Breakthrough Technologies and Incremental Innovation: the Edge of Innovation in Oil and Gas industry, Level of R&D expenditure Versus Results in the Energy Companies

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Abstract:

Energy industry, oil and gas sector to be specific, has been in a leading position in the development of new technologies and innovative ideas for the efficient production of hydrocarbons and processing. Exploration of challenging, technologicaly difficult sub salt and sab basalt fields, drilling activities in deep waters and to reach deep reservoirs, development and deployment of efficient and modern production methods, reservoir management models and enhanced recovery mechanisms to improve oil recovery, and CO2 sequestration approach to inject CO2 in geological strata emerged as main areas where major petroleum operators and service companies are focusing significantly for their Research and Development activities. However commercialization of innovative technologies is very costly and time-intensive. The risk avert attitude of major oil and gas operator companies towards promotion of new technological development and innovative tools increased pressure on innovative service companies to stick to the existing technologies. This paper unfolds various issues regarding industry's approach and attitude towards the development of new technologies and summarized benefits reaped by the companies from novel ideas.

Introduction:

Many oil and gas R&D publications and conferences are pointing out that to date the world has produced and consumed around 1 trillion barrels of oil. Current estimates indicate we'll produce and consume another trillion in the next 35 years, and even with favourable, some would say optimistic, projections on improvements in energy efficiency the third trillion barrels will probably only last 35 to 70 years after that. So, just where are the next two trillion barrels of oil going to be found? To paraphrase Tony Meggs, BP Group Vice President for Technology, they will be found by a mixture of greater recovery, greater discovery, and greater diversity. We will produce more from existing fields and from hydrocarbon deposits we've already discovered but not yet exploited. We will find new hydrocarbon reserves in what might be termed conventional environments. And we will exploit unconventional resources.

How are we going to get all those billion barrels out of existing resources? At first glance that sounds like wishful thinking in the extreme. But there can be no doubt that recovery rates being achieved now are far higher than were envisaged even only 20 years ago and this all thanks more effective R&D in oil and gas industry.

With some exceptions, future discoveries of conventional reserves are likely to be made in locations where we haven't as an industry looked very hard for them previously or where limitations in our exploration techniques mean we haven't been able to look for them very effectively in the past. Which implies we'll be finding reserves deeper below the surface, in deeper water and in hostile environments like the arctic regions? We will have to contend with higher reservoir pressures and temperatures and in some cases harder rocks. Manoelle Lapoutre, Vice President of Research and Development for Total, has said that the majority of reservoirs we've produced so far have had temperatures below 200 deg C and pressures below 15,000 psi, whereas in the future we will routinely face the prospect of developing reservoirs at temperatures and pressures above these levels.

Considerable resources exist below the icy waters of the Arctic regions. We developed technologies to explore and drill in this most inhospitable and fragile of environments during the 1970's and early 80's, but that activity went South along with the oil price in 1986. There is general consensus that we're going to be asked to go north again, that is to return to the Arctic regions where ice and icebergs remain our major challenge.

Probably the greatest source of future hydrocarbon production is what we currently regard as unconventional resources – heavy oil and bitumen, oil shales, tight gas sands, shale gas, coal bed methane, and gas hydrates which all require higher R&D expenditures from oil and gas companies.

Approach and Analysis:

The main source of data and information was international oil and gas magazines, research papers and various companies' articles and publications about their new technological advancements and projects. We started our research by figuring out the challenges faced by petroleum industry, particularly technical challenges in exploration, drilling, production and environmental sectors. This led us to a set of challenges which the large E&P and contractor companies are facing; deep water drilling, sub-salt and sub-basalt explorations, Improved Oil Recovery, efficient separation and well completion emerged as the most critical issues in today's petroleum industry. We outlined the recent efforts initiated by service companies to develop appropriate technologies to tackle these issues and recent and ongoing projects being carried out by E&P companies. The innovations can be some improvements or adaptation of current technologies to resolve new challenges called 'incremental innovation', or some breakthrough technology which resolves the barriers involved in some critical step or project.

In exploration we focused on advancements in seismic methods necessary for exploration of sub-salt and sub-basalt reservoirs which imaging requires novel seismic acquisition methods and extremely sophisticated data processing. Although most of those projects and experiments are concentrated in Gulf of Mexico, however West Africa and other parts of the world are also potential future targets. In drilling we analyzed the deep well and deep water drilling issues and discussed the current and future innovative approaches to address those hurdles. In production technologies, areas of particular interest were enhanced oil recovery methods, mature field revitalization and field production management technologies, which, with depleting resources are crucial for profitability and survival of major oil companies. Environmental regulations for operations of exploration and production are becoming increasingly stringent which are forcing E&P companies to take revolutionary actions to ensure environmental friendly and sustainable operations.

Further ahead we analyzed the R&D expenditure incurred by petroleum industry and determined that although traditionally petroleum industry is not considered as high-tech or technology-intensive one, however, changing scenarios are forcing industry players to allocate more investments for R&D activities. One dominant trend during last 15 years is the shift of technology and R&D activities from traditional major operators to service companies who now are the major source of innovations in oil industry.

Results and Insights:

1. EXPLORATION:

1.1 Subsurface Imaging:

Imaging sub-basalt targets is a key problem for the hydrocarbon exploration industry. In large parts of the world, potential oil-bearing tertiary sediments are considered to be intruded or covered by basaltic sills and lava flows.

Eruptive basalt flows over sedimentary basins may trap rich hydrocarbon reservoirs at several volcanic margins, including sites in the North Atlantic ocean, off the coast of West Africa and offshore India. These sites are often in deep water and the sub-basalt sediments often sit several km beneath the seafloor. Despite the difficult access to these sites and the potentially high cost of drilling through the overlying basalt cap, the potential of these reservoirs has stimulated significant research using a variety of geophysical methods.

Subsurface imaging using conventional seismic reflection techniques is challenging in sub-basaltic reservoirs, which are characterized by high velocity basaltic rocks underlain by low velocity rocks. The seismic image quality worsens in the presence of intercalated sediments within the basaltic rocks. Some of the vital issues associated with sub-basalt imaging are:

complex setup caused by multiple basalt flows and inter-fingering of sediments within the individual flows.

Strong reflections due to high impedance contrasts at the top and bottom of the basal flows leads to significant loss of transmitted seismic energy. Internally the velocity of a basalt flow increases slowly from the top and decreases rapidly at the bottom. Apart from the high impedance contrast of basalt with the overlying sediments, the internal layering of the basalt sequence causes severe scattering of seismic energy.

Thus the quality of the seismic data recorded is severely affected by cumulative impact of above issues.

In recent years several researches and experiments proposed long-offset seismic data acquisition using low frequency sources and making use of locally converted waves, to be effective in sub-basalt imaging. Ziolkowski et al. Proposed low frequencies for sub-basalt imaging and also advocated large airguns towed deep to generate low-bandwidth frequencies. Since sound waves travel more easily through thin layers at low frequencies than high frequencies, low frequency surveys could provide better seismic images in such geological settings.

However due to complexity caused by the surface and internal heterogeneity of the basalts, near offset data acquired during low-frequencies seismic is yet to be fully used. Dhananjai Pandey in 2008, proposed ‘synthetic seismogram modelling’ which provided a good understanding of nature of intra-basalt structures in Deccan traps and their effects on field data, and demonstrated that in simpler basalt structures, converted phases can be reasonably identified and used for seismic image enhancement. Some other algotithms have also being developed and applied for better processing of seismic data, however, recording of 3D date for hydrocarbons imaging beneath basaltic rocks is still to be achieved.

1.2 iSIMM:

The integrated Seismic Imaging and Modeling of Margins (iSIMM) project is a joint industry-university research project, aiming to tackle inability of conventional seismic reflections method to image through basalt layer ovelrying sediments, and failure of current methods and softwares to model properly stertching, subsidence and thermal history of margins. In 2002, iSIMM acquired long-offset data using an bubble-tuned source designed for low frequencies. Key aspects of processing included shot-by-shot signature monitoring allowing waveshaping and careful demultiple. The resulting TWT-migrated data revealed good imaging of structures beneath the top basalt. Further iSIMM aims to integrate OBS data and focus on long-offset arrival to identify the base of basalts and illuminate deeper structures using wide angle imaging techniques.

1.3 MARINE ELECTROMAGNETICS:

Electromagnetic methods can be used to provide valuable information on the structure and properties of the sub-surface in technically demanding environments. These techniques are particularly powerful if combined with the results of other geophysical surveys. For example inclusion of the upper-basalt boundary determined from seismic studies, can improve resolution of deeper structure by the electromagnetic data. Resistivity values from well-logs can also be used to constrain the interpretation and hence improve the resolution achieved. Resolving structure and lithological properties in areas where the target of interest is concealed beneath basalt or salt is likely to require a variety of techniques. However marine electromagnetic sounding can make a significant contribution in the context of sub-basalt imaging.

The magnetotelluric (MT) method uses measurements of naturally occurring electromagnetic fields to determine the resistivity of the sub-surface. The depth to which the incident EM fields penetrate depends on the frequency of the field and the resistivity of the medium. Thus, by studying the variation in response as a function of frequency, the variation in resistivity as a function of depth may be determined. Recent advances in instrumentation have increased the usable frequency band so that crustal scale variations can now be mapped (Constable et al. 1998). The method has been successfully applied to the study of salt structures in the Gulf of Mexico (Hoverston et al. 2000), and more recently to sub-basalt structures in the North Atlantic (Lewis et al. 2002).

1.4 DATA ACQUISITION TECHNIQUES

The seismic industry is witnessing emergence of new and sophisticated acquisition methods that use varying azimuths and offsets. These surveys are particularly required for intricacies associated with the imaging of subsalt targets. Some of these techniques are Wide Azimuth (WAZ), multi-azimuth (MAZ) and Rich Azimuth (RAZ). WAZ is of particular interest which involves widening the effective receiver array or offset in the cross line direction. This is achieved by a wide line of sources at right angles to the towed streamer direction, usually involving two to four source vessels. A MAZ focuses on a known target and crosses over it from as many as six different directions to acquire 3D data. These types of surveys have been applied primarily in Gulf of Mexico. Some processed results show that they provide an improvement in the subsalt imaging. However the cost of these seismic methods depends on the number of vessels and passes. Improvements in data sampling can be achieved by decreasing the sail-line interval and by adding more arrays which increases survey costs. Owing to huge exploration potential, already seven WAZ surveys have been completed, mostly in Gulf of Mexico and despite high costs these techniques soon will be utilized in subsalt regions of Brazil and West Africa.

2. DRILLING:

2.1. Deep water Challanges:

Deepwater is a challenging environment and Shell's ability to conquer it is providing access to the oil and gas that lies deeper, in dispersed reservoirs or is difficult to produce. Thousands of technologies are developed and used to meet these challenges – from large, complex production systems to smart chemical treatments to help the oil and gas flow.

FMC Technologies' Enhanced Vertical Deepwater Tree (EVDT) is setting a new global standard for vertical completion systems. As a slimbore subsea completion system designed to provide large bore system capabilities, the EVDT has the capability to accommodate 7 in. Tubing completions and pressures up to 15,000 psi within a 13 5/8 in. BOP stack, making it the industry's most economic and versatile subsea completion system.

The EVDT has a number of innovative features that provide versatility, installation savings, and operational efficiency to the development of ultra-deepwater fields.

The EVDT allows ultra-deepwater completions to be performed from a small drilling rig containing the surface blow out preventer (BOP), thus avoiding the need for expensive rigs during completion. This can yield savings of up to $15 million per well.

The EVDT incorporates a retrievable flow module and flow meter in its design, reducing production downtime for maintenance and meter replacement from days to hours.

Shell's newest deepwater projects such as at the Perdido development in the Gulf of Mexico, and BC-10 off the coast of Brazil are pushing boundaries in subsea technology. At both fields shell had to face the same challenge: a low reservoir pressure, which makes it difficult to bring the hydrocarbons to the surface. But by employing subsea oil and gas separation and boosting technology and the new deepwater tree system (EVDT), which allows oil from several wells to be sent to a common production facility, these fields can be economically viable.

2.2 Deep well drilling challanges:

The challenge of drilling ever longer wells comes down to how a well is 'put together'. Traditionally, a section of the well is drilled and a casing or liner is inserted in that section. Once the next section is drilled, a second casing must be put in place. But to get there, the second section has to come through the first. As such, each casing section gets progressively smaller until the well is too narrow to be drilled any further. Shell engineer solved the problem with the invention of expandable tubulars.

These tubulars are metal casings that can literally be stretched once they are placed in the well by forcing an expansion cone through it.

The concept of expandable tubulars has been transferred to a range of well products that enable longer wells, reduced use of materials and lower costs and are now deployed in some 23 countries around the world.

2.3 Future drilling technology challanges:

Safer, more automated drilling and with greater capabilities for managing difficult pressure environments than the best we have today-in other words, a reach into the future-is making good progress. Even remotely operated drilling is possible.

StatoilHydro believes that a new, fully Automated Drilling System (ADS), while a major technological effort, is achievable in the relatively near future.

Project background

Our experience is that many drilling problems are related to human error, or rather, slow response with respect to corrective actions. The ADS has the capability, if designed correctly, to eliminate this type of misbehavior. It is mandatory to design the ADS such that the general progress in operation is not slowed.

The ADS should have the function of optimizing operations; these are:

- Speeding up drilling/tripping operations.
- Early kick detection, improved well control
- Automated pump startup/stop
- Automated mud checks

Automation of the drilling process-a great opportunity to minimize operational downtime by handling borehole problems correctly and consistently, thus significantly reducing human errors.

The company is pursuing various sub-systems for incorporation into an all-inclusive integrated system. Two different solutions are the Drilltronics (IRIS/NOV) and the eControl/eDrilling (SINTEF /HPD/Aker Solutions) concepts.

The Drilltronics system is based on mathematical computer models for dynamic real-time analysis of drilling processes; critical limits for operational parameters, such as drilling fluid pump rate, trip velocity and optimal process parameters are calculated. The result is used to control drilling equipment in real time. The new system has been field tested on the Statfjord C platform. Combining the new system with wired pipe, decision support programs and continuous measurements of drilling fluid parameters give synergy effects that, in the future, may allow remotely operated drilling systems.

eDrilling is an innovative system for real-time drilling simulation, 3D visualization and control from a remote drilling expert center and is the technology basis for eControl, which is a rig supervision, optimization and control system that will integrate 3D visualization of the wellbore with advanced drilling process models.

3 PRODUCTION:

3.1. Production System:

The system of reservoir well bore, tubing string, artificial lift equipment, surface control devices, surface equipment, and gathering lines, which produces hydrocarbons from reservoir to surface in a controlled manner, is known as production system. The production of oil and gas from reservoir rocks requires that the fluids flow through a formation, into well bore, up a column of tubing, through a choke at surface, and then through gathering lines, and separators, and other surface equipments until oil reaches the stock tanks and gas flows to point of sale of flare.

Once at the surface, the production stream runs through a control wellhead into horizontal flow lines, normally of larger diameter and running at lower pressures. The flow lines carry the three phases into a separator vessel in which the gas phase flashes to the upper portion. The oil occupies the middle portion and the water drops to the bottom. Gas from the top may be re-injected into the reservoir, refined and marketed, or flared. Water is normally re-injected into the reservoir, and the oil is sent to a pipeline for delivery to a refinery, tanker terminal, or transmission pipeline system. Other oil field processes include gas processing and reinjection, seawater injection, and natural gas liquid (NGL) stripping and blending. While oil and gas production has undergone a number of rebirths in its more than 100-year history, the elements of the process remain relatively constant. The majority of the cost-savings for any oil production facility is the prevention of failure in one of the production arteries (down hole tubing, surface pipelines, production vessels). Money lost through lost production far outweighs expenses associated with maintenance. In order to compete economically, production costs must be decreased using advanced technologies. A consequence of the advanced technologies the total production of oil and gas from a reservoir have substantially increased while secondary and tertiary recovery techniques applied to old oil fields enable them to produce economically for many years after their predicted decline.

3.2. Emerging Technologies in Production:

NANO Technology:

Nanotechnology to help extract more petrol from oil fields has been developed by researchers from the University of Queensland's Australian Institute for Bioengineering and Nanotechnology (AIBN). Known as Pepfactants, the peptide technology can control the emulsions and foams used in a wide range of industry processes and could impact a range of products from petroleum to specialty chemicals. This technology will enable the reversible and controllable making and breaking of an emulsion or foam, in an environmentally friendly and sustainable manner. For example, Pepfactants allows for the very quick separation of oil and water as well as the reversible reformation of the emulsion. An obvious application of the technology is in oil production where water is used to force oil to the surface of the well. Pepfactants would allow the easy separation of the oil/water emulsion on the surface. Also, it would change the viscosity of the oil to increase the amount of oil extracted from each underground oil reserve.

In-Situ Seismic Wave Stimulation Technology:

In a recently completed 3-year field study in the Permian Basin, Applied Seismic Research’s (ASR’s) Hydro-Impact Technology reportedly reduced oil-production decline by 20%, using seismic waves that loosen trapped oil from reservoir walls by in-situ seismic-wave stimulation tool. An induced hydrodynamic shock wave is introduced into the formation which moves through perforations and propagating through the formation at speeds up to 1.5 miles/sec and a pressure at the wave front greater than 3,500 psi becoming a high-energy elastic wave reaches oil-bearing strata and thereby oil droplets dislodge from the pore walls and coalesce into larger droplets that migrate into flow streams. The speed at which the shock wave propagates from the source prevents any damage to the wellbore casing and cement. However the tool requires some basic parameters of reservoirs while the technology can bring 5 to 10% increase in total oil production within a 1/2- to 3/4-mile radius from the seismic source.

Bright Water Technology:

The chemical and application technology known as Bright Water aims to improve water-flood efficiency by directing injection water to the desired oil zones. The technology is submicron-particulate chemistry designed to improve the sweep efficiency of a water-flood. The particulate chemistry is a thermally activated technology that swells once it reaches a predetermined location in the reservoir, which is dictated by the temperature at that location. As the particles swell to several times their original size and agglomerate, they close off the pore throats of thief zones. This forces the injection water toward previously un-swept, oil-rich zones in the reservoir and subsequently pushes more oil toward the producing wells. In order to ensure that the particles reach the correct location in the reservoir before fully activating, a thorough understanding of the reservoir is helpful. The technology is designed to treat matrix rock such as sandstones excluding limestone having larger pores to plug off thief holes. The Bright Water technology has been field tested in many regions, most notably by BP and Chevron.

EXCAPE Well Completion Technology:

First intervention-less well completion technology which can significantly reduce labor hours and completion costs. After the system is positioned and cemented in place this completion technology uses a 3-stage process to complete a well. First, a remote firing system perforates the well at the lowest interval depth. The flow of natural gas is monitored and, if appropriate, stage stimulation occurs within this zone. Second, the remote firing system is used to perforate the next zone, followed by zonal isolation of the first zone immediately below, and then, stage stimulation occurs for the second zone. After all zones have been perforated, isolated, and stimulated, the zone isolation devices are removed so that gas flows freely through the well.

Teleperf Technology:

Teleperf technology is a revolution in sand control completion technology that uses telescoping devices filled with sand control media to connect the reservoir face to the production liner without perforating and provide full-bore sand control without gravel packing. By eliminating traditional perforating, Teleperf technology eliminates associated formation damage and debris removal. It also reduces risk and time. Teleperf telescoping devices connect the reservoir face to the production liner without perforating. Teleperfs are filled with sand-control media and polymer/acid sealant during manufacture so that, in addition to replacing traditional perforating, they provide full-bore sand control without gravel packing.

Subsea Water Injection and Treatment (SWIT) For IOR:

Water injection into reservoirs is a well-established practice to maintain reservoir pressure and enhance oil production, but the conventional methods of treating this water prior to injection comes at a fairly steep price. The SWIT provides a logical alternative to lifting water topsides, filtering, chemically treating, de-aerating, boosting and injecting all near the subsea injection wellhead. Thereby it also offers the opportunity to inject as much high quality water as is required to the locations in the reservoir where it will have the optimal IOR effects. This can give the reservoir engineers complete flexibility in designing the optimum water drive.

4 ENVIRONMENT:

There is growing concern that the climate is warming and that CO2 emissions play a role. The most recent report by the Intergovernmental Panel on Climate Change (IPCC) about the physical science basis for climate change states: "*Most of the observed increase in globally averaged temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations.*" ("Very likely" is greater than 90 percent likelihood, according to the IPCC report)
It is anticipated that policies aimed at curbing carbon dioxide (CO2)emissions will alter the energy mix, increase energy-related costs, and require reductions in demand growth. Effective carbon management will be aided by developing legal and regulatory frameworks to enable carbon capture and sequestration (CCS) technology into force. As policymakers consider options to reduce CO2 emissions, they face the challenge of creating a global framework that includes a transparent, predictable, economy-wide cost for carbon emissions. Moreover, initiatives in increasing number are emerging, within both the public and private sectors, aimed at reducing carbon emissions. Such a trend highlights the potential for carbon constraint to become a significant feature of future energy strategies. In particular, future carbon constraint could alter the way in which the world uses the fossil fuels, given that most energy-related CO2 emissions come from fossil fuels that currently provide most of our energy.
In a carbon-constrained world, CCS would allow us to sustain many of the benefits of using hydrocarbons. Even where the CO2 generated by burning hydrocarbons cannot be captured easily, as with using oil for transportation, sequestering CO2 from other sources (such as coal-fired power stations) can help create to some degree—the margin needed to allow for the volumes of CO2 that escape capture. Fossil fuels are likely to remain an important part of the energy mix, because of the continuing competitive (direct) cost of hydrocarbons, and the huge investment already made in infrastructure to deliver them. Therefore, the combination of fossil fuel use with CCS is likely to be emphasized as a strong complement to strategies involving alternative, non-hydrocarbon, energysupply sources, and to measures designed to encourage more efficient energy use. Foolwing are key points about the potential for CCS technology.

4.1 Contribution of CCS to Maintaining Energy Supply from Fossil Fuels

In a carbon-constrained world, CCS would play a key role in allowing the continued use of coal and the growing use of unconventional oil. By providing a means for dealing with a significant fraction of the CO2 emissions from fossil fuels, CCS would allow us to retain fuel diversity for many decades. The growing need to provide transportation will increase the pressure to move towards other fossil sources for liquid fuels, such as unconventional oil (heavy oil, shale oil, tar sands) and coal-to-liquids (CTL) technologies. Since exploiting these resources comes with a significantly heavier CO2 burden than with conventional oil and natural gas, then in a carbon constrained world, CCS would become increasingly important. CCS can be directly applied to the extraction of unconventional oil and to the CTL process, and has the potential to mitigate the extra CO2 burden beyond that from using these fuels for transportation.

4.2 Role of CSS in Enhnaced Oil Recovery (EOR)

Large volumes of naturally occurring CO2 obtained from underground deposits are currently used by the oil industry to enhance the recovery of oil from mature reservoirs. , This CO2-EOR is currently conducted without regard to storing the CO2 “downhole.” However, with relative ease present technology could be modified to emphasize such storage. In a carbonconstrained world, it could expect rising pressure to use anthropogenic CO2 to drive this recovery enhancement, which would lead to a net reduction in atmospheric CO2. While the likely extent of CO2- EOR provides a relatively small fraction of the capacity needed for CO2 sequestration, it does offer a strong technology bridge to carbon-sequestration technologies and should be encouraged as an important element of a CCS strategy. The incentives for CO2 storage in association with CO2-EOR, and new arrangements for developing suitable infrastructure for commercial use of anthropogenic CO2 for EOR with storage, could help CO2-EOR for storage succeed, particularly as CO2 becomes increasingly available (and increasingly cheap) under a wide-scale adoption of CCS.

4.3 The Level of Readiness for Large Scale CCS

The technologies for capturing CO2 from pre- and post-combustion gas streams are available. However, their costs are somewhat uncertain and constraints remain on the levels of oxygen, particulates, and sulfur oxides for effective extraction using conventional amine solvents. Current capture technologies also prefer steady-state conditions that do not always prevail in the power-generation industry. Similar concerns apply to the more sophisticated pre-combustion capture. However, broadly speaking, the capture technologies exist and are not critically dependent on new technological breakthroughs. The same is true for CO2 sequestration technologies; the oil industry has extensive experience with pumping liquids into subsurface formations and evaluating the security of these formations for storage. Currently, several pilot projects have successfully demonstrated sequestration of CO2 in volumes amounting to millions of tons. Still missing is the demonstration of fully integrated CCS at commercial scale, along with an established legal and regulatory environment that will enable and encourage CCS. There is, strongly growing need to implement full-scale integration of power generation and CCS. China, in particular, with funding from the European Union, plans a full-scale plant with CCS within the next five years.

5 R&D INVESTMENTS IN PETROLEUM INDUSTRY

Perhaps it is better to expand the definition of R&D to R&3D, or just 3D research, where 3D refers to the Discovery, Development, and Deployment phases involved in research. Although some may regard one of these stages as more important than the others, each has an important role in capturing value from research investments.

Discovery is the phase that involves problem definition, creative idea generation, and proof of concept or feasibility. Some organizations refer to it as the innovation phase, although innovation also continues in subsequent phases. Some regard Discovery as the most important phase, since starting with the right creative ideas is often critical to advancing technology. Various companies have put in place processes with names such as Breakthrough Research, GameChanger, or Innovation Process to focus on generating and selecting promising research opportunities to pursue. These companies recognize that research programs should not only support incremental technology improvements but must also include higher-risk, higher-reward projects stemming from creative ideas. Such projects, when successful, can provide step-change advancements in technology. When not successful, the organization must be willing to accept and learn from failure. As Vince Lombardi said, "In great attempts it is glorious even to fail."

Development is the "bread and butter" phase of a project that turns a proof of concept into a working model technically ready for application. Some regard Development as the most important phase, since this is usually the stage in which most of the work must be done and useful results are demonstrated. The familiar stage-gate management process is often very helpful for stewarding research projects through the Development phase, which may last for years. A common research management problem is that too many small projects get stuck in Development for too long, while producing only small improvements. Although this is usually low-risk research, it often is also low reward and perhaps not the best use of limited resources. Stage-gate stewardship can provide an effective means to monitor and perhaps terminate small, low-value projects and ensure that resources are used most appropriately.

Deployment involves taking a usable research product with demonstrated technical and application readiness and producing a final product delivered to and used by the business in a timely fashion. Some regard Deployment as the most important phase, since only if research results are effectively used can the full value be captured from the research investment. Many organizations appear to struggle with effective deployment of research results, and the problem often stems from poor planning and/or weak collaboration between the business and research organizations. In fact, oil and gas industry has a reputation for being slow to adopt technology changes. While still in the Development phase, all research projects should identify a business unit sponsor committed to a plan for first commercial application of the research results. This creates "pull" for the research product from the business and early use during Deployment. It also provides an opportunity to enhance the technology based on lessons learned from the first application before broader rollout to the remainder of the business. Usually rollout requires more than just delivery of a product; training, joint workshops, and even transfer of staff may be involved. Since today's research results are often partially or entirely embodied in software applications, having standard computing hardware and software within the business units can also significantly expedite deployment.

For many organizations ample opportunities exist to improve how they conduct the Discovery, Development, and Deployment phases of research. Of course, a successful research program also depends on sustained, consistent funding and appropriate levels of skilled staff. Success also requires long-term commitment to technology development goals, since many years of effort may be needed before benefits are realized. Funding and staffing are topics that can generate their own sets of questions, but for now let me close with just one:

In “World Energy Outlook 2006”, the IEA projects that world demand for oil will increase from 85 million barrels per day in 2005 to 99 mb/d in 2015 and to 116 mb/d in 2030. Production from existing wells will be declining over this time, and it isn’t realistic to expect every well we drill in the future to produce more than the well it replaces. Increasing the world’s collective production rate to meet the increasing demand will require us to drill more wells per year than we have been doing. We have to put in place the capacity to drill those wells. This will mean investing more in drilling rigs, equipment, materials and R&D.

Even if various published reports have observed the low level of R&D spending in oil and gas industry compared to others such as the automotive, pharmaceutical, or electronics industries (figure 1). Although R&D spending increased significantly in many E&P organizations in 2006, 2007, 2008 and further increases are expected, oil and gas R&D spending levels will likely remain significantly lower than those in high-tech industries that create new products. Thus, there is really need to maximize value capture from whatever R&D funding is available to oil and gas industry, and one means of doing so is to manage research more effectively (figure 2).

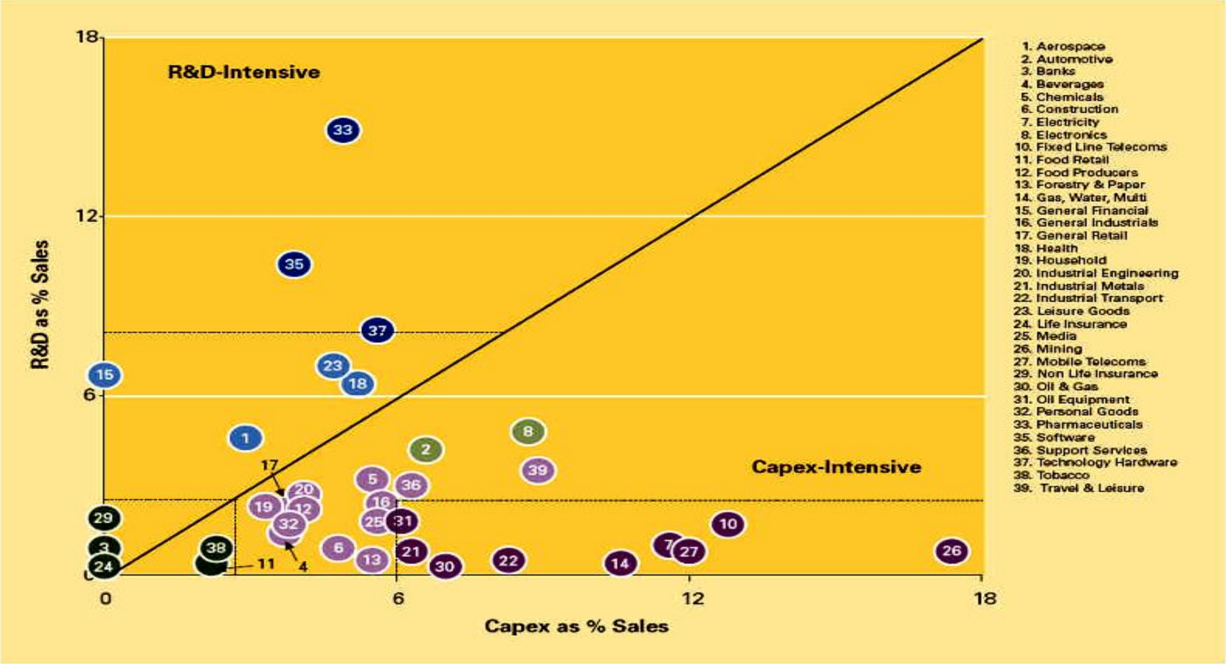
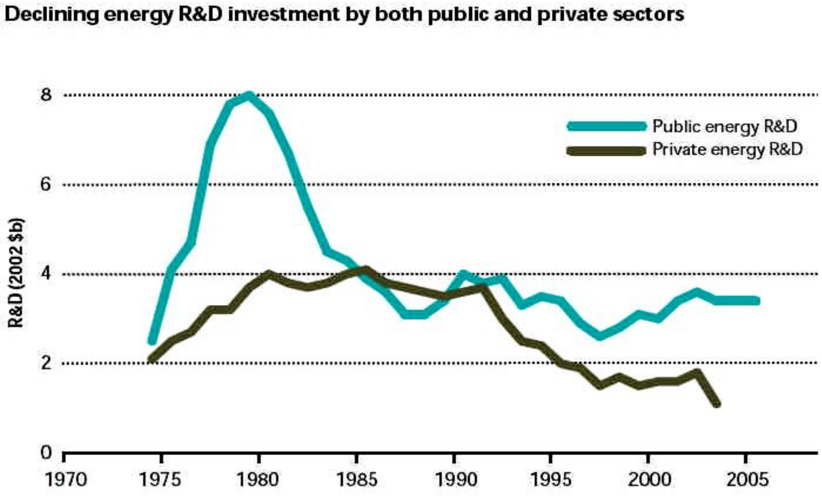


Figure 1: R&D Intensity across Industries

Declining energy R&D investment

Since 1980, energy R&D as a percentage of total U.S. R&D has fallen from 10 percent to 2 percent. Since the mid-1990s, both public and private sector R&D spending has been stagnant for renewable energy and energy efficiency, and has declined for fossil fuel and nuclear technology. The lack of industry investment suggests that the public sector needs to play a role in not only increasing investment directly but also correcting the market and regulatory obstacles that inhibit investment in new technology.


Declining energy R&D investment by both public and private sectors

Sources: R. M. Wolfe, Research and Development in Industry" (National Science Foundation, Division of Science Resources Statistics, 2004); M. Jefferson, *et al.*, "Energy Technologies for the 21st Century" (World Energy Council, 2001); R. L. Meeks, "Federal R&D Funding by Budget Function: Fiscal Years 2003-05" NSF 05-303 (National Science Foundation, Division of Science Resources Statistics, 20040; R. Margolis, and D. M. Kammen "Underinvestment: The energy technology and R&D policy challenge", *Science*, 285, 690-692 (1999).

Figure2: Investments in R&D?

The R&D expenditures hardly depend on the company's financial strength, but are liable to reinforcing R&D-races between oil the companies, initiated by common expectations among them. Despite the differences in determinants, the strategic interactions in research and investment in fixed assets have much in common. Most investment-interactions are races. These are complementary interactions where companies respond with similar investment decisions to the initiator's strategic impulse. Elimination of competitors due to lax reactions, or retraction of earlier investment initiatives, hardly occurs. Furthermore, often one company pulls out after its own first (re)action, while the other company continues in its attempt to undo the competitor's actions. The decline in R&D during last two decades is probably initiated by common expectations on research prospects. As the mature market oil companies foresaw few profitable research opportunities to improve products and processing, and therefore they reduced their research outlays for developing the technology. The R&D decline is hardly compensated by higher productivity in research laboratories, and thus results in less research outcomes. The mutual R&D-race among competitors intensifies the declining R&D. Oil companies often engage in R&D- races because they can hardly benefit from knowledge spillovers. They mainly apply for patents on similar fields and thus have hardly specialized their research. They often invest in new equipment for upstream activities, such as exploration and oil-production, but focus their R&D mainly on the downstream stage, like development of new and environmental friendlier fuels and innovations in refining. Further, the innovations on their unique production process are strongly protected because oil companies mainly compete on efficient processing and cost savings. The companies must therefore follow competitors' research strategy in order to prevent technological deprivation, cost disadvantage and loss of market share. Following table provides a brief insight of R&D expenditure of majors.

Company	*US Patents issued (2000 – 2007)*	*R & D Expenditure 2006 ($ millions)*	*R & D Expenditure 2007 ($ millions)*	*R & D Expenditure 2008 ($ millions)*
Exxon Mobil	494	712	814	847
Royal Dutch Shell	1033	885	1201	1266
BP	457	462	566	595
Chevron	552	468	562	835
Total	64	715	814	900
Conco Philips	411	117	160	209
ENI	140	278	285	319
Baker Hughes	1164	216	234	263
Halliburton	1475	254	301	326
Schlumberger	1511	619	728	819

Exxon, Shell, Chevron, Total and Schlumberger are the big R&D spenders among the ten majors illustrated in the above table.

The quickly decelerating world economy has affected global research and development (R&D), with some global R&D growth absorbed by the inflation rate for a net result of flat R&D spending. Apart from energy industry, the lower Oil Prices, already in today's uncertain economic climate have exacerbated the disparity between budgeted projections and performance and have diminished the resources available for new R&D investment.

Conclusion:

The investment in research and innovation has led to technological breakthroughs that have significantly improved the productivity of existing discoveries and facilitated access to resources from difficult and unconventional sources.

The oil and natural gas industry has a long history of technological advancement. Many technical advances have been generated directly by research and development (R&D) in industry labs, through field trials, and by applied ingenuity. Globally, it is estimated that the industry spends more than $6 billion annually on oil- and gas-related R&D. This spending is on the upswing, which will result in technological advances we can only imagine today. Enhanced oil recovery and carbon capture and sequestration (CCS) are activities for which significant advances are expected in the coming decades.

In this context it is quite obvious that technological advances destined for hostile, hard-to-reach environments such as deep offshore waters or in the high temperatures and pressures encountered at the bottoms of wells will push the industry to spare a bigger portion of investments in R & D sector while enviornmental laws will be an added force for moving towards green fuels and an enviornment of zero-carbon emission.

It is anticipated that Oil and Gas Industry Investments in the R&D will focus on the research on alternative energy, frontier hydrocarbons and advanced end-use technologies whilst progressing will be observed due to high global demand for electricity and transportation fuels, rapidly growing sectors within the energy field: renewables, solar power & wind turbine systems, most prominantly in bio-fuels and oil-exploration technologies, despite the recent downturn in oil prices. All this means the R&D spending likely will be a work in progress with unforeseen changes affecting the amount of money available, much of that hinging on the eventual price of oil

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