The Fundamentals of Frac Sand Logistics
Sand is critical to North America’s onshore oil and gas production. Much of U.S. oil and gas comes from tight, low-permeability shale, sandstone and carbonate rock that must be hydraulically fractured to stimulate fluid flow. Sand is the proppant that keeps fractures open and allows these so-called unconventional wells to produce valuable hydrocarbons.

But not any sand will do. Frac sand is a specialized product that must meet very specific standards for many different characteristics including crush strength, purity, roundness and size.

By the time it is blended into the hydraulic fracturing fluid and pumped downhole, frac sand has been selectively mined and processed, moved in very large quantities to and within active oil and gas regions, and closely managed at the wellsite using specialized equipment and personnel.

The effectiveness of frac sand is central to well productivity, and efficiency of proppant logistics is key to controlling well cost. Overall success depends on the availability of the right sand, its timely and reliable transport to the wellsite, sufficient storage in silos or containers and delivery to the blender according to the frac design.
The boom in U.S. hydrocarbon production depends on mining millions of tons of sand and pumping it back into the earth. Packed into the network of tiny cracks created by hydraulic fracturing, frac sand holds fractures open to create the conductivity necessary for oil and gas to flow from low-permeability rock. In 2017, more than 60 million tons of frac sand were used, and in 2018, that total is estimated to have surpassed 100 million tons.

Propping the Fracture

Hydraulic fracturing is a high-pressure pumping process that has been used for more than 60 years to enhance oil and gas production. Today, it is a key enabler in improving production from low-permeability reservoir rock. This unconventional resource, typically drilled with long horizontal wells, is much more difficult to produce than conventional wells that typically don’t require specialized methodologies.

While there are many fracturing techniques, one of the oldest involves mixing sand with viscous water and pumping the slurry down the well and into the surrounding formation at pressures that may reach 10,000 psi. High-pressure pumping fractures the rock, and the viscous water carries the sand deep into the cracks. Once pumping has stopped and pressure is released, fluid is returned to surface, leaving sand behind to prop the fractures open. The spaces between sand grains provide permeability needed to conduct oil and gas from the formation to the wellbore so it can flow to the surface. The degree of this conductivity is determined by fracture width and permeability of the proppant matrix. Permeability is a function of size, uniformity, roundness, strength and purity of frac sand. Creating the desired permeability and conductivity is a highly engineered process of matching reservoir characteristics to proppant selection.

Growing Demand for Sand

Sand is the original proppant. Hydraulic fracturing has since developed other types of proppants including resin-coated sands and synthetic ceramics for specialty applications. Raw frac sand makes up the majority of demand and its use has rapidly increased. In 2012, sand made up about 80% of the proppant market, and in 2017 it reached about 97%. Sand is most commonly used because it is an economical source of large proppant quantities with characteristics suitable for the majority of U.S. well completions.

Unconventional wells have caused massive growth in the volume of frac sand being used. In 2010, about 27 million tons of industrial sand and gravel were mined in the U.S., according to U.S. Geological Survey (USGS). Of that, just 27% was used in hydraulic fracturing operations. In 2017, frac sand production had grown to 63% of a total 100 million tons valued at $3.5 billion, and total production continues to increase.
Sand-Intensive Hydraulic Fracturing

Demand growth is driven by increasingly sand-intensive techniques used to complete unconventional wells. While conventional hydraulic fracturing in decades past measured sand in thousands of pounds per well, modern methods can require millions of pounds of proppant for each well.

Between 2012 and 2017, proppant intensity increased from a typical 4,500 ft lateral wellbore using less than 500 lb/ft of proppant to 7,000 ft and longer laterals using 2,000–5,000 lb/ft of proppant. A single well today typically consumes more than 15 million lb of sand delivered in hundreds of truckloads.

With higher volumes per well, sand costs have grown proportionally. Costs vary depending on such factors as sand quality and type, transportation and availability. With 2018 frac sand pricing ranging from about $25/ton for sales at the mine to $115/ton delivered in basin after transportation, proppant cost for treating a single well can approach $1 million.

As a portion of total well cost, it is a significant expense. A 2016 cost study by the Energy Information Administration (EIA) determined proppant costs make up about 14% of total costs for drilling and completing typical U.S. onshore wells.

The huge increase in the amount of proppant being used is straining traditional supply chains. Mining, moving and managing frac sand have historically been relatively discrete operations performed by multiple companies. Historically, pressure pumping companies have worked directly with the frac sand producers to purchase and distribute proppant for their E&P customers. But the large volumes of sand being used have put significant new demands on the logistical process of delivering sand from the mine to the wellsite. Logistics operations such as rail and truck transportation, regional transloading and storage, wellsite vehicle congestion, storage volume and footprint, and handling the sand at the wellsite have all become increasingly specialized to deal with the increasing inefficiencies of the sand tonnage. To reduce inefficiencies and assure adequate supply, some well operators with large completion programs are working directly with mines or acquiring their own mines.

The complexity, amount of sand involved and drive for cost reduction is resulting in the vertical integration of the sand supply chain. Integration combines traditionally separate mining, transportation and wellsite delivery to improve efficiency and safety, reduce costs and increase surety of sand supply for service companies and well owners.

In addition, the need for higher volumes at lower total cost is producing changes at the source. Mine location, type of sand, size of the deposit, and access to road and rail infrastructure increasingly are important factors in mine viability. Reducing transportation expenses and logistical complexity has led to establishing mines as close as possible to oil and gas activity. For example, in West Texas, high levels of activity in the Permian Basin and suitable sand supply meeting the stringent standards for proppant have led to the development of in-basin mines.

Cost reductions and logistical efficiency also are being sought through development of specialized equipment and processes for mining, loading, transporting, inventory management, and delivery to the wellsite and blender. Efforts to achieve greater efficiency in rail and trucking operations are most visible with mile-long unit trains, specialized last mile sand containers, large-volume silos and conveyor loading systems. Importantly, development of these specialized systems is curtailing exposure of people and equipment to the risks posed by silica dust.
Specialized Sand

Frac sand is not just any sand. Without adherence to strict industry standards, proppant utility in achieving the designed conductivity is severely constrained.

Frac sand consists of grains of quartz composed primarily of silica. Silica sand characteristics vary widely, and while there are many sand sources in the U.S., much of it is unsuitable for use as proppant. Instead, it is used in everything from glass making to swimming pool filters and golf course sand traps.

Frac sand is highly specialized silica because it plays a critical role in the design of the hydraulic fracturing treatment. The standards and specifications are established by the American Petroleum Institute (API) and the International Organization for Standardization (ISO). These organizations describe sand in terms of grain size, crush resistance, roundness and mineralogy.

**Grain size** and homogeneity are important to many aspects of a hydraulic fracturing treatment design. Consistent size is important to maximizing the space between the sand grains whereas a mix of sand sizes can reduce permeability. Proppant size relates to fluid system viscosity and its ability to transport sand into the fractures; this in turn affects pressure and horsepower requirements. Proppant size also contributes to crush resistance and affects embedment in the fracture walls, which reduces fracture width. Both are key to conductivity. Sand size is specified for the application depending on factors including depth, pressure, temperature and rock hardness.

Grain size is determined by a sieving method to produce a range of sieve cuts or “meshes.” There are many different sizes. For example, two common sand meshes used in the Permian Basin are 40/70 and 50/140 (often referred to as 100 mesh).

These numbers refer to a maximum and minimum grain diameter. For example, a 40/70 mesh means that 90% of the sand is small enough to pass through a 40-mesh screen and large enough to not pass through a 70-mesh screen, defined as the number of holes in one square inch of the screen.

**Crush resistance** is central to propping open the fracture and minimizing the production of fines that can reduce permeability and conductivity. API requires sand to withstand stress of 4,000–6,000 psi. Generally, smaller grains have higher crush strengths and are specified for deeper wells. Testing applies compressive strength to the sand grain. When crush strength is exceeded, the grain breaks and produces pieces, or fines. The fines are weighed as a percent of the grain size to calculate a k-value that designates the level of crush resistance. High-quality sand with an 8K value means that at 8,000 psi, it produces no more than 10% fines by weight.

**Roundness and sphericity** are important to attaining the permeability needed for good fracture conductivity. While a variety of shapes results in tighter packing and less permeability, similar size round grains create consistent permeability that provides greater conductivity. This has traditionally been a visual assessment done with a microscope, but increasingly roundness is calculated by multiple measurements and imaging analysis.

**Mineralogy** is concerned primarily with sand solubility and turbidity. Treating acids and formation fluids requires proppant to have a strong chemical resistance to dissolving. While pure silica is very resistant to acid, other minerals in the grain may be soluble. Sand with high silica content is very desirable. To determine mineral content of the grain, it is exposed to acid, and the resulting weight loss is measured.

Turbidity describes the presence of impurities such as clay and silt that are mixed with sand grains. This is a quality issue addressed by washing during processing. These impurities can also be introduced by contamination during transport.
Testing and Quality Control

Sand standards are implemented through extensive laboratory testing and quality control measures. To ensure sand specifications through the supply chain, testing may be done at production facilities, terminals and the wellsite. Inventory control and visual inspection of train cars, silos and trucks may be conducted to prevent contamination, either from foreign debris left in containers or from intermingling various sand sizes.

Health, Safety and the Environment

Sand presents HSE challenges at many steps from the mine to the well. In mining operations, the surface impact on plants and animals must be studied and appropriately addressed, along with reclamation planning.

Water standards are key factors in mine operations. Sand processing involves washing the grains to remove impurities which produces sediments. Settling ponds and water recycling processes are used to ensure water quality.

Silica dust produced from excavation, processing and handling is subject to air quality regulations on atmospheric particulates and must be managed. Current OSHA permissible exposure limits (PEL) restrict worker exposure to 50 micrograms of respirable crystalline silica per cubic meter of air, averaged over an eight-hour day. Specialized equipment is used to minimize the creation of dust and contain it with enclosed handling systems.
Sand-intensive hydraulic fracturing is putting new pressures on frac sand mining. Frac sand demand has grown from 7 million tons in 2010, about 27% of total U.S. sand and gravel production, to 63% of the total 100 million tons produced in 2017, according to USGS figures. In 2018, demand for frac sand alone is estimated to have surpassed 100 million tons. The U.S. is the world’s largest producer of industrial sand and gravel, and frac sand. It is also the world’s largest consumer of frac sand.

Mining Frac Sand
In a 2016 report, USGS counted more than 40 U.S. companies involved in mining transporting, processing and distributing frac sand. Industry figures show the top five sand producers account for 40% of the total production.

Frac sand is mined in many states, including Wisconsin, Minnesota, Michigan, Illinois, Texas and Oklahoma. Prior to 2017, the great majority came from traditional resources of highly pure silica sand deposits in the upper Midwest region. In 2014, the region contributed approximately 70% of frac sand production. Large amounts of near-surface Northern White and Ottawa White deposits have made the sand types synonymous with high-quality frac sand.

That dominance is changing as sand volumes and higher transportation and handling costs drive the development of in-basin and regional mines.

In central Texas, sands are mined for “Brady” and “Brown” frac sand, and in Oklahoma frac sand mined from the Oil Creek formation supports south central Oklahoma oil province (SCOOP) basin activity. Mines in Missouri and Arkansas transport sand downriver to Texas and up river to Appalachia’s Marcellus and Utica shales. In 2017, more than 20 new mining sites were announced, and several began development, opening in the second half of 2017 through the beginning of 2019 in the Permian basin. Permian in-basin sands are mined from wind-blown eolian sand dunes present in West Texas. In 2018, new mines in Texas, Oklahoma and other regions contributed more than 40 million tons of sand to the market.

Permian Basin activity accounted for about 50% of market demand in 2018 and is expected to grow. The demand for frac sand has led to quickly expanding in-basin mining operations. Industry experts estimate that mines in the Permian Basin could cut transportation costs by 40%.

What Makes a Good Mine?
Factors that contribute to good frac sand mines include sand reserve size, quality and grain size distribution, low geological overburden, geographical location and access to transportation infrastructure.

Because it is a key component of a precisely engineered hydraulic fracturing treatment, silica sand must meet strict API standards for size, roundness, crush resistance, acid solubility and turbidity. Laboratory testing is performed to assure compliance.
Beyond these standards, the mine’s commercial viability is affected by reserve size and its reliability as a resource for oil and gas operations. At production rates of a million tons or more per year, a good mine may have a reserve that will last for decades.

Sand grain size and distribution are also important to mine selection. Frac sand is generally specified in four basic sieve sizes. The size of sand grains in the deposit must meet market demand in sufficient quantities.

It’s also important that the sand deposit be near the surface to reduce overburden removal costs. The best sand resources are loose, unconsolidated, poorly cemented sand that is more easily excavated and does not require blasting or crushing operations that can fracture sand grains and reduce roundness.

Proximity to demand and type of transportation is increasingly important to reducing cost. Class 1 rail access is critical for many mines, especially when they are located at a distance from oil and gas activity. Barge transportation is also used in some instances. The genesis of in-basin mines in the Permian Basin and elsewhere is reducing transportation costs with direct truck delivery from the mine to the wellsite.

Water access also is important to a mine. Frac sand standards require the sand to be thoroughly washed to remove clay, silt and other impurities. These operations require large volumes of water along with recycling methods such as settling ponds that may be subject to permitting regulations.

**HSE Considerations**

Low-impact mining practices typically are implemented for environmental stewardship, community relations and compliance with regulatory standards. Considerations include the mine’s impact on plants and wildlife. Water use may be regulated, and air quality standards may affect dust emissions created by excavation.

Before mining begins, environmental impact studies must be conducted to identify any risks and guide protection and reclamation. These efforts may include fencing and crossing tunnels, wildlife management and programs to maintain streams, lakes and wetlands.

**Excavation and Processing**

The mining process begins by removing topsoil to expose the sand deposit. Excavation and processing procedures are determined by whether the deposit is windblown and naturally disaggregated, or consolidated sandstone. Excavation is typically done using backhoes and front-end loaders. Disaggregated sand that does not require crushing is trucked directly to stockpiles prior to washing.

Purpose-built processing operations are required to meet strict frac sand specifications. Because the process washes the sand, facilities are described as wet processing versus dry processing operations. They are further defined as single-cut or multi-cut operations depending on their capability to handle and produce different sand grain sizes.

Preparing frac sand is an integrated process that involves multiple steps of washing, drying and sorting. This generally involves initial washing, removal of impurities, and sorting, followed by drying and fine sorting of the final product. Some mines do the finishing processes onsite, while others transport sand offsite for drying and sorting at additional cost.

The washing and separation process takes place in the wet plant and may include attrition scrubbers to break up materials; density and centrifugal separators to separate sand sizes, impurities and
water; screw washers to sort out heavier materials; and dewatering screens. Thickeners and clarifiers may be used to recover process water and remove fines. Water recycling may use filter presses that reduce or eliminate the need for settling tanks.

The final drying and sorting steps take place in the dry plant and are critical to frac sand quality. Drying prepares the sand grains for size screening, and makes it easier and less costly to transport and use. Rotary drums are commonly used to provide uniform, high-volume drying. Large rotary dryers can process 300 tons of sand per hour. Temperatures are controlled to optimize drying and avoid breakdown. Water vapor from the process may be passed through cyclone separators to remove fine dust. A high-temperature bag house may also be used to remove fine particulates.

Sand screening and sizing are performed in various ways. Typically, tumbler-screening machines provide fine screening of the dry sand and can grade multiple particle sizes with a high degree of accuracy.

The finished sand product is stored according to grain size in silos equipped to load rail cars or trucks.
Each year, millions of tons of highly specialized frac sand are moved from the mine to often-distant wellsites. A critical component in oil and gas well hydraulic fracturing treatments, the volume and strict specifications for silica sand present a significant and costly logistical challenge. Moving sand by train, barge and truck has become a highly specialized service with mile-long unit trains, 300-acre storage and transfer facilities, and fleets of trucks and equipment to deliver sand to the wellsite.

From Mine to Wellsite
The frac sand journey begins at mines scattered across Wisconsin, Minnesota, Illinois, Arkansas, Missouri, Oklahoma, Louisiana and Texas, as well as Canada. The produced sand must be loaded, transported and delivered to oil and gas operations in equally scattered basins and plays.

In the northeast, activity in the Appalachian Basin’s Marcellus and Utica shale formations require frac sand be transported to Pennsylvania, West Virginia and Ohio. North Dakota and Montana need sand to frac the Bakken shale; and in Oklahoma, it’s the Anadarko Basin’s SCOOP and STACK plays that drive demand. East Texas and Western Louisiana sand demand is driven by Haynesville shale activity while southwest of there, it’s the South Texas Eagle Ford play. In far West Texas and southeast New Mexico, the Permian Basin is the industry’s biggest market for frac sand.

Historically, mines in Wisconsin, Minnesota and Illinois have accounted for much of U.S. frac sand production. But the cost and logistics of moving millions of tons of sand from Wisconsin to the Permian Basin has led to many new mines opening in West Texas. Mines operating in Missouri, Oklahoma and other areas seek similar cost advantages in transportation.

Transportation Options
Sand from the mine is typically moved to transload facilities in active oil and gas regions. Transload facilities offload from railcars to store and transfer sand to trucks for transport to the wellsite. In some cases such as West Texas, in-basin mines developed to reduce transportation cost and logistics load directly to trucks and eliminate rail use.

Moving sand through this system is logistically complex due to high volume and rigorous product standards. Because frac sand is a highly specialized product produced in a variety of mesh sizes, it is critical that each prop-pant grade is not mixed or contaminated by other sands.
Logistics services monitor the entire process, tracking the specific sand shipment from origin point through transloading and delivery to the wellsite. Loading, moving, unloading and arrival time at the destination are key logistical concerns in maximizing efficiency and reliable delivery.

**Rail Transportation**

Rail transportation is the traditional workhorse for moving frac sand from the mine to the wellsite, although growing use of in-basin mines that can truck sand directly to the wellsite can eliminate this step in some basins. Rail services provide short- and long-haul capabilities through major networks such as Union Pacific in the West and Canadian National in the East, as well as many branch line providers and other Class 1 rail services. Rail services haul frac sand using small, covered hoppers that are gravity loaded from the top and unloaded through the bottom. Hopper capacity is approximately 100–120 tons. During the last eight years, the North American revenue-earning fleet has added almost 72,000 of these hoppers, a majority of which are driven by growth of oil and gas activity in shale basins.

Generally, rail cars are moved either in manifest trains with mixed cars and cargo, or as unit trains. Unit trains are large groups of rail cars dedicated to a single commodity. The train is assembled or disassembled at a single origin or destination point and is not broken up. Similar to the coal industry, unit trains are preferred for moving very large volumes of sand. A unit train is typically about 100–120 cars or more and may occupy 7,500 ft of track. In 2016, a 150 car unit train more than a mile long moved a record 19,000 tons of frac sand from Ottawa, Canada, to transload facilities southeast of San Antonio, Texas.

The large scale of unit trains maximizes volume to reduce freight expense. Unit trains minimize rail car and locomotive turn time to increase asset utilization. They also help optimize rail car origin and destination parings to ensure route efficiency and reduce transit times. But the size of a unit train is affected by many logistical issues such as mainline track capacity, transload locations and siding and car availability.
Barge Transportation

Sand also is moved by barge where opportunity and economics permit. Barge industry experts say total demand for barged frac sand is approximately 1 million tons per year. Barged cargo travels on the Mississippi and Ohio Rivers and intracoastal waterways. Mines in Missouri and Arkansas transport sand downriver to Texas and up river to Appalachia. These operations also require transload facilities, which in some cases may be shared by rail services.

Transload Facilities

At the end of rail and barge transport, transload facilities store sand and transfer it to trucks. In the past, transloading a small volume of sand was sometimes as simple as using mobile conveyor belts to transfer directly from rail cars to trucks. But transferring millions of tons of sand hauled by unit trains has resulted in dedicated transload facilities with proportionally large capacities.

Transload facility design considers many factors, including unloading facilities, equipment and rail car management, storage and discrete handling of sand grades, truck loading and road infrastructure.

Unit train facilities can be very large. Some of the largest are able to handle multiple unit trains, and may occupy hundreds of acres and require as much as 30,000 ft of track. The logistics of transload operation requires close synchronization of incoming train loads with outgoing truck loads. Train unloading depends on available silo space, which is dependent on outgoing truck volume.

Sand from rail cars is moved to large silo storage systems with capacities that routinely exceed 10,000 tons. The silo facilities feature extensive conveyor loading and unloading systems. As with all sand handling operations, silica dust exposure is closely managed with enclosed equipment and dust collection systems.
The massive amount of proppant used in hydraulic fracturing, along with wellsite size and location, present many “last mile” challenges for wellsite delivery. Typical wells use more than 5,000 tons (10 million pounds) of proppant that is transported to the wellsite in 25-ton truckloads, unloaded and stored for delivery into the hydraulic fracturing operation’s blender. Management of this complex, dynamic process focuses on four key areas: transportation to wellsite, storage and handling at the wellsite, safety and technology.

Managing Sand Variables

Last mile frac sand logistics must address many variables that affect hydraulic fracturing efficiency, execution and safety. Proppant volume and mesh size vary per well, and sometimes per stage. Frac sand delivery must accurately and reliably support the frac design. Interruptions during an ongoing pumping operation create significant problems.

Close management of the entire last mile process is critical to job execution. Increasingly, technology for managing this complex supply chain includes specialized web-based and mobile applications and plays a vital role in ensuring successful orchestration of the process.

Trucking efficiency and reliability is vital, with many logistical considerations. Distance from the loading facility to the wellsite is important to cost and scheduling. Road infrastructure must support the heavy truck activity and provide ingress and egress from the wellsite. The size of the wellsite must accommodate hydraulic fracturing equipment, sand storage and conveyance equipment, and the uninterrupted arrival and departure of sand trucks.

At the wellsite, trucks are unloaded and sand is stored onsite in large, portable silos or smaller modular containers. With silos the sand is transferred pneumatically or via gravity-fed systems. Containers are simply removed from the delivery truck and staged at the wellsite, eliminating the need for silo storage.

During hydraulic fracturing operations, sand is delivered from silos or containers via conveyor belts to the blender equipment. This last leg of the sand delivery process directly supports the ongoing hydraulic fracturing treatment making consistent, reliable performance critical.
At every step in proppant logistics management, safety is a paramount concern. Controlling factors such as silica sand dust emission, road traffic and wellsite congestion are all factors in ensuring a safe process.

Successful management of last mile proppant logistics depends on the integration of transportation, storage and handling, safety, and technology.

**Transportation to the Wellsite**

Frac sand trucks for transport and delivery to the wellsite are loaded at regional transload or processing facilities located as close as possible to the job site. This is the case with facilities served by rail as well as in-basin mines where sand is loaded directly to the trucks. Rail system access constrains transload facility locations, while mine location affects in-basin trucking operations.

Paved and unpaved roads, difficult terrain, and general access to the location all affect trucking operations. The steady stream of trucks must be able to efficiently and safely enter the wellsite, unload and leave. Traffic congestion on roads and the wellsite can result in delays and high demurrage charges.

Key factors in wellsite congestion include unload time and volume of sand. To expedite the process, a variety of unload methods are employed. These involve specialized truck transport (pneumatic, hopper bottom and containers) and storage systems (silos and containers), supported by a complementary set of specialized off-loading and conveyor systems.

Pneumatic systems are one of the earliest and until recently were the most common methods of unloading high volumes of sand. Using pressurized trailers, these systems use air to transfer sand into storage silos.

The bulk trailer is connected with hoses to the silo and air pressure is used to transfer the sand. The transfer may take 45 minutes to an hour per truck. Some silo facilities are able to receive sand from multiple trailers at the same time, but this can increase the time needed to unload each truck.

Silica dust produced while “blowing” sand is a particular challenge, and special care is required to reduce air and dust escaping the system. Part of the challenge with these systems is sand breakage that degrades quality and produces fines that are detrimental to well conductivity and contribute to dust creation. Transferring sand via a conveyor belt helps reduce degradation. Container systems further mitigate the problem by eliminating the step of transfer to a silo.

Hopper-bottom trailers are unloaded by gravity and are similar to trailers used to haul grain and other dry bulk material. At the wellsite, trailers are unloaded by driving over a low conveyor belt and opening a bottom plate to dump the sand. The unloading takes about 10 minutes. Conveyor belt systems are used with hopper-bottom systems to load top-fill silos. Because they unload proppant via gravity, not pressurized air, hopper-bottom trailers produce less dust and do less damage to proppant than pneumatic systems. Covered belts and transfer points are also commonly used to minimize dust exposure.

Container transport systems are a recent innovation that makes the transport, delivery and storage elements of the process more fluid. The container approach is particularly well suited to single wells applications and where wellsite size and road conditions make silo-based systems logistically difficult.

As a method of transport, containers typically hold less sand per truckload than pneumatic and hopper-bottom trailers. However, instead of a single trailer filled with sand, modular containers are transported on special trucks in one- and two-container configurations. Instead of unloading sand into silos, the containers themselves are removed from the trailer and used as onsite storage.

Offloading containers at the wellsite is a relatively fast process compared to pneumatic systems, and comparable to hopper bottom unloading times. Trucks are typically on and off the wellsite in less than 10 minutes. Sand remains in the container until it is needed, helping speed the wellsite delivery process. Onsite truck time is
reduced and safety is improved by pull-through delivery that does not require backing up trucks, drivers exiting vehicles or connecting pneumatic hoses.

Modularity affords a great deal of flexibility in where containers can be placed. The easily configured footprint provides flexibility and mobility that are particular advantages on small and crowded wellsites, or completion designs requiring multiple proppant types.

**Storage and Handling**

Last mile proppant logistics are broadly defined by the size of the frac job and the size and location of the wellsite. Transportable vertical silos are used to store large volumes of sand with a minimal onsite footprint. They typically support multiwell and large-volume, high-rate frac treatments. Container systems move sand in portable bins and are favored for smaller frac jobs and where roads and wellsites present constraints. They also are used where greater flexibility in mesh sizes or proppant type are needed. Silos and containers each have a set of advantages for wellsite storage and handing that offer unique value in last mile proppant management.

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**Containers.** Because containers provide storage as well as transport, silos or other additional storage is not required. Containers enhance mobility and flexibility, and are favored for single well pads and where small wellsites and difficult roads make silo-based systems logistically difficult. Container systems do not require setup as do silo systems.

Delivery and storage in discrete loads means containers can easily accommodate wellsite footprint requirements. They also quicken unloading and reduce wellsite truck congestion.

Containers improve inventory management and reduce the potential of product contamination and stranded product. They are sometimes bar-coded to improve tracking. Precise delivery to the blender is also enhanced by improved mix flexibility at the blender when changing sand sizes.

Containers also preserve proppant integrity because less handling is required compared to pneumatic and hopper-bottom systems, limiting sand degradation and silica dust creation. Using containers and fully contained conveyor systems can reduce silica dust emissions by 90% compared to pneumatic systems. During hydraulic fracturing operations, sand from containers is unloaded onto conveyor belts that deliver sand to the blender before it is pumped downhole. Specialized conveyor technology may allow multiple containers to be positioned over the conveyor to speed unloading.

**Silos.** Portable, vertical proppant silos provide high-volume frac sand storage while minimizing wellsite footprint. They are typically used for high-sand-intensity treatments and where multiwell pads require large volumes of sand. They are available in a range of bulk storage capacities ranging from approximately 150 tons to 280 tons per silo. Multiple configurations with six or more silos can significantly increase onsite sand storage.

Silos must be erected onsite prior to being filled with proppant. Traditionally this requires a crane, although advanced trailering systems with built-in lift systems provide faster, safer silo erection.
Silos can be loaded pneumatically or by conveyor. Pneumatic loading operations typically accommodate multiple trucks to increase offload rates but can take longer and result in more silica dust and sand degradation versus conveyors. Gravity fed offload systems unload trucks without using pneumatics. Advanced drive-over conveyor systems quickly unload multiple trucks and transfer sand to the silo using a swivel discharge chute to top-fill multiple silos. These articulated conveyor systems pivot quickly between silos to speed loading. Covered and contained, the conveyors minimize the creation and exposure to silica dust compared to pneumatic systems.

**Safety**

Safety in last mile proppant logistics involves large numbers of personnel, vehicles and equipment working in close proximity under hazardous and often difficult conditions. Large numbers of trucks present noise level and traffic safety issues, so efforts are made to reduce traffic volume, simplify and quicken unloading, and cut time on location. Concerns include truck and driver movement on location, such as backing up to offloading positions and drivers exiting the trucks. High volume truck traffic also contributes to wellsite noise levels from frac-spread equipment, sand transfer and other operations. With sand transfer, pneumatic operations in particular generate a great deal of noise and dust pollution.

Silica dust is a major safety focus. During the entire process from truck unloading to blender delivery, large volumes of sand may produce silica dust that presents a risk to health and equipment if not properly managed and contained.

Exposure is regulated. Occupational Safety and Health Administration (OSHA) permissible exposure limits (PEL) restrict worker exposure to 50 micrograms of respirable crystalline silica per cubic meter of air, averaged over an eight-hour day. Respirable crystalline silica is the portion of crystalline silica that is small enough to enter the gas-exchange regions of the lungs if inhaled; this includes particles with aerodynamic diameters less than approximately 10 micrometers (μm). Specialized sand handling equipment is used to minimize the creation of dust and contain it with enclosed systems.

Silica dust also can be ingested by equipment, where it causes wear resulting in shorter service life and higher maintenance costs.

National Institute for Occupational Safety and Health (NIOSH) has identified seven primary sources of silica dust exposure during hydraulic fracturing operations:

- Dust ejected from thief hatches (access ports) on top of the sand movers during refilling operations while the machines are running (hot loading)
- Dust ejected and pulsed through open side fill ports on the sand movers during refilling operations
- Dust generated by on-site vehicle traffic
- Dust released from the transfer belt under the sand movers
- Dust created as sand drops into, or is agitated in, the blender hopper and on transfer belts
- Dust released from operations of transfer belts between the sand mover and the blender
- Dust released from the top of the end of the sand transfer belt on sand movers
Dust mitigation takes many forms. Covered conveyors and enclosed transfer points prevent dust from escaping during the transfer process from delivery truck to silos, and from sand storage to the blender. Container and top-fill silos systems significantly reduce dust by eliminating pneumatic sand transfer. For example, containers can cut silica emissions by more than 90%. New technology associated with silo systems and combined with hopper-bottom trailers eliminates the need for pneumatics when transferring from truck to silo. Enclosed operator cabs on equipment and respirators also reduce personnel exposure.

Technology

The complexities of last mile proppant logistics have produced specialized web-based and mobile-app software capabilities. Used by operators, servicer companies, sand suppliers and others, the technology, including real-time capabilities, provides a broad scope of data such as turn times, driver performance, terminal congestion and demurrage. Management capabilities include equipment tracking and geo-fencing, inventory, freight and load reconciliation. Sand stage reporting and consumption reports are also being generated by last mile software, and future capabilities may include wellsite management tools such as RFID container scanning, silo integration with trucking data, as well as order automation and payment.

Technology increases the visibility of all parties in the last mile proppant supply chain to enhance coordination and interface between the E&P company, carrier, dispatch, drivers and terminal. The acquired data also supports modifications to create operational efficiencies and reduce costs. Insights into carrier activities help minimize idle time and congestion, and improve truck utilization.

Greater automation avoids ad hoc proppant delivery by providing a centralized location for executing orders/loads, or storing data in real time. As a result, the E&P company has real-time visibility into carrier and vendor operations to understand load data, bills of lading and tickets.

Technology also provides communications with a common platform. Compared to traditional communications via phones, text and spreadsheets, a communication platform speeds reaction time, and ensures all parties are working with the same information.
The huge and growing volume of frac sand used by modern hydraulic fracturing places massive and sometimes overwhelming demands on the traditional supply chain. Mining, moving and managing millions of tons of silica quartz proppant is critical to the economics, reliability, and effectiveness of completing and producing tight, unconventional formations. Each step in the proppant logistics process, from selection of the mine site to high-pressure pumping operations at the wellsite, contributes to the overall objective of optimizing well production and profitability.

Mine. Move. Manage.

The proppant journey entails a massive mobilization of transportation resources orchestrated by logistics experts using sophisticated software and specialized equipment. It also involves a broad scope of health, safety and environmental obligations and standards, from mine reclamation and wildlife protection to wellsite traffic, noise and silica dust.

Efficient sand logistics must closely align each end of the journey and all points in between. The mine’s location and sand production must be coordinated with wellsite demand that is often hundreds of miles distant, at small, remote and difficult reach locations. The right sand must arrive on time, where it is needed.

The trip involves multiple legs anchored by specialized loading and unloading facilities. Vigilant tracking and handling is required to ensure sand quality. A precisely engineered hydraulic fracturing application demands that contamination is avoided—different sand sizes cannot be mixed, and foreign materials cannot be introduced. Handling equipment must minimize sand grain degradation, and the resulting fines and irregular shapes that can negatively impact completion results, as well as personnel health and equipment wear.

Efficient proppant logistics starts at the mine. With increasingly large volumes of sand, this requires loading facilities that accommodate hundreds of rail cars, or in the case of in-basin mines, hundreds of trucks. Specialized equipment is required to load, unload and store frac sand. Rail facilities must be located on main rail lines, and be able to handle large assemblies of rail cars—unit trains—that require many acres and miles of rail staging capacity.

When mines are distant from the oilfield, transload facilities must be located on rail lines to unload sand shipments from the mine, store it and ultimately load hundreds of trucks for wellsite delivery.

In-basin mines eliminate the rail leg of the journey along with considerable cost, time and scheduling overhead. Located near regions of oilfield activity, these in-basin operations mine frac sand and load it directly to trucks for transport to the wellsite. Convenient access to the road network is key to in-basin operations. The facilities must be able to quickly load and manage hundreds of trucks entering and exiting the facility.

The final link in the supply chain is “last mile” delivery to the active wellsite. This highly specialized logistical process transports, stores and delivers thousands of tons of proppant to each hydraulic fracturing operation.
The geographic proximity of the sand source—mine or transload facility—and the road network connecting it with the wellsite is a critical logistics element. Distance and road conditions affect delivery time and costs, demurrage, fleet size, wellsite congestion and other factors related to asset utilization.

The hydraulic fracturing application drives this last mile process. Each application varies considerably in such key factors as design and proppant intensity. Differences in proppant volume may occur between a single well and multiwell operations, and with the frac design itself. This directly affects wellsite sand storage requirements and equipment selection. In addition, these logistics are complicated by wellsite size and location.

To provide the necessary flexibility, last mile sand logistics must be able to deploy a broad scope of specialized equipment and systems to match the application. Today, silos and container systems are the core options for wellsite delivery and storage. Each offers alternative advantages depending on such factors as volume of sand, road constraints and sand storage space. Both systems address health and safety issues posed by wellsite traffic and sand handling, silica dust exposure, noise and working environment far beyond that of predecessor solutions.

In the not so distant past, when sand volumes were relatively small, this entire logistics process happened through a complex supply chain made up of many component pieces. Individual mining, moving and management segments satisfied the economic and operational requirements of much different hydraulic fracturing designs and objectives.

As sand use has grown to support modern practices, these historical links have been strained greatly by logistical costs and complexities.

Necessary performance improvements up and down the supply chain required the integration of these disparate components into a single solution for mining, moving and managing frac sand.

Hi-Crush is the first and only company to integrate the entire supply chain. Its focus on linking each step in the mine, move and manage process is a direct response to solving the economic and operational challenges posed by modern proppant logistics.

**Mine**

Hi-Crush took the first step towards integration with a portfolio of sand production assets. The company is one of the largest producers of frac sand in North America. Hi-Crush mines have a production capacity of more than 17 million tons per year of high-quality sand. Average remaining reserve life of these mines in 2019 was approximately 24 years.

The company has four mines in Wisconsin producing Northern White sand, a long-time industry standard. In West Texas, the first and now expanded in-basin mine is a game-changing advance developed to support industry-leading Permian Basin activity. Each mine site is a strategic choice based on several factors including geology, reserves, transportation and environmental impact.

Low-impact mining minimizes environmental and community impact, and a full reclamation program guides the restoration when mining is completed. The policy supports lakes and wetlands management, erosion control and wildlife management in surrounding communities. These efforts include extensive studies and planning to ensure facility locations and operations do not present a threat to endangered species or other local wildlife. Facility air quality is managed to National Ambient Air Quality Standards, and water used to wash the sand is optimized through retention and conservation practices.
Deposits in the Wisconsin mines produce up to 75% fine mesh sand reserves. They are characterized by a low overburden and a large contiguous reserve base that reduces excavation and production costs. Mined sand is processed through purpose-built facilities that clean, dry and sort sand to industry standards. Each of the Hi-Crush Wisconsin mine facilities have direct Class 1 rail access and the capability to load unit trains.

The Kermit facilities in West Texas are large, contiguous, naturally disaggregated reserves with no overburden. They have a total production capacity of 6 million tons per year of high-quality, fine mesh frac sand. The purpose-built processing facilities have direct road access and load directly from storage silos to trucks.

At each mine, purpose-built processing facilities apply multiple steps and technologies to efficiently produce high-quality frac sand.

At each mine, mining and processing facilities produce high quality frac sand through a series of steps and by applying purpose-built technologies for:

- Low-cost surface excavation
- Movement of sand from mine to plant
- Wet plant removal of impurities and initial sizing
- Dry plant drying and sizing to produce finished product
- Finished product storage in silos
- Unit train loading at mine’s rail facility for shipment to transload facilities
- Truck/container loading at in-basin mine

Move

To move frac sand to market, Hi-Crush has built the industry’s largest owned and operated terminal network. The company has 12 terminals in the Permian, Marcellus, Utica and DJ basins. Each has rail access and a majority are dedicated unit train terminals. Collectively the terminals have 140,000 tons of vertical silo storage and 109,000 tons of rail storage capacity.

Uniquely, Hi-Crush’s sand processing and loading facilities are co-located onsite, which eliminates the requirement for on-road transportation, lowers product movement costs, minimizes degradation of sand quality due to handling at the origin and lowers environmental impact. Owning and operating our terminal network provides for reduced operating and freight costs, while also ensuring our customers receive priority scheduling, expedited delivery and a more cost-effective delivery alternative.
Terminal Operations

Each owned or operated terminal location is strategically positioned in shale plays so that our customers typically do not need to travel more than 75 miles from the wellsite to purchase their frac sand requirements. Our terminals include rail-to-truck and, at silo storage locations, rail-to-storage capabilities.

Once the frac sand is loaded into rail cars at the origin, we utilize an extensive network through a combination of Class I and short-line railroads to move sand to our terminals. For our terminals with silo storage capabilities, frac sand is loaded into delivery trucks directly from our silos. Our silos deploy sand via gravity to trucks stationed directly on scales under each silo with the loading, electronic recording of weight and dispatch of the truck capable of being completed in less than five minutes. Silos are considerably more efficient than conveyors, which require trucks to be loaded and then moved to separate scales to be weighed; however, frac sand can also be unloaded to delivery trucks directly via a conveyor.

Manage

At the wellsite, hydraulic fracturing requirements drive an integrated process that connects the mine to the application. Once frac sand is specified, Hi-Crush logistics experts manage each step to deliver proppant to the blender during the frac job. Vertical integration enables logistical expertise to be focused on the entire process to produce greater efficiency and reliability and ultimately lower completion costs.

From transload facilities or the mine, the PropStream last mile proppant solution delivers frac sand to the wellsite with greater efficiency and safety than alternative methods. These capabilities rely on logistics expertise, advanced software and a fleet of specialized equipment.

The PropDispatch proppant logistics platform provides visibility for all parties in the supply chain. Web-based and mobile-app software provides real-time visibility, automation and data acquisition to increase operational efficiencies and reduce costs. A common communications platform ensures all parties have access to the same information. The technology automates the process of ordering, dispatching, hauling and invoicing truckloads of proppant. On demand ordering and dispatching flexibility is achieved via smartphone. Generation of KPI data supports vendor management and cost savings across the last mile proppant supply chain.

PropStream is a gravity fed solution based on specialized silo and container systems—the industry’s only offering to provide both options.

The two different systems, silo and container, provide the flexibility needed to address various proppant volumes, frac designs, road conditions and wellsite footprints. Each deploys a unique gravity fed system of unloading, storage and delivery to the blender. By eliminating pneumatic transfer, the gravity fed system achieves several key advantages, including greatly reduced exposure to fugitive silica dust and less sand degradation, lower noise level, faster unloading and loading, and less wellsite congestion.

For multiview operations and high-proppant-intensity completions that require large volumes, the PropStream silo system provides a vertical storage solution able to hold up to 280 tons per silo or typically 1,680 tons per standard 6-pack. The specialized system can increase wellsite storage more than 30% versus traditional silos. Individual silos are transported to the wellsite and raised to a vertical position using a unique erector trailer that eliminates the need for cranes and improves safety.
A unique advantage of the PropStream silo system is the top-fill conveyor system that quickly unloads multiple hopper bottom trucks and transfers sand to silos using a telescopic, swivel-mounted discharge chute guided by live video. From the silos, sand is transferred during the hydraulic fracturing operation to the blender with a self-contained conveyor system that improves precision and equipment control. The entire system features containment technology that minimizes silica dust emissions.

Alternatively, the PropStream container system provides a solution for single wells, challenging wellsite locations unable to accommodate silo transport or erection, and jobs requiring complex completion designs with multiple proppant types and mesh sizes. It is based on novel modular containers that each hold 12.5 tons of sand. Containers are loaded and transported two at a time on custom chassis, versus hopper trailers. At the wellsite, containers provide easy-to-handle storage that has a minimal footprint. Fast unloading and loading by forklift can cut the number of onsite trucks in half. Compared to pneumatic systems, containers cut silica dust emissions more than 90%. Delivery to the blender is done rapidly with a dedicated conveyor system that handles five containers at a time.