

TOPIC PAPER #26

OIL AND GAS TECHNOLOGY DEVELOPMENT

On July 18, 2007, The National Petroleum Council (NPC) in approving its report, *Facing the Hard Truths about Energy*, also approved the making available of certain materials used in the study process, including detailed, specific subject matter papers prepared or used by the Task Groups and their Subgroups. These Topic Papers were working documents that were part of the analyses that led to development of the summary results presented in the report's Executive Summary and Chapters.

These Topic Papers represent the views and conclusions of the authors. The National Petroleum Council has not endorsed or approved the statements and conclusions contained in these documents but approved the publication of these materials as part of the study process.

The NPC believes that these papers will be of interest to the readers of the report and will help them better understand the results. These materials are being made available in the interest of transparency.

The attached Topic Paper is one of 38 such working document used in the study analyses. Also included is a roster of the Subgroup that developed or submitted this paper. Appendix E of the final NPC report provides a complete list of the 38 Topic Papers and an abstract for each. The printed final report volume contains a CD that includes pdf files of all papers. These papers also can be viewed and downloaded from the report section of the NPC website (www.npc.org).

**NATIONAL PETROLEUM COUNCIL
OIL AND GAS TECHNOLOGY DEVELOPMENT SUBGROUP
OF THE
TECHNOLOGY TASK GROUP
OF THE
NPC COMMITTEE ON GLOBAL OIL AND GAS**

TEAM LEADER

W. Howard Neal
Adjunct Associate Professor
The University of Texas

MEMBERS

Matthew R. G. Bell*
Senior Investment Manager
Shell Technology Ventures

Christine A. Hansen
Executive Director
Interstate Oil and Gas
Compact Commission

Robert W. Siegfried, II
Manager, Research & Development
Gas Technology Institute

* Individual has since changed organizations but was employed by the specified company while participating on the study.

Technology Development and Deployment

Team leader: Howard Neal

Date submitted: November 22, 2006

I. Executive Summary

This report examines the lessons of history and current trends in oil and gas technology development and deployment to make predictions for the coming years. Since the beginning of the modern age of oil and gas, technology has played a fundamental role in supporting the efficient production of hydrocarbons. Oil and gas technologies are often destined for hostile, hard-to-reach environments such as deep offshore waters or in the high temperature and pressure encountered at the bottom of a well. Full-scale tests must be completed before a technology can be proved and the market will accept it. As a result, commercializing technology in the oil and gas market is costly and time intensive; with an average of 16 years from concept to widespread commercial adoption.

The sources of technology destined for the oil and gas markets have changed over time. Starting in the early 1980s, major oil and gas companies began to decrease their research and development (R&D) spending, driven in large part by a decision to “buy versus build” new technology. Independent oil and gas companies have historically spent little on R&D. Service companies have stepped in to partially fill the void by increasing their R&D spending. There is little doubt that new technologies will be invented and applied in the coming years to the global quest to maximize the production from oil and gas reservoirs. Given today’s R&D spending trends, these technologies must largely come from service and startup companies.

One area of risk is the availability of sufficient R&D funds from service company and entrepreneurial sources to create the needed new technologies for oil

and gas. Recently, major operators have become increasingly risk-averse as new projects have become more costly, less economical, and technically more challenging. They may consider the application of new technology to be a riskier proposition than keeping existing proven approaches. The technical innovator may be forced to offer discounts to encourage oil and gas companies to try a new approach. Consequently, there is downward pressure on prices as discounts are applied to get early sales. Thus the innovator must rely on capturing new or increased market share—as a result of introducing the new technology—to deliver a return on research and development expenditures.

The major oil and gas companies are increasingly turning their attention to overseas development opportunities, leaving U.S. production largely in the hands of independent oil and gas companies. In a worldwide marketplace, the service companies continue to respond to the needs of their worldwide customer base.

Being one of the most mature oil and gas producing countries, the USA has specific needs compared with much of the rest of the world. If U.S. production levels are to be maintained, new technologies will be needed. As a result, unless the technology needs of the U.S. oil and gas business align with the needs of the rest of the world, there is a danger that U.S. interests may not be addressed adequately. This represents a need that U.S. Government policy should address. This report outlines ten recommendations for action to improve the creation and deployment of oil- and gas-related technologies to maintain U.S. production.

II. Overview of Methodology

This report is based on a survey of available data on current trends in research and development spending for oil and gas, as well as other industries. As in other studies, this group has assumed a direct correlation between the creation and deployment of new technologies and the research and development spending directed at creating those technologies. This report also includes observations by the members of this subgroup on the state of research and development in the oil and gas industry.

This group also reviewed reports and studies to derive conclusions on the time needed to develop and deploy new technologies. This is important to the National Petroleum Council (NPC) study because it is clear that technologies in the research stage today will take a number of years to be fully developed and go into widespread commercial use.

The Technology Development and Deployment Team consists of the following members:

Participant	Title and Organization
Matthew Bell	Senior Investment Manager, Shell Technology Ventures
Christine Hansen	Executive Director, Interstate Oil and Gas Compact Commission
Howard Neal, P.E.	Schlumberger (retired), Former Adjunct Associate Professor, UT Austin
Robert W. Siegfried, II	R&D Manager, Gas Technology Institute

III. Background

A. Historical Impact of Technology on the Oil and Gas Industry

Technological innovation in the oil patch began with Edwin L. Drake. A *New York Times* correspondent reported from Titusville, Pennsylvania, on September 8, 1859, that drilling down to 71 feet, Drake “to the surprise and joy of everyone found he had tapped a vein of water and oil, yielding 400 gallons of pure oil every 24 hours.” Although the discovery was important to the US, Drake’s more significant contribution was developing the technology to separate the oil and water.

Innovation through technology and science has been a major force in this industry since that first breakthrough. Drake did not “discover” oil. It had been used for thousands of years by native peoples around the world, primarily as a medicine. What Drake developed was a method for producing large quantities of oil. Technology has continued to develop in pursuit of larger quantities of petroleum from increasingly complex geologic structures.

Drilling technology has progressed from 71 feet to many miles below the surface—horizontally as well as vertically. Technology has coaxed more resource from the tight grip of rocks where just a decade ago that grasp could not be broken.

Petroleum science has evolved from rudimentary geology to elaborate super-computer-based calculations and 3D views of the subsurface. It has taken the drilling process from a “let’s try over there” guessing game to the precise targeting of ever-smaller pockets of fields that have already produced for half a century, as well as areas that have produced nothing before.

The 21st century natural gas and oil industry is supercharged by innovation and technology. It has dramatically altered the manner in which oil and gas reserves are identified, developed, and produced. Advancements in technology have also improved environmental protection and conservation of natural resources.

B. Motivation to Develop New Technology for the Industry

Since the beginning years of petroleum production, the key to increasing recoverable reserves has been research and development (R&D). Many breakthroughs and thousands of incremental advances in exploration and production have increased oil recovery levels from less than 10 percent (of the initial volume in place) to in excess of 70 percent, in some cases.

Companies are motivated to invest in R&D by basic economics. Service companies want to sell a better service than any other company, thus increasing their market share. They also invest in technology to develop patents, later turned into products or licensing possibilities that will return a stream of revenue for years.

Large independents and multinational petroleum companies also invest in R&D. Their motivation is also primarily economic, but is focused on the near-term reward of increased shareholder value while maintaining long-term sustainability through reserves replacement. This requires some investment in unconventional resources that have the potential to add significantly to the resource base.

Company investment in training new scientists through university grants and individual fellowships also enables basic research. This investment is not always categorized as R&D, yet it is immensely important in creating the next generation of petroleum scientists, engineers, and geologists.

A strong domestic energy policy demands a robust R&D component. It is important for federal and state governments to support natural gas and oil research, and to help train that next generation of scientists, engineers, and geologists. Governments, as the largest holder of domestic oil and gas resources, should be highly motivated to invest in R&D. In addition to direct royalties on their resources, state and local governments also benefit significantly from a variety of production and property taxes, and the local economic benefit created by support industries associated with oil and gas activities.

Effective government policy would ensure that domestic resources are not abandoned and would encourage the environmentally sound production of energy that touches every citizen in every state.

C. Motivation for Companies to Adopt New Technology

On some levels, adopting new technology can be viewed as an economic risk. The cost may be higher and the result less certain than existing technology. However, the payoff from a new technology can be huge, both for the individual company and for national energy security.

It is widely accepted within the oil and gas industry that technology has reduced the risk of exploration and cut the time required to drill a well. Those advantages alone are critical factors in the decision to adopt technology. At the national level, a primary benefit of new technology has been the conservation of natural resources by increasing the percentages of oil and gas recovered from existing reservoirs. Such fuller resource development is in turn an economic motivator because it translates into increased revenue for all involved (i.e. company owners, royalty owners, and taxing governments).

Some technology has reduced costs through smaller crew requirements and improved safety. Some has created better relations with surface owners, an important improvement, though difficult to quantify.

Although some new technologies initially require steeper investments, they result in faster, more effective resource recovery and a net economic gain for the company. An example is the Jonah Field in Wyoming, where multiple horizontal wells from a single platform coupled with multiple completions have increased production while minimizing the environmental impact. In other cases, the resource itself drives technology. The Barnett Shale development in Texas is one example. New technology first made the extraction of natural gas from that shale possible, which attracted more research dollars to better understand the resource and extract even more natural gas.

In some instances, the development of technology is motivated by government policy or social pressures. State regulators have stimulated technology development through such dramatic requirements as requiring blowout preventers and limiting the venting and flaring of associated natural gas.

As yet unquantified resources, such as U.S. unconventional resources, have historically not attracted much technology investment, though a number of relevant operators may now be open to investing in new technology for such plays. Many

domestic operators, like small family farmers, simply lack the economic clout to invest individually in R&D. This also identifies a role for government.

D. Changing Realities of the Oil and Gas Business

Technology development shifts to accommodate the ever-changing realities of the oil and gas industry. Much of the industry has become intensely driven by information technology, and both enhanced recovery and unconventional resources have moved from a subtext of domestic development to major plays.

Research targeting unconventional and enhanced recovery can take years to develop, creating a barrier to companies that need to demonstrate quarterly results to stockholders. Thus, research dollars can be driven away from such longer-term projects to those that yield more immediate results.

The pressure to shift investment towards unconventional resources will continue to intensify as conventional resources diminish. However, this does not lessen the critical importance of conventional exploration and production.

The continued importance of wells with low production, practically unique to the US, must be noted. There are more than 400,000 oil wells producing less than 10 barrels a day (an average national production of 2.2 barrels), and about 289,000 marginal natural gas wells producing less than 60 Mcf a day in the USA (an average of 16.7 Mcf per well). That is 17 percent of the oil and 9 percent of natural gas produced onshore in the USA.¹

Research is key to the survival of these marginal wells. Unfortunately, the small, independent producers who operate these wells rarely have the ability to conduct research, even though R&D might keep them producing for many more years.

¹ Interstate Oil and Gas Compact Commission: "Marginal Wells: Fuel for Economic Growth" (2006).

IV. Technology Development and Deployment Cycle

The creation and evolution of technology for the oil and gas industry follows the traditional path from fundamental research to the manufacture and supply of a finished product. However, associated with each of the steps along the way are issues particular to oil and gas that influence—and to some degree restrict—the flow of ideas from drawing board to commercial reality.

An INTEK study, undertaken for the Office of Oil and Natural Gas, divides research and development expenditures into two parts—“Actual Research” and “Non-Research”—and further segments those categories as shown in Figure IV.1.²

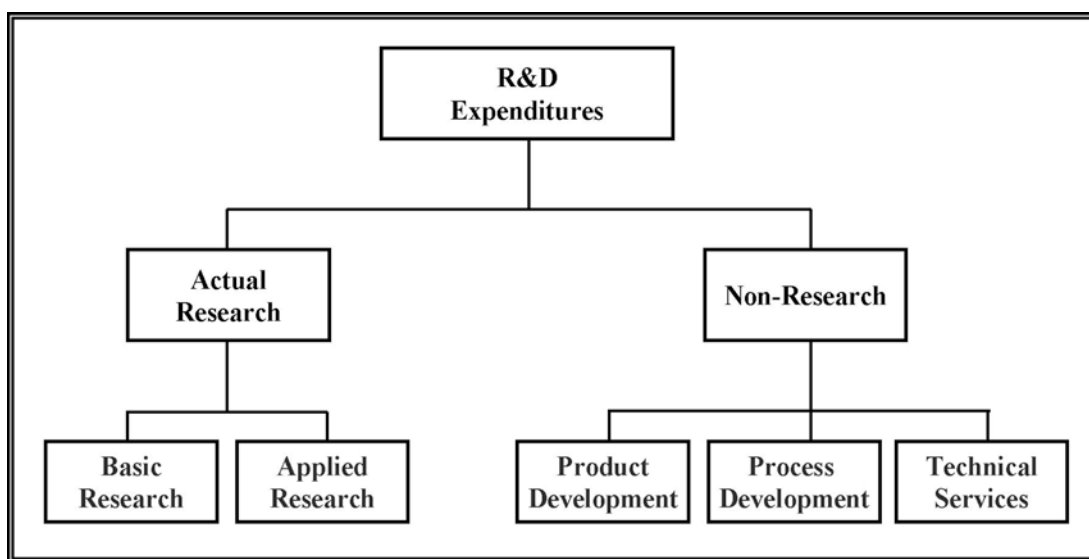


Figure IV.1. INTEK division of R&D expenditures
[reference 2].

² INTEK: “Trends in Oil and Gas Industry R&D Expenditures (2004),” presentation prepared for Office of Oil and Natural Gas, United States Department of Energy, Arlington, VA (2004).

A. Fundamental Research

Also commonly referred to as "basic research," fundamental research is defined by the National Science Foundation as research that advances scientific knowledge but does not have specific immediate commercial objectives, although it may be in fields of present or potential commercial interest.

For most organizations associated with the exploitation of oil and gas, this translates into research that does not yield intellectual property; that is, cannot be patented or usefully held as a trade secret.

While a number of both operating and service companies engage in a limited amount of "blue sky" research, work in this area is almost entirely reserved for academia, national laboratories, and other government-funded institutions. Results are generally published—often in the form of theses, papers, and dissertations—and therefore serve to expand the body of knowledge available to industry.

B. Applied Research

Typically building on the discoveries emerging from fundamental research efforts, applied research involves new scientific knowledge that has potential specific commercial objectives or advantages with respect to products, processes, or services.

The results of applied research will almost always be captured as intellectual property, either through the filing of patents or by withholding the knowledge from the industry at large as a trade secret. Therefore, the benefits of applied research generally accrue to the investigating party and do not benefit the industry at large until some period of exclusivity has elapsed.

C. Proof of Concept

Once an idea has been generated, experimental work—often involving the fabrication and evaluation of prototypes—must be carried out to confirm its technical viability. This stage may also be referred to as "reduction to practice."

Since oil and gas technologies are often destined for hostile, hard-to-reach environments, such as deep offshore waters or the bottom of a well, experiments must be

devised in the workshop or laboratory to replicate anticipated operating conditions. This can be a costly and complex task, especially when high pressure, high temperature, and volatile hydrocarbons must be safely combined. Testing a scaled-down version of the proposed solution can often mitigate some of the difficulty associated with full-scale representative testing and bring the costs within reach of self-funded entrepreneurs. Nevertheless, full-scale tests must be completed before the market will accept the new product.

Proof of concept is typically the stage at which external funding becomes more readily available since investors are generally more comfortable taking on market risk than technology risk.

D. Field Testing and First Sales

Even though a full-scale, fully functional prototype may have been demonstrated during the proof-of-concept phase, oil and gas companies are generally reluctant to embrace a new technology until it can show some track record of success. Lead implementers are needed to deploy and operate early production units so that any “teething troubles” can be worked out and the benefits of the new technology demonstrated under typical operating conditions.

While many companies claim to be “technology leaders,” lead implementers are often extremely difficult to find, even for established technology and service providers. An insufficient number of early deployments delays the technology maturation process, slows industry learning, and consequently stifles the flow of new products into the market. Many technically robust solutions are abandoned before they reach their commercial potential because of insufficient early uptake and the protracted payback period this creates.

Having proven the field-worthiness of a new product, the manufacturer naturally expects some degree of value pricing; that is, the ability to sell the product at a price that generates above-average profit margins in view of its unique benefits. However, the oil and gas industry typically fails to reward innovators in this manner. The consumer base—typically the operating companies—considers the application of new technology to be a

riskier proposition than sticking to proven solutions. Consequently, there is downward pressure on prices as discounts are applied to get early sales. Thus, the innovator must rely on capturing new or increased market share—as a result of introducing the new technology—to deliver a return on research and development expenditures.

E. Market Penetration

Even though several early adopters may have accepted a new technology, the path to ubiquity—or even a modest market share—is not certain. Operating companies are generally reluctant to accept new technology based on each other’s tests and experiences. Each will prefer to conduct its own trials before embarking on large-scale adoption. Meanwhile, because the time from field trial to commercial success is so protracted, competitors have had ample time to evaluate and “reverse engineer” the new product. Another brake on market penetration is the global nature of the oil and gas business. While technologies evolving within an established multinational service provider can simply be added to its catalogue and supplied on a global basis, those technologies originating in small-scale and start-up enterprises must somehow make the leap from local to global marketplace.

It is generally not viable for a small company to evolve from local to international supplier through organic growth; the rate of penetration is too slow, set-up costs erode return on investment, and competitors with international presence overtake the venture. Therefore, technology developed by a small company typically reaches the global market via licensing, sale of rights, or by the company being merged with—or acquired by—a larger organization.

F. Time to Market—From Idea to Commercial Success

Return on research and development investments is only achieved once the resulting idea(s) have been transformed into commercial products, purchased, and applied. The longer the time from concept to sales and application, the greater the financial commitment becomes to sustain the project or company.

The oil and gas industry exhibits time-to-market characteristics that are consistent with other heavy industries, such as mining, steel production, and power generation. Whereas consumer goods might progress from drawing board to store shelves in less than two years, oilfield technologies consistently require 15 to 20 years to complete the same maturation cycle. While this is advantageous to the producers of established technologies—the competition isn’t exactly rushing in to displace their cash cows—it makes the sector unattractive to investors and limits the industry’s ability to react to changing environments and to enter new domains.

Figure IVF.1 shows data gathered by McKinsey and Company comparing time-to-market values for the consumer products, medical, telecommunications, and oil field sectors. Fifteen oil and gas exploration and production technologies were studied, yielding an average proof-of-concept to widespread commercial sales time of about 16 years.

The McKinsey study was commissioned by Shell to evaluate to what degree its efforts to expedite the introduction of expandable tubular technology had been successful. The study found that several tens of millions of dollars of internal investment had indeed helped shorten the time to market by more than 50 percent.³

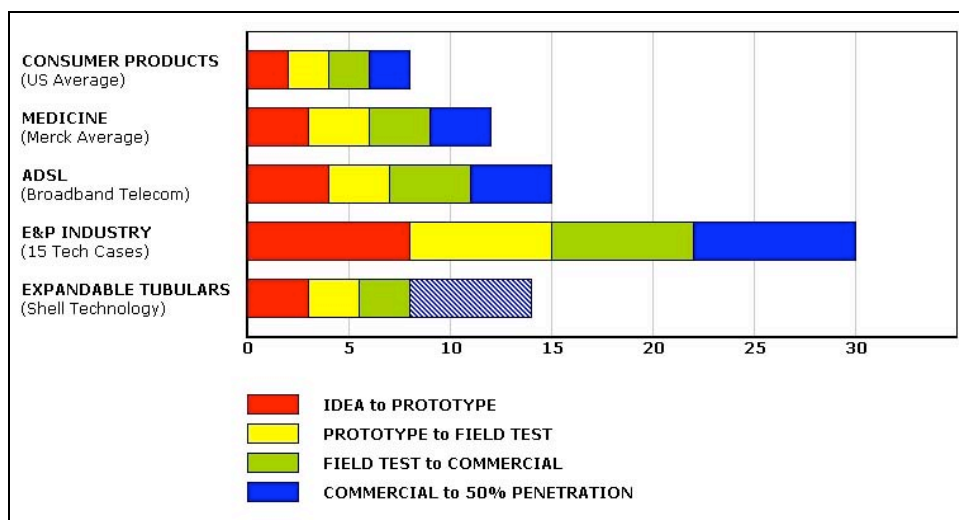


Figure IVF.1. Time to market in years for various industries
(Courtesy of Shell, originally prepared by McKinsey)

³ McKinsey and Company: Internal report prepared for Shell Oil Company (2001).

G. Case Study: 3D Seismic

The introduction and commercialization of 3D seismic presents an opportunity to expand upon the time-to-market findings of the McKinsey Study. This technology represents one of the more important technology introductions over the past decades in that it has allowed oil and gas companies to dramatically improve their oil and gas finding rates.

Using the propagation of sound waves deep into the earth as a means of locating hydrocarbon traps is an old idea. As early as 1924, seismic analysis was used to locate oil beneath a salt dome in Brazoria County, Texas. By the 1960s, the advent of portable acquisition instrumentation based on transistors and the arrival of cheaper and more powerful computers opened the door for what many call the third revolution in seismic-based exploration. This third revolution, called 3D seismic, was not a new concept, but was not feasible without the maturation of the needed underlying technologies.⁴ In 3D seismic, data are acquired in closely-spaced lines called in-lines. After processing, the reflecting surfaces deep in the earth are placed in their proper vertical and horizontal positions, and highly detailed maps of the subsurface may be produced. 3D seismic approaches produce much more detailed information than were previously possible and have been revolutionary in the oil and gas exploration arena.

The first 3D seismic survey was taken by Exxon in 1967, and subsequent field projects in the early 1970s confirmed the efficacy of this approach.⁵ Early surveys were expensive to acquire and process, but as the industry gained familiarity with the needed technologies, then costs and processing and interpretation times for 3D seismic came down. By the early 1980s, trade journals had a number of articles confirming the 3D seismic approach, but it still took many years for the oil and gas industry to fully embrace this new approach.

⁴ "Seismic Technology", Society of Petroleum Engineers. Available at http://www.spe.org/spe/jsp/basic/0,,1104_1714_1004089,00.html.

⁵ Schneider W: "3-D Seismic: A historical note," *The Leading Edge* (March, 1998): 375.

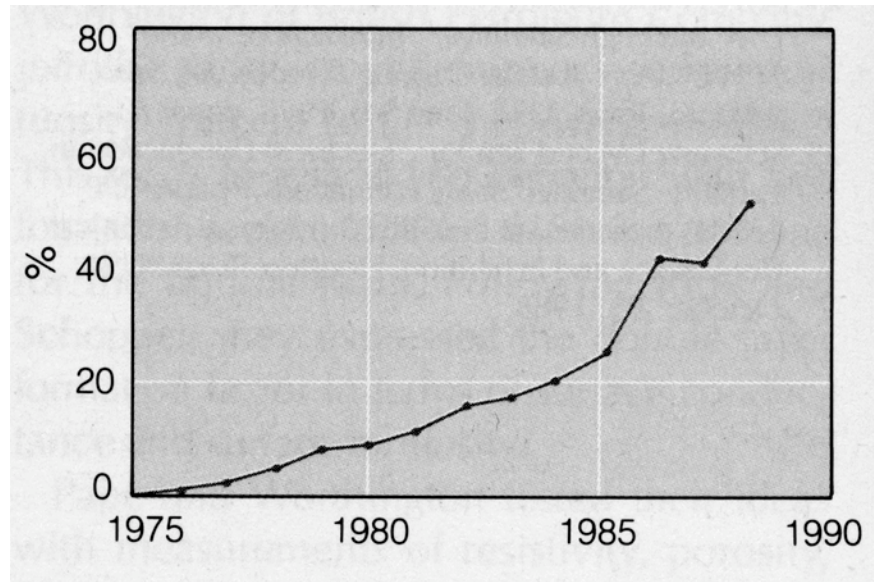


Figure IVG.1. 3D seismic surveys as a percentage of total seismic surveys for the Gulf of Mexico and the North Sea.⁶

Figure IVG.1 demonstrates the take-up for 3D seismic for two important exploration areas: the Gulf of Mexico and the North Sea. As shown in the figure, 3D seismic reached 50% of the market in roughly 1988. This was roughly 21 years after the first 3D seismic survey and represents the time required to refine the technology, reduce costs and overcome industry reluctance to adopt this new technology.

H. Case Study: Horizontal Drilling

A second time-to-market example is that of horizontal drilling. Horizontal wells are designed to increase the production and reduce the drilling and completion cost of a well by offering greater contact with the productive layer of a reservoir. A horizontal well is commonly defined as a well in which the lower part of a borehole parallels the pay zone. A horizontal well typically costs 25 to 300 percent more than a vertical well, but offers the potential of dramatically higher production compared to a vertical well. Besides the

⁶ Hansen T, Kingston J, Kjellesvik S, Lane G, l'Anson K, Naylor R and Walker C: "3-D Seismic Surveys," *Oilfield Review* 1, no. 3 (October 1989): 54–61.

promise of higher production volumes, horizontal wells can have a smaller environmental footprint, including the fact that a reservoir can be developed with fewer wells.⁷

Some of the earliest development of horizontal drilling took place in the 1940s in California, but true development and deployment of horizontal drilling began in the USA in the mid-1970s. Many technical issues needed to be overcome, including the drilling methods themselves, new ways to log horizontal wells, and new completion techniques. One of the key technical innovations supporting horizontal, or directional drilling, came in the 1980s with the introduction of a downhole steerable motor that could be controlled from the surface. A second major breakthrough was MWD, or measurements-while-drilling, that provided position, temperature, pressure, and porosity data while the borehole was being drilled. The higher cost, as well as higher risk, of horizontal drilling remained a deterrent to many companies. However, with time, acceptance of horizontal drilling methods increased as more and more success stories were demonstrated. From 1,000 horizontal wells drilled in 1990, the number rose to 20,000 in 2000.⁸

The decades-long adoption of horizontal wells is a classic example of the adoption of a new technology as costs come down, technology improves, and risks are better understood and managed.

V. Historical Perspectives and Current Trends

A. *Historical Sources of Technology*

Upstream oil and gas technologies have originated from many sources, including oil and gas operating companies, service companies, national and government-sponsored laboratories, universities, and small entrepreneurial firms. Figure VA.1 shows spending

⁷ “Drilling Sideways —A Review of Horizontal Well Technology and Its Domestic Application,” U.S. Department of Energy Technical Report, DOE/EIA-TR-0565 (April 1993).

⁸ Pratt S: “A Fresh Angle on Oil Drilling,” *GeoTimes* (March 2004).

on oil and gas related research by major U.S. oil and gas companies.⁹ Traditionally, oil and gas companies develop a technology to the point of demonstrating feasibility and then turn to other companies to manufacture the technology or provide it as a service. This company R&D spending reached a peak in the early 1980s, followed by a decline consistent with a shift in strategy by many oil and gas companies to buy rather than develop technology. This “buy versus build” strategy resulted in a significant reduction in the number of skilled people within operating companies who understood technology development and deployment, which has subsequently proven to be a barrier to the rapid introduction of technologies. Without the right people to evaluate a new technology, oil and gas companies often take a wait-and-see attitude, preferring to let other companies try technologies first. After more than a decade of decline, recent data indicate that oil and gas companies are beginning to spend more on R&D.

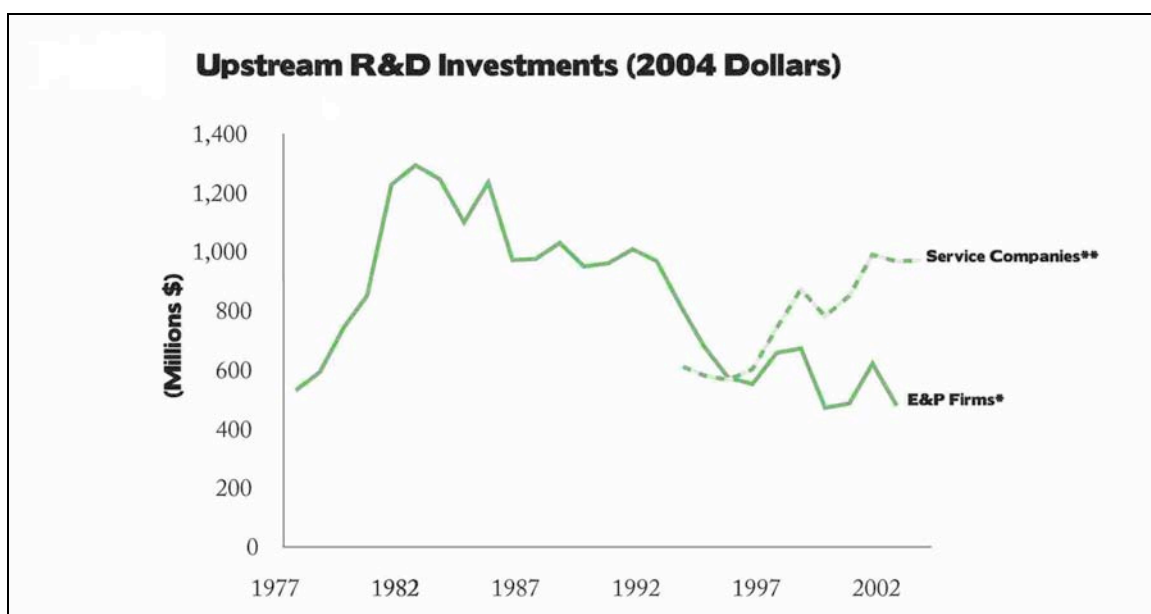


Figure VA.1 Upstream R&D investments over time
 [Lawson, 2006, reference 4]. (Used with permission from the IOGCC.)

Today, service companies are the major source of technology development in the oil and gas arena. Service company R&D spending, shown in Figure VA.2, has increased steadily over the past 5 years, and recent company announcements indicate that spending

⁹ Lawson WF: “Who Will Fund America’s Energy Future?” Interstate Oil and Gas Compact Commission report (2006).

is likely to increase rapidly in the coming years.¹⁰

In addition, service companies often acquire startup companies early in the deployment phase of a new product or service. Such startup companies are the source of many innovations in the industry. As an example, Figure VA.3 portrays a history of acquisitions by Schlumberger showing a dramatic increase in acquisition frequency over the past 15 years.¹¹ Acquisition activity at other major service providers, such as Halliburton and Baker Hughes, is known to have followed a similar trend.

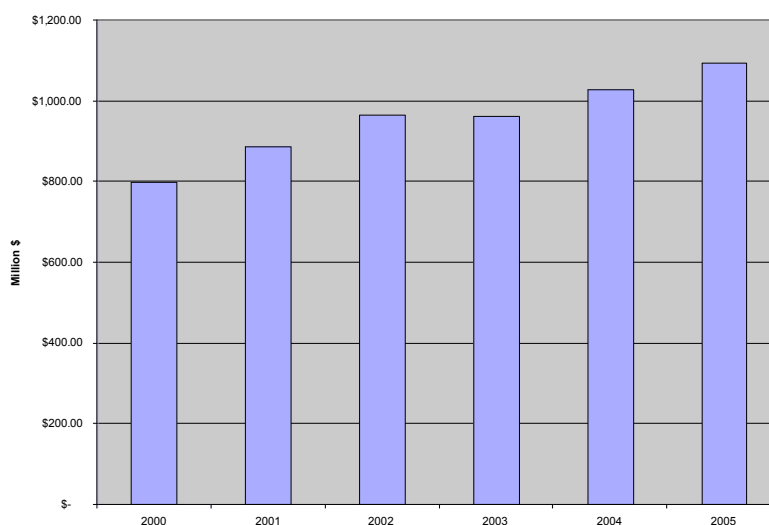


Figure VA.2. Major service company R&D spending.

¹⁰ Halliburton, Schlumberger, Weatherford, Smith International, and Baker Hughes annual company reports (2000-2005).

¹¹ Schlumberger, Ltd.: Marketing Communications Materials (2006).

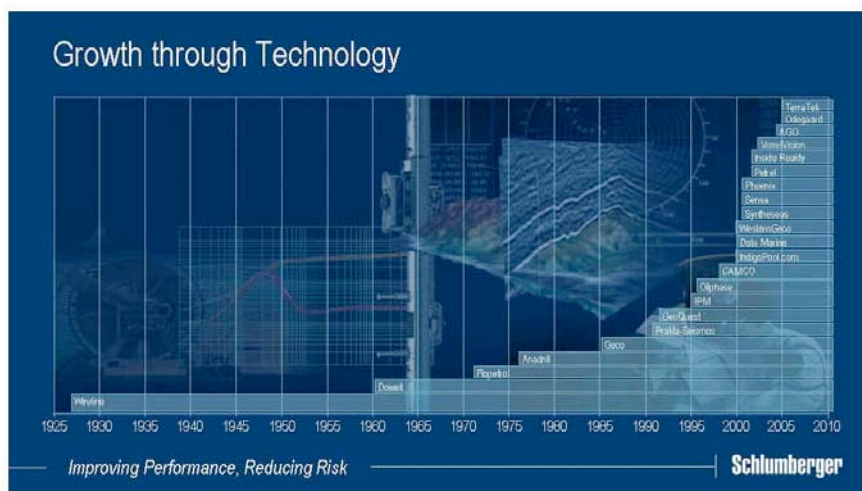


Figure VA.3. Schlumberger technology acquisitions [reference 6].

Another measure of technology development is the number of patent applications filed each year. Figure VA.4 shows the patent activity of the four largest oil and gas companies. Figure VA.5 shows patent activity at the major service companies. For the most recent year, service company patent applications show an eight-to-one ratio versus the oil and gas supermajors. This confirms that service companies are the major source of oilfield technology.

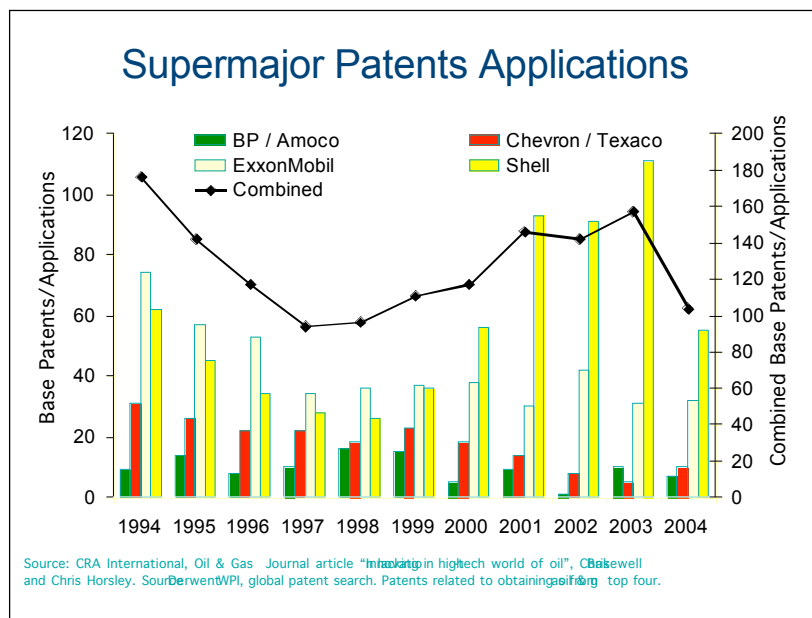


Figure VA.4. Supermajor patent applications by year.

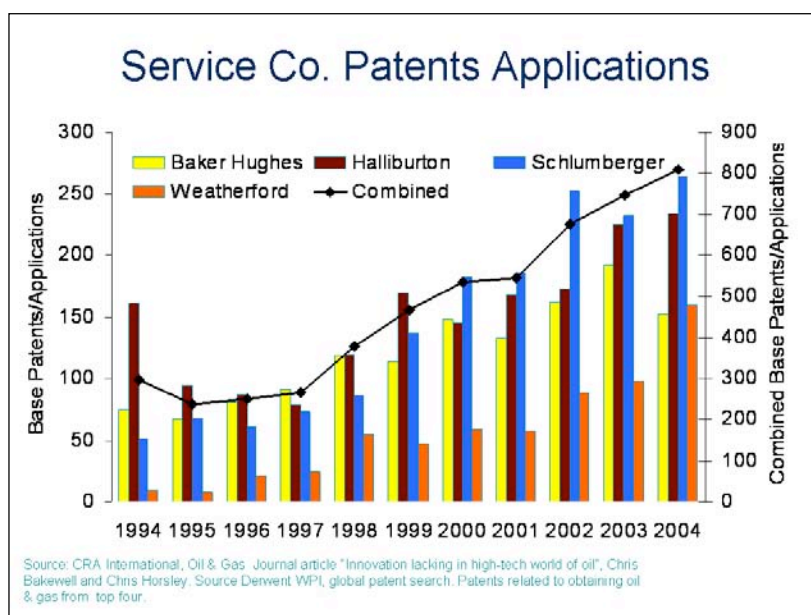


Figure VA.5. Service company patent applications by year.

The U.S. government has contributed significant research and development dollars over the years. Through the Department of Energy, and in particular the National Energy Technology Laboratory (NETL), research and development money has been made available to National Laboratories, universities, consortia, and smaller companies. Other countries also contribute to the overall technology advancement through R&D programs. Figure VA.6 shows the most significant spending by governments.¹² Spending peaked in the early 1990s, declined significantly in the following years, and has recently remained relatively stable over the past few years.

Figure VA.7 shows U.S. government R&D funding in recent years, split between oil and natural gas.¹³ Research undertaken by national laboratories and universities usually leads to fundamental understanding and base technologies. These technologies are typically reduced to practice by other entities such as oil and gas, service, or start-up companies.

¹² International Energy Agency: Online Statistics Database (2006). Available at <http://www.iea.org>.

¹³ Lawson, reference 9.

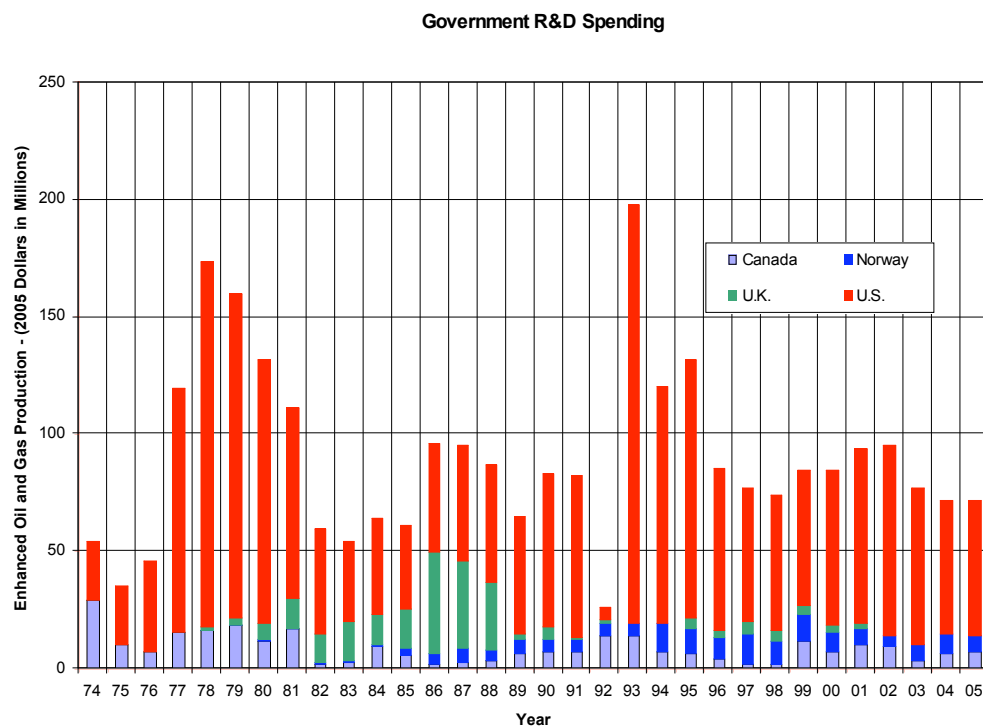


Figure VA.6. R&D funds provided by national governments.

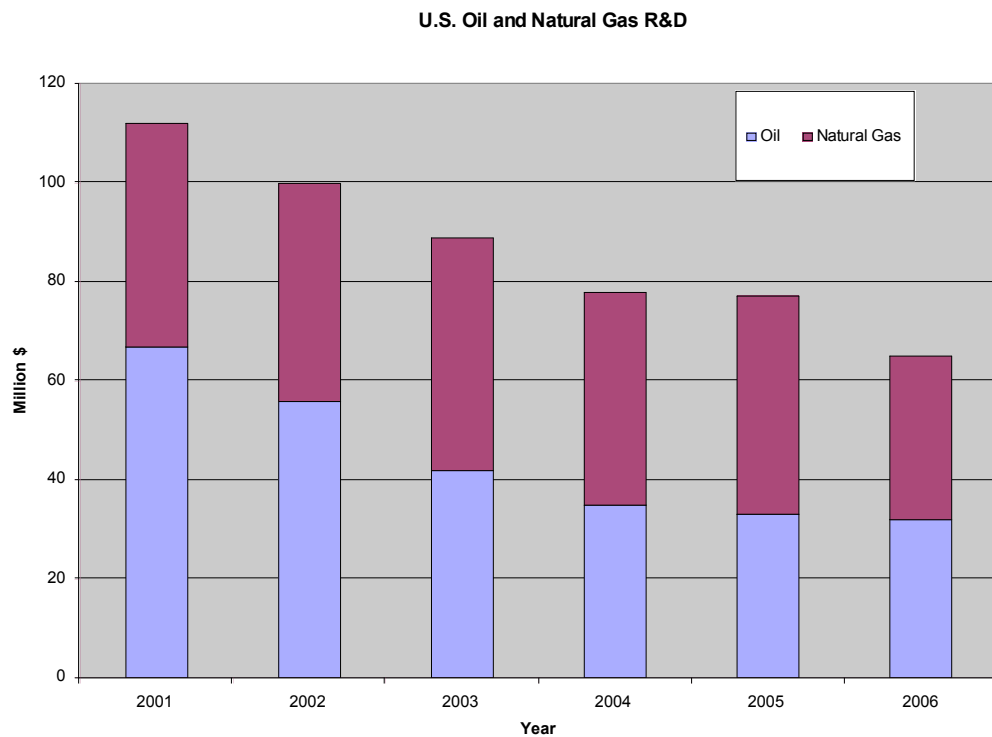


Figure VA.7. Oil and natural gas R&D funds provided by the U.S. government.

B. Inherent Differences in the Business Approach to Oil and Gas

The U.S. approach to the oil and gas business is often significantly different from that of the rest of the world. U.S. oil and gas markets are increasingly in the hands of independent operators who are often more nimble and willing to accept greater technology risk in return for greater potential impact and upside. Conversely, smaller players are more vulnerable to downside risk. With the maturity of the U.S. petroleum reserves comes a need to focus on enhanced recovery and more efficient operation. The technologies needed to support these operations are often different from those required in other world markets.

C. Technology Funding for the Future

It is instructive to study R&D spending trends in order to predict the sources of new technologies for the U.S. oil and gas business. As a mature hydrocarbon-producing country, the USA has significant resources that require new ideas or applied sciences, which should fuel technology development and adoption.

However, the U.S. government proposal for fiscal year 2007 is to terminate the oil and gas program within the Department of Energy, leaving only \$50 million in royalty receipts that were directed toward three specific programs in the Energy Policy Act of 2005. The bulk of the funds (\$35 million) are set aside for ultra-deepwater and unconventional hydrocarbon research programs as part of RPSEA (Research Partnership for a Secure Energy America). An additional \$15 million is set aside for an internal National Energy Technology Laboratory program and administrative funds.

As noted earlier, U.S. service company R&D spending appears to be increasing, and early indications are that the same is true for operating companies. However, a significant part of oil and gas company R&D is focused on alternative energy and clean technologies and not on improving oil and gas recovery.¹⁴ Service companies will continue to focus on the needs of their customers, which implies that non-U.S. markets will dominate their

¹⁴ Lawson , reference 9.

attention because that is where the majority of their business originates. Therefore, unless the technology needs of the U.S. oil and gas business align with the needs of the rest of the world, there is a danger that U.S. interests may not be adequately addressed.

VI. Roles and Resources

A. Requirements for Effective Technology Development

The development of successful technology requires the confluence of three areas of expertise:

- 1) Knowledge and understanding of the problems likely to be solved through application of the technology
- 2) Expertise in the science and engineering details behind the new technology, as well as the infrastructure for moving from scientific principles to practical application
- 3) The business acumen required to secure funding, develop products and services, and create markets.

The knowledge of critical problems generally resides within the operating companies responsible for the actual exploration for, and production of, hydrocarbon resources. The required technical expertise can be found in service companies, national labs, research organizations, and entrepreneurial companies. For the most part, operating companies do not have the required expertise or infrastructure. Both service companies and operating companies are well equipped to develop and market products within their traditional business lines, but often lack the acumen required to expand into new business areas. Many potentially expert technology development organizations also lack that acumen.

No segment of the hydrocarbon extraction industry serves as a natural integrator of the skills required for successful technology development, because no one segment encompasses all of the required skill sets. In looking for reasons for the observed slow uptake of technology in the upstream sector of the oil and gas industry, Rao and Rodriguez refer to the mismatch between the knowledge bases of the operators and the

service companies as “information asymmetry.”¹⁵ Effective (and rapid) technology development and application is impeded by the service companies’ lack of a deep understanding of the problems to be solved. Similarly, the lack of detailed expertise in new technology areas within most of the operating companies impedes their ability to properly evaluate the risks of new technology.

The sections below briefly address the role of various segments of the upstream oil and gas industry in the development and application of new technology.

B. Operating Companies

Independent operating companies have no internal R&D capability, while a few integrated companies retain some laboratory capacity. The national oil companies are expanding their labs, sometimes in partnership with international developers. Despite the capacity for some R&D within the operating segment, the greatest roles in technology development played by the operating companies lie in the clear definition of problems to be solved, in providing opportunities for testing and evaluating new technology, and in providing a certain market for viable solutions. All operating companies “fund” technology development at service companies through their purchase of existing services, with a percentage of the resulting revenue being used to fund R&D programs. National oil companies and large integrated operating companies will sometimes fund specific technology developments if they are aimed at a specific resource. As there are fewer “elephant” resource development opportunities, it is less common for a single development to justify fully funding a new technology. Independent operating companies rarely provide direct funding for specific technology developments, but often participate (along with majors and national oil companies) in research consortia and other cooperative efforts.

The evaluation and demonstration of new exploration and production technology almost always require an operator making the decision to use that technology in a commercial application. In cases where an operator was also involved in the development

¹⁵ Rao V and Rodriguez R: “Accelerating Technology Acceptance: Hypotheses and Remedies for Risk-Averse Behavior in Technology Acceptance,” paper SPE 98511, Society of Petroleum Engineers (2005).

process, this process works reasonably well. However, operating companies are generally reluctant to be the first to apply a new technology, contributing to a relatively long path to commercial application and economic impact. As discussed by Rao and Rodriguez, one factor impeding the rapid application of new technology is the lack of intimate familiarity with technology developments on the part of operators, resulting in an inability to estimate the risk associated with new technology applications and the value that successful application might create. Occasionally, an operator—usually an independent—will see an opportunity to differentiate itself from its peers through effective application of new technology. When this occurs, the introduction and acceptance of the new technology is greatly accelerated.

C. Service Companies

The current model for technology development in the upstream oil and gas industry places most of the responsibility with the service companies. They are expected to reinvest their profits in the development of technology, which will provide differentiation from competitors and lead to growth. The large integrated service companies tend to focus on developments with a large potential market that can substantially increase their market share or profits. Smaller service companies may exploit ideas with a smaller initial market, since even a small increment in market share can translate into significant growth for a smaller company. These smaller, independent companies rely on new technology and speed to market to differentiate themselves, and are often responsible for radical innovations.

As industry acceptance of a new technology grows, advantage may be gained by transitioning technology from a smaller company to an established integrated service provider with a worldwide support network. This transition is often accomplished through licensing or outright purchase, but can be impeded by a “not invented here” attitude on the part of the larger company.

D. Companies Outside the Oil and Gas Industry

Large corporations often see the oil and gas industry as an opportunity for the transfer of technology developed for other applications. These companies are often looking for horizontal growth opportunities when their core business is stagnant. Such corporations often underestimate the reluctance of the potential customers, the operating companies, to embrace and adopt new technology. A lack of understanding of the workings of the upstream industry, including the relationships between operating and service companies, may result in the allocation of insufficient resources to understanding the potential market and adapting the existing technology to market needs.

Smaller companies that have a new technology with potential application in the exploration and production sector often seem to achieve greater success. Such companies seem to have more flexibility to set up a subsidiary business tailored to providing services to the upstream industry, and are more likely to partner with established service companies that have an understanding of the exploration and production markets.

In the case of both large and small companies attempting to export technology into the oil and gas industry, the involvement of the existing service industry—providing access to established supply chain and distribution and support infrastructure—is a key ingredient for success.

E. Start-up Companies and Entrepreneurs

Start-up companies and entrepreneurs have made a number of important technology contributions. In many cases, seasoned oil and gas industry technical experts are involved, facilitating the access of the new technology to the market. Unlike at the corporation level, seasoned professionals do not suffer from information asymmetry; they bring together knowledge of persistent problems, ideas about potential solutions and how to assemble them, and knowledge of the supply chain to bring the invention to market. Most commonly, these technologies are commercialized through the sale of the company or technology to an established service provider with the sales and distribution infrastructure required to provide services on a global scale.

Most new technologies have some entrepreneurial component. An inventor or technology developer with a sound grasp of the important issues looks at a persistent problem in a new way.

F. Universities and National Laboratories

Because service and operating companies are primarily focused on technology applications that will lead to near-term profits, much of the basic research behind important technological innovations has been carried out at universities and national labs.

The national labs often work on problems in which a technology originally developed for the military finds application in the exploration and production industry. Most of the national labs have some earth science and engineering expertise associated with their primary defense mission, so there is reasonable communication between the upstream industry and their technical experts. This communication has been facilitated by past government programs, such as the Natural Gas and Oil Technology Partnership. National labs represent a valuable technology resource, especially as a source for basic research funded by other national needs.

Universities in the USA have conducted the research behind many important technical innovations across all industries. In addition, U.S. universities produce graduates that provide technical and business leadership in the petroleum industry throughout the world. The government has been a substantial supporter of university research in the exploration and production sector, primarily through Department of Energy programs. As some of these programs are reduced or eliminated, universities are increasingly looking to industry for support.

Consortia are one successful way for industry to support university research, but the results of industry-sponsored consortia tend to be focused on information or software that can be applied in the near-term and not on fundamental research with the potential to enable revolutionary advances in technology.

As the oil and gas industry moves increasingly overseas, funding for universities and research institutions outside the USA is increasing. International operators are facing ever-more stringent demands from host governments in order to maintain their licenses to

operate. One key criterion is “local content;” that is, staffing the venture with predominantly local staff—in many cases a minimum of 80 percent or more. This requires the hiring of local graduates, and therefore promotes spending at—and generally closer relationships with—local and regional universities rather than traditional hiring grounds of major U.S. and European schools.

It is worth considering the question of whether the USA will be able to maintain a leading role in the education of the world’s upstream technologists and the research that allows technology developments. Current trends seem to indicate that U.S. universities will remain at the forefront of research and education, but will increasingly do so through overseas students coming to the USA for their education, and then returning to their home country. This will not benefit the domestic industry.

The path from fundamental advances in knowledge at the university level to the commercial availability of new technology is not always smooth. University researchers may believe they have solved all of the problems in a technology area, while a company seeking to provide a commercial service based on that technology still might see significant obstacles. Recent changes in the way universities handle intellectual property may encourage professors and researchers to further develop the results of their work, but potentially at the cost of decreasing the manpower available for training students. Universities in the USA constitute a tremendous resource that could benefit from new approaches to working with industry while continuing to perform the critical mission of training the next generation of technologists, researchers, and developers.

G. The Need for an Innovative Approach

Operating companies, service companies, companies in other industries, entrepreneurs, and research organizations all have a role to play in the successful development and application of technology in the upstream oil and gas industry. The complexity of the hydrocarbon resources remaining in the USA will require new technology that must be implemented on a more rapid time scale than has been traditionally possible for the exploration and production industry. To accomplish this,

innovative ways for the various players to interact and integrate their areas of expertise will need to be developed.

One approach to stimulate technology development in the oil and gas arena is to create a lucrative prize to be awarded to companies that develop technologies that substantially improve domestic oil and gas production. Examples show that it is possible to leverage funding, such as the Ansari X prize for privately funded manned space flight, the Orteig prize to Lindbergh for his solo flight across the Atlantic, and the Board of Longitude prize for the 18th century invention of the marine chronograph that enabled navigators to determine longitude at sea.

VII. Technology Delivery

Entrenched buyer-supplier relationships, multi-national product and service providers, and an overwhelming mixture of aversion to risk and resistance to change dominate the delivery of new technology to the oil and gas industry.

In this section we examine the established supply structure, behavioral differences in the way integrated, independent, and national oil companies adopt new technology, and how industry trends might influence the uptake of technology in the future.

A. The Oil and Gas Supply Chain

Although the oil field is awash with small operators and service companies, the lion's share of the market is held by entrenched, multi-national service providers that offer bundled products and services to their clients. Operating companies prefer the simplicity and economies of scale achieved when dealing with a limited number of suppliers that can deliver a broad range of products and services to a consistent standard around the world.

There is little incentive for such global supply companies to innovate or adopt step-change technologies that would displace established profitable product lines, except to incrementally differentiate themselves from the competition. When combined with the operators' general risk aversion, this presents a significant barrier to the introduction of new technology.

Barriers to entry are especially high for small companies offering disruptive technology. Small players are forced to compete against economies of scale gained by the large incumbents, while trying to establish their technologies in the marketplace. Whenever significant sales traction is achieved—indicating that both technology risk and market risk have been managed down—smaller players become prime targets for acquisition by established suppliers, either to refresh their product lines or to remove a product threat from the market.

B. Access to New Technology

Awareness of a new technology generally relies on individuals within the various operating companies coming into contact with the technology, either as the result of a proactive search for solutions to a particular challenge or through information transfer channels such as magazines, journals, conferences, exhibitions, and Websites. Industry networks are a critical component in this information diffusion process. From personal contact circles to organized online communities, the industry relies heavily on peer experiences and case histories when deciding to try or adopt new technology.

Technology is first introduced by the originating company, which may restrict its availability to markets that it already serves. In the case of a small or start-up venture, this might mean a local or national market. For larger players, technology may be introduced quite rapidly into national or multi-national markets. As international demand grows, smaller companies must enter into licensing arrangements, alliance agreements, or even merge with overseas partners to access the necessary supply chain infrastructure.

Even when a major supplier makes technology globally available, long-term supply agreements—typically three to five years in duration—may restrict buyers from switching from a competitor's inferior product to the new offering.

C. Technology Adoption

Oil and gas companies' readiness to accept technology varies. Data provided by Halliburton indicate that major integrated oil companies are typically less likely to be early adopters of new technology than independent and national oil companies (Figure VIIC.1).¹⁶

¹⁶ Halliburton Energy Services: Internal company data (2006).

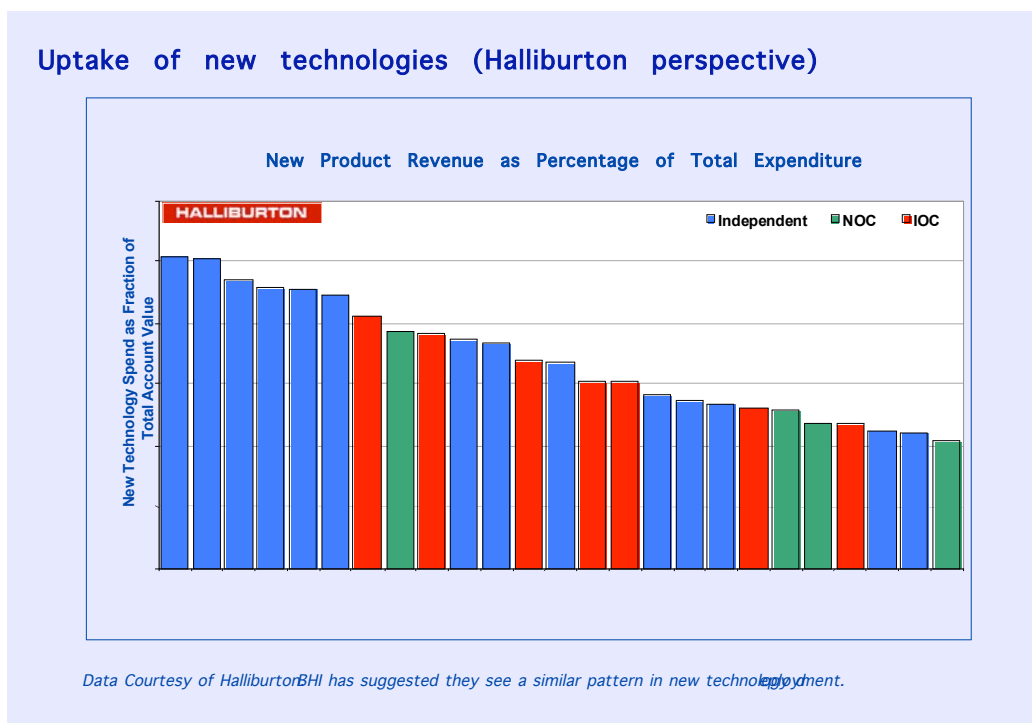


Figure VIIC.1 Uptake of New Technologies by Type of Operator
(Courtesy of Halliburton Energy Services).

Whereas larger operators focus on lower-risk technologies that reduce cost and/or improve access to new resources, independent operators may seek opportunities to differentiate themselves through higher-risk, higher-reward solutions. This behavior is tied to shareholder expectations. Integrated oil companies are constrained by promises they have made regarding return on investment, cost reduction, production levels, and reserves replacement. Greater performance volatility is anticipated for independent operating companies, allowing them to absorb the increased risk associated with new technology plays.

National oil companies are aggressive users of new technology that is aligned with particular local needs, as a result of less-stringent investment criteria and a primary responsibility to most effectively exploit national resources.

D. Domestic vs. International Practices

More than anywhere else in the developed world, the U.S. domestic oil and gas industry features a multitude of small, independent operators and service providers.

While these companies would like to make effective use of new technology, they seldom have the resources—financial or hydrocarbon—to absorb the risk associated with its early application.

Nevertheless, the service company data referred to in the previous section indicate that independent operators are leading customers for recently introduced technology. This may be because they are less reliant on long-term, umbrella purchasing contracts and can more easily switch to whichever provider offers the most compelling technical solution or service.

Therefore, it is reasonable to assume that technologies will penetrate the U.S. market faster than other regions of the world, although the diffusion rate of new technology may be constrained by the sheer number of companies involved.

U.S. oil and gas provinces are very mature in comparison with most other developed regions. This means that the technical challenges associated with primary extraction are well understood and many possible solutions have already been tried, creating an “old boy” counterculture that is strongly attached to established practices and which believes any new idea has been tried before and is doomed to fail.

However, secondary and tertiary recovery efforts open new technical challenges that must be met in the face of challenging economic criteria. The remaining resources are enormous, making enhanced oil and gas recovery a prime area of opportunity for new technology investment and delivery.

Since much of the rest of the world is only now reaching the point where secondary recovery begins to displace primary recovery as the main source of production, the development of technologies in this area may be heavily influenced by U.S. needs, investment levels, and the relative attractiveness of domestic resources compared to international opportunities.

E. The Risk-Reward Balance

Adopters of new technology must balance the technical and financial risk associated with implementing a relatively unproven solution against the expected upside if its

application delivers as promised. Such risks and rewards are highly uncertain and difficult to quantify.

Operating companies are generally more willing to take geological or political risk than technical risk. This is strongly influenced by stakeholder expectations, as discussed earlier. Most new technologies offer significant long-term benefits in one or more of: increased hydrocarbon recovery, increased short-term productivity, reduced cost, increased return on investment, or increased reserves replacement. However, most technological advances also introduce downside risk—e.g. disruptions to drilling or production schedules if the technology malfunctions—that can disproportionately impair the operator’s ability to meet short-term targets.

Operators are also prone to evaluating new technologies on the basis of a single implementation. This is statistically less attractive than trying a portfolio of technologies across multiple implementations, when the overall benefit should outweigh occasional failures (assuming intelligent selection of technologies).

F. Industry Trends Influencing Future Technology Uptake

Since the mid 1990s, the industry has moved increasingly towards broad, multi-national, umbrella supply contracts in search of global standardization and economies of scale. However, this trend may be slowing as companies recognize the penalties imposed by limited switching ability and reduced flexibility to adopt the right technology in the right place at the right time. Future contracts are likely to include stronger clauses allowing the buyer to procure new technology from a different supplier when the incumbent does not supply a comparable product or service.

Access to new technology is increasingly facilitated by the Internet, which allows a front-line engineer to research, identify, and even procure technologies from any corner of the globe. This trend will enhance the ability of smaller players to access and service global markets, although the constraints of supply and service infrastructure will remain. This could create an increasing role for companies supplying original equipment manufacturer (OEM) technology rather than exclusively developing and marketing in-house products.

Technology adoption practices show little sign of changing, although much has been made at industry conferences of the need for a new wave of technology to mitigate rising operating costs and open new resources to development. Technology is definitely a key factor in the decisions made by major resource-holding nations to grant operating licenses to international operators. As such, large operators are refocusing their research, development, and deployment efforts on technology areas relevant to the competition for new acreage, such as the exploitation of difficult gas resources and the sustainable production of resources heavily contaminated with hydrogen sulphide (H₂S) and carbon dioxide (CO₂).

Recently, major operators have become increasingly risk-averse as new projects have become more costly, less economical, and technically more challenging. Smaller, more difficult plays afford less opportunity to learn by trial-and-error and therefore favor the application of proven technical solutions. There also are correspondingly fewer “elephant” projects capable of underwriting the development of a particular technology. While the trend toward more difficult resources is unlikely to reverse, operators might be forced to accept increased technology risk to continue to compete.

The current shortage of experienced manpower—commonly referred to as the “great crew change”—will have a detrimental effect on technology uptake. New technologies require experienced champions within the business to defend them against skeptics who magnify downside risks and question the benefits. Young, inexperienced engineers cannot fall back on historical experiences when advocating the use of new technology, and are generally less able to objectively assess its value or the risks associated with its application.

VIII. Recommendations

A. Manpower recommendations

- 1) Attract, train, and retain students in degree programs in petroleum engineering, geology, and geophysics. This will require outreach programs on the part of industry and academia, scholarship programs, and research support at the university level. Funding sources must include U.S. oil and gas companies as well as state and federal governments.
- 2) To address the forecast shortage of trained U.S. personnel in engineering, geology, and geophysics, revise the current immigration policy and attract more experienced technical professionals from overseas.

B. Policies Directed Toward Companies Operating in the US

- 3) Adopt state and federal tax credits for new technologies applied in the USA to increase domestic oil and gas production or to enhance environmental protection.
- 4) Adjust the royalty structure in order to encourage technology investment. One possible approach is to link the royalty payment to the rate of recovery. Higher rates of recovery result in lower royalty payments.
- 5) Make tax or revenue policy in the USA more favorable than other regions of the world, so international players will not shift their focus to other areas, but will develop and implement technologies for the USA.
- 6) Facilitate co-operative technology development and deployment (risk sharing) between smaller, independent operators
- 7) Leverage funding to create a lucrative prize for the development of technologies that substantially improve the domestic production of oil and gas.

C. U.S. Government Funding

The technology needs of the U.S. domestic oil and gas industry may not be addressed by the R&D efforts of the international operating and service companies, and must therefore be the focus of government-funded programs. Some specific actions include:

- 8) Maintain the position of U.S. universities at the leading edge of research in technology related to hydrocarbon extraction, by providing funding for fundamental research. In particular, basic research in areas of enhanced recovery, the development of unconventional and marginal resources, and minimizing environmental impact would be well aligned with the domestic resource base.
- 9) Restore government funding to programs that seek industry matching funds for the development of U.S.-specific oil and gas technologies. Government funding attracts matching funds from international companies, often disproportionate in nature (i.e. industry funds at a level many times higher than the corresponding government grant). However, in the absence of government funds, industry funding may be applied to completely different projects, potentially unrelated to U.S. domestic needs. One example of such an approach to government/industry funding is the Stripper Well Consortium which has demonstrated an ability to produce meaningful solutions to US-specific production needs.
- 10) Provide a mechanism for consistent funding of technology development and deployment focused on the particular requirements associated with domestic resources. A consistent funding stream not subject to the vagaries of the annual appropriations process is essential for the success of such a program, as would the active participation of the producing companies expected to invest in the deployment of program results. One example of such an approach was the Gas Research Institute (GRI), with funding supplied by a tariff to allow reasonably continuous budgets and planning.

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