

Houston Business

A Perspective on the Houston Economy

Technology and Productivity In the Oil Field

This article examines two of the major technologies that have been instrumental in reducing finding costs over the past 15 years: horizontal drilling and three-dimensional seismology.

The last issue of *Houston Business* looked at recent increases in the cost of oil exploration and extraction, many due to labor and equipment shortages resulting from the current surge in drilling activity. The bottom line in that article was that technology and new management methods have raised the amount of labor and other resources required per well or per foot drilled. Figure 1, for example, shows the increase in real capital expenditures per foot drilled by major oil companies, a measure of the value of resources applied to drilling divided by total footage. Between 1988 and 1996, these costs rose 13.1 percent, and they will probably rise sharply again in 1997.

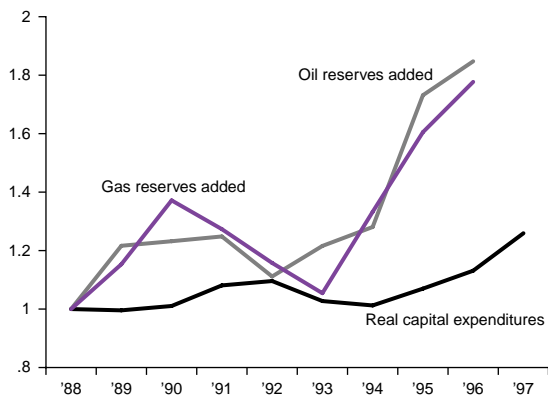
However, the last issue of *Houston Business* also showed the trend in the cost of finding and developing reserves has been opposite that of cost per foot drilled, falling steadily since 1987. This presents an apparent paradox: How can we reconcile rising expenditures with declining finding cost? The answer is higher industry productivity, partly through the application of new technologies that bring a higher probability of finding and successfully developing reserves of oil and natural gas. Consider the following formula:

$$\text{Finding costs} = \frac{\text{Real capital expenditures per foot drilled}}{\text{Reserve additions per foot drilled}}$$

Figure 1 shows the denominator of this formula—reserve additions per foot drilled for oil and natural gas—rising faster than real capital expenditures. These reserve additions are the product of new technology that requires more labor, higher skill levels and increasingly sophisticated equipment. The higher costs incurred, however, are more than

Figure 1
Capital Expenditures and Reserve Additions per Foot Drilled

Index: 1988 = 1



NOTE: All three lines in the figure have been smoothed using a three-year moving average.

offset by the volume of new reserves found.

This article examines two of the major technologies that have been instrumental in reducing finding costs over the past 15 years: horizontal drilling and three-dimensional seismology. This is a brief, layman's description of how these tools work and how they have made a difference in finding oil and natural gas in the United States.

DRILLING SIDWAYS

Horizontal wells are typically begun by drilling a vertical section of well above the target zone, usually with a conventional drill string. The well bore then bears off on an arc to intersect the reservoir at a desired entry point, where it continues through the reservoir horizontally. If the arc section of the well is long enough, it can be drilled conventionally, using the flexibility in the drill string to arc without structural failure of the pipes. New and thinner pipe is now available, using more ductile alloys that arc at a reduced angle to reach the horizontal position more quickly. Possibly during the process of drilling the arc, but certainly by the time the well is horizontal, a downhole motor takes over the work of the drill string. The drill pipe is held rotationally stable while the motor drills sideways.

The purpose of horizontal drilling is to expose more reservoir rock to the well bore than does a conventional well. If you think of a typical reservoir as a long, thin lens, with its longer axis lying parallel to the earth's surface, a conventional vertical well passes only through

the thin part of the lens and exposes only a few feet of well bore to the producing zone. By entering sideways, however, hundreds or thousands of feet of well bore can be drilled into the reservoir.

Horizontal wells provide greater production per well, the reservoir is drained faster, and fewer wells are needed to drain a given reservoir. Oil wells drilled in North Dakota's Bakken formation and Texas' Austin Chalk formation show daily production rates three to five times those of conventional wells. A study of 91 successful oil wells in the Austin Chalk found they drained three-fourths of the economically recoverable oil and gas reserves in only three years, and the wells paid for themselves in just over one year. Originally targeted to oil, 34 percent of horizontal wells were directed to natural gas by 1995, with gas wells showing similar rapid depletion and quick cost recovery.

Drilling sideways incurs higher costs, with a typical horizontal well running up a bill twice that of a conventional well. The difference in the cost per foot drilled in 1995 was 25 percent (\$106 horizontal versus \$85 vertical); however, the typical horizontal well was drilled 11,091 feet versus 5,536 feet for a conventional well. Natural gas wells are typically more expensive per foot than oil wells and entail more footage.

We cannot point to any single achievement as the breakthrough for this technology. The application for a patent to drill sideways with flexible shafts was made by a dentist in 1891, but the application also recognized the potential for several industrial uses beyond the dental chair. The first commercial oil exploration using the technique was in Europe in the 1980s, and the first production applications were in Alaska shortly afterward. The technology matured in the Austin Chalk of Texas, where two-thirds of all U.S. horizontal footage was being drilled as recently as 1995.

THREE-DIMENSIONAL SEISMOLOGY

Reflection seismology measures the arrival times and other properties of reflected seismic waves to determine the geologic structure and rock properties of the subsurface. Sound waves are generated at the surface, perhaps by dynamite on land or air guns at sea, and recorded by surface receivers as the sound waves are partly reflected back to the surface.

ASSOCIATED TECHNOLOGIES

Horizontal drilling and three-dimensional seismology have been central to recent gains in oil and gas extraction industry productivity. Other associated and parallel technologies abound, however. Here are a few quick examples:

Coiled Tubing - A continuous length of pipe wrapped around a large reel that, when straightened off the reel, functions like flexible drill pipe. Long used in workover wells, coiled tubing has found new prominence in horizontal drilling, where it can be inserted into horizontal wells to guide tools and cables, manipulate flow controls, or accurately place cement or acid treatments.

Measurement While Drilling - A package of instruments that accompanies the horizontal drilling system underground and continuously relays to the surface information such as position, direction, temperature and torque. Fire-and-forget drilling systems allow onboard or above-ground computers to make steering decisions for the motor without human intervention.

Slimhole Drilling - Drilling, completion and production conducted within the limits of smaller boreholes. Instruments and tools that work in smaller diameters save steel casing, drill pipe, drill bits, mud chemicals and cement.

Four-Dimensional Seismology - A series of three-dimensional seismic surveys taken in a single producing field over time. This technology allows a better understanding of potential production problems, such as water encroachment, and enhances long-term recovery.

NOTE: For more detail on these other technologies, read three papers by Robert Haar that appeared in the December 1992, April 1993 and December 1996 issues of *Natural Gas Monthly*, published by the Department of Energy.

Before 1980, most seismic information was generated in two dimensions. The data were collected on a line across the earth's surface, revealing information on a cross-section of the earth below the line. A pseudo three-dimensional map could then be created by combining several parallel two-dimensional surveys with enough perpendicular data to allow some cross-correlation between the surveys.

A three-dimensional survey, in contrast, provides information on a volume beneath the earth's surface. Processing and interpretation can yield exactly the same cross-sectional information as its two-dimensional cousin, but, unlike two-dimensional seismic, the cross-section can be taken in any dimension. So-called "time slices," for example, allow geologists to trace ancient rivers, sandbars or other surface features associated with a particular geologic

period. The high resolution of three-dimensional seismic is ideal for outlining structural features such as faults or to sort out complex formations.

Field development is the most common application of three-dimensional seismic. The survey is limited to the vicinity of the reservoir and used to delineate the boundary of an initial discovery. The relatively high cost of three-dimensional seismology—five to six times more expensive than two-dimensional on land, two to three times more at sea—prevents it from being used routinely for exploration. However, companies engaged in expensive or risky exploration, such as offshore or in deep formations, may commonly use this technology.

Three-dimensional seismic was first used by Gulf Research and Development in the 1970s. Its advance as a technology has come mostly as a product of rapid advances in parallel technologies. Satellite positioning, for example, has facilitated and reduced the surveys' cost. Advanced computational power has increased the sophistication of the algorithms used for processing, while the cost of this computer horsepower has fallen. Maybe most important has been the development of the interactive workstation, which allows repeated interaction between the analyst and a complicated data set.

CONCLUSION

The consequences of new technology on resource development have been dramatic. As recently as 1992, oil and gas producers had written off the Gulf of Mexico as the "Dead Sea"—a producing area that would never again attract exploration. The Gulf is now one of the hottest exploration areas in the world, and technology is largely responsible for its return to life.

One recent study estimated that between 1991 and 1995, new drilling technologies added 4.8 billion barrels of commercial reserves to the North Sea alone. The combined value to the oil industry, governments and suppliers was \$30 billion to \$40 billion. Sixty percent of the gain came from new discoveries and 40 percent from discoveries previously considered noncommercial.

— Robert W. Gilmer
Timothy K. Hopper

Houston continues to show signs of robust economic health. The city's best job growth since 1990 has generated great statistics for retail sales, housing and auto sales, absorption of office space, and new construction of apartments and single-family homes. The Houston purchasing managers index, a measure of manufacturing activity, moved back over 60 in November. An index value over 50 indicates an expanding sector, and the index has been 57.8 or better for the last year.

RETAIL SALES

Retailers report the best sales activity in many years. Following a seasonal lull, business is improving daily as the holidays approach. This year's early cold snap meant a quick pickup in clothing sales, but this just added to sales figures already at double-digit levels over last year. The outlook for holiday spending is excellent.

OIL SERVICES AND MACHINERY

High energy prices continue to provide the backdrop for activity in the oil fields. Oil prices were between \$20 and \$22 per barrel for much of October, a premium over fundamentals as Iraq continued its confrontation with the United Nations. Fear of a supply disruption, not a cutoff of Iraq's limited production, provided the motive for higher prices. Natural gas prices were over \$3 per thousand cubic feet through October, pushed up by strong economic growth, unseasonable weather, utility purchases due to delayed coal deliveries by the railroads, and gas production running slightly below last year's level.

The rig count has remained near 1,000, and capacity constraints continue throughout the industry. Shortages of pipe, casing and basic equipment are widespread, but engineering and craft skills remain the biggest impediment to expanded production.

CHEMICALS AND REFINING

Petrochemical demand remains strong and production at high levels. Third-quarter profits were strong because prices held up

better than expected and because high production levels reduced unit costs. There has been recent price erosion in a number of plastic products, especially those downstream from ethylene, and more declines are expected. Respondents expressed concern about slower growth and the potential loss of Asian markets. However, the currency crisis may have positive long-term benefits for American producers, as currency bailouts will require austerity and cuts in capital-intensive projects such as petrochemical plants.

Refining margins fell hard from the high levels of this summer. This is partly a seasonal decline, but it has been exaggerated by the high inventories of heating oil built up as a by-product of record levels of gasoline production this summer.

REAL ESTATE

The Houston office market made big strides in the third quarter, with 3.5 million square feet of space absorbed—more than in all of 1996. Continental Airlines' decision to lease 600,000 square feet downtown meant a sudden turn for the better in what had been a badly lagging market. Throughout the city, office rents are rising, with sticker shock reportedly hitting a number of tenants. The market psychology has shifted in favor of the landlord, making it difficult for tenants to negotiate a better deal in the building down the street. Also, tenants holding surplus space are less likely to return it to the landlord or to sublet, and in some cases they are leasing in anticipation of future needs.

New home sales in Houston were up 40 percent in October, compared with the same month last year, while housing starts were up 65 percent and traffic through model homes was up 77 percent. Existing home sales were similarly hot, up 26 percent above last October—and this despite an inventory of available listings that has dipped to the lowest levels in 15 years. New and existing home prices are rising in a seller's market. Even the market for homes priced above \$500,000 is hot, after several lackluster years.

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