Environmental Benefits of Advanced Oil & Gas Exploration and Production

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Credit: 3 PDH

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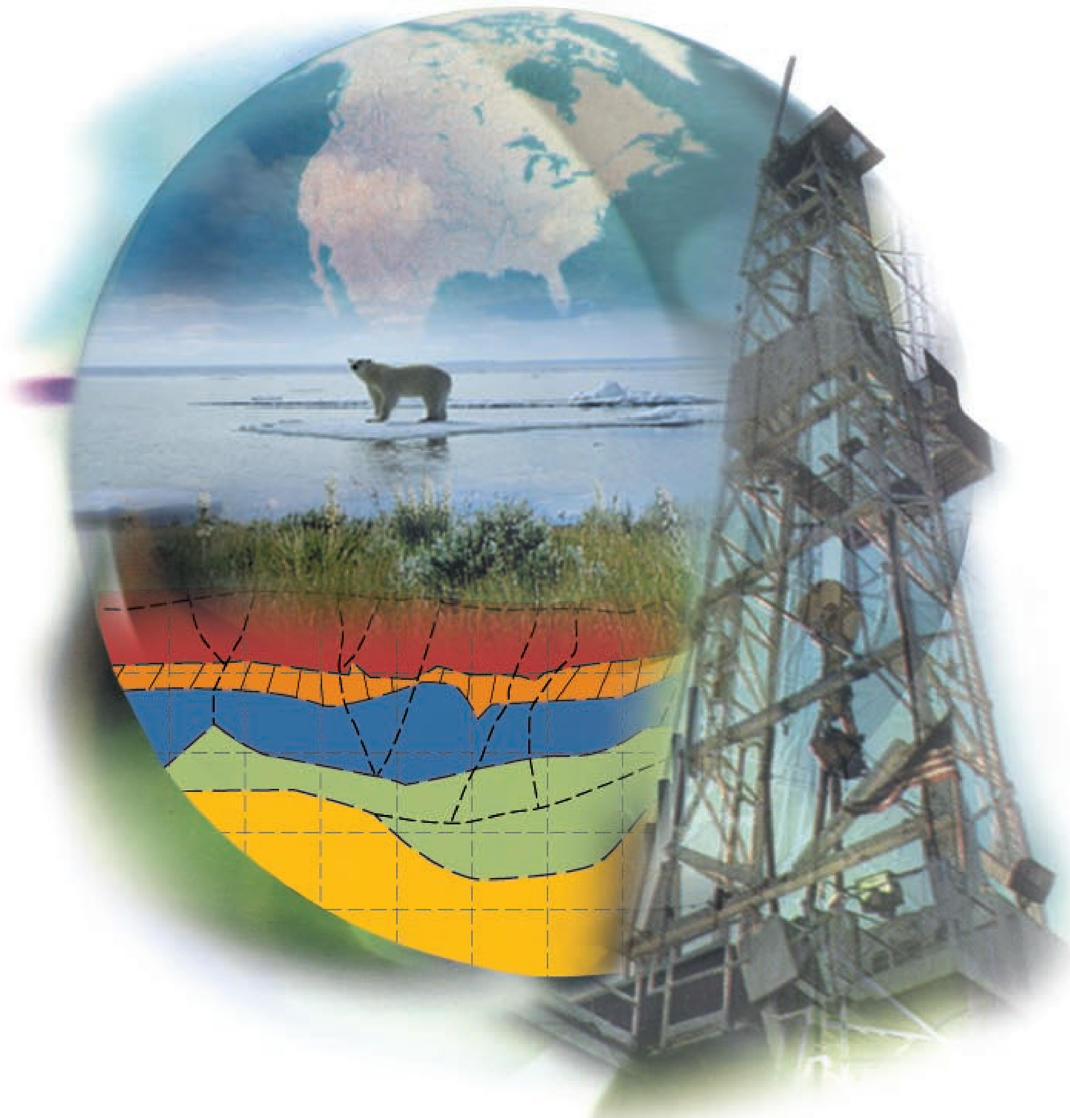
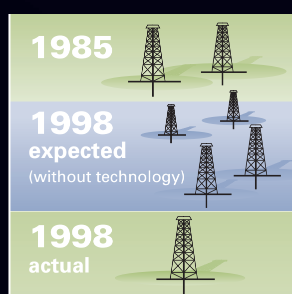


ENVIRONMENTAL BENEFITS *of* ADVANCED OIL *and* GAS EXPLORATION *and* PRODUCTION TECHNOLOGY

Environmental Advanced E&P

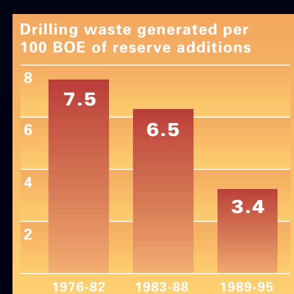
Thanks to advances in exploration and production technology, today's industry is better equipped than ever to find and produce valuable oil and gas — even as these resources become concentrated in deeper, more remote, and more technically challenging areas. Many of the same advances also support our Nation's goals for environmental protection. With each step up in performance and efficiency, the industry can recover more resources with fewer wells drilled, resulting in

- Exploration
- Drilling and Completion
- Production
- Site Restoration
- Operations in Sensitive Environments



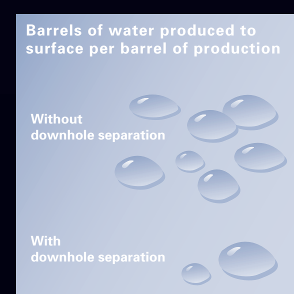
Fewer wells to add same level of reserves

If technology had not advanced since 1985, four domestic wells would have to be drilled today to maintain the production levels achieved by two wells in 1985. But, in fact, technology advances have boosted productivity so successfully that 1985-level production can be achieved today with only one well.



Lower drilling waste volumes

Volumes of drilling muds and drill cuttings per barrel of new oil reserves have steadily declined thanks to improvements in drilling efficiency.

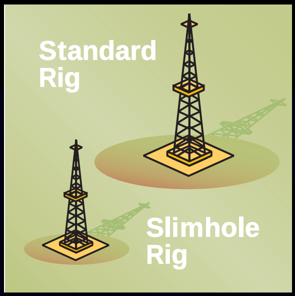


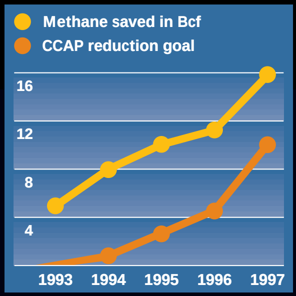
Lower produced water volumes

Emerging downhole separation technology has the potential to dramatically reduce volumes of produced water, which is the largest waste stream associated with oil and gas production.

Benefits of Technology

smaller volumes of cuttings, drilling muds and fluids, and produced waters. Technologies such as slimhole, directional, and multilateral drilling reduce the footprint of drilling rigs and minimize surface impacts. Other benefits of advanced technology include reduced energy consumption, reduced noise from operations, decreased visibility of facilities, reduced emissions of greenhouse gases and hazardous air pollutants, better protection of water resources, preservation of habitats and wildlife, and enhanced worker safety.





Smaller Footprints

Using modular drilling rigs and slimhole drilling, operators can develop the same volume of resources with a rig up to 75 percent smaller and lighter than a standard rig, reducing impacts on surface environments.

Protection of Sensitive Environments

Directional drilling, slimhole rigs, and other advances enable production of valuable oil and gas resources with less disturbance to wetlands and other sensitive environments.

Reduced Greenhouse Gas Emissions

Through the EPAÕs voluntary Natural Gas STAR program, the gas industryÕs use of innovative best management practices has reduced methane emissions by nearly 55 billion cubic feet since 1991, well exceeding the annual goals set by the Climate Change Action Plan. The natural gas production sector alone has accounted for two-thirds of this reduction.

Enhanced Worker Safety

Job-related injuries and illnesses in oil exploration and production are well below the rates in the U.S. manufacturing sector. Advanced drilling, completion, and production technologies have contributed to steady improvements in worker safety, by decreasing workersÕ time on site and enhancing wellbore control.

Photo: Larry Lee

Exploration

TODAY, FINDING BLACK GOLD IS A HIGH-TECHNOLOGY VENTURE. HIGHER SUCCESS RATES MEAN FEWER DRY HOLES, FEWER WELLS DRILLED, AND LESS IMPACT ON THE ENVIRONMENT.

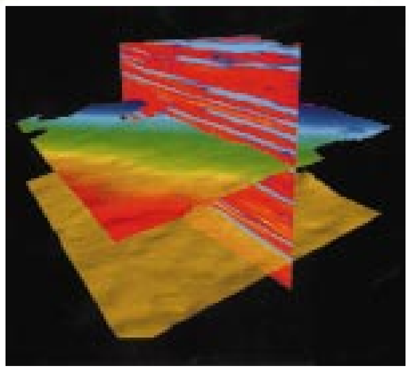

ZAPATA

Cutting-Edge Technology Revolutionizes Exploration

The Gulf of Mexico's coastal transition zone is among the most prospective, unexplored oil and gas regions in the country. Yet, the region's geological and operational complexities have long hampered E&P activities. Now, thanks to next-generation 3-D seismic imaging, new drilling capabilities, and associated technologies, the zone is coming alive with new discoveries—including successful strikes in old fields. For example, Spirit Energy '76 (Unocal Corporation's E&P unit) recently began drilling deeper targets, based on newly acquired 3-D seismic data, around the 40-year-old Vermilion 14 field, located in State waters off central coastal Louisiana. Barry Gouger, Central Gulf asset manager, reported in 1998 that 10 million barrels of oil equivalent had been added to the field's reserves since the acquisition of 3-D seismic.

"The 3-D seismic has allowed us to sharpshoot for bypassed pay and new targets within the field and new opportunities around the field," Gouger explained. "The effort and expense of acquiring 3-D seismic over these older giant fields is well worth it. We are finding significant new reserves in and around the field, and just as important are the wells that we do not drill because of the 3-D coverage." It's a story being replicated throughout the Gulf transition zone, where 3-D seismic is minimizing environmental disruption by effectively targeting new prospects and extending the life of existing reservoirs.

Source: American Oil & Gas Reporter, April 1998



Advanced technologies like seismic imaging have raised exploration success rates by 50 percent or more.

Photo: Texaco Production Operations

Searching for hydrocarbons today is about as far removed as possible from old movie images of wildcat drillers hoping for a gusher. It involves teams of geologists, geophysicists, and petroleum engineers seeking to identify, characterize, and pursue geologic prospects that may contain commercial quantities of oil and gas. Because these prospects lie thousands of feet below the earthÕsurface, uncertainty and trial-and-error pervade the exploration process. It is a painstaking and hugely expensive enterprise, with low success rates. Historically, new field wildcat exploration has succeeded at a rate of one productive well for every five to 10 wells drilled.

Over time, the more easily discovered resources in the United States have been found, developed, depleted, and then plugged and abandoned when they reached their economic limit. New fields now being discovered in the United States are generally smaller in size and found in deeper, more subtle, and more challenging geologic formations. Yet, despite the increased difficulty of discovering remaining domestic resources, technology developments have enabled the oil and gas industry to maintain or, in many cases, improve upon, historical levels of exploration success.

Today, experts can interpret geological and geophysical data more completely; manage, visualize, and evaluate larger volumes of data simultaneously; and communicate interpretations based on these data more accurately.

Advanced techniques now allow the scientist to virtually ÒseeÓthe inside of the formation. Three-dimensional seismic technology, first commercially available nearly 25 years ago, bounces acoustic or electrical vibrations off subsurface structures, generating massive amounts of data. Then powerful computers manipulate the data to create fully visualized multidimensional representations of the subsurface. Even more exciting is 4-D time-lapse imagingÑ an emerging technology developed only within the past 5 to 10 yearsÑ which adds the dimension of time, allowing scientists to understand how the flow pattern of hydrocarbons changes in the formation over time.

Fundamentals of Exploration

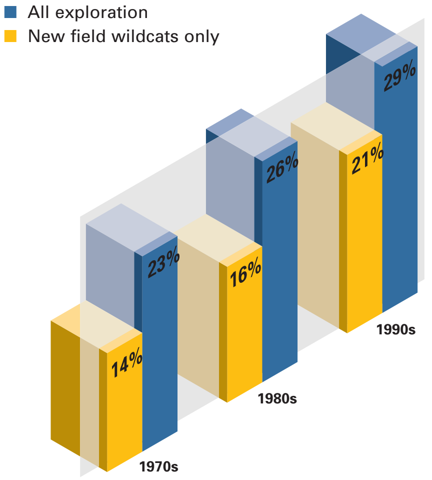
Searching for Oil and Gas

Exploration includes:

- **Surveying and mapping surface and subsurface geologic features to identify structures where oil and gas may have accumulated.**
- **Determining a geologic formation's potential for containing commercial quantities of economically producible oil and/or gas.**
- **Identifying the best location to drill an exploratory well to test the structure.**
- **Drilling exploration and delineation wells to determine where hydrocarbons are present and to measure the area and thickness of the oil- and/or gas-bearing reservoir.**
- **Logging and coring wells to measure permeability, porosity, and other properties of the geologic formation(s) encountered.**
- **Completing wells deemed capable of producing commercial quantities of hydrocarbons.**

Exploration Success Rates

Despite a dwindling resource base, U.S. exploration success rates continue to improve.



Source: American Petroleum Institute

Fewer Dry Holes, More Production and Reserve Additions per Well

IMPROVEMENTS IN 3-D SEISMIC AND 4-D time-lapse visualization, remote sensing, and other exploration technology allow explorationists to target higher-quality prospects and to improve success rates by as much as 50 percent or more. The result: fewer wells need to be drilled to find a given target, and production per well is increased, in some cases by 100 percent.

Today, fewer than half as many wells are required to achieve the same reserve additions as two decades ago. Annual reserve additions for new exploratory drilling have quadrupled, from a per-well average of about 10,000 barrels of oil equivalent (BOE)* in the 1970s and 1980s to over 40,000 BOE in the 1990s.

Thanks to today's technology, whole new categories of resources, considered inaccessible just 20 years ago, are now counted as part of the domestic resource base. Advances in exploration drilling technology have been particularly dramatic in deepwater areas, where significant expansion of the known resource base has resulted.

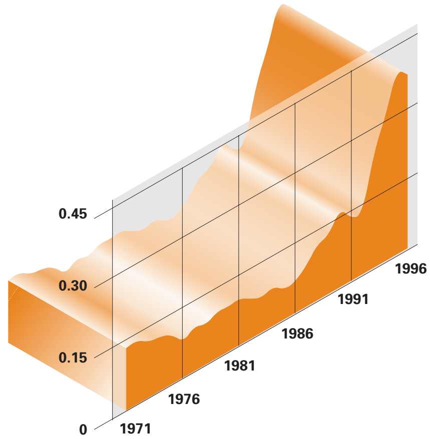
In aggregate, technology improvements have slashed the average cost of finding oil and gas reserves in the United States from roughly $12 to $16 per BOE of reserves added in the 1970s and 1980s to $4 to $8 today.

**Natural gas is converted to "barrels of oil equivalent" on the basis of 0.178 barrels of oil per thousand cubic feet of gas.*

BOE New Reservoir and New Field Reserve Additions per Exploratory Well

(Million barrels of oil equivalent per well)

The volume of reserves added per exploratory well has increased dramatically since the 1970s and early 1980s.



Source: U.S. Department of Energy

The sharply increased success rates and well productivity improvements attributable to advanced exploration technology yield substantial environmental benefits. Fewer wells drilled means reduced volumes of wastes to be managed, such as cuttings and drilling fluids (which lubricate the drill bit, circulate cuttings, and stabilize wellbore pressures).

New Resources in Old Fields

Improvements in exploration and production technology enable operators today to better tap resources that remain in existing fields. Advances in 3-D and interwell seismic technology allow operators to take another look at older producing areas, such as the fields in Appalachia, California, and West Texas, and see untapped zones of hydrocarbons that were bypassed or could not be seen in the past.

Improved computer-processing technology and interpretation software allow older seismic data to be reprocessed and reevaluated.

Photo: Sundowner Offshore Services

On the Cutting Edge

Exploration Applies High Technology

Advances in widely varied technical disciplines have boosted exploration efficiency over the past 20 years:

- **Advances in computer power, speed, and accuracy**
- **Remote sensing and image-processing technology**
- **Satellite-derived gravity and bathymetry data that enable remote sensing for offshore deepwater exploration**
- **Developments in global positioning systems (GPS)**
- **Advances in geographical information systems (GIS)**
- **Three-dimensional (3-D) and 4-D time-lapse imaging technology that permit better characterization of geologic structures and reservoir fluids below the surface**
- **Improved logging tools that enhance industry's geoscientific understanding of specific basins, plays, and reservoirs**
- **Advances in drilling that allow explorationists to more cost-effectively tap undepleted zones in maturing fields, test deeper zones in existing fields, and explore new regions**

Once untapped zones are identified, new techniques for sidetrack drilling (drilling a lateral extension from an existing wellbore) and deeper drilling from existing wells can allow some of these resources to be developed without drilling new wells or disturbing previously undisturbed areas.

Exploring New Frontiers

New deepwater drilling technology enables exploratory drilling in ever deeper offshore waters, making promising new resources accessible for the first time. Advances include high-technology floating drillships, jackup rigs, semisubmersible drilling rigs, and modular rigs. When commercial quantities of resources are discovered, discovery wells are capped until permanent production platforms can be set in place. Where dry holes are found, wells are plugged and the rigs are redeployed swiftly. As offshore technology extends exploratory reach, the industry continuously pushes to advance development and production technology to operate cost-effectively in ever deeper waters.

The 4-D Difference

At BP Amoco/Shell's Foenhaven field, estimated recovery rates of oil-in-place are expected to reach 65 to 70 percent with 4-D seismic, compared to 25 to 30 percent with 2-D technology and 40 to 50 percent with 3-D technology.

More Advances in Exploration Technology

Beyond advanced imaging, other new exploration approaches are being applied throughout the country to reduce environmental impacts, particularly in sensitive environmental areas. Redesign of drill rigs has minimized surface loading. Seismic techniques also have been redesigned to reduce impacts resulting from explosive shocksÑ for instance, through more flexible positioning of shotholes and geophones, redesign of shothole loading procedures, and use of ramming instead of drilling to set charges in hydrophones. These new acoustical and vibration devices replace explosives for generating seismic signals onshore and offshore, reducing noise, and protecting human, marine, and animal life.

These advances are enabling exploratory drilling in water depths of a mile or more, extending drilling seasons in the Arctic without disturbing the tundra or wildlife migratory patterns, and opening commercial development prospects in complex geological basins.

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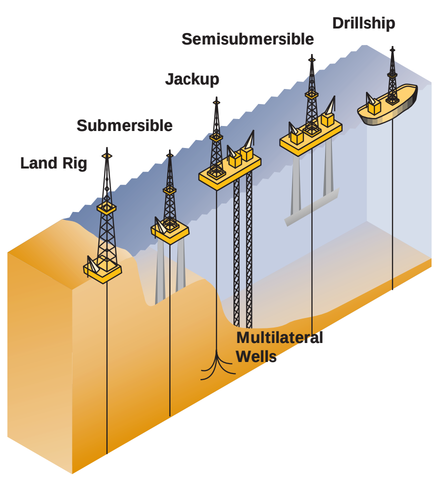
Outfitted with state-of-the-art electronics and computers, seismic survey vessels collect and process invaluable subsurface geological data to aid offshore exploration.

Exploration Drilling Techniques from Land to Deepwater

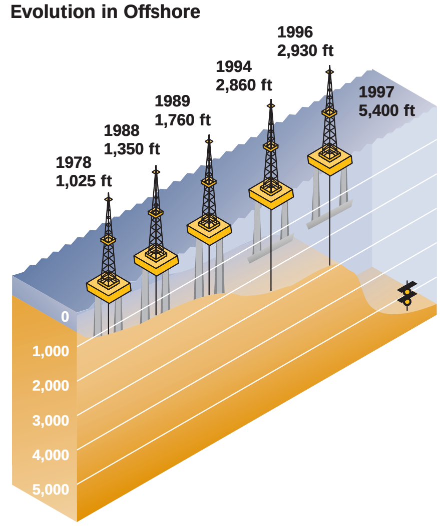


Source: Minerals Management Service

Beyond the Oil Patch

- **Advances in 3-D and 4-D seismic technology and earth-imaging systems have helped in the understanding of subsurface fluid flow, not just for oil and gas, but for groundwater monitoring and pollutant transport.**
- **Advances in geological and geophysical technologies have assisted in improving our overall understanding of "earth systems," or the major processes influencing activity in the earth's crust.**
- **Improved logging and interpretation technologies have helped us learn more about the characteristics of the earth's crust.**

Exploration Drilling Technology Evolution in Offshore



Drilling and Completion

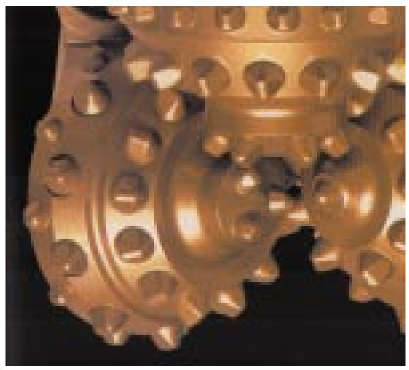
Successful drilling often means going faster and deeper, through harder rock, and in multiple directions from a single wellbore. The result? More resources are contacted with fewer wells, less drilling waste, and less surface disturbance.

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 NationÕs 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 uneconomicÑ including Devonian shales, deep gas formations, coalbeds, and low-permeability ÒtightÓ 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

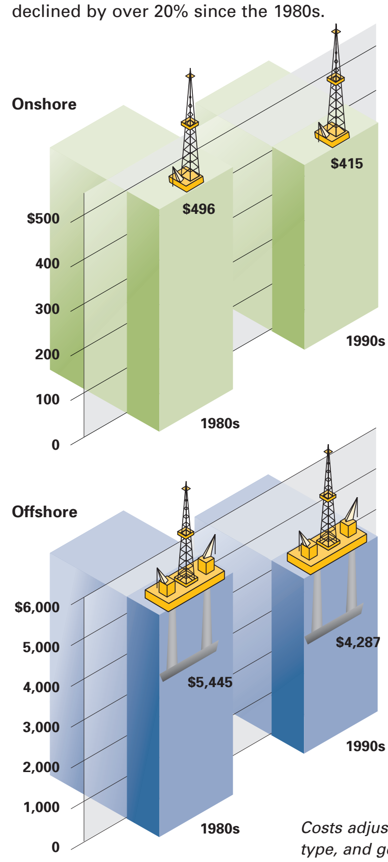
Fundamentals of Drilling and Completion

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

METRICS

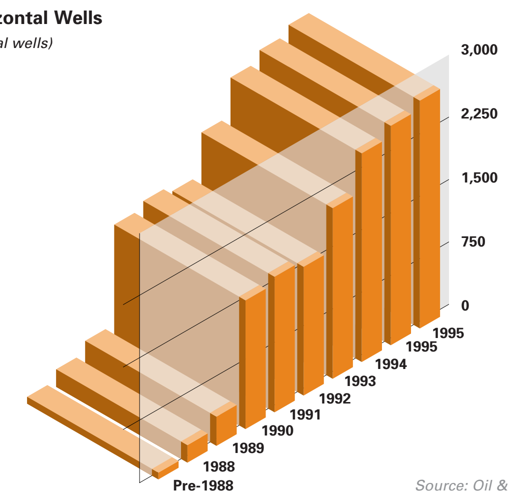
Measures of Success for Horizontal Drilling

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.**

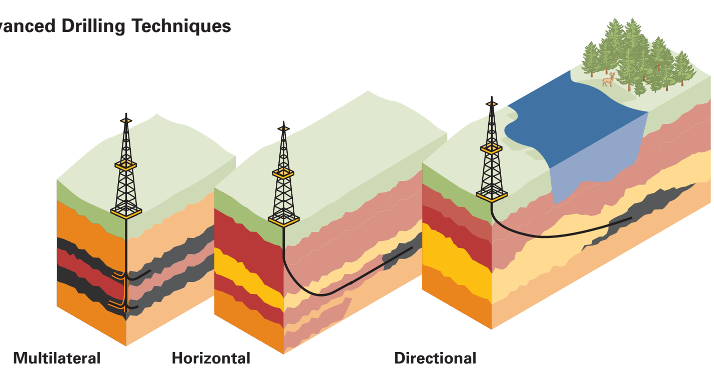
Worldwide Horizontal Wells

(Number of horizontal wells)

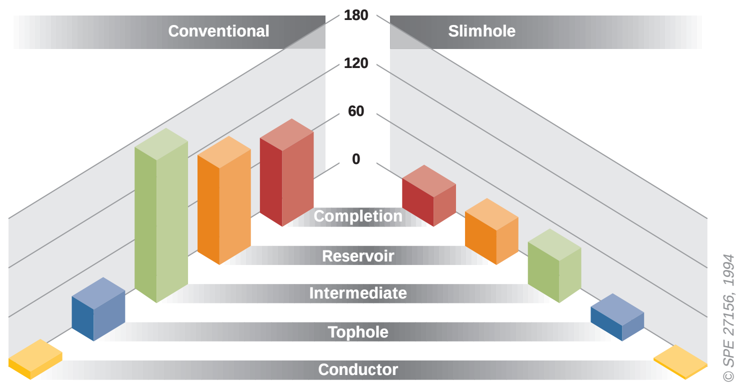


Source: Oil & Gas Journal, November 23, 1998

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 drillingÑ a technique gaining widespread use for tapping into reserves in mature fieldsÑ significantly decreases waste volumes. For example, a slimhole drilled to 14,760 feet and ending with a 4 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, todayÕs 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 technologyÑ a cost-effective solution for drilling in reentry, underbalanced, and highly deviated wellsÑ 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 equipmentÕs 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 unitÕs 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

METRICS

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

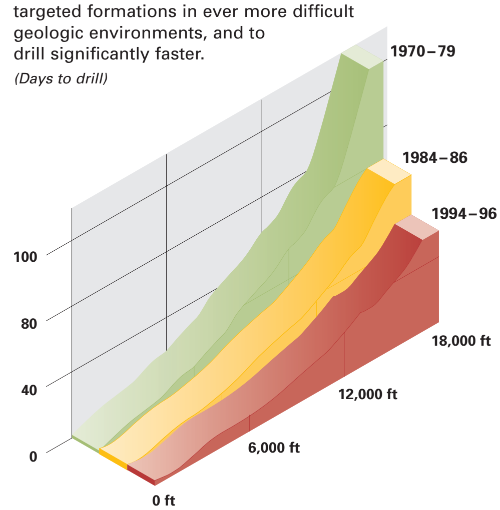
Advances in materials technology and bit hydraulics, spurred by competition between roller cone and polycrystalline diamond compact bits, have yielded tremendous improvement in drilling performance. Extensive field data indicate that, on average, a 15,000-foot well in Roger Mills County, Oklahoma, takes 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

TodayÕdrilling fluids (muds) must perform effectively in extreme temperature and pressure environments, support industryÕuse 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 drillingÑ used for natural gas wells in regions such as AppalachiaÑ 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

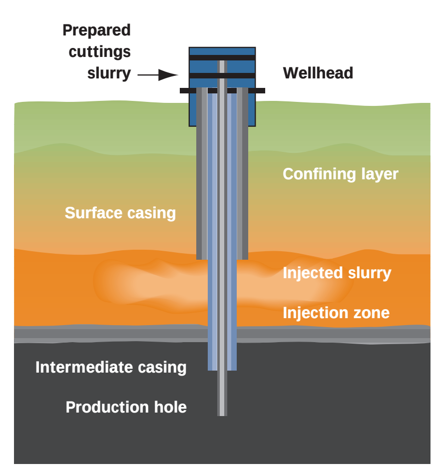
Annular injection of cuttings

In certain settingsÑ such as deep onshore wells, remote offshore operations, and AlaskaÕNorth SlopeÑ 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 earthÕsurface 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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METRICS

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.

METRICS

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.**

Production

WITH ADVANCED RESERVOIR MANAGEMENT AND OTHER PRODUCTION TECHNOLOGIES, PRODUCERS RECOVER MORE RESOURCES FROM OIL AND GAS OPERATIONS, WHILE MINIMIZING PRODUCED WATER AND OTHER WASTES.

Higher Yields Plus a Cleaner Environment

Since the beginning of the commercial oil industry in 1859, just a handful of U.S. oil fields have topped the 1-billion-barrel mark for production. California's South Belridge field recently joined their ranks, thanks in large part to enhanced oil recovery technology.

The discovery at South Belridge in Kern County was described in 1911 by a San Francisco newspaper as "a small quantity of oil, not sufficient it is believed to be a commercial success." Production levels remained modest throughout the field's early years. A new era began for the field in the 1960s with the advent of steam injection to increase oil recovery. From an average production of 11,370 barrels per day at the end of the 1950s, the field by the end of December 1979 was producing 49,500 barrels per day. With a major development program by Shell, production peaked in 1987 at an average of 174,800 barrels per day. Though decline had set in, the field remained the Nation's fifth most productive oil field in 1994, with production averaging 120,000 barrels per day. By extending the productive life of fields such as South Belridge, enhanced oil recovery technology reduces the need for new exploration and drilling operations—and eliminates their associated environmental impacts.

Source: Oil & Gas Journal, October 16, 1995

Once a field is brought on production, good reservoir management is required to ensure that as much oil and gas as possible is produced as cost-effectively as possible, with minimal waste and environmental impact. Early producers, relying on natural pressure and primitive pumps, recovered only about 10 percent of the oil in a given field. They sometimes vented or flared natural gas produced in association with the oil. In contrast, today's producers use an arsenal of advanced recovery techniques to keep oil and gas resources flowing, enabling them to produce as much as 50 percent or more of the oil resources and 75 percent or more of the natural gas in a typical reservoir.

Progress has been particularly impressive in the last decade. In response to declining crude oil prices and relatively flat natural gas prices in the 1990s, operators throughout North America have initiated major programs to reduce production expenditures, resulting in further technological advances and more streamlined operations. Technology improvements have brought a dramatic decrease in the average cost of producing oil and gas, from a range of $9 to $15 per BOE in the 1980s to today's average of roughly $5 to $9 per BOE.

Producing Energy and Environmental Benefits

IMPROVED PRODUCTION TECHnology has greatly reduced environmental impacts as well as costs. For example, better reservoir management has decreased volumes of produced water, which, at about 15 billion barrels per year, is the largest waste stream generated in U.S. oil and gas exploration and production. On average, the industry produces about 6 barrels of water for every barrel of oil. Since management of produced water is expensive—ranging from about $0.10 to more than $4.00 per barrel—technology to minimize produced water volumes can yield significant cost efficiencies.

Many other advances—such as improved treatment of produced water, better control of hazardous air pollutants, more energy-efficient production operations, and reduction of greenhouse gas emissions from E&P operations—have also made oil and gas production progressively less waste-intensive and more productive.

Production from oil and gas operations generally flows around the clock. A constant stream of performance data allows a producer to reevaluate operations and make appropriate decisions over time.

Surface facilities gather the produced oil, gas, sands, and water into distinct streams. These streams are then processed to remove impurities from oil and gas products, capture gas and water for reinjection if enhanced recovery techniques are in use, and treat and properly use or dispose of any water or solid wastes. Finally, the product is transported to market.

Fundamentals of Production

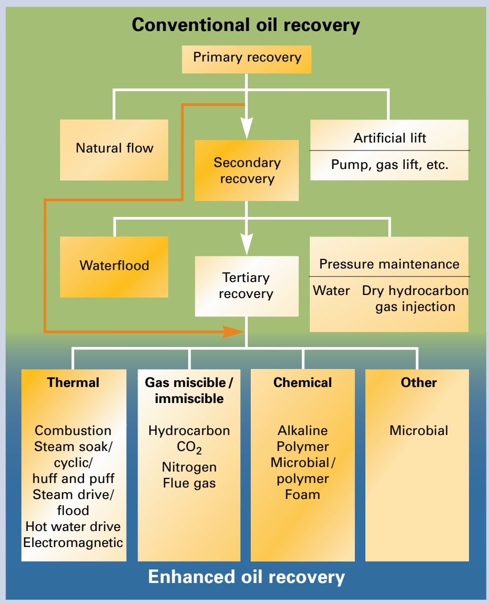
Advances in production technology that contribute significant environmental benefits include:

Improved recovery processes

Rapidly evolving oil recovery technology allows today's operators to extract more residual oil from existing reservoirs, after primary and secondary recovery. Residual oil may be either too viscous to be produced, trapped by interfacial tension, or lying in zones that have not been swept by injected fluids. The application of improved recovery technology has expanded to all producing areas of the country, allowing for production of some of the approximately 350 billion barrels of discovered but unproduced crude oil in the United States. Without improved recovery technologies, such as polymer-augmented waterflooding, the thermal processes of steam or hot water injection, and the injection of gases such as CO_2, flue gas, or nitrogen, these resources would be prematurely abandoned.

Oil and Gas Recovery Processes

Field development can occur in three distinct phases:

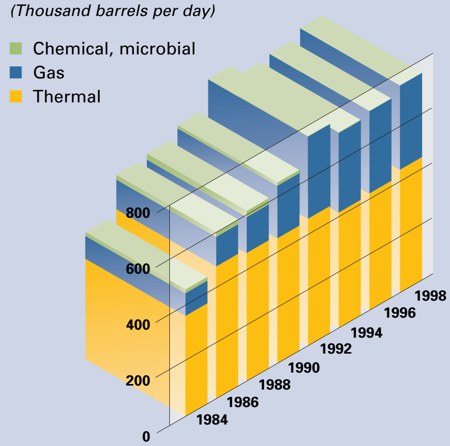


Source: Oil & Gas Journal, April 20, 1998

Enhanced Oil Recovery in the United States

Crude production from enhanced oil recovery

(Thousand barrels per day)



Source: Oil & Gas Journal, April 20, 1998

Primary Recovery

Primary recovery produces oil, gas, and / or water using the natural pressure in the reservoir. Wells can be stimulated through injection of acids or other fluids, which fracture the hydrocarbon-bearing formation to improve the flow of oil and gas from the reservoir to the wellbore. Other techniques, including artificial lift, pumping, and gas lift, help production when the reservoir's natural pressure dissipates.

Secondary Recovery

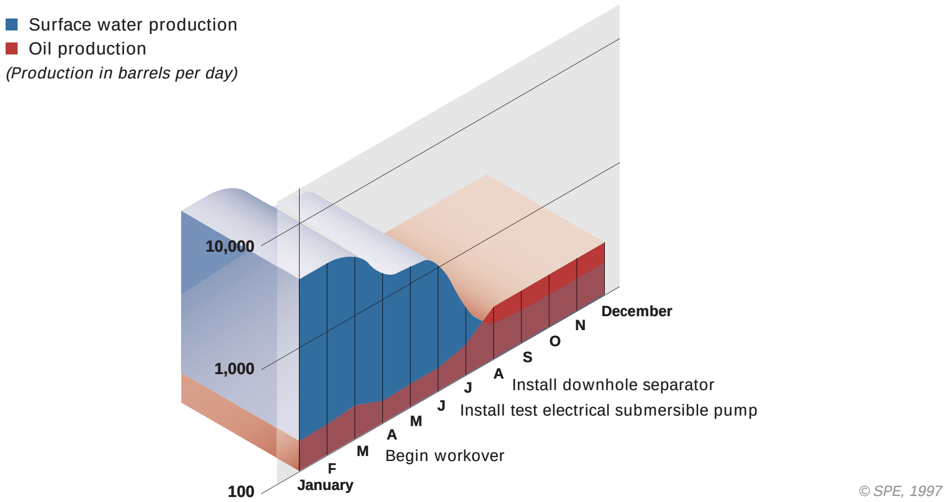
Secondary recovery uses other mechanisms—such as gas reinjection and water flooding—to energize the reservoir and displace fluids not produced in the primary recovery phase.

Enhanced Oil Recovery

Enhanced oil recovery involves the injection of other liquids or gases (such as surfactants, polymers, or carbon dioxide) or sources of heat (such as steam or hot water) to stimulate oil and gas flow and mobilize reservoir fluids that were bypassed in the primary and secondary recovery phases.

METRICS

Actual Example of Reduction in Produced Water Using Downhole Separation



Currently being tested in pilot-scale projects throughout the world, downhole separation may someday deliver significant cost savings and environmental benefits in settings where the technology is applicable. In one recent demonstration (illustrated here), downhole separation decreased surface water production by 95 percent and increased oil production by 50 percent, resulting in a 4-month payback period.

Better reservoir management to reduce water production

Improved understanding of the flow mechanics of reservoirsÑ resulting from crosswell tomography, crosswell seismology, better logging tools, and other reservoir characterization advancesÑ allows operators to reduce produced water volumes through more selective well placement and selective shutting in of some wells. Developments in completion technology, especially as applied in horizontal wells, are also helping to delay water breakthrough and maintain the ratio of produced oil to produced water as high and as long as possible.

Improved produced water treatment technology

In locations where surface discharge of produced water is still permitted (such as offshore and low-rate stripper wells in Appalachia), a variety of methods are being pursued to treat and reuse the water or discharge it to the surface without environmental impact. Approaches include hydrocyclones, gas flotation, membrane separation, granular activated carbon fluidized-bed reactors, and biotreatment technology.

One particularly promising technology for low-rate well application in some climates and operational settings is the freeze-thaw/evaporation (FTE) process. Using a freeze crystallization process in winter and natural evaporation in summer, produced waters are separated into fresh water, concentrated brine, and solids. The resulting fresh water can be used for horticulture, livestock, and other beneficial uses. The remaining volume of wastes (solids and semisolids) requiring disposal is significantly reduced. This process requires large amounts of land and high volumes of produced water retention and is limited to climates with cold winters and dry summers, such as the Rocky Mountain region, the Northern Great Plains, and virtually all of Canada.

Downhole separation technology

In certain settings, downhole separation represents a potential solution to a significant environmental and cost issue for oil and gas operators: the management and disposal of produced water. In todayÕs operations, water is generally pumped to the surface along with oil, then separated from the oil. Since volumes of produced water can exceed oil production by 10 times or more, companies incur sizeable costs to lift the unwanted water, manage it on the surface, and dispose of it (usually by reinjection into the earthÕs subsurface). The approach also has the disadvantage of bringing contaminants up through the well piping.

In downhole separation, mechanical or natural methods are used in the wellbore to separate the formationÕs oil and water. The oil is then brought to the surface, while the water is directly pumped into a subsurface injection zone. In its current state of development, downhole separation is thought to be applicable only to light oil wells with relatively high flow rates and meeting minimum casing diameter and water-to-oil ratio standards.

Field tests are demonstrating that this technology, effectively deployed, has the potential to significantly reduce the produced water brought to the surface in applicable wells, directly reducing fluid lifting and disposal costs, as well as any associated environmental concerns. Downhole separation can also increase oil production in proportion to the decrease in water production.

In many parts of the country, the high cost of produced water management is the main reason for well abandonment. By controlling the increasing costs normally incurred as water volumes increase, downhole separation can potentially increase U.S. oil production and recoverable reserves.

In some cases, downhole separation may also enable increased oil production and recovery of original oil in place through improved or altered water flow distribution in the reservoir. In addition, dynamic control of the oil-water contact can be achieved through dual completion and reinjection.

Depending on how widely downhole separation is applied in the future, as much as 5 billion barrels per year of produced water that otherwise would have been brought to the surface will remain in the ground.

Better leak detection, measurement, and control systems for hazardous air pollutants

Technology advances on several fronts are reducing emissions of hazardous air pollutants in E&P operations. In the last decade, for example, many approaches have been developed to detect, measure, and control air pollutants from a variety of oil and gas field equipment. State-of-the-art leak detection and measurement systems pinpoint fugitive gas leaks, conserving valuable natural gas and identifying potentially life-threatening hazards to workers and the community. Vapor recovery units—economical for large operations with relatively high reservoir pressures and vapor releases—are being employed to reduce emissions of volatile organic compounds from storage tanks by as much as 95 percent. Improved management approaches for glycol dehydrators are also helping to reduce emissions substantially. In addition, new technology for removal and recovery of acid gas (hydrogen sulfide, mercaptans, and carbon dioxide) shows cost savings of 40 percent compared to current technology.

More energy-efficient production operations

Operators increasingly are focusing on ways to reduce energy use in their operations. For example, new stripper well beam pumps have reduced electricity consumption substantially. Improvements in energy efficiency result in corresponding reductions in emissions of air pollutants associated with energy use in production operations.

Better facility-wide waste management planning

The E&P industry, working with States, is aggressively employing technology and practices to reduce or eliminate waste by preventing it at the source. Techniques include better planning, materials management, materials reclamation, and recycling; major changes to E&P processes; improved auditing and maintenance procedures; changes in day-to-day operations to control waste generation; and more targeted employee training.

Increased focus on reducing greenhouse gas emissions

A wide variety of approaches are currently being pursued to reduce emissions of methane, a potent greenhouse gas thought to contribute to global climate change. Methane losses from oil and gas industry operations are considerable, and emission reduction techniques reduce both global emissions of greenhouse gases and the losses of a valuable product. Technology being pursued includes glycol dehydration using a separator-condenser (which can result in emissions recovery of over 95 percent), and replacing high-bleed pneumatic controllers (a particularly large source of methane emissions) with low-bleed pneumatic devices.

METRICS

Nature's technology provides water for agricultural and other beneficial uses. In suitable environments and under certain operating conditions, initial field tests indicate the freeze-thaw/evaporation process may reduce the volume of produced water requiring disposal by 80 percent.

Recent advances in coalbed reservoir engineering and completion practices have also turned coalbed methane—historically considered a safety hazard for mines and vented to the atmosphere—into a reliable energy resource. This resource now accounts for over 5 percent of U.S. gas production and 6 percent of proved gas reserves. Recovery rates are being further enhanced by the injection of carbon dioxide or nitrogen.

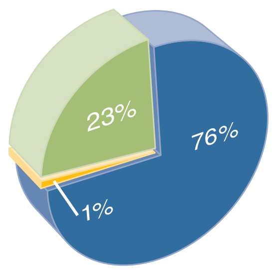
Gas-to-liquids technology is still on the cutting edge, but promises to make vast quantities of previously untapped natural gas transportable and marketable. The process chemically alters natural gas to form a stable synthetic liquid that performs more efficiently and with fewer greenhouse emissions than conventional fuels. The North Slope of Alaska alone is estimated to have 25 trillion cubic feet of natural gas that is currently undeveloped because transporting it to markets would be uneconomical. Gas-to-liquids technology may soon enable natural gas, the fuel of choice for environmental performance, to be transported around the world.

Beyond the Oil Patch

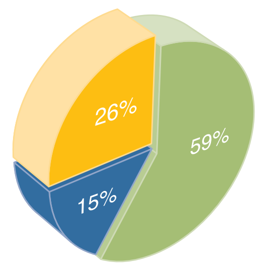
- **Developments in reservoir engineering and reservoir simulation technologies and processes have advanced our ability to predict groundwater flows, pollutant fate, and transport in groundwater, and to simulate the diffusion of air pollutants in the atmosphere.**
- **Adaptations of microbial enhanced oil recovery technology, originally developed for enhancing crude oil recovery, has proven to be quite effective in the remediation of hydrocarbon-contaminated sites.**

U.S. Oil Production

Producing oil wells

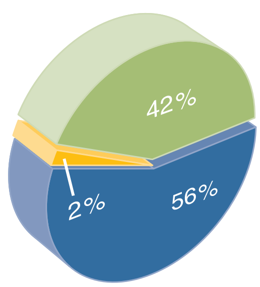


Crude oil production

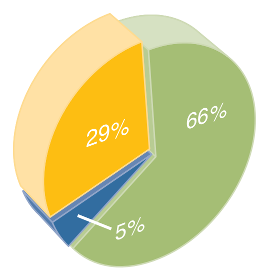


U.S. Gas Production

Producing gas wells



Natural gas production



- Offshore
- Onshore–Stripper
- Onshore–Other

In the 33 oil- and gas-producing States, approximately 574,000 oil wells and 300,000 gas wells currently yield approximately 6.5 million barrels of oil and 54 billion cubic feet of gas per day. Most of these wells—approximately 435,000 oil wells and 170,000 gas wells—are classified as "stripper wells" because they produce less than 10 barrels of oil or 60,000 cubic feet of gas per day.

About 26 percent of U.S. oil production and 29 percent of gas production comes from offshore operations, predominantly in the Gulf of Mexico. Currently, there are over 5,000 producing structures in Federal offshore waters.

Source: American Petroleum Institute; U.S. Department of Energy; Independent Petroleum Association of America; and Interstate Oil and Gas Compact Commission

Site Restoration

ON LAND AND OFFSHORE, OIL AND GAS PRODUCERS HAVE DEVELOPED INNOVATIVE WAYS TO RESTORE SITES TO ORIGINAL—AND SOMETIMES BETTER-THAN ORIGINAL—CONDITION, FOR DIVERSE USES RANGING FROM HOUSING TO AGRICULTURE TO WILDLIFE HABITATS.


Photo: Corbis Images

Leaving a Positive Environmental Legacy

Diamond Y Spring in West Texas, a rare desert spring habitat, has been the site of an actively producing oil and gas field for decades. It also has been the focus of preservationists since the 1960s, with the discovery there of the Leon Springs pupfish, a species thought to be extinct. Pecos County cattle rancher M. R. Gonzales, who bought the property in 1969, was instrumental in bringing the spring's ecological significance to the attention of oil companies operating in the area. After a series of oil spills around the property, a diversion dike was build in 1974 to protect the headspring from any future spills.

The Nature Conservancy turned to the oil companies active in the area to provide funds for the purchase of Diamond Y Spring in 1990. Donations were made by Enron Corporation, Exxon, and the Mobil Foundation, and an innovative partnership was forged with these and other oil companies to establish protection and reclamation projects in the area of the springs. Old flow lines were replaced, pipelines near the spring system were encased in steel, many well sites were diked and bermed, abandoned wells were plugged, road construction was minimized, and areas were revegetated with native grasses and marshland flora. Today, the Leon Springs pupfish—together with rare snails, a unique salt-tolerant sunflower, the endangered Pecos gambusia fish, javelinas, foxes, and other species—continue to flourish on this unique desert spring property.

Source: The Nature Conservancy

Farming and oil and gas production have coexisted beneficially for decades in rural America.

After 15 to 30 years of production, most oil or natural gas wells reach their economic limit. It is time to pack up and move on. Wellheads, pumpjacks, tanks, pipes, facilities, equipment… everything has to be removed from the site. The wells are then permanently plugged with cement to prevent future flow of subterranean fluids into the wellbore.

The vast majority of abandoned or ophaned wells in the United States today are a legacy of the industryÕearliest environmental practices, when operators took only rudimentary steps to inhibit the fluids left in the formation or the wellbore from flowing to the surface, to restore the land, or to remove used equipment. These practices often created animosity with landowners, prompting State governments to address issues associated with past closures. TodayÕindustry is responding to the environmental challenges of past closures and is treating site restoration as a critical operational activity. Specialized teams now handle site restorations, using new technology and approaches that often result in reduced liability as well as enhanced environmental conditions.

At land-based sites, the wellbore is plugged to confine the producing formation and to protect valuable groundwater resources. Waste-handling pits and other facilities are closed, and the location is then restored to near-original condition or prepared for its intended future use, whether as agricultural land, as a wildlife habitat, or as an industrial, residential, or commercial development site. Current strategies include maximizing reuse of equipment and materials still appropriate for other applications.

Closure of offshore facilities has begun only recently, so the legacy of past practices is not at issue here as it is with land-based sites. Decommissioning and removing offshore installations is a complex process, both legally and technically. It is essential to meet the wide variety of regulatory requirements and to ensure that the marine environment is not compromised. Alternative approaches are total or partial removal of the installation, or toppling on site. All require planning and preparation years in advance.

Advanced site restoration techniques enhance marine habitats.

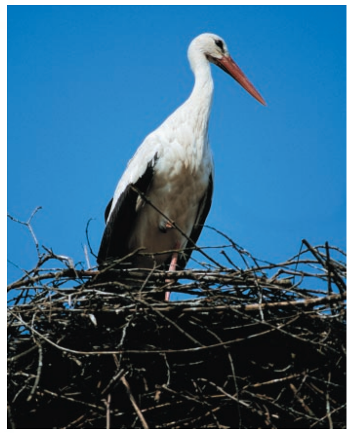
Restoring, and Even Improving, Habitats

Today's site restoration strategies are significantly more environmentally protective than past approaches. In some instances, these strategies actually enhance the environment and create economic benefits.

"Rigs-to-reefs"...presenting homes for marine life

Decommissioning operations, especially in the Gulf of Mexico, have been largely dependent on the use of explosives. But shock waves from the blasts can damage sea life, other nearby installations, and surface vessels. And when an obsolete rig structure is towed to shore, cut up, and sold for scrap metal, the platform's artificial reef habitat is eliminated and the area's ecosystem is upset.

In the "rigs-to-reefs" approach, massive offshore platforms are toppled and sent to the bottom of the ocean, providing several acres of living and feeding habitat for thousands of underwater species. The first planned rigs-to-reefs conversion took place in Florida in 1979. In 1983, the Minerals Management Service—the agency that manages leasing, exploration, and development of Federal offshore lands—announced its support for rigs-to-reefs programs. These programs are beneficial from many perspectives. Marine life is enhanced. Oil companies realize considerable savings from avoided removal costs.



And States receive a share of the savings as the companies donate operating platforms or obsolete rigs, construct reefs, and donate funds from their savings to support and enhance the State's marine ecosystems.

In 1984, the Federal government passed the National Fishing Enhancement Act, which further strengthened the program. Louisiana and Texas followed suit in 1986 and 1990, respectively, forming their own programs. Today all five States bordering the Gulf of Mexico have artificial reef programs, and such reefs also are found in other locations around the world.

Rigs make ideal artificial reefs. Constructed of corrosion-resistant steel that withstands displacement or breakup, rigs have a large, open structure that allows easy circulation for fish and provides havens for barnacles, corals, sponges, clams, bryozoans, and hybroids. Within six months to a year after a rig is initially placed on the sea floor, it will be a thriving reef ecosystem completely covered with marine life. When it is toppled, the newly created reef attracts additional mobile invertebrates and other fish species and an even more complex food chain develops.

The rigs-to-reefs approach saves the industry millions of dollars a year and also yields economic benefits for States:

- Generally 50 percent of the industry savings is donated to a host State's artificial reef program.
- Commercial and recreational fishing and recreational scuba diving prosper from the conversion, in turn increasing local tourism.
- Commercial divers are used for nearly all phases of the conversion.

Oilfield pits and pads... changing eyesores to assets

Caliche, the crust of calcium carbonate that forms on the stony soil of arid regions, is common in drilling pads and pits in many oil fields in Texas. A program recently initiated by the University of Texas converts these pits and pads into no-maintenance wildlife habitats. In the program, the pads and pits are recontoured to a depth of 18 inches, shrubs, grass, and forbs are planted, and a functional hydrologic cycle is reestablished. Natural recovery processes following drilling and production are accelerated and can quickly transform sites into desirable habitats.

Drill cuttings to create or restore wetlands

With assistance from DOE's National Petroleum Technology Office, Southeastern Louisiana University is exploring whether drill cuttings can be safely used to restore and create wetlands. Using unique temperature-controlled mesocosm greenhouse

facilities to simulate a wetland's full range of tidal fluctuations, researchers found that processed drill cuttings generally exhibited low levels of toxicity and appeared capable of supporting healthy wetlands vegetation. In some cases, the elemental composition of restored drill cuttings was found to be very similar to dredge spoil currently in use as a wetlands creation substrate.

New approaches to reclaiming and remediating abandoned well sites

The Oklahoma Energy Resources Board (OERB), with support from the U.S. Department of Energy, has been evaluating and restoring abandoned and orphaned drilling and production sites with no current owner or operator. Since 1995, OERB has restored more than 1,000 sites across 52 counties, and restoration is in process at an additional 500 sites. Under the OERB program, oil and gas producers and royalty owners in Oklahoma voluntarily finance the site clean-up—the landowner pays nothing, and OERB is not reimbursed from any other source. The OERB effort was the Nation's first industry-funded environmental cleanup and education program. Today, similar programs have been adopted in several other States.

Road mix from nonhazardous oilfield waste

In road building, native soils are typically excavated to prepare a road base and then used as aggregate (course binding material) in the on-site mixing process. For roads in oil and gas operations, a recently developed approach uses recycled crude oil tank residuals and other nontoxic wastes as an aggregate. Although this practice has limited application, it has proven effective in reducing particulate matter from unpaved roads and other road dust emissions. Roads of these materials provide all-weather access to remote exploration and production sites, improve driving conditions, and decrease dust generation in production areas.

Case Study

From Oil Fields to Housing

Here are two illustrations of how effectively exploration and production sites and their wastes can be adapted for reuse:

California (United States)

When the West Coyote oil field was discovered in 1909 near La Habra, California, it was 10 miles from the nearest town. By 1980, the field was nearly depleted and was surrounded by housing developments. Since then, Chevron's real estate management group has converted the field from a potential liability into a prime real estate asset through careful abandonments of tank farms, oil wells, and multiple surface facilities, and subsequent site restoration—all in line with very strict environmental regulations and constraints. The rolling hills are now the site of premium homes.

Colombia (South America)

In looking at options for disposing of drill cuttings from its Colombian operations, BP Amoco staff came up with a new answer: using the cuttings as a raw material for bricks. The deceptively simple idea has met a vital need in the local community, where building materials had been scarce and expensive. The approach has also eliminated the environmental impacts of traditional disposal methods, which involved placing lime-fixated cuttings in lined pits. Today, the bricks are manufactured by local companies, using a combination of cement and water-based drill cuttings. Cuttings produced from drilling just one well can make up to 700,000 new bricks.

Beyond the Oil Patch

Developments resulting from the restoration of oil and gas E&P sites have been adapted and applied to the restoration of a wide variety of industrial facilities.

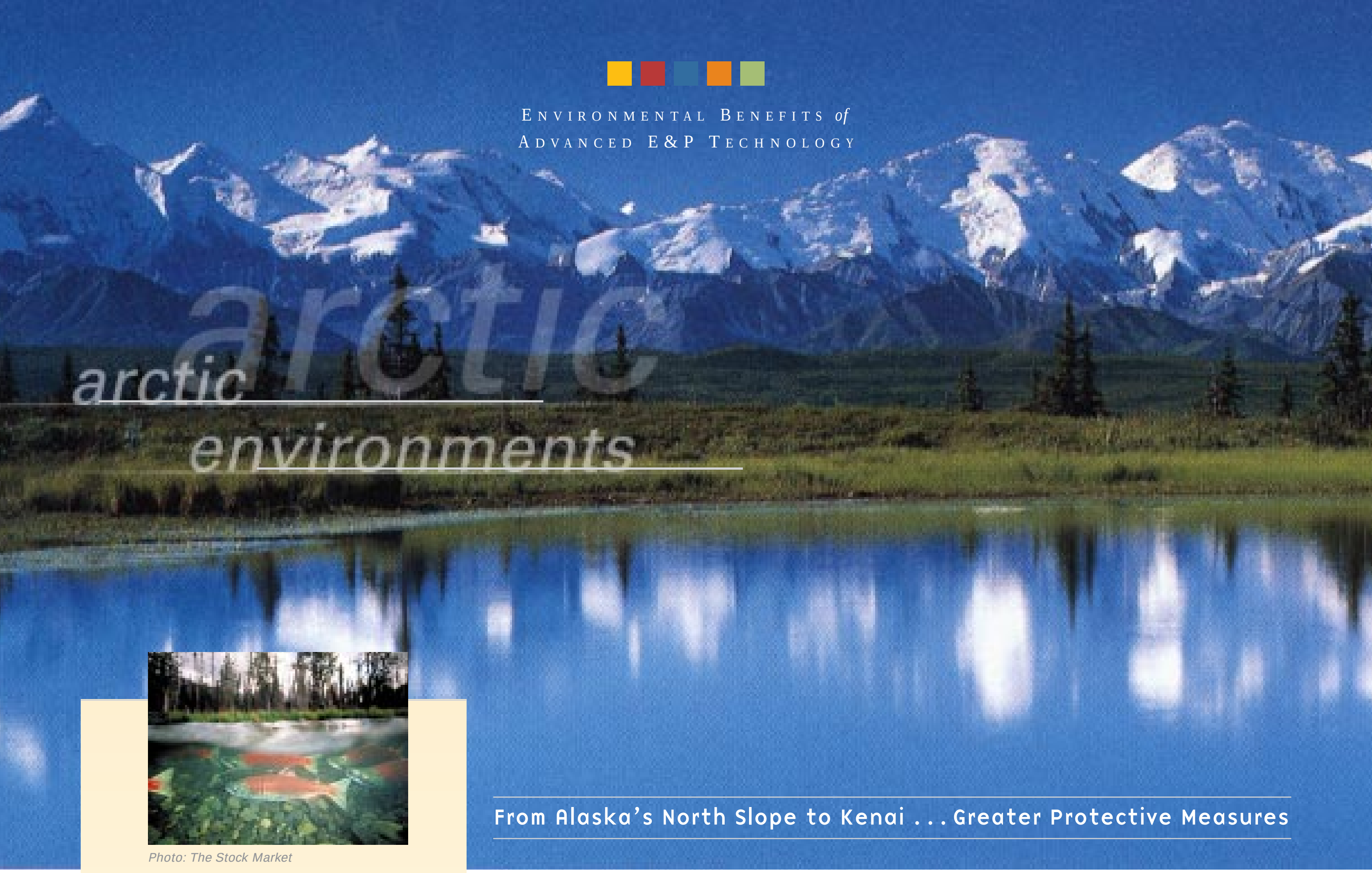
Operations in Sensitive Environments

From the tundra of Alaska to the wetlands of Louisiana, a host of advanced technologies enable the oil and gas industry to produce resources far beneath sensitive environments.

Smaller Footprints, Less Waste, Lower Impact

A growing proportion of the Nation's remaining untapped resources exist in sensitive environments—which are as varied as the mountains and tundra of Alaska, offshore California, the deepwater Gulf of Mexico, and the wetlands of coastal Texas and Louisiana—and even in the midst of bustling urban centers. Moreover, many of these fragile areas reside on our Nation's public lands, requiring industry and government to work collaboratively as stewards of these treasures. Industry simply cannot afford failures in these fragile settings. Over the last four decades, the industry has developed increasingly innovative technology and approaches for conducting operations in sensitive areas, improving not only environmental performance, but economic performance and resource recovery as well.

Technology that enables safe and efficient exploration and production beneath sensitive environmental areas includes new 3-D seismic and 4-D time-lapse imaging, satellite imaging, aeromagnetic sensing, and ground-penetrating radar. New acoustical and vibration devices have also replaced explosives for generating seismic signals onshore and offshore, reducing noise and protecting marine and animal life. And new directional drilling, extended-reach drilling, and multilateral drilling technology, coupled with measurement-while-drilling systems, allow industry to safely produce resources far beneath sensitive environments with less surface disturbance.



arctic environments

From Alaska's North Slope to Kenai . . . Greater Protective Measures

Photo: The Stock Market

Established by President Theodore Roosevelt, southern Alaska's Kenai National Wildlife Refuge is home to moose, Dall sheep, mountain goat, caribou, coyote, wolf, grizzly bear, black bear, lynx, wolverine, beaver, small mammals, birds, and salmon. It is also home to the Swanson River oil field. Unocal, operator of the field since 1992, received the "National Health of the Land" award in 1997 from the U.S. Department of the Interior for environmental excellence at Swanson River.

To ensure that its oil and gas operations within the refuge are conducted in an environmentally responsible manner, Unocal has implemented state-of-the-art practices. Plastic pipeliners have been installed on 28,000 linear feet of metal gathering lines and flow lines to avoid the potential for leaks. Specially trained dogs are used for the early detection of underground pipeline leaks. A water filtration and treatment system collects and processes runoff to prevent problems that may arise from the leakage of hydrocarbon compounds from old petroleum storage facilities. And groundwater-monitoring wells ensure that if contamination of groundwater occurs, it is quickly detected. Together, these measures protect a habitat that will be a refuge to wildlife and an inspiration to visitors for many generations to come.

Source: Unocal Corporation, 1996–97 Health, Environmental, and Safety Report

Logistical barriersÑ posed by extremely low temperatures, freezing and thawing of the tundra, and remote locationsÑ once limited drilling in arctic environments. TodayÕoperators not only cope successfully with these challenges, but also institute protective measures appropriate to sensitive environments. Improvements over the past 40 years have dramatically reduced industryÕfootprint on the fragile tundra, minimized waste produced, and protected the land for resident and migratory wildlife. Environmental advances have also dramatically reduced costs of conducting oil and gas activities. Industry innovations include:

Ice pads and roads

As ice construction technology and equipment have improved in recent years, bitter-cold temperatures have been turned to good use. Ice-based roads, bridges, drilling pads, and airstrips have become the standard for North Slope exploration projects. Not only is ice-based fabrication cheaper than gravel, it leaves virtually no footprint on the tundra; ice structures simply thaw and melt in the spring. In recent years, this approach has been further improved: BP Exploration (Alaska) Inc. (BPXA) has successfully built insulated ice pads for drill rigs, permitting the company to extend its exploratory drilling season significantly and to reduce both seasonal mobilization of equipment and drilling footprints, as well as operating costs.

Low-impact exploration approaches

When exploratory wells are too far from existing infrastructure to build ice roads cost-effectively, alternate means of transportation are now used almost exclusively. Large all-terrain vehicles with huge, low-pressure, balloon-like tires carry substantial equipment loads across the tundra, leaving practically no tracks. To protect the North SlopeÕfragile tundra, exploratory operations are now conducted exclusively during the winter.

Advanced drilling technology

Advances in drilling technology have played a major role in increasing North Slope productivity and in benefiting the environment. Horizontal drilling, introduced in 1990, now accounts for 90 percent of the wells drilled in Prudhoe Bay. Whereas early horizontal wells in Prudhoe penetrated only 500 to 800 feet of reservoir laterally, technology advances

recently enabled a North Slope operator to penetrate 8,000 feet of reservoir horizontally, greatly increasing contact with oil-bearing sands. If the bay were developed today using horizontal drilling, only 11 drill sites would be needed, compared to the 42 required in the 1970s. The area's first multilateral well was drilled less than two years ago; today there are 10 multilateral wells in the area, two of which used coiled tubing rigs.

A technology recently introduced jointly by ARCO-Alaska and BPXA is truly revolutionary. Called through-tubing rotary drilling, it allows an operator to drill a new well through the existing production tubing of an older well, saving both time and money. Another recent North Slope breakthrough is "designer wells" technology, an advanced form of directional drilling, where wells curve around and behind geological barriers to reach small pay zones. Extended-reach drilling is also greatly improving resource recovery and environmental protection in the area. Using extended-reach drilling, North Slope operators expect to develop the area's newest giant field, the 1-billion-barrel Alpine field, with 100 wells from only two drill sites, minimizing the drilling footprint. At Niakuk, operators have used extended-reach drilling to tap many offshore locations from a single drill pad on Heald Point.

By increasing resource recovery and reducing drilling costs, all these advances have benefited the economics of North Slope operators. By minimizing the number of wells drilled, drilling footprints, and waste volumes, they have benefited the environment as well.

Reduced footprint

Significant reductions in the size of production-related facilities have shrunk the footprint of North Slope operations. ARCO-Alaska's Kuparuk field, for example, uses a 55-acre facility as an operations base for contractor support, compared with a similar 1,000-acre facility in the original Prudhoe Bay field. If the entire Prudhoe Bay oil field were built with today's technology, its footprint would be 64 percent smaller than its current size—the area impacted by drilling pads would be 74 percent smaller, roads would cover 58 percent less surface area, and oil and gas separating facilities would take up 50 percent less space. Today, new production pads are up to 70 percent smaller than the original Prudhoe pads, and spacing between wellheads has been reduced dramatically. In addition, facilities are now built more quickly than previous ones, further reducing construction costs and disturbances to the environment.

Improved methods for site restoration and enhancement

In the fragile North Slope ecosystem, site restoration and habitat enhancement are a vital part of post-production. As North Slope operators continue their search for advanced environmental solutions, new technology and practices have been developed to restore areas affected by E&P activities. For example, at a number of abandoned gravel mining sites in floodplains, BPXA and ARCO-Alaska flooded the sites to create large pools and lakes that serve as overwintering habitats for fish and predator-free nesting sites for waterfowl, a practice encouraged by the Alaska Department of Fish and Game.

Revegetation of areas affected by gravel construction and drilling is also an important restoration technique. Between 1985 and 1989, BPXA and the U.S. Department of Fish and Wildlife worked jointly to restore the habitat along the 10-mile-long Endicott road. Researchers found that transplanting arctic pendant grass successfully revegetated disturbed aquatic sites. In 1988, BPXA began restoring its BP Pad, an exploratory drilling site first used nearly 20 years earlier. After equipment and debris were removed, the well was plugged and construction gravel was excavated from the site. BPXA seeded the wellsite and surrounding tundra with three types of native grasses and fertilized the area. A snow fence was erected to create snowdrifts that would increase moisture levels at the site. Within three years, the area's native vegetation had been restored.

wetlands, coastal, and offshore

Wetlands and Coastal Operations . . . Ecosystems Preserved

Growing national awareness of the environmental significance of wetlands and coastal areas has inhibited E&P operations in certain areas. Where operations are conducted, the industry takes extreme care to minimize all associated risks. Technology such as directional drilling is critical in minimizing surface disturbance in wetlands and coastal areas. Advanced site restoration methods for these sites are also a vital industry pursuit.

Today, operators employ a variety of advanced drilling and production technologies to operate safely in sensitive wetlands and coastal areas. In the wetlands of south Louisiana, for example, ARCO Oil and Gas Co. employed innovative drilling technology to conduct operations that were both environmentally safe and cost-effective. By utilizing an efficient closed loop solids control system, ARCO reduced both its drilling footprint and its waste volumes.

A recent drilling operation on Padre Island National Seashore on the Gulf Coast of Texas, the longest remaining undeveloped barrier island in the world and one of our Nation's most treasured Federal lands, also demonstrates this commitment to environmentally responsible operations. In drilling an exploratory well near the seashore's Malaquite Beach, Bright & Co. undertook extensive cooperative planning and regulatory compliance efforts with Federal and State agencies, while utilizing state-of-the-art drilling and site restoration technology to minimize impacts. For example, drilling operations were conducted with a diesel-electric rig, which operated at extremely low noise levels. Most of the rig's components were wheel-mounted, reducing the number of equipment loads moved across the beach. The drilling system's mud pumps and draw works were powered by electric motors—using electric motors not only reduced air emissions from the site, it minimized the possibility of harmful oil leaks.

Since the targeted pay zone was located under a large wetlands area, directional drilling was employed to drill beneath the sensitive area, greatly reducing environmental impacts. During its operations, Bright & Co. utilized an advanced polycrystalline diamond compact bit in order to maintain the well's angle and direction. Finding no productive zones in the well, Bright & Co. plugged and abandoned the well, restored the site to its original contours, and reseeded with native grass.

These are but two examples that represent the oil and gas industry's commitment to operate responsibly in sensitive wetland and coastal areas. This commitment is recognized outside the industry as well. Robert J. Potts, State Director of The Nature Conservancy's Texas office, recently noted, "The Nature Conservancy of Texas has a long history of cooperative partnerships with the oil and gas industry. Several of our preserves are home to ongoing oil and gas operations while at the same time providing excellent habitat for wildlife."

Offshore Operations...Operating Safer, Smarter, and Deeper

From the Gulf of Mexico's subsalt plays, to the hostile North Sea, to offshore West Africa and Brazil, as the offshore oil and gas industry moves into deeper and more remote settings in search of new resources, operators are utilizing a variety of advanced technologies to protect the environment, enhance worker safety, and increase recovery. Offshore operations, which occur in the midst of complex underwater ecosystems consisting of hundreds of aquatic species and flora types, require extreme care and planning. Today, advanced technology is meeting these challenges.

Advanced 3-D seismic and 4-D time-lapse data processing and imaging technologies, coupled with satellite-derived bathymetry and gravity data, enable offshore operators to locate oil and gas resources far more accurately than only one decade ago, resulting in fewer dry holes, less drilling, and greater resource recovery. For example, the Gulf of Mexico's subsalt play, completely undeveloped 10 years ago, is now one of the world's hottest offshore settings, thanks to state-of-art subsalt imaging technology such as Full Tensor Gradient (FTG) imaging and marine magnetotelluric surveys.

Not only is the industry finding and developing resources in more remote and challenging settings, it is significantly enhancing worker safety and pollution control in the process. Today, nearly all Outer Continental Shelf operators are collaborating with the Minerals Management Service and other Federal agencies to implement Safety and Environmental Management Programs (SEMP), voluntary, nonregulatory strategies designed to identify and reduce risks and occurrences of offshore accidents, injuries, and spills. As a result, this commitment to safer and smarter operating practices has enabled the offshore industry to practically eliminate oil spills from offshore platforms.

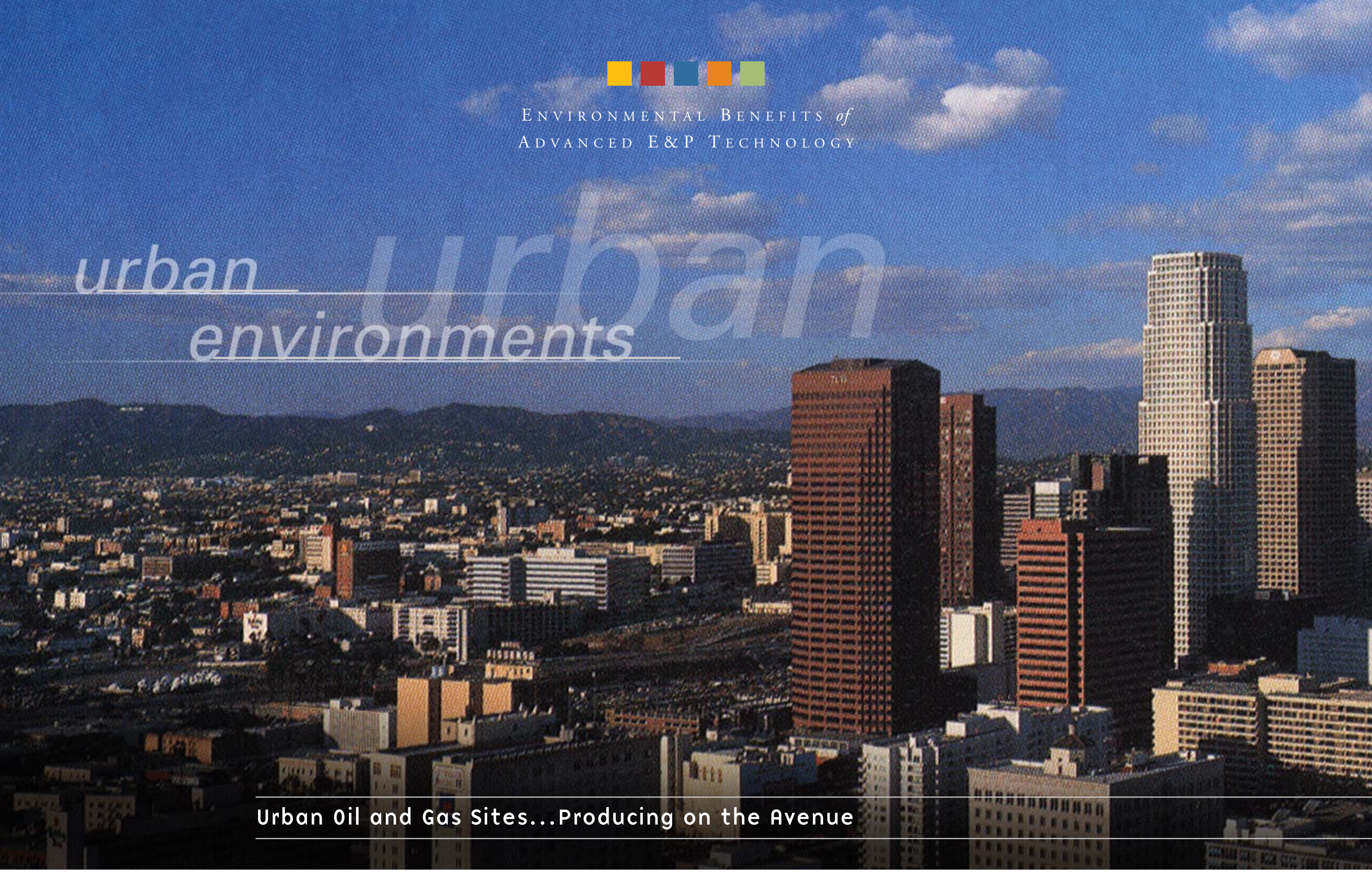
Today's advanced subsea drilling and completion technology also enables the industry to operate effectively and safely as it moves into deeper and more hostile areas. For example, advanced subsea blowout preventers (BOPs) maintain well control in deepwater environments. Current deepwater BOPs, located on the sea floor instead of at the platform level, continuously monitor subsurface and subseabed conditions.

In the event of a well control emergency, advanced "intelligent" subsea trees allow live wells to be shut in quickly under a variety of well conditions and operational circumstances. Moreover, current measurement-while-drilling technology enables drillers to accurately steer a deepwater relief well to regain well control if necessary.

Other recent advances in subsea technology are permitting operators to access more remote deepwater resources with minimal disturbance to the surface and subsea environments. Subsea production systems, aided by new-generation remotely operated vehicles, all-electric subsea monitoring and

control systems, and minimally sized umbilicals, are now able to connect remote subsea satellite wells to host production facilities tens of miles away. For example, Shell Exploration and Production's Mensa subsea production system, located in over 5,000 feet of water in the Gulf of Mexico, produces natural gas from three subsea wells connected to a subsea manifold sitting on the sea floor, which is then tied back to an existing shallow water production platform (West Delta 143) over 60 miles away via a 12-inch carbon steel flowline. At West Delta 143, a computer-based system monitors the operational status of the wells and other subsea equipment, with the capability to open and close the wells if necessary.

On the whole, these technologies are allowing the offshore industry to venture into deeper waters than ever before, while protecting marine life and subsea habitats. As a result of these advances, operators are able to locate and produce more offshore resources, with less drilling, fewer dry holes, less waste, and minimal impact.



urban environments

Urban Oil and Gas Sites...Producing on the Avenue

> "Hundreds of visitors from all around the world visit our islands every year, many of whom come here specifically to learn about this model of oilfield development in a sensitive, urban environment. I haven't met a person yet who doesn't come away impressed."
>
> James M. Davis
> *President of ARCO Long Beach, Inc.*

Diverse images come to mind when one envisions oil and gas exploration and production sites: scorching hot deserts; windblown, tumbleweed-strewn prairies; vast frozen tundra; 20-foot-high waves and churning whitecaps; and distant mountain ranges. But few people realize that the petroleum industry also explores for and produces oil and gas in the midst of our Nation's largest cities. In recent decades, the industry has successfully met the unique challenges posed by these urban environments, where operations are frequently visible for all to see. Advanced technology has been a key to meeting the challenges.

Urban operations are as varied as the cities in which they are located. For example, visitors to Oklahoma City are greeted with the sight of pumpjacks and other production equipment and facilities—Oklahoma City's Will Rogers World Airport is located in the heart of an active oil field. The Los Angeles Downtown oil field, located in the shadow of the Santa Monica Freeway and near the Los Angeles Civic Center, has produced nearly 14 million barrels of oil and 21 billion cubic feet of natural gas over the past 30 years. State-of-the-art fire prevention and gas leak detectors ensure the safety of the surrounding community. In the Southern California beach community of Huntington Beach, oil and gas development occurs both onshore and in State offshore waters. Onshore, production equipment located on the beach operates as runners and bicyclists enjoy a nearby boardwalk. Offshore, extended-reach drilling technology has permitted operators to tap nearshore reserves from onshore deviated wells.

Perhaps the most remarkable story of urban operations today is ARCO Long Beach, Inc.'s 43,000-barrel-per-day operation at the East Wilmington unit, located in the City of Long Beach's scenic harbor. The East Wilmington unit is part of the giant Wilmington field, one of the Nation's largest. Production at East Wilmington occurs from four manmade islands—built on 640,000 tons of boulders and 3.2 million cubic yards of sand dredged from the harbor, and concealed by palm trees, flowers, concrete sculptures, waterfalls, and colorful

nighttime lighting. These islands represent the centerpiece of a collaborative solution between the industry and the City of Long Beach to tap the harbor's resources without harming its natural beauty.

Daily operations at East Wilmington are a testament to advanced technology and its success in protecting the environment. Rather than using relatively noisy and polluting diesel engines for drilling and pumping, operations make use of quiet and clean electric power. To shelter operations from public view, drilling rigs are covered by structures built to resemble high-rise buildings, and wellheads and other support facilities are located below ground.

In recent years, advanced technology has played a critical role in expanding the field's production and maintaining a high level of environmental performance. In 1996, ARCO implemented the largest waterflood in California's history at the field. This oil recovery technique, combined with advanced hydraulic fracturing and horizontal drilling technology, has increased daily oil production by approximately 30 percent. Moreover, ARCO is expecting a recently conducted 3-D seismic survey to further boost production.

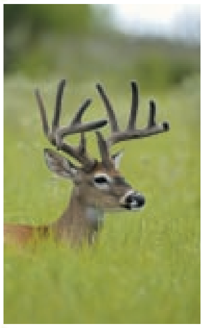
ARCO is now using chemical treatment for final separation of produced water and oil rather than gas-fired heated vessels, reducing air emissions by 60 percent. The thousands of tons of sand and shale removed during operations are now reinjected into a dedicated well on one of the production islands, rather than hauled to a landfill. Moreover, ARCO is currently testing the viability of using treated sewage effluent in its waterflood operations in order to reduce the amount of fresh water currently needed.

Advanced technology has enabled the petroleum industry to increase recovery of oil and gas resources wherever they may occur—including urban environments. As a result, oil and gas development operations are able to coexist, even thrive, in urban surroundings, as operators successfully minimize noise pollution, air emissions, and surface and visual disturbances.

Oilfield development in Long Beach harbor is a model urban operation.

public lands
public benefit

Joint Stewardship Protects Our Public Treasures



Stewardship of public lands requires close collaboration of industry and government.

Many of our Nation's oil and gas resources are located on public lands, over which the Federal government has management and resource protection responsibilities. These public lands range from wildlife refuges to national parks and seashores to the Outer Continental Shelf. Operating in these national treasures entails complex logistical, organizational, and operational challenges. The industry, in collaboration with the Department of the Interior and other Federal and State agencies, has employed a variety of advanced technologies and creative solutions to operate effectively in these areas, thus providing the environmental stewardship necessary.

In the Aransas National Wildlife Refuge on Texas' Gulf Coast, for example, Conoco has worked collaboratively with the U.S. Fish and Wildlife Service, the National Marine Fisheries Service, and the Texas Parks and Wildlife Park for 60 years to ensure that ongoing operations do not harm the refuge's whooping crane population. Once one of the rarest species in North America, the refuge's whooping crane population has increased in number from 15 to approximately 200 over the last half century. Today, Conoco performs seismic and drilling operations only when the cranes are summering in Canada, avoids the marshlands inhabited by cranes, and protects the wolfberry plants on which they feed.

In Alaska's Kenai National Wildlife Refuge, Unocal Alaska won the Department of Interior's "National Health of the Land" award in 1997 for environmental excellence in its Swanson River field operations. Employing advanced pipeline maintenance, leak detection, and water filtration/treatment technologies, Unocal continues to operate successfully in this beautiful, yet fragile, environment.

Chevron USA Production Company's recent exploratory drilling operation at the Hunter Creek site in Lincoln County, Wyoming, further demonstrates advanced

technology's positive impact on industry performance in sensitive public lands. The Hunter Creek site is located in the Bridger-Teton National Forest—approximately 20 miles from Grand Teton National Park and within the Greater Yellowstone Ecosystem—and is home to a wide variety of sensitive wildlife species, from black bears to bighorn sheep to peregrine falcons. Chevron worked closely with the U.S. Forest Service, the Department of the Interior, the Wyoming Fish and Game Department, and other Federal and State agencies to design and conduct operations with minimal impact on the surrounding habitat and wildlife. Although the site's exploratory well was not a commercial success, Chevron's goal of reducing environmental impacts was achieved.

To minimize surface impacts of equipment mobilization on the area's main access road, the Hunter Creek operation became only the second well in the lower-48 States to be drilled utilizing a helicopter to transport the drilling rig and other heavy equipment to and from the site. The drilling pad was designed to blend in with the surrounding meadows and clearings by carefully locating the site, contouring the area cleared of trees, and leaving some of the site's trees intact.

To enhance site restoration activities, Chevron stockpiled snags, boulders, and stumps so that the site could eventually be returned to its natural state.

To manage drilling wastes, a semi-closed-loop solids removal system was employed, minimizing mud volumes and thus enabling smaller reserve pits. To reduce sedimentation impacts from runoff contact with exposed soil near the pad, the drilling location was enclosed by drain canals, drainage ditches, berms, and containment pit, and capped with four inches of gravel. To further manage operations, Chevron implemented surface and groundwater quality protection plans to ensure protection of surrounding creeks and underground water supplies.

These operations demonstrate the petroleum industry's commitment to environmentally responsible operations on our Nation's public lands. By collaborating with the numerous Federal and State agencies with stewardship responsibilities over these valued areas, the oil and gas industry is today fulfilling its role as protectors of the environment—and advanced technology is playing a large part in this success.

Beyond the Oil Patch

Research and demonstrations of the restoration of sensitive environments have advanced the state of knowledge and understanding of a wide variety of sensitive ecosystems.