farther north the expansion of its Wheeler County water storage and pipeline system.

During 2013, Apache drilled about 75 horizontals in the Wolfcamp Shale around Barnhart. Completing each well with multiple hydraulic fracturing stages requires about 200,000 bbl of water. With freshwater in short supply, Apache supplements produced water from earlier completions with brackish water from the Santa Rosa aquifer that is not suitable for human consumption or agriculture.

"We decided to build the facilities at Barnhart because we have a large contiguous acreage position—38,000 acres—and we believed we would recover the investment over the course of drilling a

lot of wells," explained Cal Cooper, Apache's director of emerging technology and special projects. "Water is a local commodity; it made sense for Apache to recycle produced water and use brackish water in the Barnhart area, but you may not be able to make the same case in all places in the Permian."

Taking the recycling theme in the region one step farther, Apache is using modified grain bins to hold water awaiting treatment. These bins receive piped water from both a 500,000-bbl pond that holds brackish water pumped from the Santa Rosa aquifer and flowback water from area drilling sites. After treatment, the water is then piped back to a well site for the next fracture job. The process is then repeated.

while eschewing fixed recycling solutions, also usually come down to project economics.

"We were doing a project in Colorado recently and one of the drivers for them was to eliminate as much of the disposal as they can," Halliburton's Dale said. "So [with] that process, we run it through a basic water treatment technology, and if we put 100,000 barrels though that system, we get 95,000 barrels out, and then we get 5% of that water that's tied up in the sludge. We then dewater that sludge and create a dried cake taking that water back. There is really no water loss. For every 100 barrels of water we recycle, that's 100 barrels of water that does not have to go to disposal or come from a freshwater supply."

> **"WE NEED TO PUT THE WATER INFRASTRUCTURE** in place that can reduce the reliance on freshwater but also source, transport and store water for these wells to be completed. The plan is to stay away from potable water."
>
> *—Stephen McNair, Pioneer Water Management LLC*

Apache shies away from using water from other sources in the Permian, however, outside of the West Texas region, the company has at least one municipal wastewater deal like Pioneer. Apache has an agreement with the city of College Station, Texas in Brazos County to use effluent water from its Carter Creek wastewater treatment plant. The water sourced there is earmarked for a large part of the company's Eagle Ford drilling program in Brazos County. The project currently is in the permitting phase.

While the Permian emerges as a top candidate for water recycling technology and implementation, areas like the Marcellus and other midcontinent areas have faced their own share of reuse challenges. In the Marcellus, water solutions are restrictive. Operators can face the choice of either recycling or moving the water out of state for disposal. That driver has led to the region having the lion's share of North America's permanent water recycling facilities. Water reuse in areas like the Midcontinent,

Eyes on supply

Water management encompasses more than just sourcing, use and disposal. It also calls for effective monitoring of supply. The forward deployment of sourced water is key to an effective development program. Being able to monitor various sources of water allows operators to keep tabs on levels of both in-ground and above-ground storage. One company that assists with that effort is Select Energy Services. The contractor is such a firm believer in the need for quality water management that earlier in 2014 it completed a reorganization effort that saw it spin off its convention oil service business into standalone entities so it could focus 100% on water solutions.

Select is approaching 2 Bbbl of water at its access across the Lower 48 made up of groundwater, surface water, industrial water and produced water sources.

"If you're going to effectively work and improve water management and gain any benefit from it, you have to look at it on a very regional level," explained

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Dave Henley, senior vice president of business development for Select Energy Services. "When you take it across the Lower 48, you have different regulations in Louisiana than you do in Colorado. Things are very unique in the West Texas, the Eagle Ford and the Bakken. It is important to every single operation in every single region, but the particulars and the requirements are unique to every region."

As part of its suite of services, the company offers up a real-time monitoring solution called AquaView. Born in-house, the system gives an operator the capability of seeing real-time volumes of specific tanks or ponds via wirelessly transmitted data. The suite also includes hydrographic mapping using sonar remote control and GPS data. A remotely operated surface vehicle that resembles a recreational remote-controlled boat is deployed and gathers data regarding volume and makeup of the water. That data is collected and fed back to Select and beamed out to users. The results give users total volumetric output of water in storage, estimation of usable storage, contour map with depth measurements and 3-D bathymetric imagery.

"Clients can have that information on their iPhones, iPads or desktops," Henley said. "It involves very specific and detailed mapping of pits, then generating profiles for the pits and calculating volumes for them, and tanks. It's got a mechanical element to it in the sense that we map it, but it also has the data element to it because we stream that data to the operator around the clock."

Water variability makes it imperative for a water-centric contractor to have access to a multitude of different solutions for getting users not only the volumes they need but the quality as well—be it from surface sources or the recycling and reuse of produced and flowback water. There is no specific technology that is going to always be the answer. Front-end analyst is important to finding the solution that fits the specific project.

"In some instances, treating can be as simple as physically broadcasting chemicals into water to change the chemistry or it might be more complex like evaporative distillation, where you come out with a distilled water... and the technology scales from bottom to top are pretty much in line with the cost as well. A low-end chemical treating may be very economical where as a higher-end, 'get it to drinking water' quality, is definitely going to be more costly... and everything in between. You have to look at it on a case-by-case basis to determine what quality you need the water to be... and what you are trying to accomplish—dropping out the sulphur and sulfides or if you're worried about solids or whatever it may be."

> **"IN-GROUND PIPING SYSTEMS** are gaining more favor as we prove the economic viability of those. When you look at the true, all-in cost of trucking water, it is a significant number."
>
> *—Dave Henley, Select Energy Services*

In a recent case study, Select had a Permian client on a four-well program near Notrees, Texas, where fresh and brackish water wells were not producing volumes needed to maintain the operator's desired fracture schedule. Couple that with the sour water being produced by the existing wells in the field and Select was challenged to meet both the volume quality and quantity thresholds while keeping a lid on costs.

The contractor tapped joint venture partner Fountain Quail and its mobile Rover onsite treatment system to purify the operator's produced water at a disposal site near the well. Caustic, polymer and hydrogen sulfide management chemicals were added to the feed water at the front end of the system. The water passed through various mix and settling tanks. An inclined plate separator was used for the best turbidity removal results.

The sludge made from chemical treatment was then reduced down to a contained dry cake, which easily is disposed. The cleaned brine is then pH adjusted back down to neutral, which decreases the water hardness to below saturation levels.

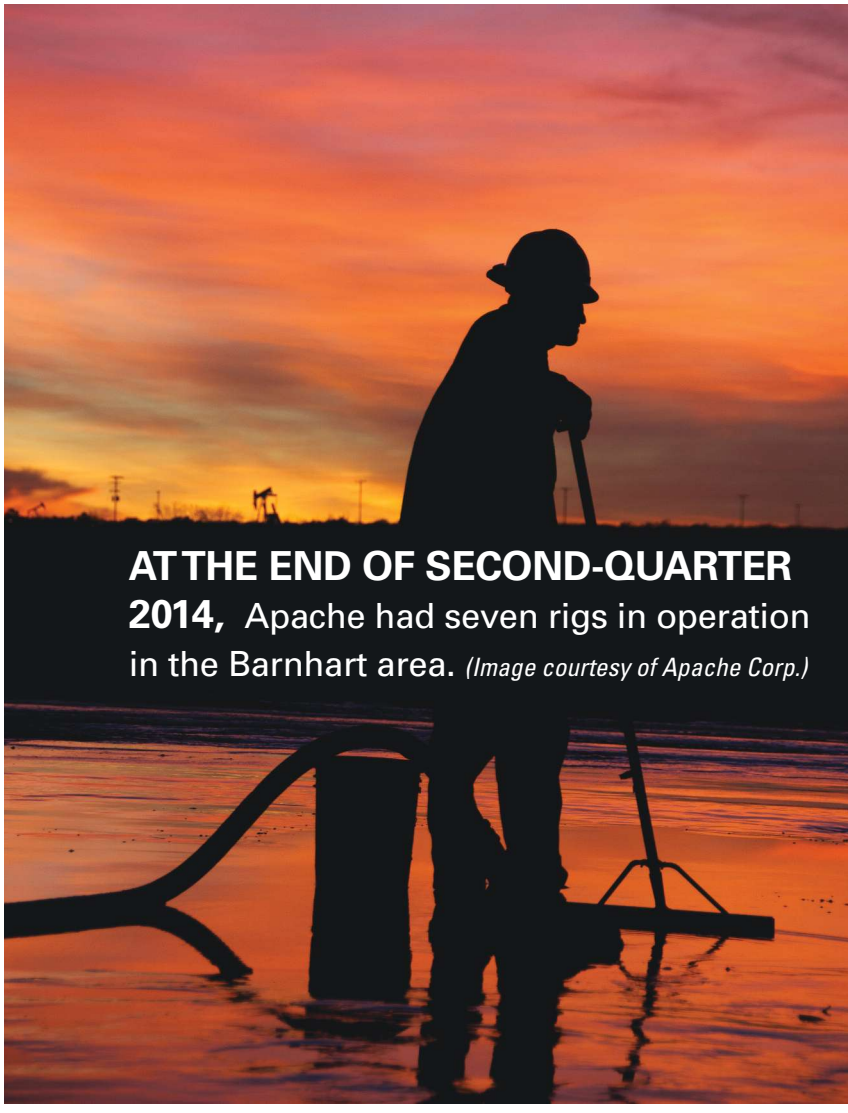
Following the treatment, water was moved into one of Select's large volume steel storage tanks with a 38,000-bbl capacity. The large tanks require less site preparation and space than typical fracture tanks and also decrease the amount of trucks on the road during mobilization and demobilization. They're also less land intrusive than a traditional in-line pond. Ultimately, the steel storage solution was both cost effective and environmentally mindful. For delivery, the company used a pipe system to transfer water from the staging container to the well site.

Improving water logistics

Sourcing, treatment, use and reclamation is a large part of the water cycle in hydraulic fracturing, but an equal challenge for those involved is the efficient and responsible transportation of water from project to project. A mobile strategy to recycle and reuse usually means the use of trucks to move water to and from drilling sites. Trucks can be used to both bring usable water in and move used water out for recycle or disposal. Adding a wheeled water fleet typically adds congestion to rural shale areas not built to handle that sort of influx of road traffic. More recently, operators have started turning to above-ground and in-ground pipeline solutions to move water.

"We're a lot farther down the road than we were two years ago, but we're not as far down the road as we need to be," Select's Henley said. "In-ground piping systems are gaining more favor as we prove the economic viability of those. When you look at the true, all-in cost of trucking water, it is a significant number. If you have an asset as an operator that has a volume required then you can invest in significant infrastructure projects to support that via fixed pipelines. We do see a trend in favor of piping both freshwater and produced water throughout a lot of these new fields."

Pioneer's Permian operation is trending more toward permanent water recycling facilities and use of pipelines for water transportation. The company already employs "lay-flats," or expandable hoses, like those on a fire truck, for use in bringing water to the well site from area ponds. However, such above-ground transportation solutions need landowner approval and only addresses a small portion of the truck traffic building in the region.



AT THE END OF SECOND-QUARTER 2014, Apache had seven rigs in operation in the Barnhart area. *(Image courtesy of Apache Corp.)*

"Our plan is to further reduce our truck traffic, but it's not high right now on the water side," Pioneer's McNair said. "With recycling, we have a plan that sees a pretty significant ramp up with recycling in the next three to five years. The challenge is the water balance. You need to figure out how much water is going to be produced in the area vs. what is needed. If you produce more than what's needed then you're laying more pipe or

Select Energy Services uses a remote-controlled unit to assist it in data gathering and mapping of water pits as part of its AquaView suite of services. *(Image courtesy of Select Energy Services)*

you have to truck. It's a very careful balance between sourcing and recycling produced water. Then, the other part of the equation is how much do you dispose into saltwater disposal wells. We own and operate our own saltwater disposal wells. That eliminates trucking because the disposal wells are in the immediate vicinity of the producing wells. There is a challenge just putting in the infrastructure. We're talking about big pipe and lots of miles of it to be truck-less."

For most operators, the logistics solution is all about costs. Installing pipeline infrastructure to move water is an expensive proposition, and given the immaturity of some of the shale plays it is an investment few have decided to pursue in lieu of retaining flexibility. However, trucking is expensive as well once you factor in competition for truck use, even within the oil and gas industry as well as the consistently high price of fuel.

"Most customers now understand that you save a lot of money when you invest in gathering systems and transfer lines as opposed to trucking water across the industry," Halliburton's Dale said. "However, if you look at where the industry is today, 68% of the total market is in trucking. It is still a huge industry. There are still a lot of trucks moving up and down the road. You do see a lot of companies that are being more progressive and looking at how to build gathering systems or convert to pipelines to remove those trucks as well." ■

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Regulatory Balancing Act

As lawmakers weigh industry and anti-fracking interests, state and local authorities fight for the right to control.

By Bethany Farnsworth
Associate Managing Editor, *E&P*

The oil and gas industry might be in the middle of a boom, but regulators of the industry are stuck in the middle of a battle. Lawmakers are tasked with finding the right balance between the industry's needs and the concerns of environmental groups and communities. If they tip the scales in favor of industry too much, many will worry about the impact of fracking on the environment, water, air and overall quality of life for those who live nearby. If the scales are weighted too far toward the interests of anti-fracking groups, the consequences could affect the economy, job creation and energy supply.

Throw political agendas and legal intricacies into the mix, and the regulatory landscape becomes even more complex.

While several states are adding or discussing regulations to handle the rapid growth of fracturing, some groups want to speed up the process or make requirements much stricter. This has led many municipalities across the country to try to take the matter of regulating fracturing into their own hands. Whether this is a successful tactic depends on the state and what the courts decide is in line with the state's constitution.

State authority

Regulations that concern hydraulic fracturing are mostly handled at the state level. This allows states to take action specific to each one's situation. "The predominance of states in regulating shale gas development activities allows them to weigh their own trade-offs between the costs and benefits of regulation, taking into account history, geology, demographics and other factors, as well as the public's tolerance for risk," according to a Resources for the Future (RFF) report titled "The State of State Shale Gas Regulation."

A few exceptions exist to states' authority. The Safe Drinking Water Act allows the Environmental Protection Agency (EPA) Office of Water to protect water quality, and while Congress has specifically excluded hydraulic fracturing from this regulation in most instances, the use of diesel fuel during hydraulic fracturing still is regulated by the EPA under the Underground Injection Control (UIC) program. According to the EPA website, any service company that performs fracturing using diesel fuel must receive prior authorization through the applicable UIC program.

In addition, the Clean Water Act gives states or the EPA authority to regulate discharge of produced waters from hydraulic fracturing operations. The EPA has said that it will write Clean Water Act rules for disposal of shale gas wastes through wastewater treatment plants.

The Fish and Wildlife Service under the Endangered Species Act has listed the endangered species that are impacted by fracturing, including by water withdrawals for fracturing, according to Hannah Wiseman, assistant professor at Florida State University College of Law who specializes in energy law, environmental law and land use regulation and is a leading expert in the area of hydraulic fracturing regulation. Also, proposed Bureau of Land Management rules would manage fracturing on federal lands, and emissions of volatile organic compounds

A RIG DRILLS FOR OASIS PETROLEUM CORP. near a former homestead in western North Dakota.

(Photo by Stephen Collector, courtesy of Oil and Gas Investor*)*

> **"SOME ARGUE** that [giving municipalities power to ban or allow fracturing] will stymie oil and gas development, although it is not clear yet how extensively giving municipalities the power to ban and/or allow fracturing will in fact impede development."
>
> *—Hannah Wiseman, Florida State University College of Law*

from fractured and refractured wells are regulated under a new Clean Air Act rule effective in 2015 requiring operators to use green completions (with some exceptions).

The power of the municipality

One growing area of contention, Wiseman said, is whether control should be more local—regulated more by municipalities than state government.

Examples of regulations municipalities might pass that would apply to fracturing activities include light or noise ordinances, placing limits on the weight of equipment on roads, and taxing oil and gas operations, but they also can include moratoria and land use regulations that ban fracking activity. Some states are attempting to preempt local drilling and fracturing regulation, keeping municipalities from regulating activity within their borders.

"Some argue that [giving municipalities power to ban or allow fracturing] will stymie oil and gas development, although it is not clear yet how extensively giving municipalities the power to ban and/or allow fracturing will in fact impede development," Wiseman said. "In Texas, municipalities have relatively extensive authority to regulate oil and gas development, including fracturing, yet there is a great deal of development moving forward. Giving municipalities some control over oil and gas development allows the governments that bear the brunt of the impacts (road congestion and damage and localized spills and air pollution, for example) to have some control over those impacts."

Colorado, Pennsylvania and Ohio have been relatively aggressive in updating regulations and expanding enforcement, but all three states have attempted to limit local control over oil and gas operations, failing to address certain localized impacts experienced by municipalities, Wiseman said.

In Pennsylvania, for example, the battle went to court. In Pennsylvania HB 1950 (Act 13), the state preempted local regulation of most oil and gas activity but implemented a variety of state laws intended to enhance environmental protection, Wiseman said. The Pennsylvania Supreme Court held that the preemption portion of Act 13 was unconstitutional in the Robinson Township case.

Preemption is an issue often heard in reference to New York and fracking. New York has a statewide moratorium on fracturing while the health department studies its effects, but some towns have used zoning ordinances to ban hydraulic fracturing even if the state moratorium is lifted. An energy company brought suit, and the State Court of Appeals has ruled that towns do have the authority to ban fracturing through land use regulations.

Preemption itself is really a technical issue that only legal scholars are typically interested in, but it's being used as a tool in the fracking battle, said Erica Levine Powers, a land use and environmental lawyer and co-editor of *Beyond the Fracking Wars: A Guide for Lawyers, Public Officials, Planners and Citizens*.

Regulations that affect fracking

The aspects of fracturing activities that are regulated vary from state to state, but some of the general types of regulations include, according to Wiseman:

- Requirements that the well casing be pressure-tested prior to fracturing to show that it can withstand the maximum pressure that will be placed on the well prior to fracturing;
- Chemical disclosure;
- Prohibitions on the use of diesel fuel or benzene, toluene, ethylbenzene or xylene;

- Specific allowances for the reuse of flowback water for other fracturing jobs;
- Requirements that operators describe where they intend to withdraw water for fracturing and report water use—source, quantity, rate of withdrawal—after fracturing; and
- Requirements that operators submit a notice of intent prior to fracturing and/or notify the state regulatory agency so that an inspector can witness the fracturing operation.

The requirement that companies disclose fracturing chemicals might be the most common type of regulation being implemented recently. Some states require disclosure of chemicals anticipated to be used as well as those actually used, Wiseman said. Others only require post-fracturing disclosure.

Some states—Montana, Oklahoma, Texas, Pennsylvania, North Dakota, Colorado, Louisiana and Mississippi—are requiring operators to use FracFocus, a national hydraulic fracturing chemical registry managed by the Ground Water Protection Council and Interstate Oil and Gas Compact Commission. The registry website allows the public access to reported chemicals used for fracturing within their area as well as explanations of the purposes different chemicals serve and the means by which groundwater is protected.

In addition to these direct rules on fracking activity, there are also many regulations that don't specifically apply to hydraulic fracturing but affect operations.

"Many states have changed, updated or added oil and gas regulations that do not directly address

Patterson UTI Energy's Rig 246 drills ahead on the Riedesel 01-02H pad site for Pioneer Natural Resources Co. in the Eagle Ford Shale play near Yorktown, Texas. *(Photo by Tom Fox, courtesy of* Oil and Gas Investor*)*

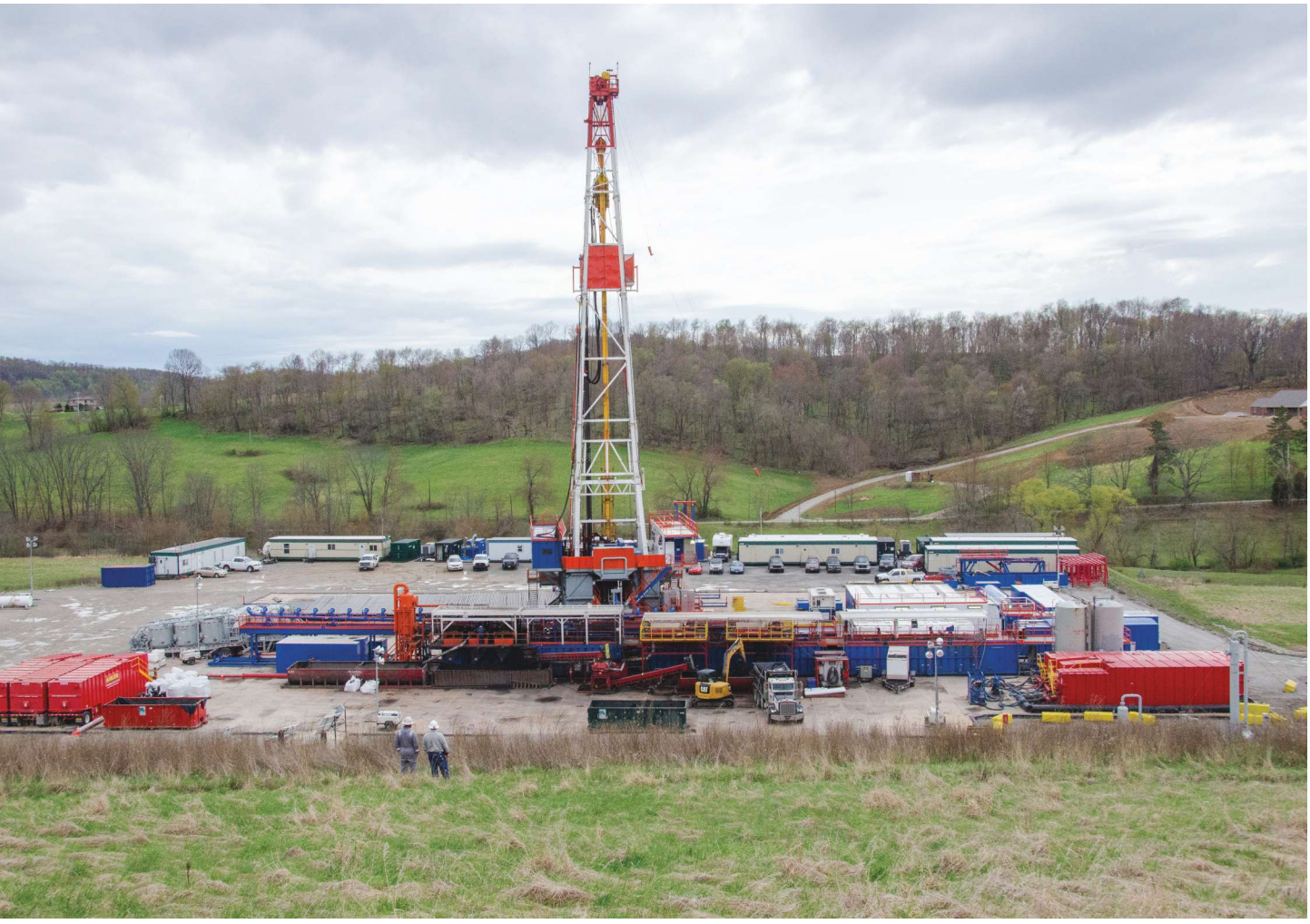
fracturing. Instead, these regulations address the fact that fracturing has enabled the drilling of thousands of new wells that otherwise would not have been drilled and are thus creating the need for new disposal options (more underground injection control wells for flowback and produced water, for example) and the need to address other impacts that accompany the drilling and fracturing of more wells," Wiseman said.

Other nonfracturing-specific regulations involve minimum required setbacks between wells or well sites and natural resources, like streams and wetlands, and drinking water, and updated requirements for the lining of surface pits and/or requirements that closed-loop systems be used, Wiseman said.

Best practices role

Though many nonindustry groups call for greater regulation of hydraulic fracturing across the board, many areas that aren't specifically regulated might be addressed by best practices. Best practices are defined by the Shale Gas Production Subcommittee of the Secretary of Energy Advisory Board as "industry techniques or methods that have proven over time to accomplish given tasks and objectives in a manner that most acceptably balances desired outcomes and avoids undesirable consequences."

These guidelines, though not mandatory, are in the best interest of the industry to develop and implement when applicable to the situation, but Powers said, the industry is concerned that codifying these best practices into regulation would harm innovation.



Patterson-UTI Rig 349 drills the Big Daddy Shaw-14H well targeting the Marcellus for Rice Energy in Washington County, Pa. *(Photo by Glenn Kulbako, courtesy of* Oil and Gas Investor*)*

For example, a method for processing frack water for reuse could become a best practice, but the industry would rather not have regulations to dictate specifically that a certain piece of equipment must be used in processing or that there is only one way allowed to process frack water. The industry argues this would cramp innovation; it would take a long time for new technical procedures to be passed into regulation and their use allowed. "The drilling technology is rapidly evolving, so there is understandable concern lest a specific technology becomes a regulatory requirement," according to the section of *Beyond the Fracking Wars* authored by Powers.

On the other hand, Powers said, there are areas where best practices might not be effective and regulation is needed. In boom areas especially where so much fracturing activity is going on, companies might make mistakes or unintentionally cut corners. Casing the well, for example, is a technical process that many groups believe would be better managed with regulations than best practices with a state enforcement mechanism within sectors to test as the well is being drilled to ensure the casings are strong enough.

The American Petroleum Institute, a national trade association, has best practices on many aspects of hydraulic fracturing available to the industry. Other groups, such as the Center for Sustainable Shale Development, which focuses on shale development in the Appalachian Basin, are working with energy companies and environmental groups to develop performance standards and certifications.

State fracking roundup

Since each state has its own policies, problems and public opinion wars, the regulatory issues in each vary widely. Here are some of the highlights of what's going on regarding regulations in the states where fracturing activity is happening or being discussed in depth.

Texas

Texas is generally regarded as a frack-friendly state with activity booming in the Barnett, Eagle Ford and Permian. But that doesn't mean communities aren't concerned.

Many municipalities in Texas have passed oil and gas ordinances that address some of the environmental impacts of fracturing and imposed other restrictions. The city of Dallas, for instance, has requirements for the use of tracers in fracturing. In 2013, the city also passed a restrictive natural gas drilling ordinance, which prohibits drilling within 1,500 ft of homes, schools, churches and other protected sites—a move that effectively bans drilling in the city.

Denton, also in North Texas, will be letting its voters decide whether to ban fracking altogether on the November ballot. Already in 2013, the city upped its setback requirements from 1,000 ft to 1,200 ft of homes, schools, parks and hospitals.

The state of Texas has not revised many regulations recently, though it has passed a relatively comprehensive chemical disclosure law and recently updated its casing regulations, Wiseman said.

The Hydraulic Fracturing Disclosure Rule requires Texas oil and gas operators to disclose chemical ingredients and water volumes used in hydraulic fracturing treatments on the FracFocus website, according to the Railroad Commission of Texas, the state's oil and gas regulating body.

Texas has requirements for studying UIC wells and earthquakes that might be caused by them. It also has updated fines and penalties for repeat violators in the state, Wiseman said.

The state requires permits for surface water withdrawals but not for groundwater.

Hydraulic fracture flowback fluid and the formation water that is produced with oil and gas, must be disposed of "in a manner that will not cause or allow pollution of surface or subsurface waters."

The legislature has suggested that it might introduce legislation that could incentivize the recycling or reuse of flowback water, Wiseman said.

Pennsylvania

As mentioned above, parts of Pennsylvania's Act 13 in 2012 were contested by local authorities. The state Supreme Court ruled that portions of the law dealing with restrictions on local zoning violate Pennsylvania's constitution. The portions struck down called for statewide rules on oil and gas to pre-

empt local zoning rules and required municipalities to allow oil and gas development in all zoning areas, rules that the justices said violate the Environmental Rights Amendment of the state constitution. Lawyers involved with the case said the decision does not mean towns can zone out oil and gas development entirely, State Impact reported.

The court also ruled a section of Act 13 unconstitutional that would have allowed the Department of Environmental Protection to grant waivers for setback requirements from water sources.

State laws include the Water Resources Planning Act, which requires anyone withdrawing more than 300,000 gal of water over a 30-day period to register their water withdrawal. The state requires a water management plan covering the full life cycle of the water used, including the location and amount of the withdrawal and an analysis of the impact of the withdrawal on the body of water from which it came, according to a review by State Review of Oil & Natural Gas Environmental Regulations.

Pennsylvania also requires the disclosure of the percentage by volume of each additive in the stimulation fluid.

Unconventional well operators must prepare and implement a plan for the control and disposal of fluids, residual waste and drill cuttings that identifies the control and disposal methods and practices. Hydraulic fracturing waste characterization requirements are provided through the residual waste program implemented by the Department of Environmental Protection Bureau of Waste Management.

New York

New York is a battlefield for both legal and political fracking fights.

In Wallach v. Town of Dryden and Cooperstown Holstein Corp. v. Town of Middlefield, the courts found that the zoning laws prohibiting all oil and gas exploration in the municipalities were valid. Essentially, they said the state law doesn't expressly preempt or take away the authority of the municipalities to regulate oil and gas production activities through zoning laws.

These local bans are unnecessary, however, unless Gov. Andrew Cuomo lifts the statewide moratorium, a decision he's been delaying. A decision was due by Nov. 29, 2012, but because a report by the state's health department wasn't completed, the administration missed the deadline. In February 2013, the administration missed another deadline. In December 2013, the report still wasn't done. Now many people, both pro-industry and anti-fracking, believe Cuomo is merely delaying the decision for political reasons. He has indicated he won't make a decision before the gubernatorial election in November.

> **"THE DRILLING TECHNOLOGY** is rapidly evolving, so there is understandable concern lest a specific technology becomes a regulatory requirement."
>
> —*Erica Levine Powers, co-editor of* Beyond the Fracking Wars: A Guide for Lawyers, Public Officials, Planners and Citizens

Colorado

The state of Colorado is butting heads with local authorities over who can control oil and gas development. The city of Longmont passed a ban on fracking in 2012, and in November 2013, four more communities—Lafayette, Broomfield, Boulder and Fort Collins—passed bans or moratoria. The Fort Collins moratorium was overturned by a judge, and the Colorado Oil and Gas Association is proceeding with lawsuits against Lafayette and Longmont.

Fracking measures that were set to be on the November ballot were removed by a compromise made between the measures' supporters. Measures dropped include requiring drilling rigs to be set

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back 2,000 ft from homes; strengthening local control by adding an environmental bill of rights to the state constitution; withholding state oil and gas revenue from communities banning drilling; and requiring fiscal impact notes for all initiatives, according to *The Denver Post*.

In 2008, Colorado made a relatively comprehensive revision of its oil and gas rules, stating in its Statement of Basis, Specific Statutory Authority and Purpose that "These rules are promulgated to protect public health, safety and welfare, including the environment and wildlife resources, from the impacts resulting from the dramatic increase in oil and gas development in Colorado."

Colorado has implemented higher fines for many offenses and updated enforcement priorities at well sites by direction of the governor, Wiseman said.

The Colorado Oil and Gas Conservation Commission requires operators to inventory chemicals kept at well sites during drilling, completion and workover operations, including hydraulic fracturing, with exceptions made for trade secrets.

Regulations impose mandatory setbacks, baseline sampling and other enhanced environmental protections on oil and gas development occurring near sources of public drinking water.

Colorado requires collection of baseline surface water data consisting of a predrilling surface water sample collected immediately downgradient of the oil and gas location and follow-up of surface water data consisting of a sample collected at the same location three months after the conclusion of any drilling activities, operations or completions, according to ALS, a testing services provider. Operators must use EPA-approved analytical methods for drinking water, and analyses must be performed by laboratories that maintain state or nationally accredited programs.

Groundwater protection rules make operators sample nearby water wells both before and after drilling activities.

California

Last year, a judge stopped the federal Bureau of Land Management (BLM) from granting leases on public land in California finding that the BLM violated the National Environmental Policy Act by failing to take the necessary "hard look" at the impact of fracturing. In August 2014, however, after a report came out from the California Council for Science and Technology saying that fracking in California is not poisoning air or water or increasing risks of earthquakes, the BLM announced it would resume oil and gas leasing for fracturing on federal land in California in 2015.

Wide-reaching fracturing regulations are scheduled to take effect in July 2015, though they still must be finalized by the Department of Conservation. The proposed rules include requirements such as mandating that operators must provide at least 30 days advance written notice to landowners and neighbors within 1,500 ft of the well before fracturing and they must disclose fracking chemicals.

Ohio

The Ohio SB 315 bill was passed and signed into law in 2012 to deal with expanding hydraulic fracturing activity. Even though the Ohio Department of Natural Resources (ODNR) called the law one of the nation's toughest regulatory frameworks at the time, several communities in Ohio are taking it a step farther and have banned fracking or are voting on bans. Broadview Heights and Oberlin have passed community bills of rights to ban the activity, Kent citizens will vote on a bill in November, and other community activists are trying to get enough signatures to get similar bills put on their own ballots, *The Columbus Dispatch* reported.

Industry groups oppose these measures saying that the authority over oil and gas operations falls to the state. The Ohio Supreme Court has heard a case involving Munroe Falls passing zoning restrictions that prevent oil and gas operations there, but it hasn't ruled on it as of press time.

SB 315 requires chemical disclosure during all aspects of the initial drilling process and during hydraulic fracturing while adhering to trade secret/proprietary laws. ODNR can request proprietary chemical formulas to conduct an investigation or in response to a spill.

Ohio has instituted more requirements for UIC wells (such as monitoring pressure), made more requirements for operator liability insur-

A rig worker shields himself from the water drop as the cleanout team drills out plugs at RSP Permian's Keystone 1003 targeting Lower Spraberry in Ector County, Texas. A construction boom is taking place in Midland and Odessa, where drilling rigs now share space with residential and business developments. *(Photo by Tom Fox, courtesy of* Oil and Gas Investor*)*

ance (increased the requirements by five times in rural areas and nearly doubled in urban areas), and implemented mandatory daily fines, Wiseman said.

The state generally requires oil and gas companies to sample water wells within 1,500 ft of a proposed horizontal well in both urban and rural areas before a well is drilled. Operators must disclose the results in permit applications.

Brine and flowback water must be sent to an ODNR-permitted Class II injection well.

The state requires well operators to disclose the proposed source of water used in the well drilling and fracturing process when applying for a permit, including the rate, volume and source of water that will be used for production operations.

The state requires registration and reporting of water withdrawals that are more than 100,000 gal/d but doesn't require permits unless withdrawal is greater than 2 MMgal/d.

West Virginia

West Virginia's legislature passed new hydraulic fracturing rules in 2011.

The city of Morgantown enacted a ban on hydraulic fracturing in June of that year, but a state court said the West Virginia Department of Environmental Protection has the exclusive authority to regulate oil and gas extraction in the state.

A bill was introduced in the state senate in February 2014 that would allow landfills to accept unlimited amounts of solid waste from hydraulic

fracturing, excepting the practice from the rules that limit landfill intake to 10,000 or 30,000 tons a month. It hasn't been passed into law.

The state requires registration and reporting of water withdrawals. In 2011 legislation, West Virginia introduced water management plan requirements for withdrawals of more than 210,000 gal/month that documents the source of the water withdrawal and demonstrates that its impact will be minimal.

Underground injection, recycling of flowback fluid and (to a limited extent) disposal at a centralized treatment plant are options. Underground injection falls under EPA UIC regulations and there are no additional testing regulations specific to shale/fracking operations, according to ALS.

Oklahoma

Oklahoma's increased earthquake activity has been a concern for citizens, and while scientists mostly agree that hydraulic fracturing itself is not causing the activity, some deep wastewater disposal wells might be at fault. The Oklahoma Corp. Commission (OCC), which regulates oil and gas activity, works with the Oklahoma Geological Survey to respond appropriately when seismic events might be connected to disposal wells.

The OCC has adopted the "traffic light" system recommended by the National Academy of Sciences, which designates an area or disposal well operation as a red, yellow or green light based on the level of concern it poses. It then approves permits or applies safeguards accordingly.

The OCC also has approved new rules to increase reporting of the volume and pressure of many disposal wells and to increase testing requirements.

For fracking operations, operators must submit information on the chemicals used in a hydraulic fracturing operation within 60 days after the conclusion of the fracking operations to the OCC or to FracFocus.

Permits for streamwater use must be obtained from the Oklahoma Water Resources Board (OWRB). In Oklahoma, groundwater is considered private property that belongs to the overlying surface owner. Operators can get groundwater permits from the OWRB; provisional temporary permits allow use for up to 90 days and do not require public notice and hearing.

Arkansas

The Arkansas Oil and Gas Commission requires all hydraulic fracturing fluids, additives and chemical constituents operators plan to use and actually use to be disclosed to the commission.

The state has general rules for handling and disposing of flowback fluids but has put moratoria on the use of UIC wells in some areas of the state.

North Dakota

North Dakota's hydraulic fracturing is regulated by the Department of Mineral Resources' Oil and Gas Division.

The state has specific requirements for hydraulic fracturing stimulation performed through a frack string run inside the intermediate casing string and for hydraulic fracturing stimulation performed through an intermediate casing string. These involve things like the specifications of pressure monitoring and casing evaluation.

Companies must disclose the chemicals they used in the stimulation via FracFocus within 60 days after a hydraulic fracture stimulation is performed.

Other rules regulating oil and gas development in general apply to hydraulic fracturing activities as well.

Wyoming

The Wyoming Oil and Gas Conservation Commission (WOGCC) requires chemical disclosure, but there has been litigation over the WOGCC's use of trade secret exemptions.

In March, a rule went into effect requiring operators to submit a groundwater baseline sampling, analysis and monitoring plan with an application for a drilling permit. The groundwater monitoring program will consist of initial baseline water sampling and testing followed by a series of subsequent sampling and testing after setting the production casing or liner.

Montana

Operators must disclose well stimulation fluids to the Board of Oil and Gas or via FracFocus.

The state has requirements for well evaluation prior to fracture stimulation based on the fracturing method to be used. ■

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