In 2010, the US petroleum industry accomplished a feat that not many thought was possible only a few years ago—annual production of crude oil on American soil rose two consecutive years for the first time in almost 25 years. This is incredible, considering the battering this industry suffered during the 2008 financial crisis.

The sustainability of this achievement likely will depend on successful economic exploitation of a handful of oil-rich resource plays, all of which will require hydraulic fracture stimulation. These fracs provide conductive paths from the wellbore to the fracture surface area in the formation. However, in most reservoirs fractures are known to collapse if not sufficiently propped. The induced conductivity is intended to convert the wells to successful economic ventures. Economic conductivity principally will be provided (or not) through the type and quality of proppant employed.

A simple way to define economic conductivity is “the incremental investment made by an E&P operator in higher quality proppant in the pursuit of a superior financial return achieved through an increase in production rates and elevated EURs.” When the price of oil is north of USD 50/bbl, the internal rate of return tends to increase rapidly for a nominal incremental investment in conductivity.

The benefits of increased conductivity have been documented in more than 200 SPE technical papers. Enhanced return on investment has been achieved in all types of reservoirs. From shallow to deep, from North Dakota to south Texas to the Far East, oil and gas investors have been rewarded for following good engineering practices and banking on conductivity.

The history of proppant use in the field of hydraulic fracturing is well known. The search for higher strength proppant was initiated in the mid-1970s by E. Claude Cook of Exxon Production Research, and resulted in a patented hydraulic fracturing method using sintered bauxite. Ceramic proppant was born. Curable resin-coated sands were introduced in 1975 to reduce flowback of critical propping materials, and pre-cured resins were soon applied to sand to encapsulate crushed sand particles and prevent migration and the resulting loss of conductivity. For many decades, though, the utilization of high quality proppant was mainly limited to deep, hot, vertical gas wells. Increased usage was noted in 2003, when the price of natural gas pushed through the USD 4/MBTU level. As the economics of natural gas production improved, the employment of higher quality proppant, especially ceramics, increased. This industry trend continued steadily from 2003 through 2007. What occurred next changed the proppant industry permanently.

By 2008, several oil and gas operators had begun experimenting with fracturing long horizontal sections in the natural gas bearing Haynesville formation located in north Louisiana and east Texas. Most experts recognized that to maximize the area contacted by the wellbore, hydraulic fractures would need to be purposely designed to propagate transversely from the horizontal wellbores. However, transverse fractures provide only a limited intersection with the wellbore, resulting in tremendously high produced fluid velocity within the proppant pack. These phenomena increased the need for obtaining maximum fracture conductivity which in turn catapulted the usage of ceramic proppant.

In the past, a “typical” 10,000 ft vertical well would be fracture treated in about three stages, consuming around 600,000 lb total. With the onset of efficient directional drilling techniques came the enormous opportunity to expose more rock surface to be stimulated. Proppant requirements quickly rose above 2,500,000 lb per well as the number of frac stages increased fivefold. As the drilling rig count in this area increased, the supply of quality ceramics soon became scarce. Resin-coated sand (pre-cured) was introduced as a lower cost (albeit lower conductivity) substitute for ceramic proppant when necessary. At this point horizontal drilling in the oil-rich Bakken/Three Forks resource play had already begun, and its multiphase fluid production needed higher conductivity, while the nominal price of oil was taking a monumental leap.

As recovery from the 2008-2009 industry crisis began, E&P companies began to take a closer look at the cost/benefit ratio of increased conductivity (Fig. 1).

The pyramidal shape illustrates the pecking order of proppant. Tier 1 (ceramics) provides the highest conductivity and the best well productivity due to the strength, uniform size, and shape, and the inherent thermal resistance of a man-made proppant; tier 2 (resin-coated sand) provides moderate conductivity and has moderate strength, but is somewhat irregular in shape and size; tier 3 (uncoated sand) provides the lowest conductivity due to diminished strength combined with asymmetrical size and shape.

As one would suspect, the hierarchy of conductivity also follows a hierarchy of cost: the higher the conductivity of the proppant, the higher the investment. The issue, however, is whether the increased investment in a higher tier proppant leads to a higher return on investment. The topic is really that simple. Divergence from this concept sometimes leads to proppant decisions being made to fit the authorization for expenditure vs. fitting what maximizes profitability of the well. Early production figures may seem adequate; however, over time basic chemistry and physics principles always prevail. Ideally from an economic standpoint, a well would be fractured only once in its lifetime, provided that the economic benefits justified this approach. The scientist and the financial manager alike know that the application of best reservoir practices and sound investment economics are not necessarily mutually exclusive.

The pursuit of creating optimal economic conductivity for a particular reservoir will not end with today’s greatly improved practices. Innovation will bring us closer to the perfect proppant as reservoir conditions become more challenging. Radioactive isotopes will be replaced by non-radioactive tracers. More will be learned about actual proppant placement, perhaps through far-field detection. Proppant will be invented that can withstand the harshest of environments.

The renaissance of US production is an exciting phenomenon enabled by novel engineering applied in a fiscally correct manner. Economic conductivity will continue to provide a bright path for the future of hydraulic fracturing and assist in sustaining this remarkable rejuvenation. Efficient technology transfer should accelerate the application of this model in the international resource plays.
With the rise in hydraulic fracturing over the past decade has come a steep climb in proppant demand. Global supplies are currently tight. The number of proppant suppliers worldwide has increased since 2000 from a handful to well over 50 sand, ceramic proppant, and resin-coat producers. The estimated amount of proppant used has grown tenfold since 2000, when little more than 3 billion lbs was supplied, according to research by Proposition and Kelrik. Circumstances appear favorable for those seeking to enter the market.

However, gearing up to take advantage of these propitious conditions represents a daunting task, requiring coordination of complex logistics, material resources, and processing knowledge, as well as a substantial capital investment in processing and material handling facilities.

The price proppant manufacturers can charge must be figured in to the overall cost of producing a well, which in the Bakken, for example, can be approximately USD 6 million, with proppant representing about 5% of well costs. Since a majority of proppant is currently used in fracturing unconventional gas wells, depressed natural gas prices tend to keep a cap on the prices proppant suppliers can demand.

However, as hydraulically fractured wells proliferate, a growing body of data is continually being generated to aid in the creation of targeted fracture stimulation plans, with more highly engineered stages—boosting the demand for greater volumes of proppant—being performed per well to maximize production. For example, a typical Barnett Shale well would in the early 2000s have consumed approximately 300,000 lbs of proppant. The longer horizontal wells drilled today, produced with often 20 or more stages, might consume 3 to 5 million lbs.

Still, proppant supplier margins are relatively slim, requiring the steady, high-quality production and distribution of large volumes to sustain a profitable enterprise.

Proppants: Earth to Earth
The journey of an individual grain or bead of proppant is a circular one, making its way from its origins as a substance mined from the Earth to its final destination deep within the Earth in the far reaches of the filigree-like or dendritically shaped fractures emanating from the long horizontal borehole. It is the only substance operators want to remain downhole following a successful hydraulic fracturing treatment and performs the vital function of propping open the fractured formation to promote the economic flow—or conductivity—of hydrocarbons in the ensuing months and years over the well's productive life.

The primary order of business for a proppant facility, therefore, is choosing the optimum location—preferably one close to both raw material supply and enduser. The immediate proximity of railcar and possibly barge transport is critical, as well as a good road system and the availability of a reliable trucking fleet.

The Ubiquitous Silica Sand
By far the dominant proppant is silica sand, made up of ancient, weathered quartz—the most common mineral in...
Unlike common sand, which often feels gritty when rubbed between the fingers, sand used as a proppant tends to roll to the touch as a result of its round, spherical shape and tightly graded particle distribution.

Sand quality is a function of both deposit and processing. Grain size is critical, as any given proppant must reliably fall within certain mesh ranges, subject to downhole conditions and completion design. The smaller the number, the coarser the grain. The vast majority of grains range from 12 to 140 mesh and include standard sizes such as 12/20, 16/30, 20/40, 30/50, and 40/70 whereby 90% of the product falls between the designated sieve sizes.

Coarser proppants, such as 16/30 and 20/40, can be more difficult to effectively place in fractures due to their size and higher settling rates compared to, for example, 40/70 and 100 mesh. According to Brian Olmen, owner of Kelrik, the supply outlook for high-quality coarse sands is severely strained in 2011, largely due to a resurgence in oil and liquid-rich drilling activity in areas such as the Bakken, Eagle Ford, and Permian Basin.

“Sand is not an engineered product, but rather a natural mineral subject to deposit yield and processing efficiency,” says Olmen. “The percentage of grains coarser than 40 mesh in many quality deposits is often less than 20%, if any.”

This is not a new challenge as, historically, 20/40 is the single most demanded gradation.

The increasing use of 40/70 and finer 100 mesh sands beginning in 2001—rising particularly since 2006—is a rather new development resulting from the rise in high-volume slickwater fracturing of unconventional horizontal gas wells such as those in the Barnett, Fayetteville, Haynesville, and Marcellus shales.

Industrial silica sand has a wide range of uses, and is commonly used in the metal casting industry to make cores and molds, but particularly in the manufacture of various types of glass—including solar energy collecting panels—as well as in the creation of highly flame-resistant industrial molds and construction materials for the kilns used in the manufacture of sintered ceramic and bauxite proppants.

Companies with established sources of high-quality silica, with decades of experience in manipulating this raw material, have commonly added or modified production facilities to increase proppant capacity over the years. These include the industrial giant Sibelco Group, whose Unimin division has a stated annual production capacity in excess of 10 billion lbs making it the largest supplier of proppant worldwide.

According to Olmen, the industrial frac sand industry has fundamentally
changed in the last five years. While in 2006, the vast majority of frac sand and sand substrate for resin coating was produced by four primary companies, now more than 40 industrial sand producers process frac sand from nearly 100 facilities worldwide. In 2010, close to 50% of sand-based proppants were supplied by either newly established or nontraditional frac sand suppliers, with several more operations pending.

**The Rise in Resin-Coated Proppant**

According to Chris Coker, president of Oxane, coating silica sand with resin has two principal functions: The first is to improve the proppant’s effective strength, by spreading the pressure load more uniformly. The second is to trap pieces of proppant broken under high downhole pressure, thus preventing the flow of proppant fines into the borehole. In addition, a curable resin coated both on sand and ceramic proppant is also used whereby the resin-coated proppant (RCP) grains bond together when subject to downhole pressure and temperature to minimize or prevent proppant flowback.

Largely because silica substrate is readily available and relatively inexpensive, the RCP market is sharply increasing. According to figures shared by PropTester and Kelrik, from 1988 to 2010 RCP achieved a 23.16% compound annual growth rate (CAGR). However, it was not until 2005 that total usage finally exceeded the 1-billion-lb benchmark. From 2006 through 2010, RCP experienced a 26.64% CAGR, the highest of any proppant type.

The present RCP market—whose volumes are roughly the same as those for ceramic proppants—is dominated by Santrol and Momentive.

Santrol Proppants, part of Fairmount Minerals, one of the largest producers of industrial sand in the US, announced early this year the sizable expansion of its RCP facility in Roff, Oklahoma, scheduled for completion late 2011, with an increased annual capacity of 500,000 US tons. “The facility is close to a number of very active shale plays,” says Pat Okell, Santrol’s executive vice president and general manager, “and serves as a convenient transportation hub thanks to the number of trucking and rail options available.”

Momentive (formerly known as Hexion) is a specialty chemical company, with control over the materials used in creating the high-strength curable phenolic coating for its sand-, bauxite-, and ceramic-substrate proppants. The company expanded its current transplant facility in Cleburne, Texas, in 2010 into a proppant coating plant to better meet the demand for its RCPs.

Startup company, Patriot Proppants, added RCP operations in Shreveport, Louisiana, in 2010 and is completing another facility in Guion, Arkansas, this year. Patriot’s two-line Shreveport facility was built on 27 acres in the 260-acre South Webster Industrial District park. The industrial park’s nearby rail line and the emerging Fayetteville, Haynesville, Barnett, and Eagle Ford shales are what lured Patriot to Webster Parish, company president Jason Renkes says. Rail access is essential in delivery of the raw and finished product, and Interstate 20 and Highway 371 also are “perfect routes” to get the finished product to market, he says. A typical railcar holds approximately 100 tons (200,000 lbs) of sand. A 1-million-lb fracturing job therefore requires five railroad cars of sand, and a 5-million-lb job requires 25 railroad cars of sand. With few wells located near rail lines, the proppant eventually requires trucking to the site.

Like the frac sand market, several other new operations have emerged to vie for a share of the growing RCP market, including Atlas Resin Proppants in Wisconsin, Southern Precision Sands in Alabama, CRS Proppants in Louisiana, and even ceramic-proppant giant CARBO, with a facility in New Iberia, Louisiana, that opened in 2010 and another planned for 2011.
Engineering the Proppant: Sintered Ceramic and Bauxite

Proppant manufactured from a type of ceramic material—generally either nonmetallurgical bauxite or kaolin clay—can be engineered to withstand high levels of downhole pressure, and to achieve relatively uniform roundness, sphericity, and size. Bauxite is an aluminum ore from which most aluminum is extracted, found in Australia, China, Brazil, Guinea, and India. Kaolin, one of the most common minerals, is mined in Brazil, Bulgaria, France, the UK, Iran, Germany, India, Australia, Korea, China, the Czech Republic, and the US. Both bauxite and kaolin are noted for their superior strength characteristics after undergoing a process called sintering. Sintering occurs in high-temperature kilns that, through baking bauxite or kaolin powder that has been shake-formed into specifically sized particles, decreases the water content thereby changing the particles’ molecular structure, rendering them more spherical and more uniformly dense.

Unlike frac sand and RCP which are primarily North American-based industries, ceramic proppant manufacturers are distributed the world over: In addition to CARBO and Saint-Gobain’s US and international operations, there are Brazil’s Mineração Curimbatá Group, Russia’s producers Fores and Borovich, and a host of existing and pending manufacturers in the Far East, particularly China.

CARBO’s Toomsboro, Georgia, facility is situated close to sources of kaolin, which is trucked in on a continuous basis to feed the plant’s 24/7 operation. Its brand-new line 3 just added 250 million lbs per year of proppant to the marketplace, and a fourth line, currently being constructed, under the design and coordination of KBR, will add the same amount by late 2011. According to CARBO Ceramics’ Toomsboro plant manager Roger Riffey, the 500-million-lb additional capacity represents overall growth of 40% for CARBO, bringing its total global capacity to approximately 1.75 billion lbs per year.

Houston-based Oxane was formed in 2002 to commercialize nanomaterial research performed at Rice University’s department of civil and environmental engineering and department of chemistry. After examining hundreds of potential applications, they chose to focus on proppants because of the quantity consumed and the perceived opportunity to differentiate themselves from competitors.

“We’re strong because we’re ceramic, and we’re light because we’re hollow,”
explains Coker. “Our process produces very tight, near monodispersed size distributions, with extremely round, spherical particles.”

Oxane’s Van Buren, Arkansas, plant has one line fully operational 24/7, with the capacity for as many as six lines.

Another engineered proppant start-up, Nittany Extraction Technologies Company (NETCo), is based on research conducted at Penn State University’s College of Earth and Mineral Sciences and college of engineering. NETCo uses waste material—including glass, alumina silicate mine tailings, fly ash, and metallurgical slags, as well as rock cuttings produced to the surface during oil and gas drilling—in the manufacture of high-performance proppants.

“Drawn by proximity to the Marcellus Shale, we are using raw materials indigenous to Pennsylvania,” says John Hellmann, professor of earth and mineral sciences at Penn State and one of Nittany’s founders.

The company uses nanotechnology to control the microstructure and crystalline phase assemblage of its ceramic proppant. It is developing relationships with landfill, mining, and glass companies and is currently in the process of batch testing, while gearing up to conduct 150-ton field testing by early this fall.