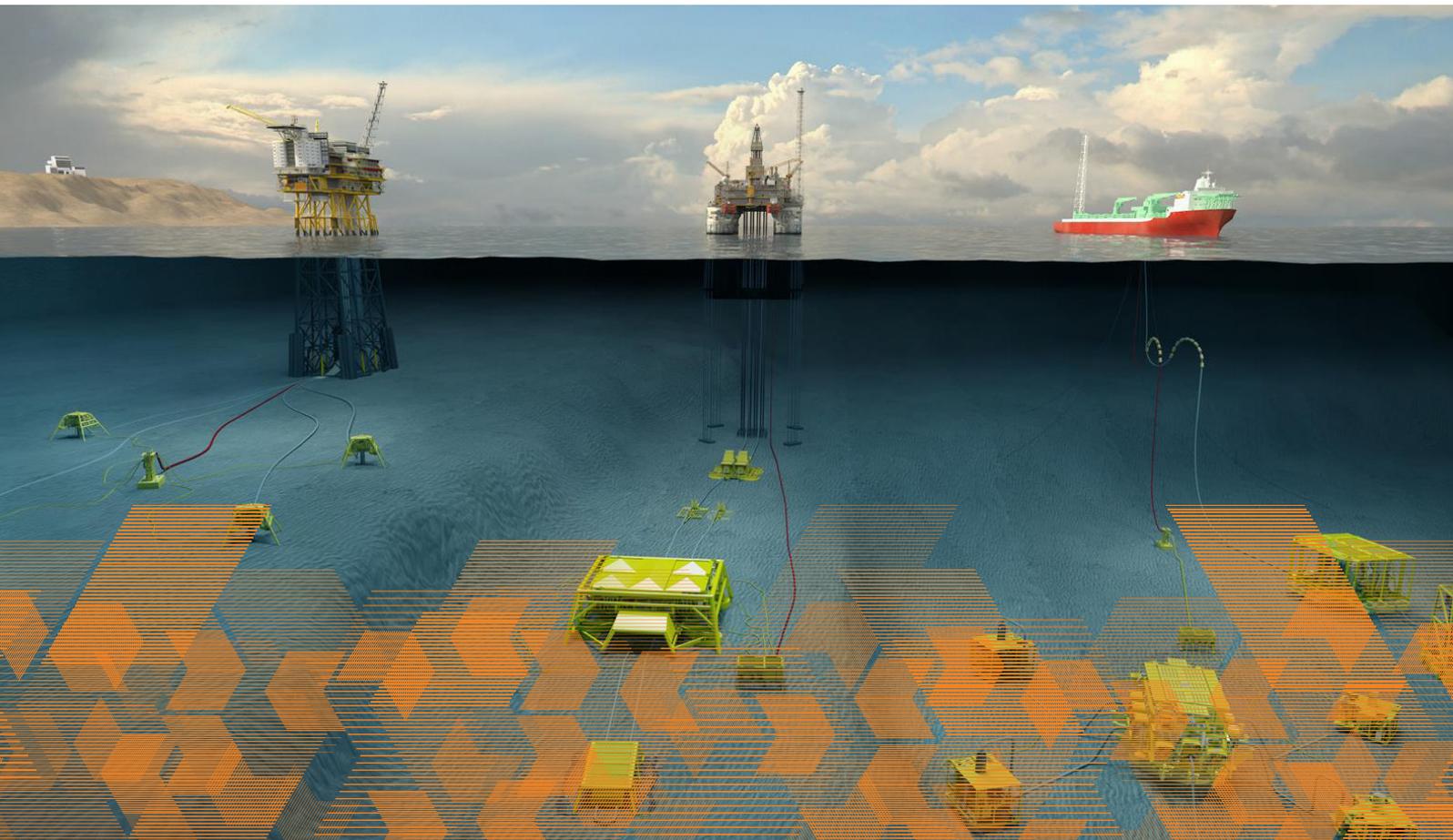


R&D Solutions for OIL & GAS

EXPLORATION & PRODUCTION

The Best Path to Operational Excellence May Require Being More Innovative



Summary

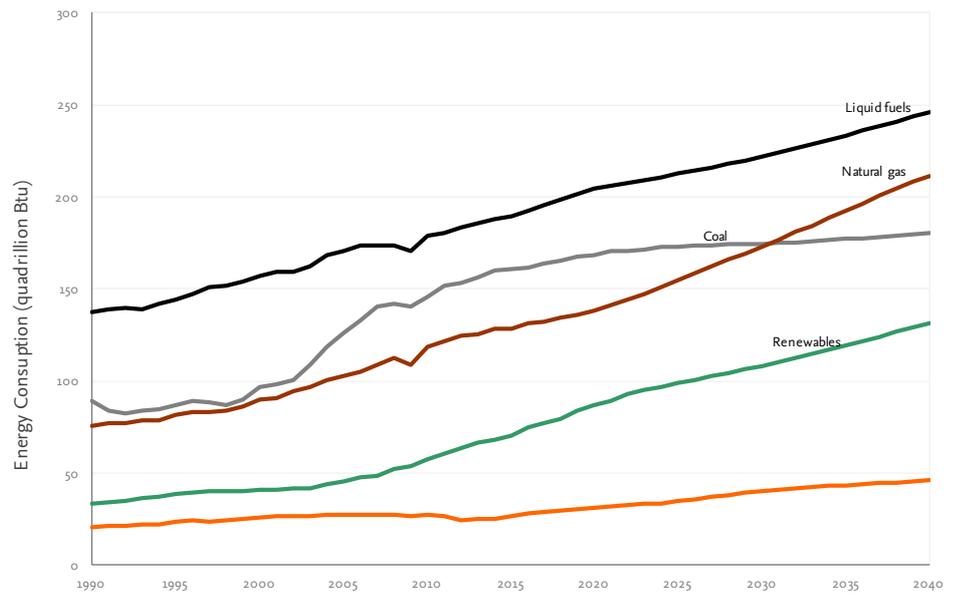
The pace and volume of engineering and technological innovations—from the micro to the macro—throughout the history of the oil and gas industry are impressive. Perhaps even more remarkable is that many of these innovations have consistently occurred against the backdrop of a crisis or in times in which the industry was undergoing a dramatic transformation. Why should this era of \$50 per barrel oil be any different? This white paper explores how the industry has approached innovations in technology and engineering in the past and how it is often closely related and driver for achieving operational excellence across the value chain.



Since the 2014 oil price shock, oil and gas companies, large and small, have been challenged to find ways to significantly reduce their costs, rethink their strategies, and optimize their operations to achieve more with less—to find and produce more with less budget, less bodies, and less room for failure.

According to the International Energy Agency, oil and gas companies need to invest \$250 billion per year in exploration, and drill approximately 670,000 wells to meet the world's 2020 energy demands.¹ Achieving operational excellence requires a sustainable commitment to investing in projects and ideas that can truly deliver both cost savings and improve business outcomes.

Total World Energy Consumption by Fuel Type
(1990 - 2040)



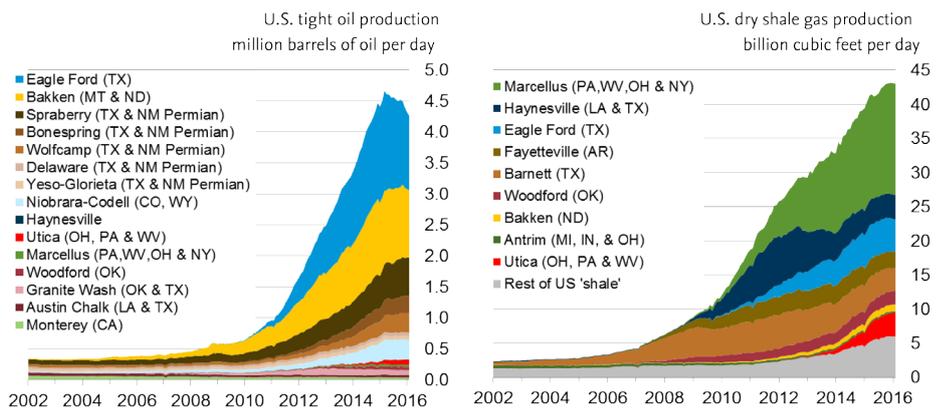
(Source: U.S. Energy Information Administration)¹

Technological advancements that have allowed the oil and gas sector to push the limits of exploration and production have often occurred against the backdrop of low prices. Previously, a decade of rising prices and uncharacteristic stability had helped the industry move into riskier and more capital-intensive projects, including the ultra-deepwater and the Arctic. The focus on achieving incremental advancements in technology facilitated the development of previously inaccessible shale reserves, transforming the U.S. into one of the world's largest producers of oil and gas, demonstrating once again that innovation can thrive in times of crisis.

With the latest downturn, many observers expected these capital-intensive projects would be the first to fail. Indeed, one could argue that the Organization of Petroleum Exporting Countries (OPEC) strategy relied on it. And yet, the agility with which unconventional producers

in particular have responded has belied expectations, as incremental technological improvements and improvements in operational efficiency have halved the cost of shale oil production since 2014.

Unconventional oil and gas production, specifically shale oil and gas, in the U.S. provides a particularly salient example of the influence of both high and low oil prices on innovation in the energy industry. The incremental optimization through applied R&D and innovation in the areas of horizontal drilling and hydraulic fracturing, or "fracking," during the high oil price period drove U.S. oil and gas production growth from 2007 to 2014. The acceleration in production also led to a rapid increase in oil supply, which directly contributed to the subsequent oil price collapse.



Sources: EIA derived from state administrative data collected by DrillingInfo Inc. Data are through February 2016 and represent EIA's official tight oil & shale gas estimates, but are not survey data. State abbreviations indicate primary state(s).

(Source: U.S. Energy Information Administration)²

Yet just as high oil prices created a market for previously economically unviable exploration and production techniques, low oil prices spurred technological innovation at an even faster pace, enabling many of these companies to increase productivity both at the well site and along the supply chain. Continuous investment and focus on optimizing drilling techniques and drilling efficiency (e.g., multi-well pad drilling) helped producers adapt to a low oil price environment. These effects are not only evident in U.S. oil and gas production but also other previously high-cost operations, including deepwater E&P.

Overall, the pace and volume of innovations—from the micro to the macro—since 2014 have been impressive. Perhaps even more remarkable is that this is occurring against the backdrop of a dramatic transformation of the oil and gas industry.

According to Ram Shenoy, Chief Technology Officer (CTO) at The RBR Group and Former CTO at ConocoPhillips, we could be seeing a “creative disruption” within the sector, resulting in an upending of the traditional dominance and approach of large oil companies. This is a trend already underway in the United States and one that will affect the way research and development is funded and will redefine who leads innovation in the sector. The low oil price environment is also sparking a rethink of how we drill. Shenoy notes that without the luxury of high oil revenues, the industry can learn from and adopt technologies to the oil and gas industry that have successfully transformed production processes in other industries, such as the automotive and aviation industries, something the industry has been very good at.



The “Old Normal”

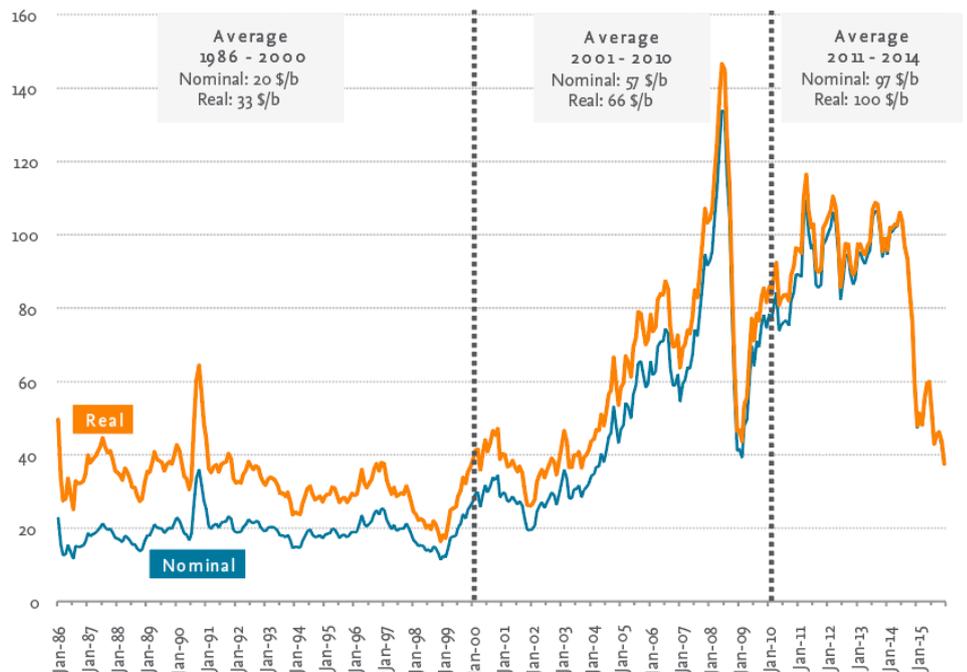
Two years after a dramatic collapse in oil prices, markets are yet to rebound to pre-2014 levels. Although many analysts have been quick to label this a “new normal,” it would be more accurate to characterise the post-2014 era as the “old normal,” with oil markets resuming their historically low and volatile pricing. The decade of rising prices and stability immediately preceding the 2014 price collapse is better understood as a historic anomaly. The price of West Texas Intermediate (WTI), which is generally used as a benchmark for U.S. oil prices, averaged \$100 per barrel from 2011 to mid-2014. Between 2001 and 2010, WTI averaged \$66 per barrel, and between 1986 and 2000, WTI prices averaged just \$33 per barrel.

Rising prices over the course of the last decade allowed oil companies to go further, farther, and deeper and helped to drive new innovations to overcome the challenges associated with these high-risk, potentially high-reward prospects. However, with the crash many of these high-cost projects and frontier regions have been abandoned and will be the slowest to recover when, and if, the price of oil rebounds.

Oil prices fluctuations do not occur in a vacuum. Geopolitics and macroeconomics have always played an important role. In addition, the relative influence of OPEC and non-OPEC producers in shaping oil markets cannot be ignored; their behavior has a significant impact on the success, failure or potential advancement of technological innovations applied in the field. For example, majority of the OPEC producers now require bidding partners to provide an enhanced oil recovery (EOR) strategy as part of their field development plans.

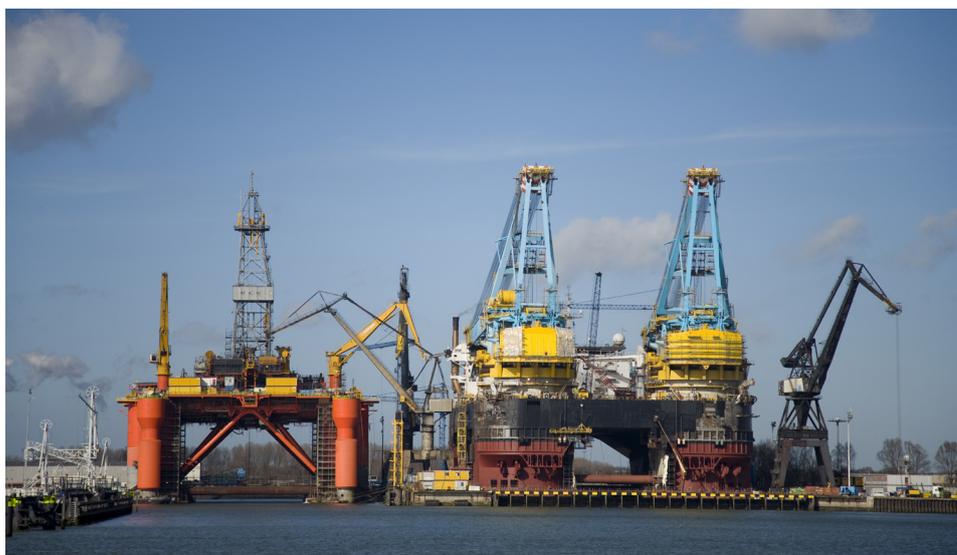
R&D—History Repeats

Many of the great advances in oil and gas exploration and production occurred outside the boom times. In 1986, oil prices dropped 67 percent, from \$27 per barrel (\$59 in today’s terms) to just over \$10 (around \$21 in 2015). In 1999, oil lost half its value to hit \$10 (just over \$14 today) and experts fretted that a “new normal” could settle at just \$5 a barrel (a little over \$7 today).⁴ Between 1986 and 1999, technological advances drove down the costs of conventional drilling, notably in the Middle East, but also in North America.



(Source: Inter-American Development Bank)³

New drilling techniques and logistics helped operators move into riskier, more remote areas that had previously been inaccessible.



The Rise of Deepwater Drilling

Low oil prices in the second half of the 1980s spurred innovation in deepwater exploration and production, particularly in the North Sea. New drilling techniques and logistics helped operators move into riskier, more remote areas that had previously been inaccessible.

Exploration off the coasts of Germany, Netherlands, Denmark, Norway and the UK began in the 1960s and increased dramatically in the 1970s and 1980s. By the 1980s, technological improvements saw drillers move from 30–40m depths to 150–200m. Floating production, storage, and offloading systems were also developed during this period. These floating structures were less capital intensive, allowing developers to access larger drilling areas at a time when belts had to be tightened.

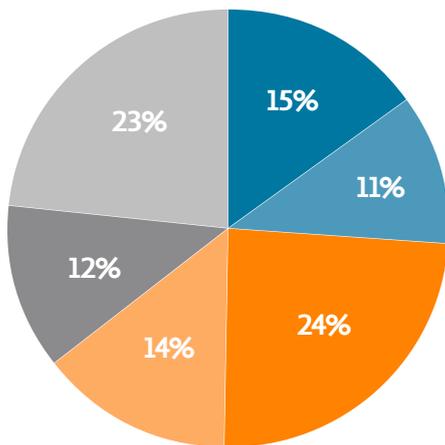
In a reflection of the current situation, operators were under pressure to cut development costs by 30 percent and operational costs by a staggering 50 percent.⁵ As a result, development was limited to the largest and most productive fields.

Like 2014, the 1986 oil price collapse also forced oil and gas companies to focus on optimizing exploration and production technologies and processes, which resulted in marked improvements in computing capability, paving the way for progress in seismic technology and analysis. The first great achievement was the transition from 2D to 3D data in the 1960s and 1970s. This was followed by texture mapping, and eventually the development of fully-interactive 3D workstations in the 1980s, enabling the oil and gas industry to capitalize on these innovations, taking the early research and development from adjacent industries and further advancing technologies in order to apply to an energy context.

What may seem quaint to today's observers was revolutionary in the 1980s and was made possible because of the incremental effort and investment in adopting and developing this technology, making detailed, accurate, and almost real-time analysis possible. Geologists could now see reservoir images in 3D rather than pouring over reams of paper printouts and marking them with colored pencils. Where early drilling involved a lot of guesswork and with access to data to understand latest technologies and innovation meant better analytics, more targeted, efficient and productive operations.

The implications of 3D visualization and analysis were felt far beyond deepwater drilling. Greater access to accurate and multi-disciplinary scientific and engineering data greatly influenced global oil and gas exploration and production over the next two decades, including the development of the vast shale reservoirs in the U.S.

Where the break-even price in U.S. shale wells once ranged from just below \$60 to more than \$80 per barrel in 2014.



- Rig and drilling fluid
- Casing and cement
- Frac Pumps, Equipment
- Proppant
- Completion fluids, flow back
- Other

Source: IHS Oil and Gas Upstream Cost Study commissioned by EIA

The Age of Unconventionals

The rise of unconventional oil and gas production in the U.S. has reshaped global oil markets. By the time of the oil price collapse, in 2014, the U.S. had become the world's largest producer of petroleum and natural gas. The dominance of U.S. oil production has not only impacted global oil prices, but has also made shale producers major swing players in response, undermining the ability of OPEC countries to manipulate production and influence markets.

There has been a lot of excitement around so-called Shale 2.0—that is shale oil and gas production in a low oil price era. The industry's second iteration is characterized as a slimmed down, agile, responsive, and data-driven process. These developments were already underway in the U.S., but were greatly accelerated by the sudden drop in oil prices in 2014.

The same business drivers that fostered the rapid expansion of the industry from 2007 to 2014 have also facilitated its recovery since the price collapse. Even as the rig count plummeted since 2014, production has steadily increased, initially confounding observers. In North Dakota, where the Bakken field is located, just 34 rigs were active as of September 2016, down from a high of 198 in 2014. By contrast, new oil production per rig has been steadily climbing.⁶ The picture is similar in the Permian and Eagle Ford plays.

The results of this new era of innovation are clear. Where the break-even price in U.S. shale wells once ranged from just below \$60 to more than \$80 per barrel in 2014, consulting firm Rystad Energy estimates this has almost halved, to \$32 to \$39 in 2016.⁷ Bloomberg Intelligence reckons some counties in the Eagle Ford have break-even prices as low as \$23.⁸ Of course this is still well above the cost of oil production in parts of the Middle East, where it can cost less than \$10 to produce a barrel of oil.

According to energy consulting firm IHS, 75 percent of costs can be grouped into five main areas:⁹

- rig and drilling fluid;
- casing and cement;
- frac pumps and equipment;
- proppant; and completion fluids, and
- flow back.

Within these five groups, improvement in **scientific** and engineering technologies has helped increase productivity and efficiency above ground (e.g., drilling fluid treatment and waste management), as well as below ground (e.g., horizontal drilling, proppant, and fluid makeup), which when taken together add up to significant gains in operational efficiency and production.



Innovations in Horizontal Drilling

Research and development in horizontal drilling was another major factor in bringing down drilling costs in the 1990s and later facilitating shale resource development in the United States. In fact, Saudi Aramco reported that onshore and offshore application of horizontal drilling techniques—as well as improvements in drill bits, drilling fluids, and other technologies—increased well capacity by between 150–400 percent.¹⁰ Furthermore, the company was able to reduce the number of wells required to exploit plays by 30 percent and lower costs by 20–25 percent, demonstrating that productivity and efficiency gains are palpable with incremental innovations.

While the technology spread quickly across the Middle East, the most prolific adopter of horizontal drilling in the 1990s was the U.S. Globally, the number of horizontal wells drilled more than quadrupled, from 257 in 1989 to 1,190 in 1990.¹¹ Of these, close to 1,000 were located in the U.S. Canadian operators also found success as wells could be drilled at lower pressure without reducing production, which increased recoverability of the heavier crude present in the oil sands.

As research and development of horizontal drilling was brought to market, improvements brought costs down to an economically viable point at a time when low oil prices were driving innovation. The technology would require considerable additional R&D, as well as the innovative

combination of horizontal drilling with hydraulic fracturing, before it could be applied to shale development in the mid-2000s.

The Ultimate Recovery

Many innovations have emerged in the wake of low oil prices, from the relatively simple, such as drilling multiple wells on a single pad, to recycling and reuse of drilling fluids to both optimize production efficiency and reduce costs. The U.S. Department of Energy's Quadrennial Technology Review estimated that recovery for gas-rich plays remain just 20 percent and 10 percent for oil-rich plays.¹² On the conventional side, recovery rates still average around 35 percent, however, during the period of high oil prices, a variety of technologies were developed and optimized to improve secondary and tertiary recovery rates. For those companies who have continued to dedicate time and money towards optimizing enhance oil recovery (EOR) technologies (e.g., Oxy, Chevron, Pioneer, etc), they are reaping the benefits (See *Elsevier's Enhance Oil Recovery—Do you have the right strategy?*). For companies seeking to optimize production from existing wells and mature fields rather than take on risk of drilling new ones, development and implementation of new recovery technologies will be critical for both survival and success.



Refracking

One area that has received considerable attention has been the concept of refracking, or conducting additional stimulation in a declining well to revive production. Secondary and tertiary refracturing has been conducted successfully across the U.S., but the process also has its critics. One study found that refracking was less profitable per barrel of oil produced than simply drilling a new well.¹³ However, the same report noted that refracking costs did decline from 2014 to 2015, and critics have argued that the process is simply too unpredictable.¹⁴ Although, the method can be very successful, the failure rates are high. With access to the right information and data, and continued investment and incremental development and incremental optimization of these technologies, this downward trend is likely to continue, making refracking more attractive in the future. Overall, refracking technology is one potential game changer among many, pending further study and refinement.

Waterless fracking and HSE

Challenges with access to water in some areas and waste disposal, a constant point of contention, the concept fracturing with dry or non-waterbased fluids is experiencing a revival. Fracking with carbon dioxide (CO₂) was first attempted in the 1930s and has been widely used to extend the life of mature conventional wells in North America. Several U.S. companies are re-examining the potential of fracturing with supercritical CO₂, as well as liquid petroleum gas (propane butane or pentane).¹⁵ Since the oil price collapse, the total number of annual patents filed has doubled as had total number of published articles and abstracts.¹⁶ Research institutions, including Stanford University, the University of Texas at Austin, and the University of Colorado at Boulder, have also been investigating the issue.

Critics have been quick to highlight potential barriers, however, including the requirement of a proximate, reliable source of CO₂, and a pipeline to transport the gas. Water, by comparison, is generally accessible and frequently cheap, although, disposal can be challenging and costly. Fracturing with CO₂ has been

in use on a small scale in unconventional plays for decades, but it has yet to become popular—or economically practical—on a large scale. Additional challenges include: post-fracturing clean-up issues, the separation of CO₂ from the natural gas extracted, sequestration of CO₂, among others.

With short-term and long-term changes in health, safety and environmental (HSE) policies and regulations, innovations which focus on both cost reduction and reduced HSE impacts provide a win-win for all. With further research and development on the technology and infrastructure side, waterless fracking technologies and other technologies may become a viable alternative in a low price environment.

Data management

Many companies focus their efforts on optimizing drilling and production activities, which clearly have significant benefits and payoff as this can be the most cost-intensive part of the exploration and production value chain. However, a significant amount of value is immediately lost if companies do not manage the internal data and reports collected and generated across the value chain.

This results in companies wasting budgets in purchasing the same data multiple times, rampant loss of time and money with E&P teams spending 80% of their time looking for information and data from external and internal resources, increase in interventions, workovers and downtime because access to the right engineering solutions and technologies were not readily available, and in the most egregious of examples—drilling dry wells in nearby locations where dry holes were previously drilled because no one knew or had access to previous analyses and interpretations.

Focused and sustained development and investment in a data management strategy and plan is essential for enabling smarter decisions and managing risk all along the value chain.



Beyond Shale

While scientific and technological advances have undoubtedly made deepwater exploration and production less risky, the question remains whether they have made it less expensive. More importantly, is deepwater E&P (including ultra deepwater and pre-salt) economically viable in a low oil price environment? Unlike onshore conventional and unconventional hydrocarbon development, deepwater operators have not been unable to capitalize on the standardization of drilling and completion practices. Each drill site is markedly different and requires a specialized—and costly—approach.

Producers in the North Sea have struggled to respond to low oil prices. Some new projects have managed to reduce development costs by 40 percent, according to the Norwegian Petroleum Directorate.¹⁷ However, with sustained low oil prices affecting exploration and investment into new projects, players in the North Sea will need to find ways to optimize and increase productivity of existing assets.

In the Gulf of Mexico, shallow water drilling is reportedly at its lowest level since exploration began in the 1940s. Deepwater drilling has also seen a decline.¹⁸ One reason, again, is the complexity of offshore drilling, in which the rig and related costs account for an estimated 90 percent to 95 percent of total expenditure, leaving less room for quick savings.¹⁹

Increased automation, data-driven analysis, and smart technologies are helping deepwater operators reduce costs. Rigs are increasingly unmanned, and drones can monitor drilling activity and operations. In one pilot study in the North Sea, drones carried out an inspection in two days that would have taken 12 men over the course of seven two-week trips.²⁰ While the unmanned inspection is a tenth of the cost, it requires focused investment in research and development in the adaption and deployment of these new, 'borrowed' technologies.

Still, deepwater drilling is an expensive business. In 2015, the breakeven price per barrel of oil in the Gulf of Mexico was estimated at above \$60. The breakeven prices vary greatly across Gulf of Mexico projects, with those farthest from existing infrastructure hubs and pipelines costing more. These will have important implications for future deepwater exploration, in particular for countries opening new areas, such as Mexico.

Canada's oil sands producers have faced a similar predicament as high oil prices encouraged exploration and production. At an estimated breakeven price of \$70 per barrel, the oil sands are second only to the Arctic in terms of high-cost extraction associated with high energy inputs required and management of discharges. Political uncertainty regarding production and pipelines and environmental regulations and policies, combined with low prices, have complicated the outlook for Canadian operators.

Hydraulic fracturing and horizontal drilling techniques are also being "re-adopted" by conventional oil and gas operators to revive productivity in mature wells in North America. In Canada, IHS found that producers in the Alberta Basin more than tripled production between 2009 and 2014, by incorporating horizontal drilling techniques. Conventional well recovery rates worldwide are only an estimated 35 percent, meaning that enhanced recovery techniques could increase productivity from mature wells to stimulate global oil and production for decades to come.

Efficiency has never been sexy, but it is critical for meeting future demand

Efficiency has never grabbed the headlines like new technology, and yet since throughout the decades of high and low prices, it has been one of the main drivers behind the unconventional sector's rebound.

Efficiency can take many forms; it is interconnected with technological innovation: improvements in data management, subsurface visualization and processing, advancements in drill bit materials and drilling technologies, adopting renewable resources to power operations, inventing ways to recycle and reuse waste water and capture CO₂ emissions. Ultimately, optimization through incremental technological advancements all add up to lower operational costs per barrel of oil equivalent. In terms of human resources, identifying top-performing crews and replicating their practices can increase efficiency across the board. The EIA Drilling Report highlighted streamlining of surface operations as critical to the downward costs trends in unconventional plays, as well as standardization of drilling and completion techniques, a trend that the industry has benefitted from in mature basins, such as nearshore Gulf of Mexico.

Some companies have simply improved logistics around the drill sites from reducing the number of trucks, for example, by transporting water onsite via pipelines to deploying automated monitoring systems and/or robotics for maintenance checks. Transport of fluids, gas, people, and equipment is an area ripe for efficiency gains. So is the transport, decommissioning and disposal of waste. Individually, each of these factors is optimizing the production value of a single process or single site. Together, they translate into significant cost savings, bringing operators ever closer to an economically feasible breakeven price.

This is an area in which the oil and gas industry has much to learn from other segments of the economy as they to invest in applied R&D and innovation. In the upstream oil & gas sector, the sheer number of complex scientific, engineering, logistical challenges that companies must manage and overcome, combined with the fact that drilling success rates and recovery rates continue to average around 40%, are strong indicators that there is a lot of optimization to do.

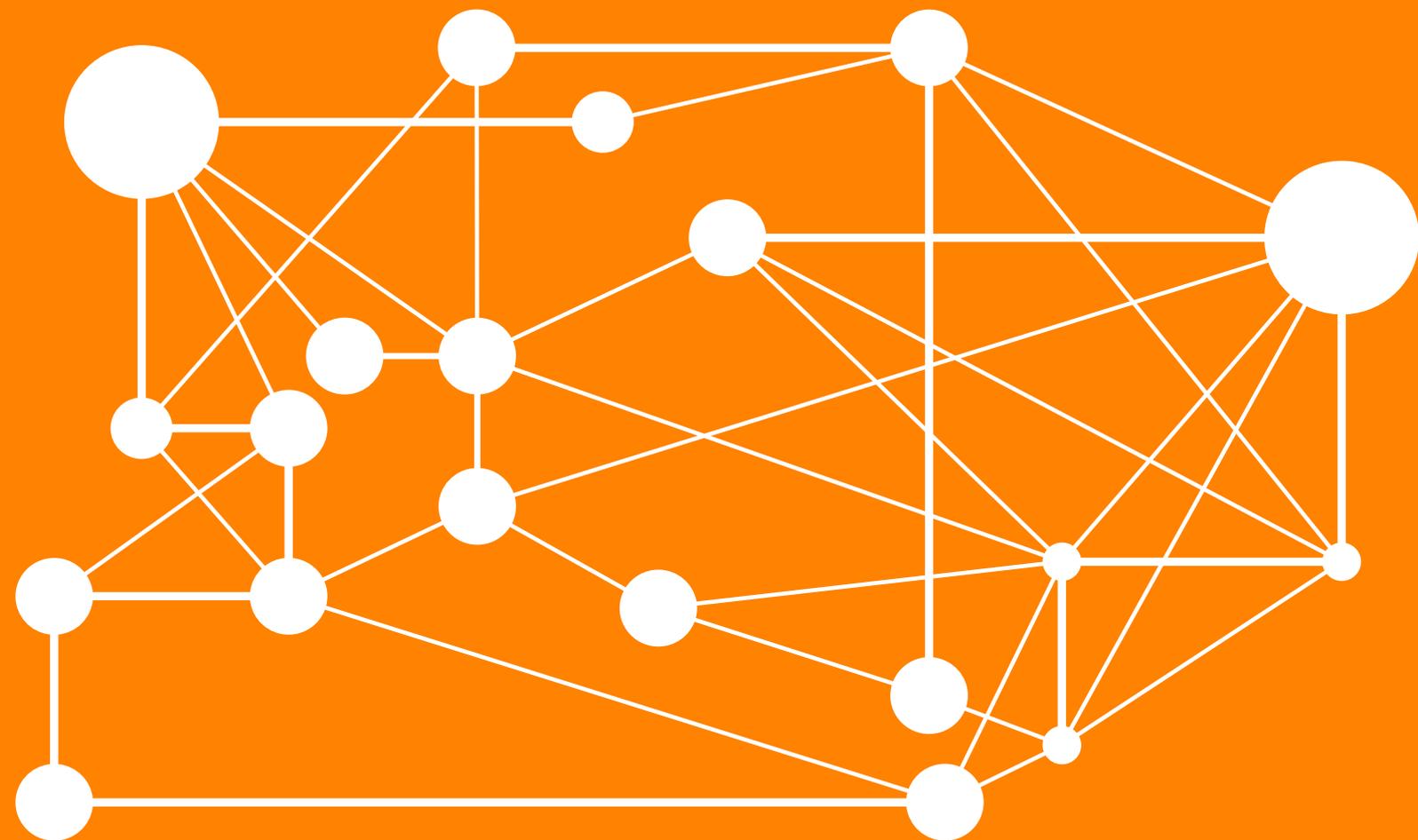
The agility with which the U.S. unconventional sector has responded to low oil prices could offer insights for other players in the industry, in terms of efficiency, innovation, and revisiting scientific, engineering and technological advancements that transformed an industry by making commercially unviable opportunities, economically viable.

In an era of low oil and gas prices, innovation and applied R&D play an even more critical role in reducing costs, improving operational efficiency and effectiveness, enabling both large and small oil and gas companies to achieve more with less.



Resources

- 1 U.S. Energy Information Administration. 2015 World Oil Outlook Report.
Available: <https://www.eia.gov/forecasts/ieo/pdf/o484%282016%29.pdf>
- 2 U.S. Energy Information Administration. Available: www.eia.gov/pressroom/presentations/gruenspecht_05042016.pdf
- 3 Ramón Espinasa, “Brand New Model, Same Old Price.”
Available: <https://publications.iadb.org/handle/11319/7446>
- 4 “The next shock?” Available: <http://www.economist.com/node/188181>
- 5 “Floating Production Systems Hit Stride in North Sea Fields.” Available: <http://www.ogj.com/articles/print/volume-92/issue-21/in-this-issue/drilling/floating-production-systems-hit-stride-in-north-sea-fields.html>
- 6 U.S. Energy Information Administration, “Drilling Productivity Report.” Available: <https://www.eia.gov/petroleum/drilling/pdf/dpr-full.pdf>
- 7 “Average Shale Wellhead Break-even Prices are Below \$40, Rystad says.” Available: <http://www.worldoil.com/news/2016/8/2/average-shale-wellhead-break-even-prices-are-below-40-rystad-says>
- 8 Asjlyln Loder, “Oil Bust of 1986 Reminds U.S. Drillers of Price War Risks.” Available: <http://www.bloomberg.com/news/articles/2014-11-26/oil-bust-of-1986-reminds-u-s-drillers-of-price-war-risks>
- 9 U.S. Energy Information Administration, “Trends in U.S. Oil and Natural Gas Upstream Costs.” Available: <https://www.eia.gov/analysis/studies/drilling/>
- 10 Leo Alund and Keith Rappold, “Horizontal drilling taps more oil in the Middle East” (1993). Available: <http://www.ogj.com/articles/print/volume-91/issue-25/in-this-issue/general-interest/horizontal-drilling-taps-more-oil-in-the-middle-east.html>
- 11 Schlumberger, “Horizontal Highlights” (1995). Available: http://www.slb.com/~media/Files/resources/mearr/wer16/rel_pub_mewer16_1.pdf
- 12 U.S. Department of Energy, “Quadrennial Technology Review.” Available: <http://energy.gov/under-secretary-science-and-energy/quadrennial-technology-review>
- 13 Magnus Nysveen and Leslie Wei, “Refracking the Shale Plays.” Available: <http://www.ogfj.com/articles/print/volume-13/issue-1/features/refracking-the-shale-plays.html>
- 14 Velda Addison, “Operators Have Room to Grow: Refrack Opportunities Exist.” Available: <http://www.epmag.com/operators-have-room-grow-refrack-opportunities-exist-1326526#p=1>
- 15 “Fracking Goes Waterless.” Available: http://www.rigzone.com/news/oil_gas/a/129261/Fracking_Goes_Waterless_Gas_Fracking_Could_Silence_Critics/?pageNum=2
- 16 Data sourced from Scopus®. Available: <https://www.elsevier.com/solutions/scopus>
- 17 “Development Costs Cut by Nearly Half.” Available: <http://www.npd.no/en/news/news/2016/development-costs-cut-by-nearly-half/>
- 18 Bruce Beaubouef, “Low Oil Prices Continue to Take Toll on Drilling.” Available: <http://www.offshore-mag.com/articles/print/volume-76/issue-6/gulf-of-mexico/low-oil-prices-continue-to-take-toll-on-drilling.html>
- 19 U.S. Energy Information Administration, “Trends in U.S. Oil and Natural Gas Upstream Costs.” Available: <https://www.eia.gov/analysis/studies/drilling/pdf/upstream.pdf>
- 20 Karolin Schaps and Jessica Jaganathan, “Oil majors experiment with technology to weather crisis.” Available: <http://www.reuters.com/article/us-oil-companies-costs-insight-idUSKBN12Go8N>



LEARN MORE

To learn more about Elsevier's R&D Solutions, visit www.elsevier.com/rd-solutions or contact your nearest Elsevier office.

ASIA AND AUSTRALIA

Tel: + 65 6349 0222

Email: sginfo@elsevier.com

JAPAN

Tel: + 81 3 5561 5034

Email: jpinfo@elsevier.com

KOREA AND TAIWAN

Tel: +82 2 6714 3000

Email: krinfo.corp@elsevier.com

EUROPE, MIDDLE EAST AND AFRICA

Tel: +31 20 485 3767

Email: nlinfo@elsevier.com

NORTH AMERICA, CENTRAL AMERICA AND CANADA

Tel: +1 888 615 4500

Email: usinfo@elsevier.com

SOUTH AMERICA

Tel: +55 21 3970 9300

Email: brinfo@elsevier.com