PDHonline Course C270 (3 PDH)

Advanced Oil & Gas Drilling Technology

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2020

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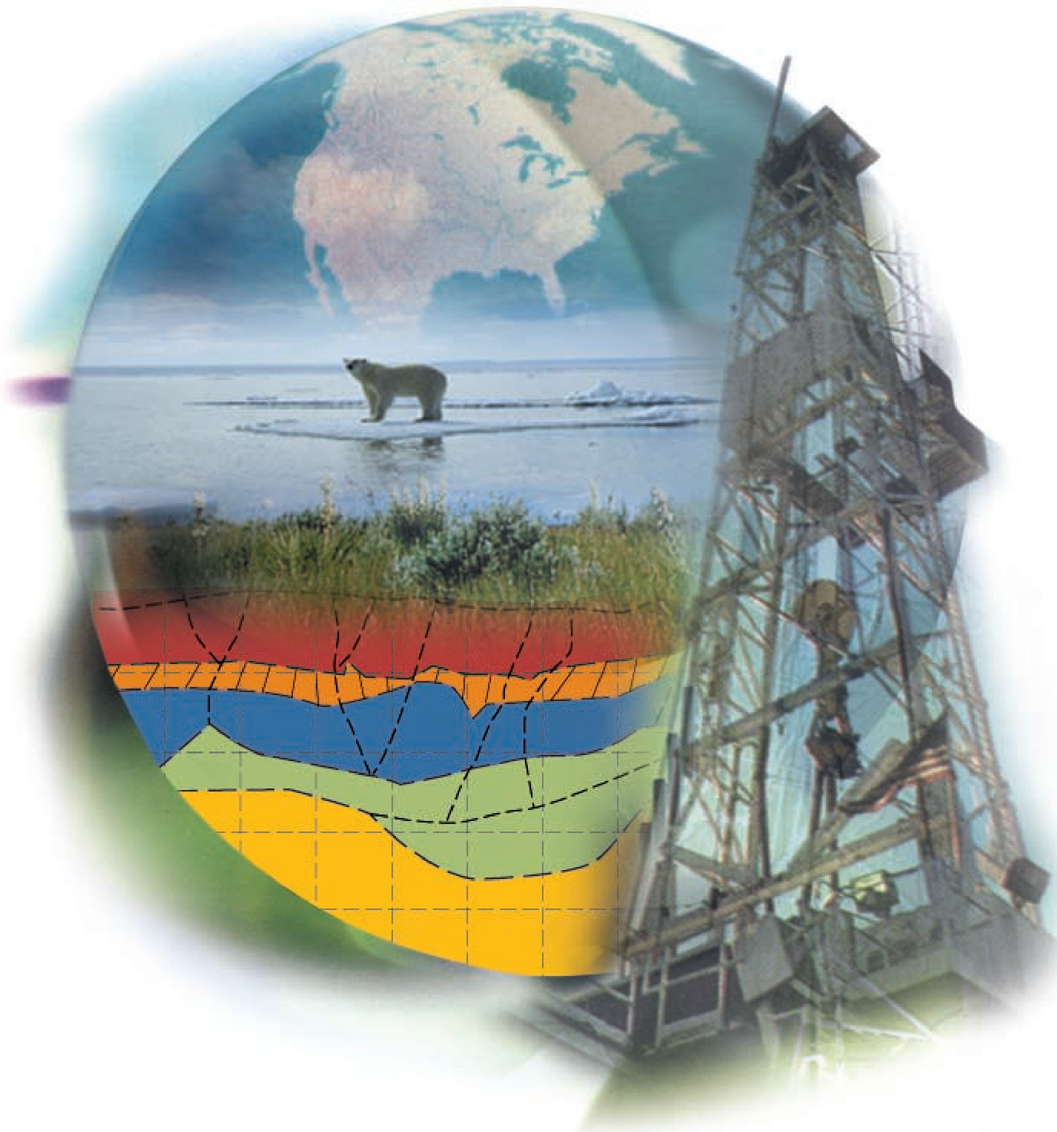


Environmental Benefits *of* Advanced Oil *and* Gas Exploration *and* Production Technology

Drilling and Completion

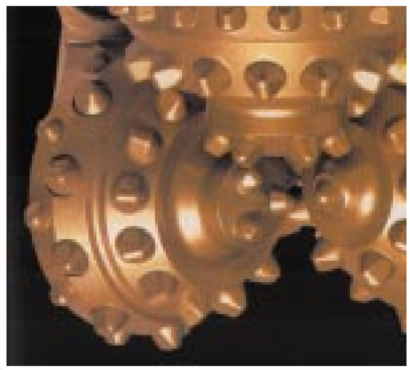
Successful drilling often means going faster and deeper, through harder rock, and in multiple directions from a single wellbore. The result? More resources are contacted with fewer wells, less drilling waste, and less surface disturbance.

Greater Drilling Efficiency, Less Environmental Impact

With horizontal drilling, today's oil and gas industry has an extraordinary capability: the power to navigate three-dimensionally through the earth, contacting and economically producing resources while minimizing surface disruption. A case in point is the Red River B Formation in the Williston Basin (North Dakota, South Dakota, and Montana), where Burlington Resources Inc. and Continental Resources are using horizontal technology to drain a narrow but oil-rich, low-permeability dolomite zone. Historically, vertical wells completed in the Red River B produced an uneconomic 20 or 30 barrels a day. New wells penetrate the zone laterally, extending a mile or more within a porosity window of only 2 feet. Initial daily production from the longest of the 123 horizontal wells drilled and completed to date was 575 barrels of oil.

Horizontal drilling was instrumental in Burlington Resources' discovery of an estimated 150 million barrels of recoverable oil in the Cedar Hills play in the Williston Basin, the largest onshore discovery in the last 25 years. The technique complements waterflood recovery efforts there. "With two horizontal wells per section, Burlington is replacing traditional line-drive techniques in the area where operators have typically drilled eight to 10 wells per section," said drilling manager Doug Harris. "In fact, the horizontal wells will result in a more efficient flood than the vertical-drilled line-drive patterns, with only one-fourth the number of wells."

Source: American Oil & Gas Reporter, September 1998



Advanced drill bits reduce time on site and associated environmental impacts.

Photo: RBI-Gearhart

Drilling is the moment of truth for oil and gas producers. After all of the analyses and preparation, have explorationists pinpointed the reservoir? Will it be productive? Are development wells being drilled in the right pattern for efficient extraction?

Substantial investments ride on the answers. Drilling activities for a given field or reservoir may require the investment of hundreds of millions of dollars or more. Justifying such investments in developing domestic resources is increasingly difficult, since much of our Nation's remaining oil and gas is locked away in geologically complex and challenging structures that necessitate deeper drilling or enhanced completion and production technologies.

Despite these challenges, drilling is now safer, faster, more efficient, and less costly than in the past. High-resolution 3-D seismic and improved reservoir imaging and characterization are combined with improvements in drilling technology to increase drilling success rates, reduce drilling costs, and reduce the environmental impacts of both exploratory and development drilling.

Onshore, typical drilling and completion costs have dropped by about 20 percent, from an average of about $500,000 per well in the 1980s, to about $400,000 per well today, adjusting for inflation, depth, type of well, and locations of wells drilled. Similarly, offshore drilling and completion costs of about $5.5 million per well in the 1980s have dropped to an average of $4.3 million today.

In addition to expanding the deepwater oil and gas resource base, technology advances in drilling and completion have added new gas reserves from sources once considered uneconomic—including Devonian shales, deep gas formations, coalbeds, and low-permeability "tight" gas sands.

"High technology has migrated to almost all phases of exploration and production, and that includes stepping right up to the drilling rig floor. That's right, the rig floor—the domain of the roughneck and the pipe wrench, where the real 'nitty gritty' gets done—is becoming more technology-oriented by the day.... Technology is markedly improving drilling performance and enhancing safety even as it helps trim cost."

Maggie Lee

Source: The American Oil & Gas Reporter, April 1998

Photo: CANRIG

Fewer Wells Mean Less Waste

Environmental benefits from drilling and completion advances are significant. For example, new exploration and drilling technology has, on average, doubled the amount of oil or gas supplies developed per well since 1985. Thanks to this productivity increase, today's level of reserve additions is achieved with 22,000 fewer wells annually than would have been required with 1985-era technology.

Reducing the number of wells decreases wastes generated from drilling operations. Assuming an average well depth of 5,600 feet and 1.2 barrels of waste per foot drilled, with 22,000 fewer wells, the average annual volume of drilling waste is reduced by approximately 148 million barrels. Avoiding this waste—enough to cover about 1,440 football fields to a depth of 10 feet—reduces waste management and disposal requirements.

Other environmental benefits of advanced drilling and completion technology include:

- Smaller footprints
- Reduced noise and visual impacts
- Less frequent well maintenance and workovers, with less associated waste
- Reduced fuel use and associated emissions
- Enhanced well control, for greater worker safety and protection of groundwater
- Less time on site, with fewer associated environmental impacts
- Lower toxicity of discharges
- Better protection of sensitive environments

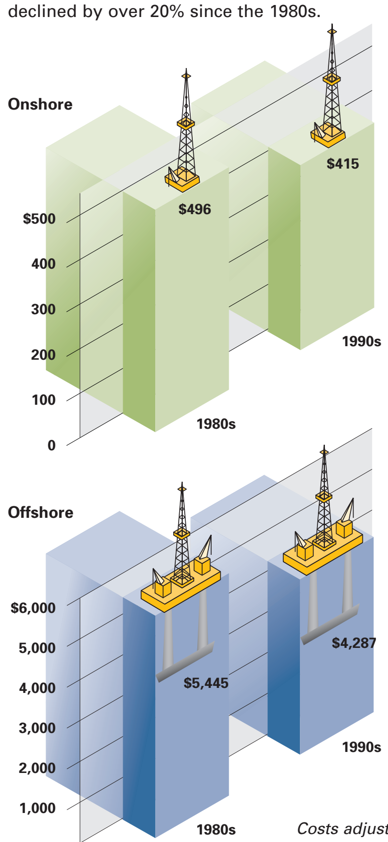
Fundamentals of Drilling and Completion

Contacting a targeted formation involves:

- **Using rotary equipment and hardened drill bits, weighted and lubricated by drilling fluids, to penetrate the earth's surface.**
- **Inserting casing and tubing into each well to protect the subsurface and control the flow of fluids (oil, gas, and water) from the reservoir.**
- **Perforating the well casing at the depth of the producing formation to allow flow of fluids from the formation into the wellbore.**
- **Installing a wellhead at the surface to regulate and monitor fluid flow and prevent potentially dangerous blowouts.**

Average Onshore and Offshore Drilling Costs
(Dollars per well, in thousands)

Both onshore and offshore drilling costs have declined by over 20% since the 1980s.



Costs adjusted for 1996 activity (i.e., depth, type, and general location of wells drilled).

Source: American Petroleum Institute

Some technology advances key to improved drilling and completion efficiency are described below:

Horizontal and directional drilling

Oil and gas wells traditionally have been drilled vertically, at depths ranging from a few thousand feet to as deep as 5 miles. Depending on subsurface geology, technology advances now allow wells to deviate from the strictly vertical orientation by anywhere from a few degrees to completely horizontal, or even inverted toward the surface. About 90 percent of all horizontal wells have been drilled into carbonate formations, which account for about 30 percent of all U.S. reserves.

Directional and horizontal drilling enable producers to reach reservoirs that are not located directly beneath the drilling rig, a capability that is particularly useful in avoiding sensitive surface and subsurface environmental features. New methods and technology allow industry to produce resources far beneath sensitive environments and scenic vistas in Louisiana wetlands, California wildlife habitats and beaches, Rocky Mountain pine forests, and recreational areas on the Texas Gulf Coast. Even some offshore resources, including many off the coast of California, can be produced from onshore wells.

Horizontal drilling may also allow a producer to contact more of the reservoir, so that more resources can be recovered from a single well. In Mississippi's Black Warrior Basin, for example, horizontal wells provide six times as much natural gas deliverability as conventional vertical wells do at the Goodwin natural gas storage field. In growing numbers of operations, the benefits from this increased production far outweigh the added cost for these wells. This was the case in the remote South China Sea, where Phillips China Inc. recently used advanced horizontal drilling and completion technologies to successfully complete a 5-mile-long extended-reach well.

Advances in directional drilling also facilitate multilateral drilling and completion, enabling multiple offshoots from a single wellbore to radiate in different directions or contact resources at different depths. Recent and very rapid development of such radial drilling technology has spurred a boom in horizontal drilling. Since the mid-1980s, the drilling of horizontal wells has grown from a few to more than 2,700 wells per year worldwide. In the United States, horizontal drilling now accounts for 5 to 8 percent of the land well count at any given time.

Environmental benefits of horizontal and directional drilling include:

- Fewer wells
- Lower waste volumes
- Protection of sensitive environments

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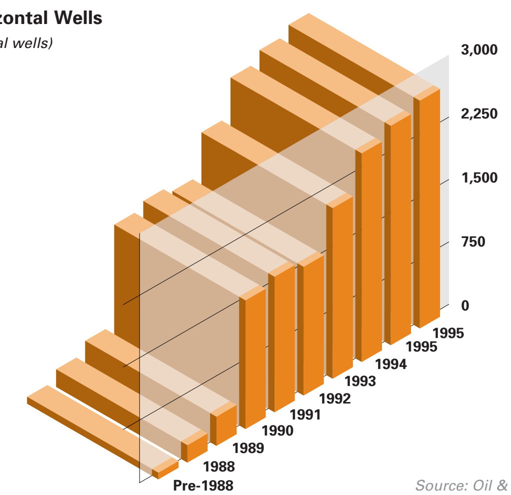
Measures of Success for Horizontal Drilling

According to a 1995 DOE study, horizontal drilling has improved:

- **Reserve additions: Reserves are potentially increased by an estimated 10 billion barrels of oil, nearly 2 percent of original oil-in-place in the United States.**
- **Speed of delivery: Carbonate production is nearly 400 percent greater in horizontal projects than with vertical wells, yet costs are only 80 percent more.**
- **Average production ratio: The ratio is 3.2 to 1 for horizontal compared to vertical drilling, offsetting a higher average cost ratio of 2 to 1. Average increase in reserves derived from horizontal well applications is approximately 9 percent.**

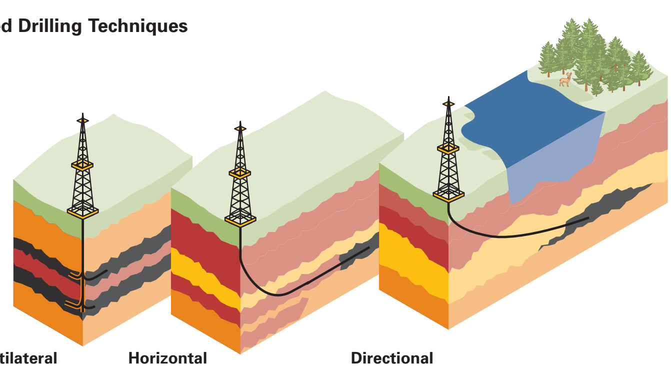
Worldwide Horizontal Wells

(Number of horizontal wells)



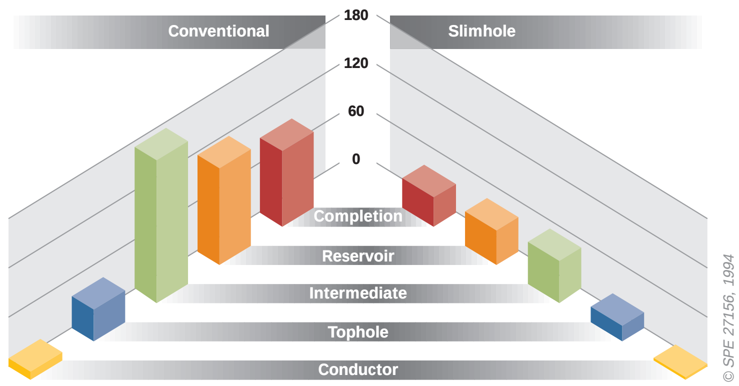
Source: Oil & Gas Journal, November 23, 1998

Advanced Drilling Techniques



Mud Disposal Reduction in Slimhole Coiled Tubing Operations vs. Conventional Drilling Operations

Maximum fluid volume (m3)



Slimhole drilling and coiled tubing

Slimhole drilling—a technique gaining widespread use for tapping into reserves in mature fields—significantly decreases waste volumes. For example, a slimhole drilled to 14,760 feet and ending with a $4\frac{1}{8}$-inch bottomhole produces one-third less volume of cuttings than a standard well at the same depth. Operational footprints are also reduced, since equipment for slimhole drilling is smaller than that used in conventional operations. The area cleared for drilling locations and site access can be as little as 9,000 square feet with mud holding pits, as much as 75 percent less than that required for conventional operations. In contrast, if technology development had stopped in 1985, today's drill pads would cover an additional 17,000 acres of land in the United States, an area roughly the size of 12,900 football fields.

Coiled tubing technology—a cost-effective solution for drilling in reentry, underbalanced, and highly deviated wells—has similarly impressive benefits, reducing drilling wastes and minimizing equipment footprints. A typical coiled tubing layout requires a working space about half that of a conventional light workover hoist. The drilling site is easier to restore when operations are completed, and the impact of equipment mobilization on the environment is reduced.

In addition, coiled tubing and slimhole drilling enable less disruptive, quieter drilling operations, minimizing the noise impact on wildlife or humans near the well site. Since coiled tubing is a continuous pipe, most noises associated with conventional drilling pipes are avoided. Efficient insulation and the equipment's smaller size further reduce noise levels. For example, the noise level of a conventional rig at a 1,300-foot radius is 55 decibels, while a coiled tubing unit's noise level at the same distance is 40 decibels, or 27 percent less. The smaller size of coiled tubing drilling also cuts fuel use and reduces emission of gaseous air pollutants, compared with traditional rotary drilling.

Environmental benefits of slimhole drilling and coiled tubing include:

- Lower waste volumes
- Smaller footprints
- Reduced noise and visual impacts
- Reduced fuel use and emissions
- Protection of sensitive environments

Use of coiled tubing redefines equipment footprints.

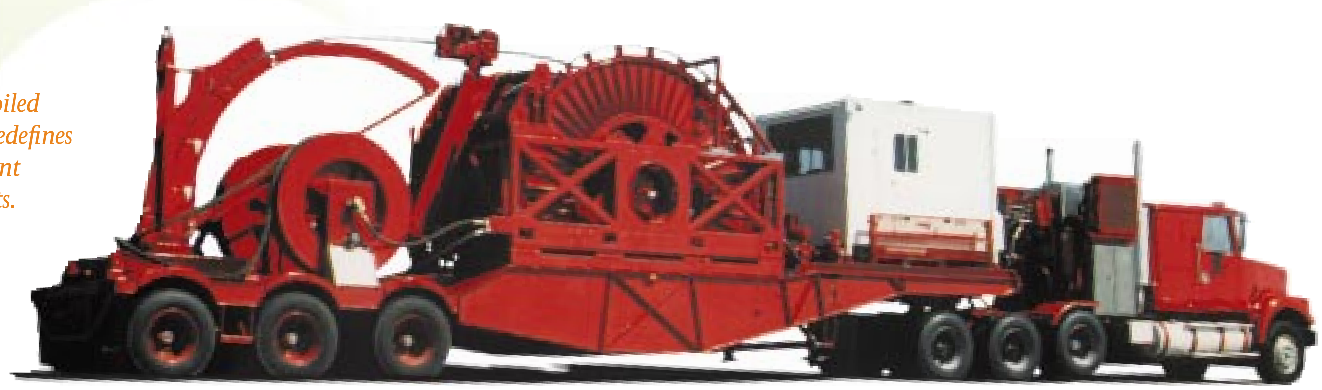


Photo: Haliburton Energy Serivces

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Impressive Performance from Modern Diamond Bits

Polycrystalline diamond compact (PDC) drill bits have become increasingly effective:

- **Between 1988 and 1994, technology advances increased the average footage drilled per PDC bit by over 260 percent (from approximately 1,600 to 4,200 feet per bit).**
- **Total footage drilled worldwide by diamond bits has climbed steadily, from approximately 1 percent in 1978, to 10 percent in 1985, and to 25 percent in 1997.**
- **Latest-generation PDC bits drill 150 to 200 percent faster than similar bits just a few years ago.**

Light modular drilling rigs

Now in production, new light modular drilling rigs can be deployed more easily in remote areas than conventional rigs. Fabricated from lighter and stronger materials, these rigs are built in pieces that can be transported individually and assembled on site. The lower weight of components and the rig reduces surface impacts during transport and use. The modular design also allows the rigs to be quickly disassembled and removed when drilling operations are completed.

Environmental benefits of light modular drilling rigs are:

- Smaller footprints
- Reduced fuel use and emissions
- Protection of sensitive environments (decreased surface impacts of transportation)

Measurement-while-drilling (MWD)

MWD systems measure downhole and formation parameters to allow more efficient and accurate drilling. By providing precise, real-time drilling data on bottomhole conditions, these systems reduce costs and improve the safety of drilling operations.

Combined with advanced interpretive software, MWD tools allow drilling engineers to more accurately determine formation pore pressures and fracture pressures as the well is being drilled. Such accurate geopressure analysis can help reduce the risk of life-threatening blowouts and fires. In the event of the loss of well control, MWD tools help engineers to quickly steer a relief well and regain control.

Environmental benefits of MWD systems include:

- Fewer wells
- Enhanced well control
- Less time on site

Improved drill bits

Advances in materials technology and bit hydraulics, spurred by competition between roller cone and polycrystalline diamond compact bits, have yielded tremendous improvement in drilling performance. Extensive field data indicate that, on average, a 15,000-foot well in Roger Mills County, Oklahoma, takes about 39 days to drill today, while that same well would have taken over 80 days in the 1970s. By reducing the time for the rig to be on site, advanced drill bits reduce potential impacts on soils, groundwater, wildlife, and air quality.

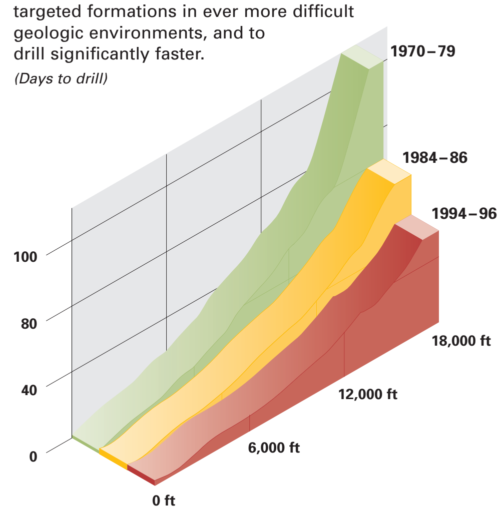
Environmental benefits of improved drill bits are:

- Lower waste volumes
- Reduced maintenance and workovers
- Reduced fuel use and emissions
- Enhanced well control,
- Less time on site

Decreased Drilling Time

Modern drill bits enable operators to contact targeted formations in ever more difficult geologic environments, and to drill significantly faster.

(Days to drill)



Source: Hart's Oil & Gas World, November 1996

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Synthetic Drilling Fluids (Muds) Cut Costs

An operator in the Gulf of Mexico found that synthetics significantly outperformed water-based fluids in a recent drilling operation. Of eight wells drilled under comparable conditions to the same depth:

- **The three wells drilled using synthetic fluids were completed in an average of 53 days at an average cost of $5.5 million.**
- **The five wells drilled using water-based fluids were completed in an average of 195 days at an average cost of $12.4 million.**

Advanced synthetic drilling fluids

Today's drilling fluids (muds) must perform effectively in extreme temperature and pressure environments, support industry's use of increasingly sophisticated drilling and completion technology, and be compatible with current environmental disposal standards. To meet these challenges in deepwater formations, synthetic drilling fluids combine the higher drilling performance of oil-based fluids with the lower toxicity and environmental impacts of water-based fluids. Because synthetic fluids can be recycled, they generate less waste than water-based fluids. Also, unlike oil-based fluids, these synthetics produce wastes that are thought to be environmentally benign, thus minimizing impact on marine life. Moreover, by eliminating the use of diesel as a mud base, synthetic fluids have low-toxicity and low-irritant properties that significantly enhance worker health and safety.

Environmental benefits of synthetic drilling fluids vs. water-based fluids are:

- Lower waste volumes
- Enhanced well control
- Lower toxicity of discharges
- Less time on site
- Protection of sensitive environments

Air percussion drilling

Air percussion or pneumatic drilling—used for natural gas wells in regions such as Appalachia—can eliminate the need for drilling liquids during drilling operations. As a result, only drill cuttings are generated, significantly reducing requirements for waste management and disposal. Although this technology has limited application, it can be an effective underbalanced drilling tool in mature fields, in formations with low downhole pressures, and in fluid-sensitive formations.

Environmental benefits of air percussion drilling include:

- Lower waste volumes
- Protection of sensitive environments

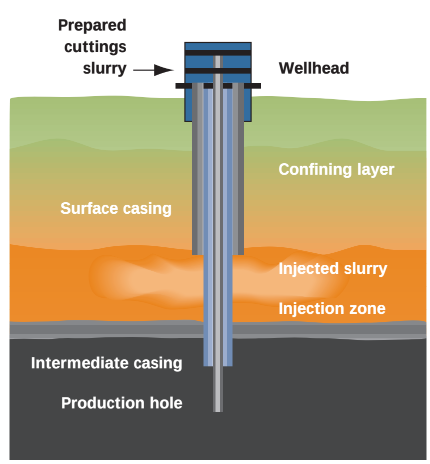
Annular injection of cuttings

In certain settings—such as deep onshore wells, remote offshore operations, and Alaska's North Slope—drilling cuttings can be disposed of by reinjecting them into the annulus around the drill pipe. Reinjecting wastes down the annulus eliminates several needs on the surface: waste management facilities, drilling waste reserve pits, and off-site transport. Returning the wastes to geologic formations far below the earth's surface minimizes the impacts of drilling operations on sensitive environments, and in many cases reduces the costs of drilling operations in these environments.

Environmental benefits of annular injection of cuttings include:

- Smaller footprints
- Lower toxicity of discharges
- Protection of sensitive environments

Downhole Cuttings Injection
Annular injection wellbore configuration



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Productivity Gains from CO_2-Sand Fracturing

CO_2-sand fracturing may greatly improve productivity in certain wells. After 37 months of DOE-supported field trials at 15 Devonian Shale test wells, wells fractured with CO_2-sand technology produced:

- **Four times as much gas per well as wells fractured with nitrogen foam and proppant.**
- **Twice as much gas per well as wells fractured with nitrogen gas.**

Corrosion-resistant alloys

New alloys and composites for drill bits, drill pipe, and coiled tubing—particularly for equipment designed to operate in deep, hot, and sour (high concentrations of H_2S) wells—reduce well failure rates and the frequency of workovers and increase equipment life.

Environmental benefits of corrosion-resistant alloys are:

- Fewer wells
- Reduced maintenance and workovers
- Enhanced wellbore control
- Protection of sensitive environments

Improved completion and stimulation technology

Advanced completion and stimulation technology includes CO_2-sand fracturing, which yields clean fractures to increase well deliverability while avoiding the waste management and well maintenance costs associated with more traditional fracturing operations. In addition, advances in hydraulic fracturing technology—such as state-of-the-art fracture simulators and improved microseismic fracture mapping—have improved well placement and design, and increased ultimate recovery. In the over-pressured, highly permeable San Juan Basin fairway, operators are using advanced open hole cavitation techniques to produce more coalbed methane. Operators have found that dynamic open hole cavitation boosts production when compared with conventional cased and fractured completions, generally by three to seven times as much.

Environmental benefits of improved completion and stimulation technology include:

- Increased recovery
- Lower waste volumes
- Fewer wells drilled
- Protection of groundwater resources

Improved offshore drilling and completion technology

Today's offshore operations include more stable rigs and platforms, can drill in far greater water depths, and apply new controls to prevent spills. Subsea completion technology, for example, allows multiple wells to be drilled through steel templates on the seafloor. A small number of lines (or risers) then carry produced fluids from the templates to production facilities on the surface or to a platform collection system. This technology reduces the risks of spills and allows safe production from multiple wells as the industry approaches water depths of 10,000 feet.

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A Major Contribution

In addition to being critical to natural gas production, hydraulic fracturing has enabled recovery of 8 billion barrels of additional oil reserves in North America.

New offshore platforms and wells feature extensive blowout prevention, well control, oil-spill contingency, and safety systems. All offshore wells have storm chokes that detect damage to surface valves and shut in the well to prevent spills. Blowout preventers are located at the seafloor instead of at the platform level, protecting sea beds and sea life, and sensors continuously monitor subsurface and subsea-bed conditions.

Environmental benefits of improved offshore drilling and completion technology include:

- Fewer wells
- Lower waste volumes
- Reduced maintenance and workovers
- Enhanced well control

Beyond the Oil Patch

- **Advances in horizontal drilling and technologies supporting its application, such as measurement-while-drilling (MWD) and coiled tubing, have expanded the technology's application to such areas as groundwater remediation and pipeline construction.**
- **Advances in drilling technologies for E&P, such as slimhole drilling, have been adapted for mining, geothermal, and water supply applications, as well as for application to research geology.**