Apache

EXPLORING WHAT'S POSSIBLE

HYDRAULIC FRACTURING 101

What every
representative,
environmentalist,
regulator,
reporter,
investor,
university researcher,
neighbor
and engineer
should know about
its risks
and benefits

HYDRAULIC FRACTURING:
The answer or the problem?

Some suggest hydraulic fracturing of natural-gas shales as the answer to America's energy deficit. Opponents say it is fouling our environment. Who's right?

This brochure lays out the facts. Yes, it's produced by an energy company. But we're scientists and engineers who understand the fracturing process and the geology of our world, and we adhere wholeheartedly to scientific methods. Our goal, in this brochure, is to address the issues that have been raised by those opposed to American shale-gas development. Honestly. Scientifically. Unemotionally.

We don't offer this information as the be-all and end-all, but only as a starting point for transparent discussions about well development and risk evaluation.

THE POTENTIAL

Hydraulic fracturing enables the production of natural gas from shale rock far below the Earth's surface. Its effectiveness is spectacular, and that's no exaggeration.

Without hydraulic fracturing, shales will not produce gas in commercial quantities; with hydraulic fracturing, these same shales can produce vast quantities of clean, domestic natural gas—enough to supply the nation for the next century, without foreign imports or serious risk to the environment.

Not only that: Hydraulic fracturing has sharply increased U.S. oil production, reversing a downward trend that began in the early 1970s.

The use of horizontal wells and hydraulic fracturing is so effective that it's been called "disruptive." That is, it threatens the profitability and continued development of other energy sources, such as wind and solar, because it is much less expensive and far more reliable. Not only that, but compared to coal, natural gas produces only half the carbon dioxide and almost no sulfur, nitrous oxides or mercury.

Naturally, those demonstrable benefits over both traditional and alternative energy draw monetary and political attacks.

THE PROBLEM?

University and media reports have focused on two main environmental concerns about using hydraulic fracturing to recover shale gas:

- Groundwater and/or surface-water contamination by methane or chemicals
- Escape of methane gas to the atmosphere

These risks come from:

- Well construction
- Transport of chemicals and fluids to the well site
- Operation of the wells and the gas-transport system

This brochure addresses the risks involved in fracturing—everything from transporting chemicals to removing wastes. The fracturing process is similar from well to well, with minor differences as required by the properties of the shales themselves.

A SUMMARY OF THE RISKS

You can read more about each of our conclusions in the references we cite. This is only a summary of our research.

1. Deep-well hydraulic fracturing does not travel through the rock far enough to harm freshwater supplies. Thousands of field-monitoring tests and millions of fracturing jobs have confirmed this point.

2. In the deep, properly constructed wells that produce most American shale gas, the chance of even minor water contamination from frac chemicals is less than one event in a million frac treatments, based on statistical analysis. When compared to the frequency of pollution from chemical dumps, acid mine drainage, general manufacturing, oil refining and other energy- or product-producing activities, natural gas from conventional and unconventional sources generates *more* energy with the *least* impact and *fewest* problems.

3. Even as underground fractures grow (mostly outward with limited upward and downward growth), the total fracture extent remains thousands of feet below the deepest freshwater sands. The height of any fracture is limited by rock stresses, leakage of frac fluids within the target fracturing zone, and the hundreds of natural rock barriers that border the shale zone.

4. Water contamination occurs rarely and comes exclusively from careless road transport, on-site storage and surface mixing, or well construction. These failings can be addressed successfully with existing technology and effective regulations. It is interesting to note that the states with the fewest problems are those with strong state regulations. Appropriate regulations already exist in most producing states and work very effectively to protect the environment.

5. In the deep wells typical of shale gas, we have found no documented case of any chemical contamination from hydraulic fracturing.

6. The impact of chemical spills and leaks is low and can be decreased further by improvements in transport containment, storage methods and frac chemicals.

7. Although hydraulic fracturing does not increase the presence of methane in water wells, poor well construction and natural seepage can create methane movement. Eliminating this potential problem requires the proper cement isolation of any methane-producing section of rock. This prevents the wellbore from conducting the methane that is sometimes found in shallow coals or thin shales into fresh-water zones or wells. High-pressure air drilling also may play a role in stirring up sediment and activating natural bacteria that produce odors, color and foul tastes in shallow freshwater zones. This potential problem can be addressed with changes in drilling techniques.

WHY THE FUROR?

Since widespread shale development began a few years ago, we have witnessed a growing furor about hydraulic fracturing to recover shale gas. We believe the concern grows from three sources:

- Lack of chemical disclosure by the drilling companies
- Inadequate pre-2011 well-construction regulations in some states
- Widespread misinformation, sometimes from poor communication and some spurred by the threat of cheap natural gas to the development or profitability of other energy sources

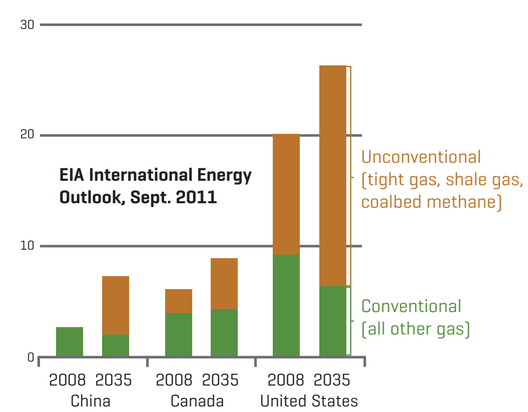
Some anti-fracturing charges in media articles and university studies are true and require improved well design for certain geologic areas, as well as better state oversight of well development.

NOTHING NEW UNDER THE GROUND: A SHORT HISTORY

Hydraulic fracturing and horizontal wells are not new tools for the oil and gas industry. The first fracturing experiment took place in 1947, and the process was commercial by 1950. The first horizontal well was envisioned in the 1930s, and horizontal wells were common by the late 1970s. Millions of fracs have been pumped, and tens of thousands of horizontal wells have been drilled worldwide during the past 60 years.

The recovery of shale gas is not new, either—especially from the Devonian shales in western Pennsylvania. This is, after all, where Edwin Drake, exploring the area's natural seeps of oil and gas, drilled the first U.S. oil well in 1859—to a grand total of 69 feet deep. In fact, native North Americans gathered oil and tar from natural seeps more than 1,500 years ago. And the first shale-gas well was drilled in Fredonia, New York, in 1821. Concentrated shale-fracturing research was funded by a U.S. Department of Energy grant in the 1970s.

Even so, shale gas only became economically attractive in 2001. Gas recovery from shales has increased from just 1 percent in the early 1990s to more than 40 percent in 2010. Even as the successful production of so much natural gas has suppressed prices, technological advances have made shale gas the darling of the oil field.



Natural gas production in China, Canada and U.S., 2008 & 2035, EIA International Energy Outlook, Sept. 2011.

Is the discussion just about fracturing?

Hydraulic fracturing is just one component of well development. Sometimes the objections to fracturing are, instead, responses to other aspects of the entire well-development process.

Here, in brief, are the steps in well development:

1. **Exploration.** Finding a potential oil or gas resource requires many people to collect and evaluate various data in the field, laboratory and office. This takes time and money before any drilling occurs. However, these investments reduce economic risk and environmental impact.

2. **Permitting.** Well developers must receive drilling permits from federal, state and/or local governments. This process, which can take as little as a few months or as long as several years, may include meetings with citizen groups as well.

   Sometimes energy companies are criticized for "holding" leases without drilling, but these delays allow time for planning. No one wants to make a mistake by rushing to drill. The development schedule also is affected by weather, wildlife, neighbors and pipeline activity.

3. **Drilling.** To truly understand the productive capacity of the rock formation requires drilling, which can take a few weeks to a few months. After this step, well planners focus on the areas with the greatest potential and the least environmental impact.

   Drilling rigs and equipment transport are perhaps the most visible reminders of well development. During the three to five weeks that a rig drills the average shale well, nearby neighbors may notice noise, the tall rig mast, extra dust and truck traffic.

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Because of shale gas, the United States has transformed itself from an importer of natural gas to *total energy independence* in natural gas. In fact, we have a surplus. During the next 20 to 25 years, shale gas will come to account for as much as 45 percent of all natural gas produced in the United States. If we add to these figures other forms of "unconventional" gas, hydraulic fracturing will enable production of the majority of all natural-gas supplies in the United States.

ADVANCING TECHNOLOGY PROMISES A SECURE ENERGY FUTURE

The oldest modern shale-gas wells are only about 13 years old. Yet many of these wells already have produced more gas than initially estimated. Shale-specific fracturing technology has increased production rates dramatically and is reversing the rapid decline witnessed in many early shale-gas wells. The bottom line is that shale gas has increased our gas reserves far beyond initial hopes.

Today's advanced shale-gas technologies help engineers place wells in the most productive areas. These technologies are enhancing the economics of shale, even with a surplus of gas available.

These are secure energy reserves for our future.

EXTENSIVE RESEARCH BACKS SHALE-GAS TECHNOLOGY

As shale technology has developed during the past 30 years, more than 550 technical papers have investigated it. Horizontal drilling has been the subject of more than 3,000 technical papers. These papers have been presented publicly to a worldwide review audience of 100,000 experienced energy-industry scientists and engineers. Just since 2008, technical papers about shale gas have been produced by:

- More than 70 universities
- Four U.S. government labs
- More than a dozen agencies at the state, federal and international level
- Upwards of 100 energy-industry companies

A 2010 paper, *"Thirty Years of Gas Shale Fracturing: What Have We Learned?"* reviewed more than 270 literature sources and documented a steady progression of technological advances.

BUTTING HEADS

Critics of hydraulic fracturing say that some fracturing jobs have contaminated ground and surface waters. Engineers insist that not one deep-well frac has ever contaminated groundwater.

They can't both be right. But a little explanation goes a long way.

Part of the problem is how each group defines fracturing. For critics, fracturing has come to represent nearly every phase of the well-development cycle—from the exploration that precedes drilling all the way through to gas production. For engineers, fracturing is a portion of this process: a means of using fluids, under pressure, to open, enlarge and stabilize cracks in deep, gas-producing rocks far below the Earth's surface.

We will limit our discussion to the engineering viewpoint. But we also offer a primer about well development on page 8.

FREQUENTLY ASKED QUESTIONS

If the fracturing process is thousands of feet beneath the water table, then why is methane showing up in residential water wells?

Methane is a contaminant in many water wells, and its causes are both natural and manmade. If oil and gas wells are poorly constructed, they may allow methane from shallow formations, such as coals and thin shales, to migrate into water supplies. This is a common cause of contamination in northwestern Pennsylvania, where century-old wells and natural seeps are often at about the same depth as nearby water wells. Proper well construction, with sufficient cement to isolate the drilled hole, prevents shale-gas wells from creating migration paths for methane.

The vast majority of oil and gas from shale does not seep to the surface. In fact, it is difficult to produce. What keeps it in the ground for millions of years?

In nearly all areas, oil and gas is sealed in place by rock that is virtually impermeable, such as high-clay-content shale (vs. productive shales, which contain natural fractures and microfissures). These durable natural barriers, which have withstood tectonic forces and Earth movements for millions of years, also prevent migration of the fluids used for hydraulic fracturing. The containment capability of these rock seals is proved by the fact that oil, gas and saltwater are still in place after millions of years: The lighter gas and oil have not migrated upward through the heavier saltwater found in shallower zones. This is further documented by fracture-monitoring methods such as microseismic monitoring, which detects and locates the sounds of fracturing. Oil companies use these techniques to monitor the first few wells in an area so they can optimize their fracturing design.

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A prudent operator will invest time in the community explaining the operations, answering questions (about chemicals, pressure control and air emissions, for example) and working through solutions to objections. Almost any realistic objection can be overcome with technology and effective planning.

4. **Completion.** After drilling, the formation is evaluated through the use of electric sensors, called logging instruments. The combination of steel pipe, called casing, and cement keeps oil and gas sealed inside the pipe and away from freshwater supplies.

   Casing and cementing are regulated, and many operators go beyond regulatory requirements. Tests, often witnessed by regulators, ensure that the well is sealed, and regular monitoring ensures that the well remains sealed.

   The multiple barriers of pipe and cement, plus the wellhead controls and the post-fracture tubing and packer, form multiple barriers—usually two to five layers of isolation between the hydrocarbons and any part of the rock or air.

5. **Fracturing.** The goal of hydraulic fracturing is to improve the flow of oil and gas from the well. Fracturing is the lowest-risk action in the well-development process, especially in wells more than about 2,000 feet deep. Fracturing is a regulated activity.

6. **Facility and pipeline construction.** Once the well is ready for production, the operator installs multiple control valves and contracts with a pipeline company to deliver the well fluids to production facilities. These facilities separate the produced fluids into individual streams of gas, oil and water.

What about radioactivity from fracturing?

Our planet and everything on it is radioactive and has been that way since it was formed. Every piece of rock or dissolved soluble ion has a radioactive signature, including the purest drinking water and the dirtiest mine waste.

Frac flowback waters may have a radioactive signature, picked up from the rocks the fluid passes through. Where Apache operates, the radioactive levels of frac-fluid flowback are far below the background limit set by U.S. government agencies. Because the radioactivity in a formation is reasonably consistent, initial monitoring of flowback is usually sufficient to assess any risk. However, disposal companies measure radioactivity a second time, before they dispose of the fluids. The radioactivity in shale may be slightly higher than that of other rocks, but the formations we deal with return flowback fluids that are well below the safety threshold.

What stops the upward growth of hydraulic fractures?

Fractures usually grow upward until they contact a rock of different structure, texture or strength. These "seal" or frac-barrier rocks stop the fracture's upward or downward growth. They are very common in every set of rocks where shale occurs.

The loss of fracture fluid, called leakoff, also stops fracture growth. During leakoff, part of the frac fluid seeps into permeable parts of the gas-bearing formation below the cap rock, decreasing the amount of frac fluid and frac pressure.

What kinds of chemicals are used in fracturing?

In a properly designed and executed fracturing plan, the few toxic chemicals—principally low-dose biocides—can be replaced with materials that are effective, but that will biodegrade or be completely consumed in their destruction of biological organisms. Preferred biocides and nonchemical approaches are the same ones used in municipal drinking water. Other common fracturing biocides are used in hospitals and food preparation as well. These "greener" chemicals and nonchemical approaches are catching on quickly with technology-savvy operators.

Indeed, one of the most pressing issues in the oil and gas industry is to examine and adopt technologies, both chemical and nonchemical, to replace as many "non-green" chemicals as possible.

It seems clear that fracturing does not contaminate water supplies. A U.S. city drinking-water evaluation from the Environmental Working Group (which is decidedly anti oil and gas) notes that three of its Top 10 U.S. municipalities with superior drinking water are in Texas, including Fort Worth—the middle of the Barnett Shale, the site of intensive hydraulic fracturing.

Are produced water and oil-field wastes exempt from federal hazardous-waste regulations?

No, although they are not considered highly toxic under federal regulations. After a 10-year study, the U.S. Environmental Protection Agency exempted oil-field wastes from RCRA Subtitle C regulations. They fall, instead, under Subtitle D and other federal and/or state waste regulations.

Most oil-field produced water, including frac flowback, is reused repeatedly at the well for pressure maintenance. When it is ready for disposal, it is into a deep well. In locations where Apache operates, regulations prohibit the release of this water into any surface waters.

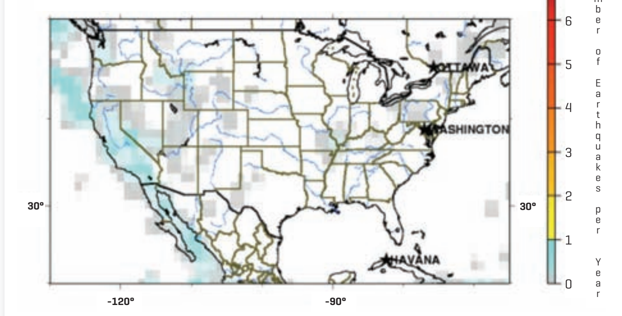
Does the water used in hydraulic fracturing contribute to water shortages?

It can in arid areas. In the Horn River gas shale of Canada, Apache uses a closed-loop saltwater system, instead of freshwater, for our fracture fluids. In other areas, we are likewise developing alternate water sources, such as saltwater from the drilled formations.

The volumes of water required for fracturing are low compared to agricultural, municipal, recreational and other industrial use. However, we can reduce pressure on local freshwater supplies by using produced and natural high-salinity waters that are not suited for use as drinking water.

Does fracturing cause damaging earthquakes?

No. Fracturing, in very rare cases, may generate a minor seismic tremor by changing local rock stresses. But fracturing does not penetrate deep enough to reach major faults and tectonically active plate boundaries, which are two miles to more than five miles beneath the Earth's crust. If a deep disposal well is very close to a major fault or plate boundary, which is unusual, then large volumes of waste disposal could create a larger tremor.



U.S. earthquake density (Mm>5.0) - all depths. Average earthquakes per year (Source USGS)

Currently, some 144,000 fully regulated Class II injection wells in the United States inject more than 2 billion gallons of saltwater into the Earth every day, according to the Environmental Protection Agency. According to news reports and the U.S. Geological Survey (USGS), only a very few of these wells have been identified as possible sources of deeper tremors, the largest of which is reportedly about a Magnitude 5 quake. Overall, the rate of even small seismic events from these deep disposal wells is very low: on the order of 0.008 percent affected of the total 144,000 wells. Other human activities, such as deep man-made lakes and large open-pit mines, create a much higher incidence and severity of seismic disturbances. USGS earthquake-frequency mapping shows that the areas where Apache operates are usually very quiet. Where required, we can use seismic techniques to examine unusual subsurface conditions before we choose to fracture a shale formation.

What about emissions from the production and burning of natural gas?

The production and burning of natural gas creates two kinds of emissions: direct (from methane venting, fugitive emissions and combustion) and indirect (from trucks, pumpers and processing equipment that burn diesel or other fuels). Using pad operations and transferring water via pipeline can reduce truck traffic, as well as ground disturbances. With pad-oriented development, operators can access about 6,000 acres of reservoir from a single six-acre pad area. Pad developments also offer economies of scale that encourage the use of low-pressure methane-recovery units. These units sharply reduce the need for methane venting and thereby reduce direct emissions of methane.

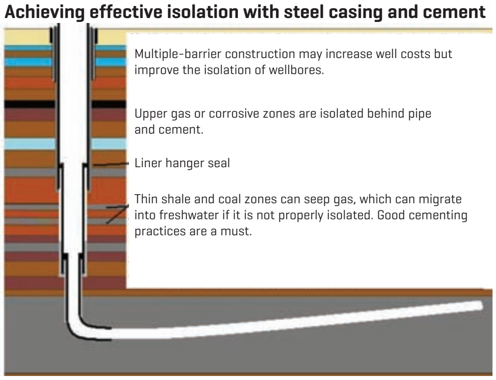
Effective well construction

Well-construction problems are fairly rare, with only 1 percent to 5 percent of wells requiring any modifications or repairs before they can be drilled beyond their test depth. The American Petroleum Institute recommends practices for well construction, and many states set specific requirements based on local geological conditions. Many energy companies set even higher standards based on their experience.

Good engineering creates a well-specific design that will control any fluid, any reservoir and any frac pressure—and that will last much longer than it will take to produce the oil and gas. The goal of well design is to:

- Protect the surrounding nonhydrocarbon zones, including freshwater aquifers
- Protect the well from formation problems external to the well, such as corrosive gas or saltwater
- Protect the well from the forces of Earth movement

Achieving effective isolation with steel casing and cement



Effective well designs use multiple barriers of pipe, as well as cement, to isolate the well. They are designed so, if one component fails, the inner pipe may collapse, but the outer, protective pipes will remain in place, isolating the well.

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A Cornell study suggested that natural gas produces more harmful emissions than coal. Is that true?

The 2011 Cornell study citing an 8 percent loss of the total methane produced from every shale well has been refuted by four subsequent 2011 studies. Each of those studies concluded that methane gas is much less harmful, in terms of emissions, than coal.

Using scientifically verified data, several universities and corporations have calculated actual methane losses over the life of a shale-gas well at less than 1 percent total. Also, total emissions of carbon dioxide, nitrous oxides and sulfur oxides, as well as toxins such as mercury, are either absent in shale-gas production or sharply lower than those of coal.

A Duke University study linked methane in well water with shale-gas production. Is this true?

The study sampled a very small number of wells—and it took place in an area where methane is present in most freshwater wells, usually from natural seeps. The conclusions drawn by the authors of the study, as well as some of their media comments, do not match their limited data. For example, they did not establish baseline methane-content data; they found methane in many areas that have not undergone hydraulic fracturing; and they included a group of what appear to be poorly constructed wells. Other studies have connected methane found in water wells with higher occurrence of natural seeps, regardless of whether or not hydraulic fracturing had occurred.

A Carnegie Mellon study projected increased greenhouse gases (GHG) from domestic shale gas. Is this true?

Yes. Shale wells initially may create larger volumes of GHG than conventional gas production because intense hydraulic fracturing uses diesel power. However, the study also shows that shale-gas production still creates a much lower GHG footprint than coal. Natural-gas and electric-powered engines for frac pumps could further reduce shale's GHG footprint.

An MIT study noted that the environmental record of shale-gas development is, for the most part, a good one. True?

Yes. The MIT study was properly run, interdisciplinary, and benefited from oversight and perspective from an advisory committee comprising academic, alternate-energy, environmental, energy-industry and financial experts. The study focused, in a balanced and fair manner, on the stability of gas supplies, regulatory needs, energy costs, climate policy and several other impacts.

The MIT findings were positive for the most part—and stressed the need to ensure that environmental actions, such as proper transport and well construction, keep pace with shale developments. Shale developments have advanced at a fast pace and, in some areas, have challenged the limited infrastructure and state regulations that prevent pollution. This problem is being solved rapidly.

Apache carefully selects the areas where we will develop unconventional gas. In the Horn River area of British Columbia, we use pad operations because they reduce our environmental footprint. The close proximity of wells on a pad gives us more time to optimize each well's design and operation.

A Rice University study stressed the increased national security offered by shale gas. Is this a valid point?

Yes. The study says, "By some estimates, there is as much as one thousand-trillion cubic feet of technically recoverable shale gas in North America alone, which is enough to supply the nation's natural gas needs for the next 45 years." Industry experts believe that this is a very conservative number, estimating that sufficient shale gas can be recovered to bring the United States more than 100 years of secure and dependable energy supplies.

CONTINUING THE DISCUSSION

We advocate transparency in this discussion. Transparency is a two-way street.

- The oil and gas industry needs to explain its processes, publicly identify its chemicals and, in some cases, improve its well development. It should eliminate carcinogenic chemicals or proven endocrine disruptors and reduce toxic chemical use where possible, substituting chemicals that have less environmental impact and are biodegradable.

- The public needs to understand oil-field operations well enough to discuss their impact fruitfully.

- The media needs to quote sources that follow accepted scientific methods, without overt or covert political objectives and/or corporate influence.

We appreciate your interest in this subject. For the full paper* upon which this brochure was based—and other details, please contact George.King@ApacheCorp.com or 713-296-6281.

* This paper investigates the risks of hydraulic fracturing, from the normal to the most unusual. It plots environmental impacts, modeled after either real events or projected from models, against events from similar industries or activities. It expresses probability as one undesirable outcome among a number of fracturing treatments (e.g., one in 100,000) and is constructed from scientific literature, historical reports or worst-case scenarios.

  This type of ranking helps identify the risks of high-impact and high-probability events and shows where technology can be focused to reduce risk. The full report contains the rankings and full explanations of the risks, as well as methods for reducing or totally eliminating them.

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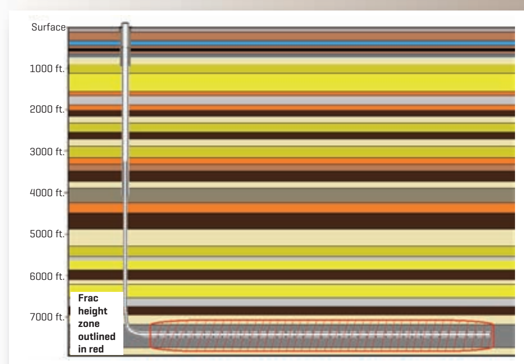
For most wells, the outer pipe (casing) extends from ground level to several hundred feet below the deepest freshwater aquifers, ideally into a sealing-rock barrier. After they place the pipe, workers pump specially formulated cement to the bottom of the casing string and continue pumping, displacing the cement so it moves upward around the exterior of the pipe. The cement holds the casing in place and isolates the well from the surrounding formations. When properly formulated and placed, cement creates an extraordinarily long-lived seal.



Fractures, which often follow the natural fractures present in shales, have a maximum width of about a quarter of an inch and are usually a few hundred feet long. Fracture height is limited by natural barriers in the rock, with effective height normally about 300 feet or less. The tops of most fractures in shale formations are separated from freshwater sands by 3,000 to 5,000 feet—or about two-thirds of a mile to more than one mile.

Pad operations, such as this Apache Canada pad in British Columbia, group multiple wells and all well-development activities in a single location. This reduces the total footprint of the wells and offers advantages in well monitoring, noise and dust control, safety inspections, onsite supervision and traffic reduction. Pads as small as six acres have been used to develop areas as large as eight square miles–with only one road and pipeline to the pad.

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