Energy Services Innovation: Transforming a continent's hydrocarbon supply

pwc

Leader's message

The upstream petroleum services sector has assumed a significantly expanded role in the oil and gas industry in recent years. This has been driven by strong demand for better technologies, a widening variety of highly-specialized products and services, and ongoing improvements in all three areas. The challenges posed by hard-to-access unconventional oil and gas in Canada and the US gave rise to this demand.

Some of these resources had been known for decades, but attempts to turn them into producing fields had achieved, at best, mixed results. Then, three game-changing technologies arrived in the 1980s and 1990s and made it possible to produce oil and gas successfully from these unconventional resources:

1. With additional components and other enhancements, improved horizontal drilling systems provided much better access to challenging reservoirs.
2. New hydraulic fracturing methods and technologies unlocked previously stranded hydrocarbons.
3. 3D seismic exploration offered a quantum leap in mapping techniques for underground oil and gas reservoirs.

To address the demands related to the growing complexity of operations, the role of service sector companies began to shift beyond their traditional, relatively straightforward operations such as drilling and cementing wells.

Also, faced with low crude oil prices in the late 1980s and throughout most of the 1990s, major international oil companies reduced their R&D spending.

In the 2000s, this trend was reversed. Over the last decade, leading oil and gas producers have doubled spending on R&D, exceeding US$5 billion in 2013, up from about US$2.5 billion in 2004.

Other pivotal trends in the oil and gas industry also emerged around 2000:

- New economic conventional oil and gas resources grew increasingly scarce.
- Oil prices per barrel underwent a step-change, from the US$15 to US$25 range to the US$80 to US$100 range.
- The industry, globally, moved increasingly into challenging, complex developments like the Arctic, deep-water offshore, oil sands, and tight oil and shale gas.

> In light of lower oil prices, industry technology expectations will change from that of technology to help expand production to that of technology to help companies operate more efficiently and at operating costs that allow them to compete globally.

Aside from Alberta's oil sands, it has been the tight oil and shale gas sectors that have seen an exponential rise in production in Canada and the US over the last decade, thanks to the three areas of technological advancements mentioned. Canada's upstream oil and gas services sector has played an important role in this tight oil and shale gas revolution.

In preparing this report, we interviewed some key players from a broad cross section of companies involved in the upstream oil and gas services sector. These included executives from companies like Canadian Energy Services & Technology Corp., Ensign Energy Services Inc., Anton Energy Services Corp., General Electric (GE), Packers Plus Energy Services Inc., and Trican Well Service Ltd.

Our conversations, as well as the track record of these and other companies, depict an industry with a clear commitment to innovation. Taken together, the various sections of this report illustrate ways in which innovation from Canada's upstream services sector drives technological change that continues to transform a continent's hydrocarbon supply, benefit service companies, their clients and the economy as a whole.

Technological innovation:

- improves efficiencies, reduces the footprint, and supports a company's growth and profitability.
- provides solutions for clients' challenges.
- generates export income from services, products and systems.
- spurs the creation of spin-off industries and new sectors.

We believe this report demonstrates these principles in action and how oil price reductions drive changes in the technological needs of the energy industry.

Reynold Tetzlaff
National Energy Leader
PwC Canada

Contents

The shale gas and tight oil revolution: Game changing technologies that unlocked a stranded resource

1. Horizontal directional drilling

Most oil and gas wells were drilled vertically until about 15 years ago. An early breakthrough that made today's horizontal directional drilling possible was the development of mud motors more than 30 years ago. Horizontal drilling is a type of directional drilling in which the departure from the well-bore from the vertical exceeds about 80 degrees. Driven by 'mud' pumped down-hole, these can rotate the bit at the bottom of the well without the entire drill string rotating, and help the operator steer the bit in the desired direction. In recent years, global positioning and advanced sensor technology, stabilizers and specialized drill bits have contributed to making directional drilling one of the technologies that is transforming the continent's oil and gas sector. It is not surprising, though, that these cutting edge technologies first got their feet wet in the high-cost, high-stakes environment of ocean drilling. "Now, we are starting to get our technological edge on land as well. Top drives and horizontal wells were mostly part of off-shore operations before making their way back to land," says Robert Geddes, President and COO at Ensign Energy Services Inc.

2. Multi-stage fracturing

Hydraulic fracturing, or fracking, was first done in the 1940s. Fracturing today is typically done in stages along the lateral section of a horizontal well. It involves the injection under high pressure of large amounts of water and sand, plus some chemicals, into the formation. The underground rock is thus fragmented, creating pathways for natural gas or oil to flow through to the horizontal well-bore. Typically, when the technique was first used for vertical wells, only one fracturing treatment was performed along a well-bore in the pay-zone formation. Also, with early horizontals, only one or two fracturing treatments were done along the laterally-extended well-bore. Today, in multi-stage fracturing operations, as many as 30, 40, or more fracturing treatments are done at designated intervals along the horizontal section of the well-bore.

3. Greater computing and better-targeted software

The third technological leg in the shale gas and tight oil revolution – today's greater computing and better targeted software – is growing in importance. These are improving everything from 3D seismography and stratigraphic analysis of geological formations to detailed studies of formations that cross-reference production curves with operational measures and a range of formation characteristics. It's expected that money spent on information technology will pay off in increased efficiencies and profits which are critical to the future success of higher cost production territories.

Origins of the shale gas and tight oil revolution:

George Mitchell's looming natural gas production problem

When George Mitchell, an independent Houston-based producer, realized that he was going to have difficulty delivering on future gas contracts because of declining production, the push to produce unconventional oil and gas took off.

His company, Mitchell Energy & Development Corp., began experimenting with hydraulic fracturing in the Barnett Shale of Texas in the 1980s. Despite US government efforts and several public-private partnerships set up in the 1970s, no one had found the key to the Barnett. Finally, after more than 15 years of mostly trial and error, with the help of the US Department of Energy, the Gas Research Institute, geologists and service sector experts, Mitchell hit upon a technique, known as light sand fracking, to produce gas economically from the Barnett.

Then, in 2001, a surge in the gas supply from the Barnett was noticed by executives at Devon Energy, another independent that had passed on a chance to buy Mitchell Energy a few years before. The following year, Devon acquired Mitchell Energy for US$3.5 billion.

Directional drilling: The 80-year evolution of a complex technology

Modern directional drilling began to emerge in the 1980s. Then, in the 1990s, as a looming supply crunch in conventional oil and gas became apparent, the development of a host of improvements gathered speed, driven by demand for better technologies to tackle less accessible, unconventional resources.

Directional drilling has been part of the industry ever since the 1920s. The practice remains the same today as it did then: drilling wells at various angles to better access and produce oil and gas reserves found in laterally-extended hydrocarbon-bearing formations or reservoirs.

One of the advantages of directional drilling is that it allows for multiple horizontal wells from the same vertical well-bore, or from a single small patch of land. Before the late 1990s, few wells in Canada or the US cost more than a million dollars. The rise in costs per well has been steep since about 2005, which has driven the need for innovation to compete. We've seen technology advancements grow significantly as a result, saving producers time, money and resources:

- Before pad drilling was invented, the operator would have to disassemble the rig and move it to another location after drilling a single well. This might take two days to disassemble or 'tear down' a rig, a day to move it and two or three days to 'rig up.'
- Pad drilling, on the other hand, only required moving the drilling rig a few metres, with almost no disassembling, before starting to drill another well.
- Today's 'rig-walking' technology can move up to 12 million pounds of fully-loaded big rig about one metre in 60 seconds.

It also saves a lot of time and money, reducing the capital cost per barrel of oil produced. That's become very important in challenging plays where wells don't always turn a profit yet often cost CA$7 to CA$10 million, including the 60 per cent or more spent on multi-stage fracture completions. Continued technology-led innovation will help practices become more resilient in rapidly changing drilling environments.

> "When I look at innovations driven by the service industry, I would have to say that drilling horizontal wells and multi-stage fracturing have been crucial. They have had a bigger impact than anything that has ever happened in our industry."
>
> ***Dan Themig, President and CEO of Packers Plus Energy Services Inc.***

Impacts of horizontal drilling and multi-stage fracturing

Today's better directional drilling techniques and technologies get you to where you want in the pay-zone formation, while increasingly sophisticated multi-stage fracturing along the horizontal section of the well-bore enables access to hydrocarbons. The result has been a transformation of the continent's petroleum supply that has been nothing short of spectacular.

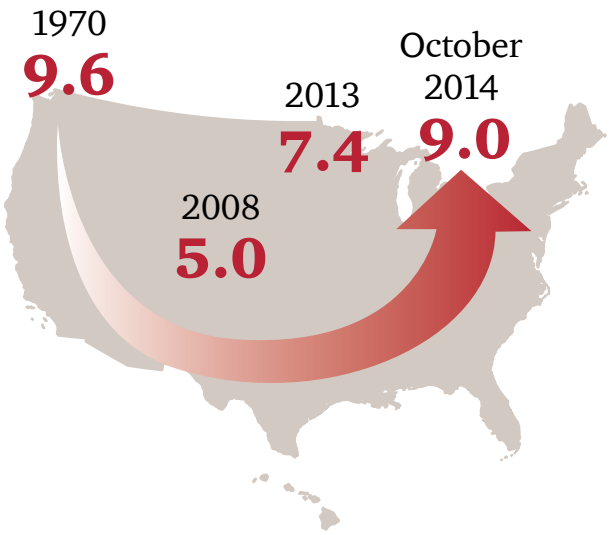
Two major impacts:

1 The US, the world's third biggest oil producer, has seen its daily oil production increase by over 50 per cent since 2008. It averaged 7.4 million barrels of oil per day in 2013 and had grown to 9.0 million barrels per day by October 2014. US oil production had peaked in 1970 at 9.6 million barrels per day and declined until 2008, when production was 5.0 million barrels per day.

2 In Canada, the world's fifth largest producer of natural gas, an 11-year decline in annual natural gas production ended in 2013 with a slight increase to 14.1 billion cubic feet per day – up from 14.0 billion cubic feet per day of natural gas in 2012. Production is on target to hit 14.3 billion cubic feet per day in 2014.

US – World's 3rd biggest oil producer

Daily oil production (million bpd)



Canada – World's 5th largest natural gas producer

Daily gas production (billion cubic feet)

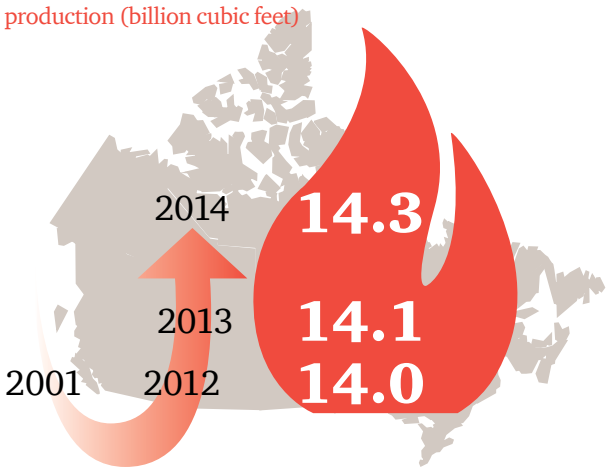


Photo provided courtesy of Ensign Energy

Photo provided courtesy of Packers Plus Energy Services Inc.

The key to the turnaround in both countries has been horizontal directional drilling and multi-stage horizontal fracturing.

In Alberta, as in many other oil and gas producing regions across North America, horizontals today outnumber traditional vertical wells by four to one, or more. That, compared with twenty years ago, where barely one per cent of wells drilled in Alberta were horizontal, speaks volumes of the transformation taking place.

The plays

Here are the shale gas and tight oil plays that show the increase in production of oil and gas due to the impacts of horizontal drilling and multi-stage fracturing.

The story of the Bakken

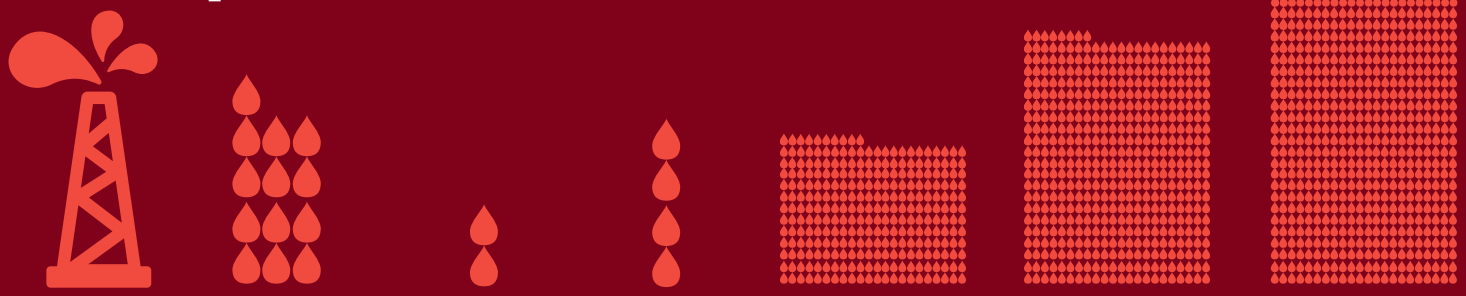
An oil-rich play that has come from almost nowhere in little more than a decade is centred in North Dakota. The Bakken formation also occupies sub-surface areas under parts of Saskatchewan, Manitoba, and Montana.

In 2006, a 'frac job' in the Bakken likely had only one stage. Besides increasing the number of frac stages, producers and service companies experimented with frac sequencing and other variables to make the oil flow better. Today, in the Bakken, companies are often doing more than 40 frac stages along the lateral section of a well. More frac stages raise the overall cost of a well completion, but can dramatically boost production and improve the economics of a well.

> "After directional drilling, the second wave of innovation was completion technology – multistage fracturing along a horizontal well-bore – and that has massively changed the industry on a world-wide scale."
>
> ***Dan Themig, President and CEO of Packers Plus Energy Services Inc.***

Packers Plus Energy Services Inc. which introduced a new open-hole completion system more than a decade ago, has been a key player in this technological revolution.

Bakken oil production



1951
Oil was discovered in the Bakken

1991
13,171 bpd
Production peaked

2000
2,000 bpd
Attracting little attention

2005
3,902 bpd
x2

2010
274,000 bpd
Horizontal wells accounting for nearly 90 per cent of volumes

2011
470,000 bpd
The Bakken was straining local pipeline capacity

2014
+1 million bpd
In July over 600,000 barrels of oil left North Dakota by train each day

The Barnett shale gas play

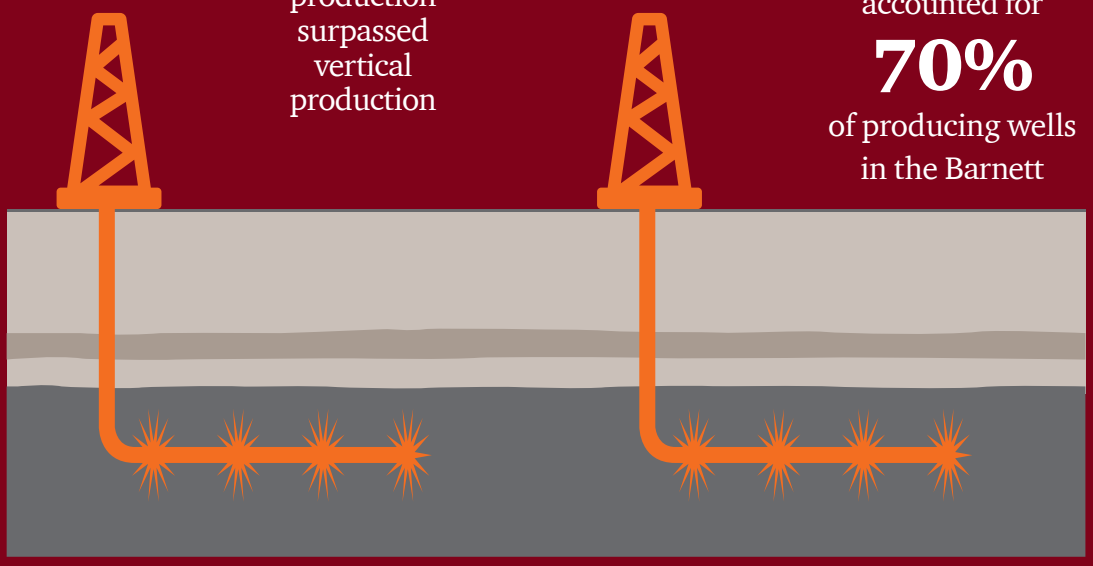
Horizontal drilling and fracturing technology has changed the game in the Barnett.

2004
400 horizontal wells

2007
Horizontal production surpassed vertical production

2009
10,000 horizontal wells

2010
Horizontal wells accounted for
70%
of producing wells in the Barnett

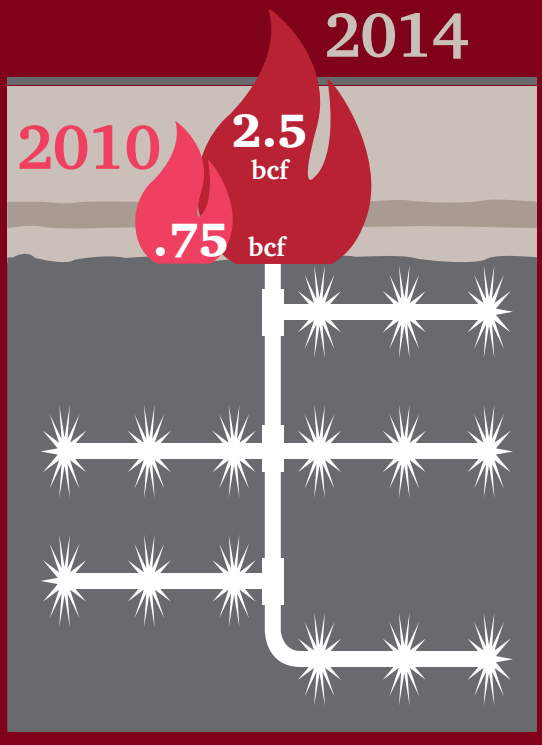


The Montney play

Multi-stage horizontal fracturing has transformed the Montney play into a power-house producer of natural gas and natural gas liquids (NGLs) over the past seven years.

The formation occupies about 12,000 square kilometres beneath parts of Alberta and BC. A vast amount of gas is trapped within siltstone and shale of the Montney, a hybrid tight gas and shale play. To access the pay zones, horizontal wells are drilled at depths ranging from 1,700 to over 3,000 metres. The approach is making a difference.

> "The Montney is a tight reserve. There was no way to extract oil and gas from it prior to multistage fracking."
>
> *Craig Nieboer, CFO at Canadian Energy Services*



The plays

The Cardium play

The Cardium play in west central Alberta has been producing oil since 1953, and now, thanks to horizontal well drilling and fracturing technology, experts believe it's good for another 50 years.

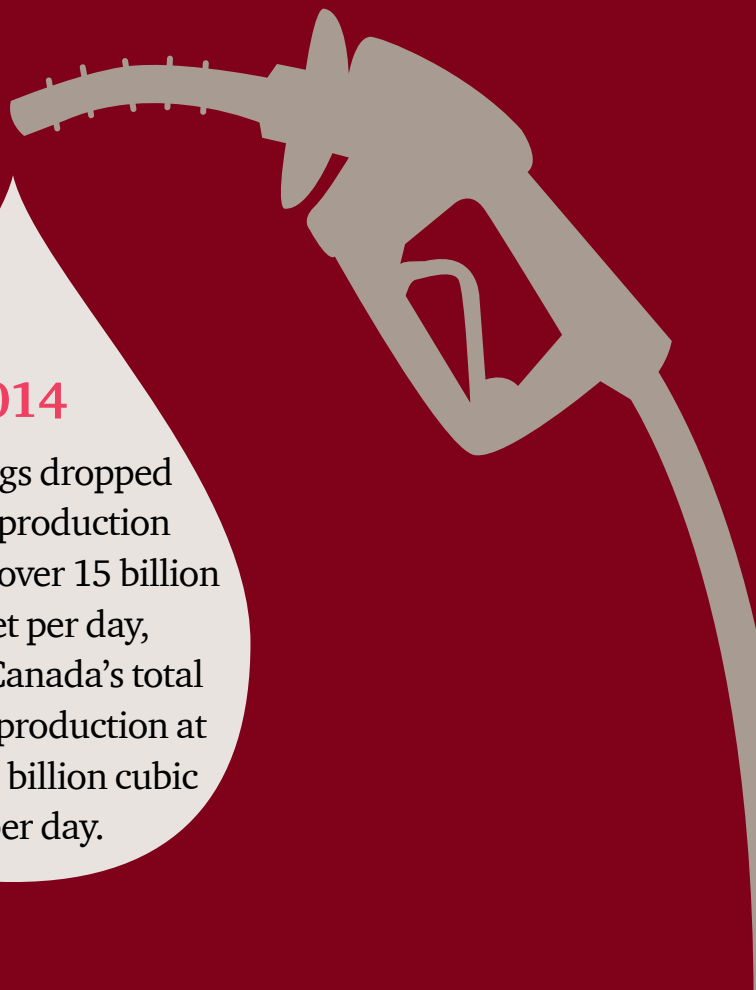
2008 – Unconventional production started

2014 – 95,000 barrels of new tight oil per day

The mighty Marcellus

The Marcellus shale formation extends through northern Appalachia, primarily in Pennsylvania, New York, Ohio and West Virginia.

Its recent staggering increase in natural gas output is a testament to modern drilling and fracturing completion technologies.



2010 to 2012

141 drillings rigs and production of 2 billion cubic feet per day

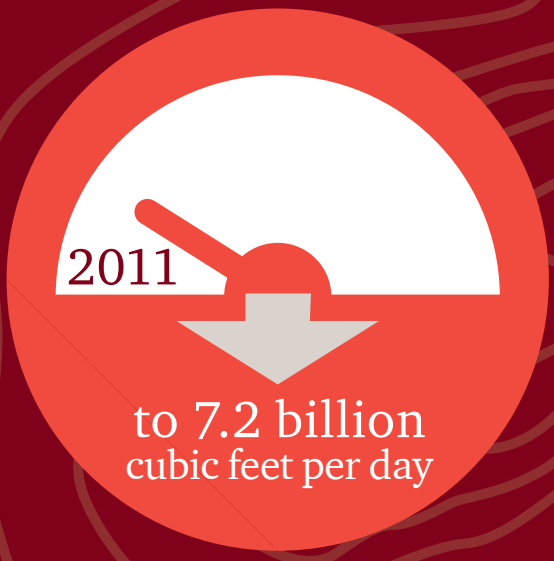
2014

Drilling rigs dropped to 80 but production increased to over 15 billion cubic feet per day, exceeding Canada's total natural gas production at just over 14 billion cubic feet per day.

Eagle Ford shale play

Based on the amount of capital invested, the Eagle Ford shale play ranks as perhaps the biggest economic development in the history of the state of Texas. Almost US$30 billion was spent in developing the play in 2013. It is rich in oil, gas and condensate. A recent month-over-month incremental production was 39,000 barrels per day. Eagle Ford spending for 2014 has been forecast at US$26.9 billion.

1.6 million bpd
2014



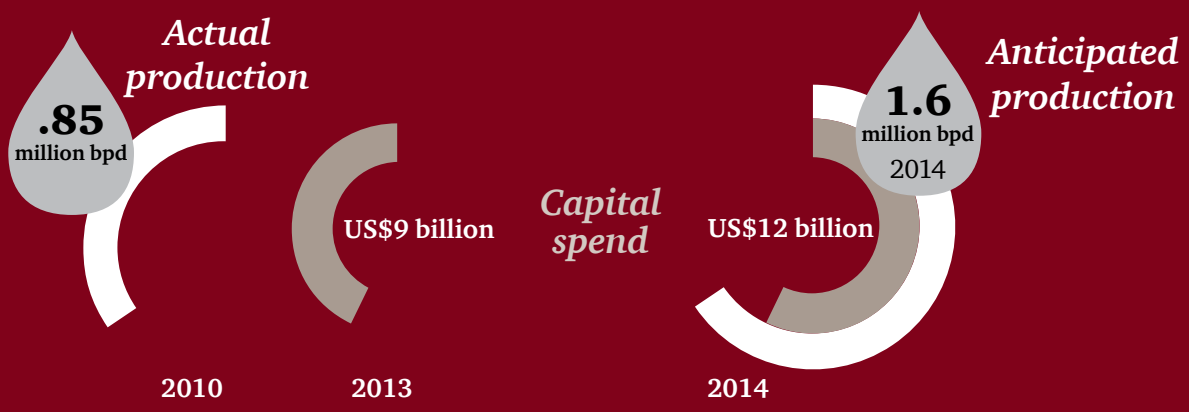
Haynesville shale

Production from the shale member of the Haynesville boomed after 2008. But, relatively high costs and weak natural gas prices resulted in a decline in volumes after production from the Haynesville shale hit 7.2 billion cubic feet per day in November 2011. Oil and gas is produced from other Haynesville members that include carbonate reservoirs.

The plays

The Permian Basin's turnaround

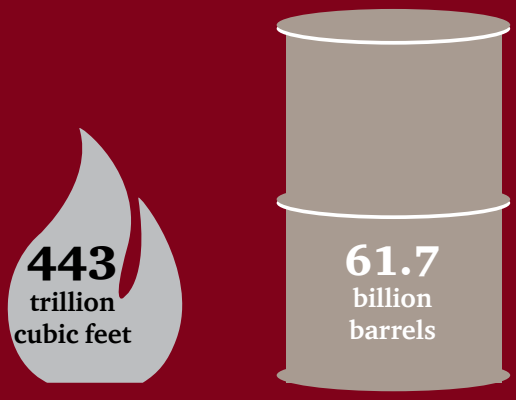
Horizontals in this century-old play have tapped into shale reservoirs to produce oil with increasing success over the last decade. Oil is also now being coaxed from multi-layered reservoirs in this play, which covers parts of west Texas and southeast New Mexico. The steady climb in production from the Permian since 2010 is mostly due to the growth in horizontal drilling and improvements in multi-frac completions. Production from the Permian and Eagle Ford has pushed Texas oil output above three million barrels per day for the first time in three decades.



Duvernay

This promising shale play runs from just below the Peace River arch to the Olds area south of Edmonton, Alberta, and contains three resource windows – oil, condensate and dry gas. Analysts say that once development ramps up, production will average one million barrels of oil equivalent per day (boe/d) by 2024 in a mix of 47% gas, 33% oil and condensate, and 20% natural gas liquids.

Drilling and completion costs are high, averaging around CA$12 million per well, but such costs are in line with comparable plays at a similar stage of development. As a comparison, the Oil & Gas Journal reported in September 2014 that costs per well in the Eagle Ford had dropped from US$14 million in 2010 to US$8 million in 2012. Economies of scale kick-in as operators shift from single exploration wells to factory approaches using pad-drilling. One Duvernay operator estimates well costs will drop 20-30% by 2015.



The liquids-rich play holds an estimated 443 trillion cubic feet of natural gas and 61.7 billion barrels of oil.

Innovations from the service sector that have made today's drilling and completions techniques possible

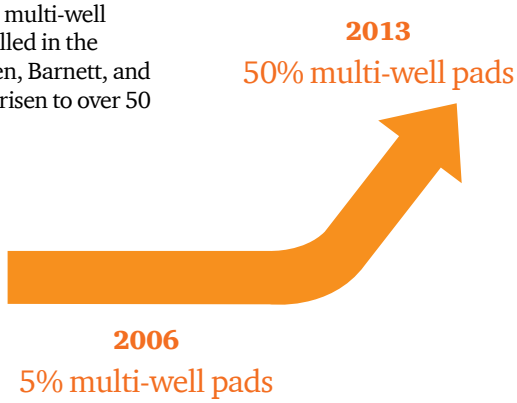
Directional drilling and horizontal fracturing evolved as clusters of systems and components that with each improvement worked better.

> "It wasn't one big technology. It was a whole lot of little things combined with the input of drillers and other specialists that resulted in a game change for the industry."
>
> ***Dale Dusterhoft, CEO of Trican Well Service***

Below is a sampling of innovations that support modern drilling and completions.

Multi-well pad drilling

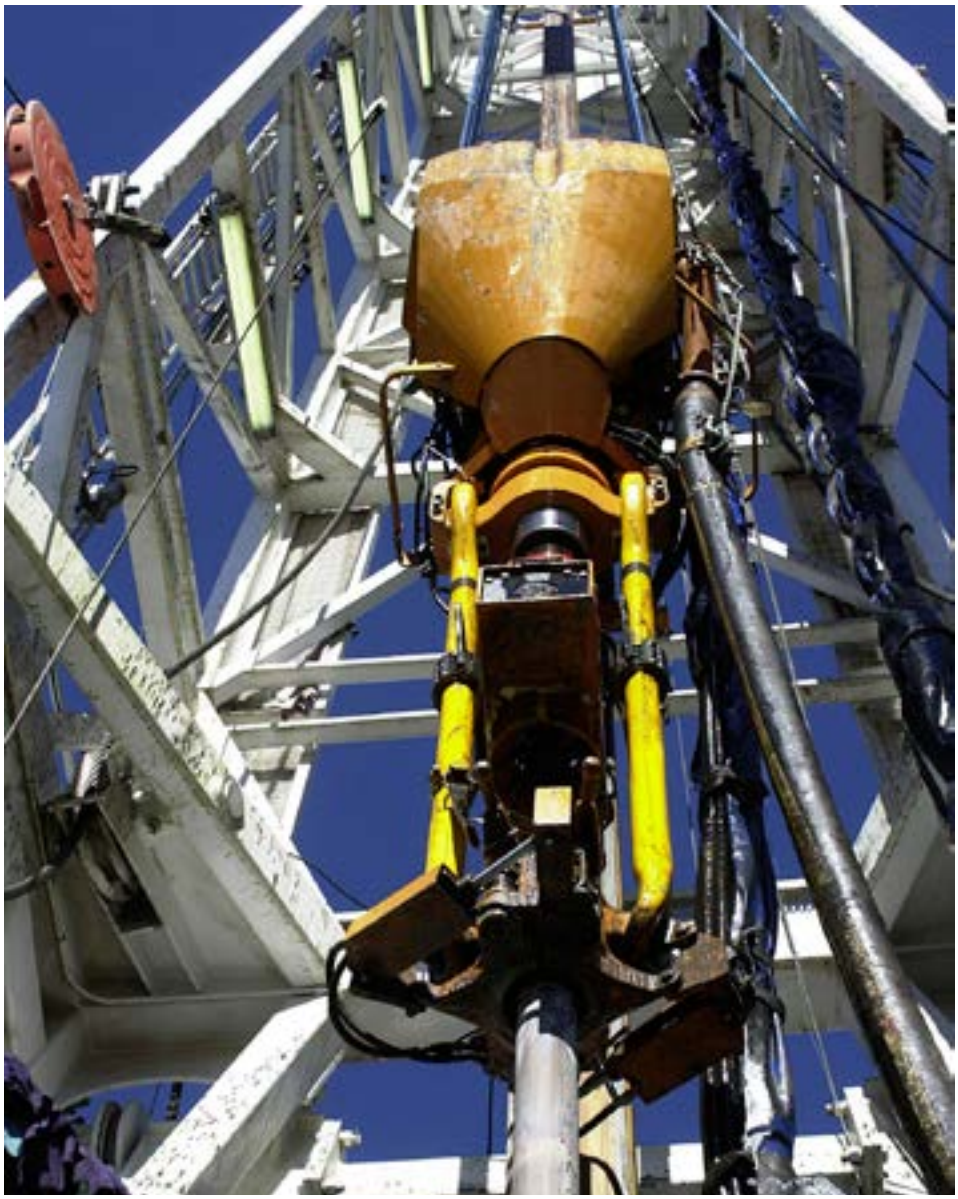
In 2006, when pad drilling began to take off, multi-well pads made up about five per cent of wells drilled in the main US unconventional plays like the Bakken, Barnett, and Eagle Ford. By fall 2013, the percentage had risen to over 50 per cent.



> The PDC bit, or polycrystalline diamond compact bit, has cutters that shear rock with a continuous motion. It was an innovation about 15 years ago. It's able to stay in the hole three or four times longer than the traditional rotary cone bit. Because we were pushing the dirt out of the hole faster, we needed bigger mud pumps.
>
> ***Robert Geddes, President and COO of Ensign Energy Services***

Real-time data flows from down-under

Besides a down-hole steerable mud motor, and a special bend or 'bent sub' near the bit, instruments today are more flexible. The drill-string, as the once rigid stem of drill pipe is now called, transmits an array of measurements to a directional driller in the rig's control room. Supported by the latest sensor, gamma ray and neutron porosity measurement technology, the data from the down-hole instruments provide key information on the formation's characteristics.



The PDC bit

Earlier breakthroughs like the PDC bit provide a solid foundation for ongoing innovations. "The PDC bit, or polycrystalline diamond compact bit has cutters that shear rock with a continuous motion. It was an innovation about 15 years ago. It's able to stay in the hole three or four times longer than the traditional rotary cone bit. Because we were pushing the dirt out of the hole faster, we needed bigger mud pumps," says Robert Geddes, President and COO of Ensign Energy Services. "Bigger mud pumps soon led to bigger motors, but the weight of really big diesel-fired motors prompted a switch to electric-powered drive-train for pumps."

The drilling rig — then and now

Just a few decades ago, when the driller began operating the draw-works to run a drill-stem back in the hole, two roughnecks busied themselves on the rig floor. Meanwhile, far above, the derrick-hand was latching sections of pipe to the 'elevators' that raised them from the rig floor, where they sat racked. Once a section of pipe was raised, the floor hands or roughnecks below attached it to the drill-stem with the help of a spinning chain and manually-operated tongs to tighten the connection.

Besides skipping the wire-line truck altogether, and using logging-while-drilling, today's driller, who has hours of paper work to do each day, often has an assistant driller. The rig crew includes roughnecks and a derrick-hand, but they are not clambering up the derrick each time pipe is run into the hole, nor perhaps are roughnecks on the floor. Today, racking and connecting sections of pipe are being done by robotic equipment known in the industry as 'iron derricks' and 'iron roughnecks,' freeing up human resources to do higher value work.

Instead of a rotary table set in the rig floor, a modern top drive, either electric or hydraulic, powers operations, replacing the more high-maintenance, but less-powerful, diesel-fired motors of the past. A modern trailer-mounted rig that might accommodate coil tubing would likely include a mast with integral substructure and work floor, draw works, storage reel with level wind, injector, top drive and a hydraulic system, all supported by electricity and electric-powered motors.

Photo provided courtesy of Trican

Small-to-medium enterprises step up to the plate

Many innovative service sector small-to-medium enterprises (SMEs) are based in western Canada, at the hub of the nation's oil and gas industry.

The era of horizontal drilling and multi-stage fracking in unconventional, hard-to-access formations has seen costs per well skyrocket. A decade ago, most wells in western Canada cost less than CA$1 million to drill and complete. Today, about 65 per cent of wells drilled in the region are horizontally fractured, putting the cost per well at CA$5 million or more. Recent years have also been a game-changer for many aspects of field operations. This has included assigning priorities and using innovative tools for drilling programs and testing new techniques for multistage fracturing completions.

Service sector companies not only help clients boost efficiencies with better tools, but also streamline their internal operations to cut costs and be competitive. That can mean finding the best cost-benefit option. "If you don't have a better mousetrap, you need a better price," says Barry Evans, VP business development and general manager at Anton Energy Services Corp.

In today's unconventional sector, the cookie-cutter approach is often the wrong approach. Quickly understanding the mix of tools and techniques that work best in a given field or play can fast-track return on investment.

This has helped drive demand for a host of niche and specialized tools and technologies. SMEs in the upstream service sector have responded with innovative new products that successfully target specific emerging and continuing challenges.

> "Operators and service companies often work hand in hand. There's an advantage to having this level of concentration of the oil and gas industry expertise in Calgary, so industry can run fast. We can squeeze the sponge here better than anywhere else in the world."
>
> ***Craig Nieboer, CFO at Canadian Energy Services***

Some recent innovations

Rapid pulse tool for faster drilling

In higher-cost environments, issues can become more urgent. Drilling rate of penetration (ROP) is a case in point. Fast ROP can mean substantial savings. Drilling costs are often around $100,000 per day, so shaving five days off a type of well that usually takes three weeks to drill can lead to significant cost savings.

Two companies, Wavefront Technology Solutions Inc. and Sicotte Drilling Tools Inc., teamed up to develop a rapid pulse tool (RPT), which became commercially available about 18 months ago. It applies the principles of cavitation – that's what causes the pitting on the propellers of boats and ships – to enhance rock-breaking while drilling through the sub-surface.

QuickFRAC system for multi-stage fracturing

Calgary-based Packers Plus Energy Services Inc. holds around two dozen patents for fracturing technology and is a pioneer of a number of innovative techniques. The company was in on the ground floor of the shale oil and gas revolution and first applied its open-hole approach in the Barnett shale almost a decade ago. Using the company's StackFRAC HD technology, fracturing can be done on a multistage basis along the horizontal without having to keep removing and re-inserting equipment, as had to be done with earlier fracturing systems. This innovative ball-drop completion system saved time and money when completing a well. Recent enhancements to this technology include the QuickFRAC system, which allows multiple fracturing stages to be completed with one ball, further saving time and money, and increasing the number of stages that can be completed in a well. This can be especially beneficial in higher-cost remote locations.

New electrochemical oxidation technology

A low-cost, chemical-free catalyst for removing organic toxins from industrial waste water is helping oil and gas companies stay environmentally responsible when disposing water after fracturing treatments. The new electrochemical oxidation technology was developed by Axine Water Technologies Inc.

FlareAdvisor – a compliance management software tool

A new software product from Process Ecology, a Calgary-based oil and gas consultancy, is helping companies in the upstream oil and gas sector estimate and manage their flaring and venting of gases like methane, the main constituent of natural gas. The company's Internet-based FlareAdvisor provides operators in the field with immediate information on where venting or flaring is happening and helps pinpoint equipment failure or problems.

WellEXPERT – making pumpjacks smarter

Nodding pumpjacks have rivalled the derrick as an emblem of the oil industry for about a century. With oil often around US$100 per barrel, recent years have seen an interest in smartening up these reciprocating devices that are used to lift oil from a well. Automation, software, feedback loops, sensors and some higher math comprised the lion's share of a control system to improve the efficiencies and profitability of pumpjacks that was developed at Pumpwell Solutions Ltd. With its WellEXPERT technology, Pumpwell is now enabling oil producers to outsource the management of their artificial lift operations in the field. By having experts at a service outfit like Pumpwell focus on this specialized area, production engineers with oil producers can more easily meet the growing demands of running today's complex drilling and fracturing operations.

> "Producers have two key goals: reduce operating costs and improve the environmental performance. Technologies that address these goals can expect to see producers buying in."

James Cleland, Global General Manager for heavy oil at General Electric (GE)

The proppant sector arrives from obscurity

The exponential growth in horizontal fracturing has given rise to a burgeoning new industry that was barely on the radar a few years ago.

Photo provided courtesy of Trican

One of the critical components of a fracturing treatment is silica sand, sometimes called 'frac sand,' but known in the oil and gas industry as proppant. This refers to its role in a fracturing operation. During a fracturing treatment, proppant is forced down the well-bore and into the formation along with water and chemicals as a result of high-pressure pumping. This induces fractures and fissures in the formations. The role of the proppant, as the name suggests, is to make sure these new openings stay open in order to improve permeability – providing a flow path for the gas or oil.

As one might expect, with frac jobs in some liquids-rich natural gas plays using as much as 2,000 to 3,000 tonnes of sand per well, demand for frac sand has taken off. The proppant industry has been on a double-digit-per-annum growth curve for a while now, despite what some see as the risk of a glut in the wake of an influx of new entrants into the sector.

With proppants often accounting for up to five per cent of the cost of a well, this sector's starting to acquire some heft within oil and gas services across the continent.

Photo provided courtesy of Trican

Looking to older technologies to solve new challenges

Although the stunning growth of the unconventional sector owes much to innovations of the last 25 years or so, systems and technologies from an earlier time are also lending a hand. An example of this is a General Electric (GE) 25-megawatt electrical power generator that has been around since 1969.

A quick look at what's involved in power requirements for some of today's big frac jobs and it is not hard to see why the portable edition of this GE workhorse seems purpose-built for today's unconventional environment. As Apache Corporation explained on its web site, "Multi-stage horizontal well completions in the Horn River Basin are massive operations, involving a field team of about 280 workers and requiring some of the largest fleets – pressure pumpers, wire line trucks, cranes, coil tubing service rigs and other vehicles – ever assembled in Canada's energy industry."

That was about five years ago. A fracturing operation of that scope today would take about half the time it did then, but the complexity of it would be about the same. The number of diesel-powered pump trucks in this type of operation posed several concerns: many are not designed to run hard for long hours. With trucks just a foot or two apart, ambient temperatures can hit a scorching 82 degrees Celsius. Then there is the risky business of refuelling engines while operating in the midst of this heat.

Instead of a tight cluster of two or three dozen pump trucks, the operation is simpler, quieter, safer – and cooler – with a big portable GE gas turbine generator juicing the required array of heavy-duty, 2,500 horsepower electric pumps for the frac job.

Driving demand for better data analytics and computing

Information is becoming a more valuable asset for all industries, but for oil and gas companies, knowing where to look, where to drill, how deep, and so on has always been a key driver of innovation.

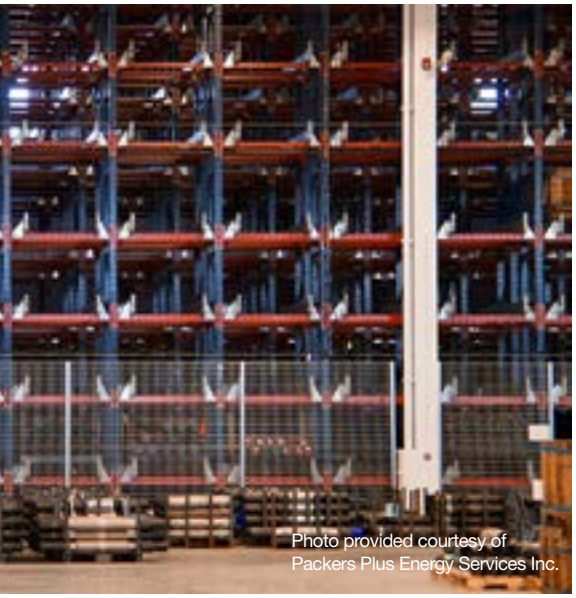


Photo provided courtesy of Packers Plus Energy Services Inc.

As the increasingly digitized oilfield operations generate more varied and bigger streams of data from seismic mapping, drilling and fracking, demand for data from a range of other sources – including well production curves, service schedules – is expected to grow, spurred by the challenges of unconventional oil and gas. This is leading to the use of big data analytics for all facets of operations – to monitor equipment, identify operational or well performance issues, and optimize production and revenues.

Big Data's key advantages for better predictive analytics are that it involves a vastly more comprehensive sampling of coded data variables, reduces the number of flawed assumptions and gets more accurate results.

Hunting hydrocarbons: The seismic exploration technique

In the early 1900s, oil field exploration was a guessing game that often relied on surface signs like oil seeps. But seismology, the scientific study of earthquakes, which began in earnest after the 1755 Lisbon earthquake, led to the development of a method of geophysical exploration known as reflection seismology. It involves the use of a controlled explosion to propagate a seismic wave from a surface "shot-point" to estimate the properties of the earth's sub-surface. Surface receivers called geophones pick up the energy waves reflected by the sub-surface geology and convert them into electrical signals that are recorded over a predetermined time period. The signals are processed and used to map sub-surface formations.

The concept of applying the principles of seismology using reflected seismic waves to ascertain properties of the earth's sub-surface first occurred to Canadian inventor Reginald Fessenden a century ago. It was prompted by work he had done on the propagation of acoustic waves in water to measure depths and detect icebergs after the sinking of the Titanic by an iceberg in 1912. He applied for a patent on a seismic exploration method in 1914, which was issued in 1917. Fessenden's innovation was to have far-reaching effects, and modern versions of his concept in the form of 3D seismic exploration continue to benefit the global petroleum industry.

Good enough for a while, 2D seismic eventually had to get better

Petroleum's information age, it could be said, began in 1924 with the first use of a 2D seismic map leading to the discovery of an oil field. It lay beneath the Nash salt dome in Brazoria County, Texas. It was not until the 1970s, however, that companies began to experiment with 3D seismic surveys. Fortunately, these complex, very detailed surveys coincided with the dawn of modern computing. But the amount of 3D survey data gathered in just one month could take a main-frame computer back then a year or two to process.

In the past decade, with horizontal drilling and completions often costing in the CA$5 to CA$10 million range per well, 3D surveys have become the norm. Today's software programs can provide 3D visual interpretations of geologic data, much as a CAT scan presents a 3D visualization or image of a patient's internal organs.

Such innovations have boosted success in exploration drilling. For example, in 2014, new field wildcat wells have a success rate of 50%. Forty years ago, only 15% of such wells panned out. (In 2013, only 50 wildcats were drilled in western Canada, compared to 976 in 1966, according to figures from Canadian Association of Petroleum Producers or CAPP.) The challenge now, in North America, is perhaps less about finding the oil or gas, and more about extracting the maximum hydrocarbon payload from a formation, especially given today's costs.

Drilling and completions get smart for the 21st century

With sensor-supported geo-steering

The boom in unconventional oil and gas has occurred not only as a result of software-supported 3D surveys being more precise, detailed and accurate, but also because drilling and fracture completions have become a lot smarter. Fifteen years ago, the bottom-hole assembly (BHA), a grouping of tools and specialized equipment, including the drill-bit, that operates at the business end of a drill string, was often quite simple, and cost less than $100,000. In today's complex directional drilling operations, a BHA includes mechanisms for steering, as well as sensors and other devices to gather and send real-time data about the formation being drilled through, and often costs more than $1 million. Software processes the data to adjust the direction of the drill-bit and keep it in the "pay-zone" – where the oil is.

And micro-seismic monitoring

To better stimulate the well at the completion end, fracturing operations are increasingly resorting to a technique known as microseismic monitoring. It provides details on the propagated fractures and related seismic events in response to high-pressure pumping and the resulting "fracking." When software-based images of the monitored activities are displayed in real time, an operator can make design changes for the next fracture stage and – hopefully – improve reservoir contact and future production.

Photo provided courtesy of GE

The quest continues for technological game-changers

Reducing costs, increasing efficiencies and making operations cleaner will require more technological innovation. At least three core areas of potential improvement are receiving scrutiny as well as R&D money from the upstream energy services sector.

Real-time fracture monitoring using micro-seismic analysis

It is widely accepted that the industry's understanding of sub-surface fracture behaviour needs to improve. To address this, better information that combines high-quality geophysical data with real-time fracture monitoring is required. Real-time fracture monitoring using micro-seismic analysis, in which sets of geophones measure the small amounts of seismic activity caused by hydraulic fracturing, is seen as a promising emerging technology. The development of predictive algorithms could provide insights into what happens when a certain type of formation is fractured. Such insights, in turn, could help engineers decide where to place fracturing stages and how best to set fracture design parameters. One of the aims here is to improve the effectiveness of each fracture stage.

Reduce, re-use, recycle: Finding a low-cost technology

A second area of improvement involves the treatment of water used for fracturing. At present, somewhere between 7 to 19 million litres per well are often required to create fractures in the subterranean rock. The issue is especially acute where water is being used for frac jobs in regions experiencing water shortages. The quest is on for low-cost, high-volume techniques for cleaning water that has been used in fracturing. This will cut upstream industry's reliance on fresh water. "The one thing we're working really hard at is water management. It's not how to store or pipe water. It's reduction of fresh water. That's important for our industry going forward. It ultimately has to save our customers money, but it is also environmentally friendly and helps our social licence," says Dale Dusterhoft, CEO of Trican Well Service.

A desalination process called membrane distillation and a treatment system that uses positively charged ions and bubbles are both attracting some interest. Other emerging technological possibilities include centrifuges, electro-precipitation and the use of ultrasonics and ultra-violet lights. It's possible that a combination of some of these technologies will offer a solution.

Non-water-based fracturing

The ideal upstream solution, non-water-based fracturing, could be the ultimate result of some combination of the above technologies. Besides reducing the environmental impact of fracturing, this could potentially open up new areas for development, now off limits because of the lack of water. Carbon dioxide was used for fracturing gas wells decades ago, and has been used on a limited basis ever since. Companies are continuing to explore its potential. "We have a pilot testing our CO_2 technology for fracturing in the Bakken," says James Cleland, Global General Manager for heavy oil with General Electric (GE).

The wider use of CO_2 for fracking would likely require its transport on an industrial scale. This would entail a substantial investment in infrastructure to bring the CO_2 by pipe to regions where it was needed. Nitrogen and liquid-petroleum-gas (LPG) are also being used for fracturing. Some believe a carbon price would provide an incentive to capture carbon dioxide from utilities' smokestacks, but, these non-water-base techniques, entail either safety, technical or logistical concerns.

Concluding comments

This report has touched on some of the key aspects of a technological revolution that has enabled the renewal of legacy oil fields and greater access to previously uneconomic oil and gas prospects. These new sources of hydrocarbons are continuing a process of transformation in the supply of oil and gas for Canada and the US. In many of our interviews, executives have emphasized the primary role of technological breakthroughs in horizontal directional drilling and multi-stage fracturing.

Service-sector majors have also stepped up to the plate with game-changer innovations like the polycrystalline diamond compact bit (PDC) and recent improvements in geo-steering technology.

Some, both from inside and outside the oil and gas industry, have pointed with concern to the significantly higher costs per well of today's upstream drilling and completion operations in the unconventional sector.

The increase in production showcased in this report demonstrates what a combination of innovative technologies and gains in formation knowledge can achieve.

> "For Canada and all of North America to remain competitive at a global level, we need to continue to focus on technology so that we are able to withstand downturns in the energy industry and take full advantage of the upturns. Technological innovation is the key to our success today, and into the future."
>
> ***Reynold Tetzlaff, National Energy Leader, PwC Canada***

Technologies of the future

> Almost every well we drill now is directional. It's rare to drill a vertical well anymore. So that has been a big change. The evolution I see is in the controls of various machines and systems. We are working hard on interactive control loops that tell the different machines what to do.

Robert Geddes, President and COO at Ensign Energy Services Inc.

> Companies understand rocks and petroleum reservoirs, and there continue to be incremental advances in this area. But if I look at our industry now, and then look at it 10 years from now, what is going to be different is that we will understand everything that's going on down-hole. I don't know how it's going to happen, but if we have a horizontal well that's two miles long, we'll know what's going on in every foot of that well. We almost have no clue what's going on right now.

Dan Themig, President and CEO of Packers Plus Energy Services Inc.

> The majority of the changes will be on the equipment side, the efficiency side, and the fluid side. I think we're still going to be drilling, fracturing and running pipe into wells, but I think we're going to find a better way to do it in all cases.

Dale Dusterhoft, CEO of Trican Well Service

> Apart from figuring out ways to access new reserves, significant components of new technology will be focused on achieving an improved recovery factor for existing and known oil fields. Advanced chemistry and science are likely to be key to increasing the recovery factor.

Craig Nieboer, CFO at Canadian Energy Services & Technology Corp.

> I can see the industrial internet and big data and analytics playing a much bigger role. I think over the next 5 years big data and analytics are going to play a very critical role in helping industry fine tune what it is doing to get better results. These will be important for predicting failures and understanding what's happening down-hole. It's going to be transformative for the industry.

James Cleland, Global General Manager for heavy oil at General Electric (GE)

> Developing a fuel or motorized technology that would run at considerably lower prices so that it would be available worldwide, and developing diesel engines for high mileage for commercial applications. The innovation for diesel technology is still young. North America needs to move forward faster with technology for diesel. It can run cleaner than gasoline.

Barry Evans, VP Business Development and General Manager at Anton Energy Services Corp.

Key contacts

Reynold Tetzlaff
National Energy Leader
+1 403 509 7520
reynold.a.tetzlaff@ca.pwc.com

Calvin Jacober
Calgary Managing Partner
+1 403 509 7531
calvin.b.jacober@ca.pwc.com

David Bryan
Edmonton Managing Partner
+1 780 441 6709
david.j.bryan@ca.pwc.com

Assurance

Shannon Ryhorchuk
Calgary AAG Site Leader
+1 403 509 7506
shannon.g.ryhorchuk@ca.pwc.com

Khurram Asghar
Energy Services Leader
+1 403 509 7501
khurram.asghar@ca.pwc.com

Tax

Domenico Baruffaldi
National Energy Tax Leader
+1 403 509 6676
domenico.baruffaldi@ca.pwc.com

Angelo Toselli
Calgary Tax Leader
+1 403 509 7581
angelo.f.toselli@ca.pwc.com

Consulting

Matthew Wetmore
National Energy Consulting Leader
+1 403 509 7483
matthew.b.wetmore@ca.pwc.com

Deals

Clinton Roberts
Alberta Deals Leader
+1 403 509 7307
clinton.l.roberts@ca.pwc.com

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