Technology Strategy in the Upstream Petroleum Supply Chain

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SUMMARY

This study focuses on technology activities in the upstream oil & gas industry. Data from the period 1984 to 2002 is studied for evidence. The objectives are to describe technology strategies within this sector and to develop an understanding of how technology-related tasks and the control of technology are distributed throughout the supply chain. Frameworks for decision-making around technology strategy are presented.

Firms that operate internationally and with the widest range of technological capabilities (so technology strategy is not modified strongly by any specialisation) are studied. These firms are large, private international oil companies and large integrated service and supply companies.

Technology has different and distinct capabilities; it is a response to growth opportunities, it is a way to lower costs and it can lower the risks of certain business activities. Firms engage in Research and Development (R&D) to provide new technology. However, R&D is risky due to its typically long payback period and during this time many changes to forecasts and unforeseen paths may arise. These unforeseen circumstances provide unexpexted benefits or expenses. In the context of this report, technology is defined as something that gives the user competitive advantage.

Evidence points to having access to technology as a source of competitive advantage but oil companies and their suppliers have very different competitive objectives and strategies around technology. The former compete over the acquisition, exploration and production of crude oil and natural gas; competition is based on having some lead-time and/or cost advantage in terms of integrating the best technologies into any project. The later compete for the supply of products and services; competition is based on their technology content, quality and price.

The international oil companies (IOCs), who are the traditional big spenders on technology, have reduced their technological activities. Increasingly, the integrated service and supply companies (ISCs) now provide the industry with its technology and related expertise needs. Precise data is difficult to find and often not wholly comparable, but some global figures in Table 1 suggest the transfer of technological activity from the oil firms (technology users) to the supply sector (technology providers). Drivers for the IOCs to divest activities have included the move to asset-based organisations and downward pressure on discretionary spending.

Table 1 highlights that since peaking most recently in the period 1991 – 1992 the R&D budgets of the IOCs have fallen quite steadily and over the period 1984 – 1997. IOC patenting has declined. Since around 1995 R&D spending by the ISCs has risen steadily, as has their patenting from 1984 to 1997. How this spending and patenting have evolved is consistent with the emergence of collaborative networks between the two groups. These collaborative networks have delivered real and evident benefits, including leveraging of IOC R&D budgets. However, these networks have their limitations and weaknesses and their present forms may not always be optimal or sustainable over the long term.

The distribution of spending on technology between oil firms and their suppliers is dynamic. It is driven by oil companies reviewing which activities must be in-house and which can be outsourced. The decision of in-house over outsourced depends upon three factors: the nature of the firm including the preferences of management, the nature of the technologies concerned and the stage of development of those technologies.

Table 1- R&D spending and Patent data summary

R&D spending highlights (sources: company SEC filings, Luca 2003 and Acha 2002)			
Estimate of total R&D spending in upstream petroleum sector	$2.5b to $3b annually		
Estimate of Upstream R&D spending within the oil and supply firms studied here	$1.6b to $1.9b annually		
	1995	**2002**	
Total R&D spend by top 6 ISCs	$477m	$976m	
	1985	**1991**	**2000, 2001**
Total R&D spend by top 6 US IOCs plus BP	$2.2b	$2.3b	$1.2b
Patents and Publications data highlights (source: Acha 2002)			
Average number Upstream technology patents awarded annually	**1984 - 1988**	**1989 - 1992**	**1993 - 1997**
ISCs	209	257	282
IOCs	387	295	159
Other suppliers plus research institutes	366	338	177
Total	**962**	**890**	**618**

Table note: ISC is Integrated Service and Supply Company and IOC is International Oil Company

Despite IOCs having withdrawn partly from innovation and ISCs now increasingly having ownership over technologies (even where these have been developed in collaboration), the incumbent major oil companies remain at the head of many innovation networks, a consequence of their continued responsibility for purchasing decisions and oilfield operations. The major oil companies are therefore in a position to reinforce competitive barriers by influencing or directly controlling the specification and application of many oilfield technologies.

In conclusion, the question for an oil company is not so much which technologies to develop but which technologies to influence and gain access to and the best route for this, from many available. Collaboration with selected external partners, so acquiring competence, access to and influence over technologies but without seeking ownership necessarily, appears a feasible model in many circumstances. Collaborating in networks is a workable and attractive system of innovation and may itself provide competitive advantage.

METHODOLOGY

Extensive literature and data (financial and non-financial) searches have been made. In a study of this nature, data alone is not sufficient and several industry professionals, each working with technology in some way, were interviewed. These structured interviews were conducted between July 2003 and February 2004 with technology and R&D managers in oil and supply firms and with professionals close to the upstream petroleum industry, consultants and researchers for example. Two types of supply firms were interviewed: one firm involved in relatively high technology products and services (Schlumberger) and two firms in relatively lower technology services and construction (Saipem and ENSCO). Technology managers in three oil and gas operator companies (Gaz de France, Shell and Total) were interviewed.

Throughout, the terms $m and $b refer to millions of US dollars and billions of US dollars respectively.

1 - INTRODUCTION

Considerable advances have been made in upstream petroleum, the result of a continuous R&D effort pursued in large part by the International Oil Companies(1) (IOCs) and the Integrated Service and Supply Companies(2) (ISCs). While important contributions have come from smaller or specialist suppliers, smaller oil companies, research institutes and universities, the R&D spending of the IOCs and ISCs has dominated.

In the context of unrelenting scrutiny of company profitability, it is undeniable that innovation around technology plays a fundamental role in controlling costs and risks, and also of realising new business opportunities. This is illustrated in Table 2.

Table 2 - Illustrative technological developments in the upstream oil & gas industry (source: Total)

- Time for 1000 sq km offshore 3D seismic campaign (acquisition and processing)
  - 1985: 18 months
  - 1998: 6 months or less

- Cost of a well (subsea production wellhead) in Norway
  - 1987: $18 m
  - 1991: $13 m
  - 1994: $5 m
  - 1995: $3.8 m

- Orinoco extra heavy crude extraction (a $2b to $4b capital expenditure project)
  - 1985: crude price at over $30/barrel - Orinoco project hardly economical
  - 1998: crude price below $15/barrel - Conoco, Total, Mobil and partners launched the first major Orinoco project

There have been many attempts to investigate a relationship between disclosed R&D expenditure and business performance, for many types of firm. Acha (2002) refers to a 1993 study of 100 oil and gas production firms and 60 service companies around the world that could show no correlation between R&D spending and operating performance. When upstream businesses were looked at specifically, no correlation could be found between R&D and profits, finding rates (of reserves) and production costs. The study's author concluded that enough of the companies had sufficiently equal access to technology (regardless of whether they had invested or not) and this reduced the competitive advantage from having an internalised technological capability. However, Acha argues that R&D spending is an incomplete measure – perhaps a poor measure - of a firm's technological activities and capability. Thus, in seeking a correlation between investing in technology and business performance, disclosed R&D spending is only part of the data to use.

IEEE Spectrum concluded in it's most recent annual R&D spending review that "it is possible to divine some macro trends" but that it is "nearly impossible to assess companies' R&D spending and, by extension, their commitment to competing in dynamic technology markets… comparing one company's R&D spending with another's is a difficult, if not spurious, exercise" (Goldstein and Hira, 2004).

Jonkman and de Waal (2001) describe one method used by Shell(3) of estimating, retrospectively, the return on investment for R&D projects. The approach used is to work at the level of a single business – the organisation responsible for operating a production asset, for example – and define all the costs and benefits associated with an identifiable and successful R&D project, with the active involvement of those close to the project and its implementation. The objective is to demonstrate the profitability of R&D on small projects and hence provide assurance for projects of all scales. The authors reported that these exercises were

(1) The International Oil Companies, the IOCs, as discussed here are listed in page 10
(2) The Integrated Supply and Service Companies, the ISCs, as discussed here are listed in page 11
(3) Royal Dutch / Shell Transport and Trading

conducted from time to time in several business units and the intention was to expand the scheme. Interview with Shell (Luca et al, 2003) confirmed that these exercises are indeed not done regularly. We argue that the method suffers from three shortcomings: the exclusion of unsuccessful projects, the temptation to assign flattering cost/benefit outcomes to successful projects and the assumption that the few projects capable of being so studied are globally-representative. Thus, the method analyses selective R&D projects in a way that may bias the results.

Acha (2002) points out that the long time horizon of R&D projects makes forecasting and then tracking performance difficult, and describes that in practice any company that does this evaluates only short-term or small, easily defined projects in any detail. Upon such evidence, technology managers build the case for longer-term and more ambitious R&D. This does align the priorities of the R&D function with those of the operating business units, towards meeting short-term objectives, but may harm medium - to long-term research and development.

What is certain is that technology is indispensable in the upstream petroleum business, where it is necessary to continuously find and develop new reserves. New discoveries are increasingly remote, hold ever-smaller volumes of oil and gas and present rising exploration and production difficulties. It is, thus, a necessity for oil companies to be able to operate in new geographic locations (for example in deepwater offshore) and with new reservoir types (high pressure fluids, for example). In this report these new areas – geographic and reservoir types – are termed Frontier. Additionally, oil companies must often respond with technology to new business or regulatory constraints.

After a brief description of the actors within the upstream petroleum supply chain, we look at the data describing technological activity, obtained from several sources. How the IOCs and ISCs work together within collaborative networks is then investigated, with the ISCs apparently assuming certain technology activities done previously by the IOCs. However, the oil companies remain in control of many of the decisions around technology and investors in or buyers of technology, and we analyse the parameters that explain IOC technology strategies and that play a part in deciding whether activities should be done in-house or outsourced. Our report concludes by considering frameworks for decision-making around technology strategy.

2 - THE UPSTREAM PETROLEUM ORGANISATIONAL STRUCTURE

The upstream petroleum industry is part of the hydrocarbons industry, itself part of the wider energy sector, and includes all activities involved in the exploration for and production of oil and gas (often referred to as E&P), up to the point of entry or sale into the downstream hydrocarbons industry. Downstream includes refining, chemicals and retail. It is common to use the term Operators for oil companies, as they are responsible for operating the E&P activities. Oil firms present in both upstream and downstream are termed integrated.

The Upstream industry comprises several categories of actors, all within a supply chain, which increasingly collaborate together within networks. This report looks specifically at networks for the innovation of technology.

Jacquier-Roux and Bourgeois (2002) point out that the study of the operator firms in the energy sector must be widened to include their suppliers, as increasingly since the mid-1980s operators and suppliers have collaborated in technology creation. The strategies of operators and suppliers are often complementary; to understand the technology strategies of the operators, it is necessary to study those of their principal suppliers (this close collaboration over technology should not be confused with the suppliers otherwise building their own competitive and bargaining barriers against the oil firms). Thus, although this paper's primary focus is the major private oil companies, it looks at the major service firms (here, the ISCs) also.

2.1. The Players

Only firms that operate internationally and with the widest range of technological capabilities, so technology strategy is not modified by any specialisation, are studied. Also, there is generally wider availability of information on the largest firms.

The technology strategy of individual IOCs and ISCs has not been investigated in great detail, but rather features of the two groups have been looked at, illustrated with specific examples. The strategies of the companies interviewed – Shell, Total and Schlumberger in particular – have naturally been discussed in some more depth.

2.1.1. Oil companies

The core functions of the upstream business of an oil company are securing access to, finding and producing oil and gas, for supply or sale into downstream operations. For this report, two categories of oil companies are recognised:

- Integrated oil companies, whether international (the IOCs) or regional
- Non-integrated, or independent, oil firms (often with exploration or production activities only)

The National Oil Companies (NOCs) are largely excluded from our discussion as their input to technology at an international level is marginal (with some exceptions like Petrobras in deep offshore) and reliable, meaningful data is not always available.

Throughout the 1980s and 1990s there was much consolidation between both oil companies and suppliers. Consolidation among the major oil companies occurred in two waves, the first triggered by the 1983 purchase of Gulf Oil by Standard Oil of California to form Chevron. Consolidation over the following three years involved 50 oil firms in the US alone (Acha, 2002). A second wave, one that formed the present very largest oil companies, started with British Petroleum's 1998 purchase of Amoco. The increasing purchasing power of these enlarged oil companies combined with them seeking to reduce their procurement management costs were factors that led the service sector to itself consolidate.

Among the private companies, the following six and their predecessors (prior to mergers and acquisitions) are detailed in this report.(4)

List 1 - The IOCs

- ExxonMobil ($309 b), formed by the 1999 acquisition of Mobil by Exxon
- Shell (Royal Dutch/Shell Transport and Trading) ($180 b)
- BP ($198 b), formed by the 1998 acquisition of Amoco by British Petroleum, with Arco (Atlantic Richfield) acquired later the same year
- Total ($129 b), formed by the 1999 acquisition of PetroFina by Total, with Elf (Elf Aquitaine) acquired in 2000
- ChevronTexaco ($108 b), formed by the 2001 acquisition of Texaco by Chevron
- ConocoPhillips ($54 b), formed by the 2002 acquisition of Phillips (Phillips Petroleum) by Conoco

With one notable exception, these are the IOCs that have reported the highest R&D spending in the period studied (1984 to 2002). The exception is the Italian firm ENI, historically a big spender on R&D - in recent years over €200 million annually – but for which a sufficiently long time series of R&D expenses could not be found. There are other private integrated oil firms operating internationally, but their R&D expenses are substantially below those of the IOCs.

The scale of R&D spending within the companies chosen varies greatly (as illustrated later in Table 3). Acha (2002) advises, however, that among the large IOCs scale effects in R&D are not significant. Thus, it is possible to compare the technology activities of these companies without making allowances for scale.

2.1.2. Oil service and supply sector

The oil service and supply sector works under subcontract to the oil companies in the development and operation of oilfields and also of technology. The sector's activities include geophysics (acquisition, processing and interpretation of seismic data), drilling and associated services, engineering, subsea work (laying of pipes, for example) and the construction of oilfield facilities. There are a multitude of suppliers and service providers.

What all of these enterprises have in common is that they are service companies to the oil industry; first-, second- or even higher-order service providers (depending on the number of subcontract tiers). Traditionally, oil companies themselves designed, planned and carried out oilfield exploration and development engineering. The service companies performed various limited tasks under the permanent oversight of the client's coordinating personnel. Up to 50 separate contracts, often more, being co-ordinated by the IOC in any one project was not uncommon.

Oil firms used to be uniformly highly vertically integrated with their supply functions, but this has been for many years generally reversing. More recently, the oil companies have focused on what they regard as their core business and have outsourced a large number of activities to oil service and supply firms. These subcontracted tasks are managed through service contracts(5). This appraisal of what is core, to what extent to outsource activities and what form outsourcing will take has preoccupied the oil firms since at least the early 1990s.

The ISCs are characterised by a high technology content in their products and services, and they compete on the basis of the technology content, as well as cost and delivery. In contrast, the construction and drilling companies are characterised by more standardised products and services and compete on the basis of execution and cost; spending on technology is less important for these companies. The products and services

(4) Market values of these oil companies at 17 September 2004, from The E&P Daily, Ogilvie Publishing
(5) Under a service contract the primary contractor becomes responsible for oversight of all project activities

offered by construction and drilling firms typically have a lower technology content and these firms are not our primary focus here. The following six ISCs are detailed in this report(6) :

List 2 - The ISCs

- Schlumberger Ltd. ($38 b) (NYSE stock symbol SLB)
- Baker Hughes Inc. ($14 b) (BHI)
- Halliburton Company ($14 b) (HAL)
- Smith International Inc. ($6 b) (SII)
- Weatherford International Ltd. ($6 b) (WFT)
- BJ Services Company ($8 b) (BJS)

We identify this group of six firms as constituting the international and integrated service and supply segment (these six firms are also the biggest spenders on R&D in the supply sector). Other supply firms are described in filings as being regional or not sufficiently integrated (lacking a sufficiently complete range of service and supply).

2.1.3. Research Institutes

Research institutes, national laboratories and universities are also involved in technology creation for upstream petroleum but are not studied in this paper. Interactions between these and IOCs are very different to those between IOCs and ISCs, and their R&D spending is relatively small.

2.2. The upstream petroleum "supply chain"

This report uses Supply Chain in its title to emphasise that, as with many industries, upstream petroleum relies on a chain of supply; supply of goods, services, capital and labour. This report is about technology in this industry, and the two items – technology and the supply chain – are treated together. Technology strategy can be seen as a major influence on the supply chain, in terms of which technology tasks are performed where. The supply chain adjusts dynamically in response to environmental changes (e.g. the market, regulation, competition); the shape of the industry is not fixed. One of the important features of upstream petroleum is the strong interdependency of the different companies involved. The service companies depend for most of their revenue on the major oil companies, who naturally rely on a pool of suppliers for goods, labour and services.

The UK government established the CRINE initiative (Cost Reduction In the New Era) in the 1990s to help the UK oil industry continue to operate under conditions of low oil prices and increasingly economically marginal oil fields. The CRINE Supply Chain work group reported in April 1999 that UK firms were failing to manage supply chains at all well and were not treating SCM (Supply Chain Management) as strategic (Offshore Technology, 1999). Among the group's recommendations were two relating to technology:

- Suppliers (suppliers of goods) and contractors (suppliers of services and labour) must be involved early in a project, to provide technical expertise and help deliver creative solutions
- Customers should provide functional specifications for goods and services to suppliers, not technical specifications. This is to promote innovation within suppliers and encourage the whole sector to be less risk averse.

(6) Market capitalisation of these companies at 17 September 2004 from The E&P Daily, Ogilvie Publishing

3 - PROXY DATA DESCRIBING TECHNOLOGICAL ACTIVITY

In the upstream oil and gas businesses, competitive advantage for oil firms is based largely on access to reserves and capital, and also, we argue here, to technology and the capability to absorb technology and to innovate.

This report studies technological innovation. Innovation takes many forms within upstream petroleum: business models, organisational forms, human resource management and finance strategies, to name a few, and all of these forms, including their interdependencies, must not be overlooked. All must be innovated upon, to respond to the dynamics of the competitive environment.

Literature (see for example Robinson, 1994) describes three functions of technology:
1. Create and capitalise upon opportunities (i.e. where absence of the technology would prevent or retard any involvement)
2. Bring cost advantages (i.e. lower operations costs vis-à-vis competitors)
3. Reduce risks (i.e. ability to place higher certainty on outcomes, reserves estimates for example)

The upstream oil and gas business environment is favourable to technological change, since such change offers the possibility of achieving some competitive advantage. Therefore, operators will invest in innovation – whether alone, in collaboration or bought from others – subject to their ability to apply the technology in their portfolio of assets. This is functioned upon the ability of operating units within oil firms and also technology organisations to absorb new technology.

The external evidence used normally to study an oil company's technology strategy is proxy data: disclosed R&D spending, patents applied for and granted and technical/scientific articles published (by the company and it's employees). Additionally, other data can be gathered, such as from different forms of corporate communications. Finally, expert opinion and interview with technology managers and other specialists are essential complements to all this data.

This data must be interpreted with care and the following points should be noted.

- **Poor taxonomy of R&D spending data**

The US Department of Energy's Pacific Northwest National Laboratory makes the following points on collecting and analysing data on energy R&D (PNL website), a definition for which varies from source to source. Many international organisations collect and publish energy R&D data, but much of this is government spending only. Private company R&D spending is surveyed by certain government agencies and industry associations (notably in the US, the Energy Information Administration and the Gas Technology Institute), but this data can suffer from poor taxonomy: the R&D figures supplied may not be strictly comparable across all questionnaire respondents and will likely not be comparable with figures from other sources. For example, the Energy Information Administration's (EIA) data excludes a portion of R&D spending (certain subcontracted R&D and R&D by smaller oil and gas producers).

- **Over-aggregated data**

Many of what are often highly diversified and global firms report just a single R&D value once per year, to account for R&D activity across all their businesses. There is a wide variety of product and service offerings across the service sector and of businesses across the oil companies, so comparing R&D spending between companies and between sectors is not straightforward. The reported values are over-aggregated.

FASB (the US Financial Accounting Standards Board) first required US-listed firms to disclose R&D expenditures in annual accounts from 1974 and published a definition of R&D from 1975 (Petersen, 1980 and FASB, 1974). In a few rare instances, Upstream companies disclose R&D data in quarterly accounts (Schlumberger and Shell). Most of the largest service firms detail R&D for their oilfield and non-oilfield businesses; Schlumberger and Halliburton report a value for their Oilfield and Energy Services businesses respectively and the other ISCs provide some percentage breakdowns. Of the major oil companies only Elf and ENI ever gave such a breakdown annually. Some R&D spending data specific to upstream activities is available and Acha (2002) and the EIA provide some aggregated data on US oil company Upstream-only R&D spending.

- **Accounting standards**

The R&D spending values given in financial statements respect the accounting standards followed by the companies (accounting standards specific to R&D include international accounting standard IAS 38 Intangible Assets from IASB and US standard FAS 2 from FASB). Although all companies apply these standards rigorously, what spending meets certain criteria and hence qualifies as R&D is ultimately a management decision. The accounting criteria are very conservative, so it follows that spending on technology development by firms, both oil companies and their suppliers, is higher than the disclosed R&D values. This has been confirmed by interview. The R&D budget values used for internal management purposes reflect different criteria to those mandated for published accounts.

Some authors (Mansefield, 1968 – quoted in Acha 2002 – and Petersen, 1980) have pointed out the inconsistencies of certain costs being proscribed by accounting standards from being counted as R&D. Exploration costs, for example, despite undeniably providing "new knowledge" (one of the R&D qualifiers, see FASB, 1974), cannot be included as R&D. Acha notes that in process industries it is not uncommon for operations expenses to include items that could be argued are legitimate research or development costs, but that fail the accounting criteria.

- **Organisational design and management philosophy**

Fieldwork and literature suggest that how technological activity is organised and management's attitude to R&D has a large influence on whether money spent on research and development is reported as such or under another expenditure item even where such spending meets accounting criteria for R&D. When IOCs were organised with centralised research departments, it was straightforward to assign costs to R&D, apart from exceptional projects that might be undertaken. However, as these R&D silos were dismantled and their staff distributed among project organisations (with the added complexity that activity moves between projects) accounting against R&D became more complex. Spending that could otherwise be reported as R&D is spread around possibly several expenditure items.

- **Prior-period restatements due to acquisition and disposal transactions**

Among the oil and service companies there have been many prior-period restatements of R&D expenditures, owing to acquisition and disposal. For example, Halliburton's 1996 acquisition of Landmark Graphics Corp. boosted HAL's R&D figure by around $20m. Exxon's 1999 purchase of Mobil Corp. added around $200m to R&D expenditures. Schlumberger sold several businesses during 2002 and its disclosed R&D consequently fell. These increases and decreases do not, however, represent necessarily any change in R&D spending in the upstream petroleum sector as a whole. The spending was already being made or will continue to be made by another company. To arrive at a complete picture, it would be necessary to account for these R&D sums, but this is only possible where the spending was disclosed prior to the combination or continues to be disclosed after disposal, which is rare. Also, a charge for In-Process Research and Development (IPRD) may often be made to R&D following an acquisition, boosting the disclosed R&D. For example, Baker Hughes' 1997 R&D spend included $118m IPRD linked to its purchase of Petrolite Corp. Thus, it is not straightforward to arrive at a complete picture of whole-sector R&D spending, and the data must be interpreted with this in mind. For these reasons, generally only the largest acquisitions and disposals have been corrected for in the data presented here.

- **Message to the market**

Jacquier-Roux and Bourgeois (2002) charge that companies in the energy sector report R&D values according to what message they want the market to receive. Given the evolution of technology strategies and reported R&D figures since the mid-1980s it would appear, using Jacquier-Roux and Bourgeois' logic, that oil service companies have sought to report high and rising spending and oil firms the opposite. To recall what has been stated earlier, management does have some reasonable discretion in deciding what qualifies as R&D expense, while all the time respecting the accounting standards.

Despite these limitations, however, the aggregated R&D spending across all the major firms in the sector is believed to give a fair picture of underlying expenditure magnitude and trend. We now look at the R&D expenditure data gathered. It is noted that a source of error is that dollar values shown in non-US company accounts and SEC filings are calculated using currency exchange, not PPP(7), rates.

3.1. Presentation of R&D expenditure data sets

This data for IOCs and ISCs is reviewed. The main elements are presented here and several graphs of expenditure are shown in Appendix A.

Figure A1, Appendix A, shows upstream R&D spending by the IOCs and ISCs in the range $1.6 - 1.9 billion in the period 1998 -2002. A recent estimate (Luca, 2003) of total R&D spending in upstream petroleum is $ 2.5 - 3 billion. Hence, the spending totals shown in Figure A1 account for the majority (in the range 60-70%) of total research and development spending in the sector.

Total disclosed R&D expenditures of the large oil companies have declined greatly since peaks in the mid 1980s and early 1990s, while those of the major suppliers have increased markedly in the same period. Total R&D spending by the US's largest oil firms(8) declined from over $2.2 billion in 1985 and $2.3 billion in 1991 to $1.2 billion in both 2000 and 2001 and a similar pattern was repeated by major oil firms elsewhere. Spending among the major oil companies has recovered a little since 2001. Illustrative R&D spending figures are quoted in Table 3.

Table 3 – The top 4 spenders on R&D (sources: Value disclosed in company SEC filings)

Values in $m, acquisitions accounted for	2002	2001	2000	1999
Shell	472	387	389	505
Total	662	695	686	715
Exxon Mobil	631	603	564	630
BP	373	385	434	310

Data gathered on the ISCs indicates that their R&D expenditures rose quite steadily just as IOC spending was declined (see Figure A2, Appendix A). Total disclosed R&D for the six suppliers investigated more than doubled over seven years, rising from $477m in 1995 to $976m by 2002.

Table 3 presents some R&D spending values for the larger IOCs. These illustrate generally the decline in expenditure through to 2000 and 2001 followed by some recovery in 2002. It is noted that the data is total R&D, not upstream activities only. The Upstream component of total R&D is anywhere in the approximate range 20 – 40% (see Table 4 and subsequent discussion), hence a precise ranking of Upstream R&D cannot be obtained from Table 3.

(7) Purchasing Power Parity, which is the currency exchange rate to apply when comparing the cost of a fixed amount of something (here, a quantity of upstream oil & gas R&D activity) between countries

(8) In 1985 these were Exxon, Mobil, Chevron, Texaco, Phillips, Atlantic Richfield (or Arco), Standard Oil of Indiana (later Amoco) and British Petroleum

3.1.1. US major oil company R&D spending

This data, for 1979 to 2000, is graphed in Figure A3, Appendix A. Consolidation among the major oil companies has happened most recently in two waves: from 1983 when Chevron was formed and then from 1998 when ExxonMobil, ChevronTexaco, ConocoPhillips, TotalFinaElf (renamed Total) and BP formed (British Petroleum bought Amoco to become BPAmoco and then Arco was added, to form what is now BP). Thus, the most recent round of consolidation was truly substantial and complicates interpretation of R&D figures in the period 1998 to 2001.

3.1.2. International Energy Agency (IEA) member state energy technology R&D for oil and gas

This data, for 1974 to 1998, is graphed in Figure A4, Appendix A. The reductions in R&D spending among the privately owned IOCs matches the fall in state financial support for oil and gas research. The 26 member states of the IEA (a sub-set of OECD countries) include the home countries of all the world's major IOCs and include no OPEC countries. The IEA data is thus a reasonable comparator with IOC data for R&D spending(9).

3.1.3. FRS companies R&D spending (total and upstream)

Data for 1983 to 2001 is graphed in Figure A5, Appendix A. The EIA collects data for its Financial Reporting System (FRS) database from all the main oil and gas producers in the US (numbers surveyed vary, there were 25 in 1983 and 33 in 2000, for example). Upstream R&D as a % of Total R&D, calculated from the FRS data, is presented in Table 4.

Table 4 - FRS companies Upstream R&D as a % of total R&D (sources: data shown in Figure A3)

	Top 6 (Note)	Total sample
1983	28,3%	
1984	25,4%	
1985	31,4%	
1986	30,5%	
1987	34,7%	19,1%
1988	37,0%	19,6%
1989	32,9%	18,7%
1990	31,8%	18,6%
1991	32,4%	20,3%
1992	30,0%	20,9%
1993	28,5%	19,7%
1994	26,8%	18,8%
1995	27,0%	17,3%
1996	27,0%	17,7%
1997	31,1%	20,3%
1998	34,0%	35,5%
1999		30,2%
2000		34,2%
2001		37,7%
Average	30%	23%

(Note – for reasons of confidentiality, the Top 6 companies are not identified specifically)

(9) It is noted that IEA has prepared its data using Year 2002 exchange rates to the US dollar, rather than the PPP rate for each year

Acha (2002) provides FRS data aggregated over just the top six FRS firms, and different behaviour is observed between the two data sets, as shown in Table 4. Notably, R&D for upstream activities appears to have concentrated within the largest firms. Data after 1998, which includes the most recent industry consolidation, is not available at the time of writing.

Acha found that for the years 1983-1998 the Upstream part of total R&D spending was in the range 25-37% for the top six US major oil companies (this is an average for all six and the range is therefore wider). The average overall was 30% but this is a guide only. For example, Elf, prior to its acquisition by TotalFina, disclosed that 16% of its total R&D costs (most of them spent by Sanofi) were for Upstream activities (Elf annual report, 1999). Thus, Upstream R&D is a minority component of total R&D for oil companies, which makes it difficult to analyse in detail technology strategy within upstream businesses using R&D figures only.

After Acha, we apply the value of 30% calculated from the FRS Top 6 data to the three European IOCs to estimate their Upstream R&D spending. This approach has one important drawback: it ignores the asset-specificity of technology strategy for a group of firms characterised by great differences in assets. Characterising the European firms' R&D spending patterns – which are factored upon differing portfolios of assets, management decisions and investment cycles - based on US company data introduces uncertainty into the estimates. This is, however, the best estimating technique available to us.

3.1.4. Upstream R&D spending for ISCs and IOCs separately

R&D spending is graphed in Figure A2, Appendix A, for various dates from 1991 to 2002. R&D expenditures have not been found for every company in every year, therefore data are plotted over several time series. Approximate Upstream R&D and estimated Upstream R&D is plotted for ISCs and IOCs respectively. The 30% average value calculated in Table 4 is used to estimate IOC Upstream R&D (the US Top 6 correspond closely with the IOC group). The ISCs disclose sufficient information about how much of their R&D budgets is dedicated to Upstream petroleum activities for a good approximation to be made.

3.1.5. Upstream R&D spending for ISCs and IOCs combined

Data is graphed in Figure A1, Appendix A, for various dates from 1991 to 2002. The same source data as used in Figure A2 is plotted in Figure A1 but ISC and IOC Upstream R&D expenditures are combined and adjusted to Year 2002 dollars using 2.5% inflation in all years. This is done to observe how upstream petroleum sector R&D spending has evolved overall. The combined spending of the largest oil firms (six IOCs, having consolidated from 13 in 1998) and ISCs has remained reasonably stable since at least 1996. This is the same conclusion as described by Luca (2003): Upstream R&D has remained fairly stable in recent years, thanks to increased ISC expenditures.

3.1.6. Factors behind the decline in IOC R&D budgets

Dooley (correspondence, 2004) explained that a contributor to falling operator R&D budgets was the progress made in technologies like 3D seismic and Measurement-While-Drilling (MWD) during the 1980s. This progress rapidly satisfied many of the technology challenges of the time and continued R&D spending at the old rate would have been unproductive. Fagan (1997) estimated that finding and development costs fell sharply from the mid-1980s. There are two probable contributors to this fall: scale effects following the industry consolidation begun in 1983 and the technological innovations themselves. Acha (2002) provides a different explanation: the major oil companies concluded that both the low oil prices seen in 1985 – 1986 and rising production costs were here to stay, and cost-cutting was therefore necessary.

3.1.7 Evidence of dynamic equilibrium of distribution of R&D between operators and suppliers

ISC R&D spending has been rising steadily since at least 1995 and IOC R&D spending has fallen steadily since the period 1991 – 1992. However, IOC spending has shown a slight recovery in 2001 and 2002

generally and, although ISC spending on R&D remained strong through to 2002, the most recent quarterly data reveals that the direction of the trend can change. Shell and Schlumberger are unique among the IOCs and ISCs in disclosing R&D expenditure (a total value) quarterly (see Figure A6, Appendix A). Shell's R&D has been rising since 2001 and Schlumberger's has been falling since 2002 (the exchange rate between the €/£ and the $ is a part of the explanation of this new trend). Thus, there is no certainty that the divergence of IOC and ISC expenditure on R&D, seen over the last ten years, will continue.
Managers in both Total and Shell did speculate (interviews with Préel, 2003 and Luca et al, 2003) that there could be scope to reassess the distribution of technology tasks throughout the supply chain.

3.2. The transfer of technology activities from oil companies to their suppliers

Downward pressure on discretionary spending forced oil firms to reduce R&D (a particularly visible expenditure due to the requirement to report it separately in accounts) and oil firms then began outsourcing some R&D activities as a way of maintaining innovation. Jacquier-Roux and Bourgeois (2002) describe that British Petroleum outsourced either entirely or in collaborative partnership all "pre-competitive" (p. 404) research and development from the early 1990s.

Tecnomare[(10)] in a 1996 report for the European Commission concluded that oil companies had reduced their involvement in managing technology projects as well as their investments in technology (First Break, 1997), and "much of the initiative and responsibilities in technology development as well as project accomplishment is now left to the contracting industry" (p. 24).

Jacquier-Roux and Bourgeois (2002) describe that oil operators have generally (not always, see Shell p.24-25) followed the established trend: shifting from an in-house, integrated strategy toward an external, co-ordinated network strategy. This trend is described in the context of evolving generations of R&D by Amidon (1996). Contrary to Tecnomare, however, Jacquier-Roux and Bourgeois concluded that the larger oil companies, able to afford it, have retained effective technological and innovation capabilities in-house (often biased toward core technologies) and so have retained the option of being technical leaders.

However, smaller oil operators – in reply to cost pressures - did not retain their strong technical competences to the same extent and have moved toward "follower" strategies of subcontracting innovation and sourcing technology, or perhaps specialising in niche technologies only (Koen, 2001).

It is our contention that whether the control of a particular technology has remained with any IOC or been assumed by its suppliers is context-dependant, with one factor being the strategic importance of that technology to the IOC's portfolio of assets. In the case where technological capability shifted to external firms then the "dynamics of learning" (Jacquier-Roux and Bourgeois, p 414) (an essential function that must be done somewhere in the supply chain; akin to moving along the learning curve through developing and using) moved also.

3.3. Benchmark Ratios: The information that emerges from the data

To compare spending on R&D among the IOC firms, the disclosed R&D values are expressed in a number of different ratios. The principal ratios discovered during our research are described here.

The large US oil firms appear to benchmark R&D amongst themselves. Data gathered by Acha (2002) suggests that the three largest firms - BP, ExxonMobil and Shell - are one peer group and the remaining IOCs are a second peer group. However, there does not appear to be any further sophistication in how the peer groups are defined or positions ranked.

All of the Benchmark ratios discovered have their limitations. None, for example, account for the variations in asset portfolios, hence the underlying technological challenges, between the major oil companies.

(10) An upstream oil & gas engineering design and consultancy firm, part of the ENI group of companies

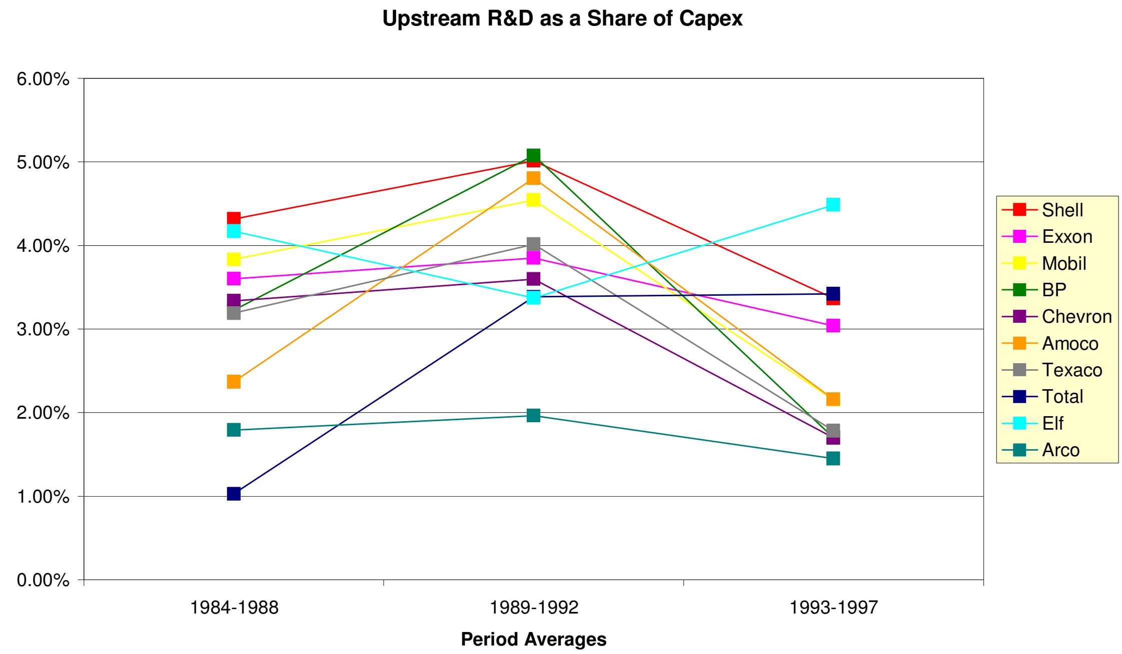
- **Upstream R&D/Capex Ratio**

Acha (2002) reported that oil firms benchmark R&D spending in their upstream businesses using this ratio, where Capex is total capital expenditure and exploration costs. The ratio gives an idea of Upstream R&D relative to total discretionary spending. The limitation of this ratio is that the disclosed R&D value is not a wholly precise measure of research and development activity or of wider technological activities. R&D spending is much less transparent than many other cost items.

Acha showed there had been some convergence in this ratio among the major oil companies since the mid-1990s, shown in Figure 1. She concluded that the convergence was "as much the result of mimicking behaviour as of long-term changes in market forecasts" (p 125) and goes on to relate the rationale of a technology manager in Arco. Since there are no objective criteria to guide R&D investment then maintaining position within the peer group was the only way to satisfy the firm's finance committee. The manager is quoted as saying of the peer group that "If we all have it wrong then at least [Arco] has not lost any ground" (p. 143). Acha goes on to say about firms' attitude in general to technology that:

> "companies actively explore and occasionally adopt the attitudes of peer[s] to matters of operation, investment and technology once they appear to have been proven. This bandwagon effect is an expected outcome of the process of learning and justification in an uncertain environment" (p. 143).

Figure 1 - Estimated Upstream R&D as a share of Total Capital and Exploratory Expenditures (Capex), by period averages (reproduced from Acha, 2002)



It is noted from Figure 1 that Upstream R&D was small relative to Capex, in the range 1-5%. In 2001, global E&P expenditure for the six IOCs was $39.9 b (Salomon Smith Barney, 2002), compared with $2.4 b in total disclosed R&D (or an estimated $0.8 b for Upstream R&D).

- **R&D/Turnover Ratio**

As illustrated in Table 5 petroleum industry firms spend relatively little on R&D, both in absolute terms and as measured by R&D intensity (i.e. as a percentage of turnover), in comparison with other industrial sectors. But, this comparison deserves closer inspection.

R&D intensity is a very common measure of R&D spending, especially as a way of comparing different sectors and, often, individual firms. The ratio is frequently used as a proxy for entire technological activity.

However, we argue here that the ratio has no meaning at the sector level and must be used carefully when comparing between firms within a sector. Petersen (1980) observes that turnover overstates the size of petroleum firms relative to their R&D opportunities and that the disclosed R&D values are in any case ambiguous and spillovers exist between sectors. He found that oil firms' R&D spending was in-line with the technological opportunities available in upstream petroleum and that their innovation rates, shareholder returns and productivities each compared well with those of other sectors.

Table 5 - R&D intensity for several industrial sectors (source: Technology Review 2002, except ISC data, which is from company accounts for financial years ending in 2001)

Sector	Average R&D spending of top 4 firms by R&D spending	Average R&D intensity of top 4 firms by R&D spending
IOC (ExxonMobil, Total, Shell, BP)	$459m	0.3%
ISC (Schlumberger, Halliburton, Baker Hughes, Smith International)	$277m	2.7%
Automotive	$5914m	4.0%
High-Technology conglomerates	$1254m	5.1%
Chemicals	$1518m	5.7%
Computer hardware	$3358m	6.4%
Aerospace	$1885m	8.4%
Electrical and electronics	$4596m	9.0%
Computer software	$1734m	15.9%
Pharma and medical	$4340m	16.3%
Semiconductors	$1965m	18.0%
Telecommunications	$4048m	19.2%

Note: The tabulated data is derived from total R&D spending and total revenues for the companies

- **R&D / Barrels oil equivalent production and Upstream R&D / Upstream Revenues**

Interviews highlighted two more benchmarks used by Upstream petroleum technology managers to rate spending against peers: Upstream R&D / Barrels oil equivalent production and Upstream R&D / Upstream Revenues. Illustrative values for these ratios are given in Table 6. Both ratios rely upon an estimate of the value of Upstream R&D, for which we use 30% of total R&D (as calculated in Table 6) and the approximate nature of the estimates must be borne in mind when interpreting these benchmarks. The second ratio – the Upstream R&D Intensity – is influenced by movements in oil and gas price, set by the external market and little to do directly with the costs of production. This can cause apparent volatility over time in this benchmark.

Table 6 - Comparison of ratios for selected IOCs (source: company accounts for year to 31 Dec 2002)

	Upstream R&D (estimated)/BOE production	**Upstream R&D (estimated)/upstream revenues**
EXXON MOBIL	0.12 $ per BOE	1.1%
SHELL	0.10 $ per BOE	0.5%
BP	0.09 $ per BOE	0.4%
TOTAL	0.25 $ per BOE	1.3%

Note: BOE = Barrel oil equivalent

3.4. Presentation of Patent data sets

Companies often disclose how many patents have been applied for or granted each year but specialist data sources must be consulted to provide classified information. Acha (2002), for the years 1984 to 1997, and Jacquier-Roux and Bourgeois (2002), for the years 1985 to 1998, have provided some data, mostly aggregated across companies and patent classes.

Bourgeois and Jacquier-Roux have confirmed a strong and positive correlation between R&D spending and patenting for upstream petroleum, as has Acha. The benefits of patenting can be numerous but often uncertain and difficult to quantify. There are several reasons for an inventor to patent a novel technology:

- Wish to commercialise for external application (to sell a product or service, licence the technology, etc.). In this case, a patent is necessary to avoid direct copying of the technology and slow the development of substitutes by others. Also, having a patent is some protection against being challenged with infringement.
- Wish to develop for internal application, hence need to ensure access. If the technology is for internal use only then the risk of diffusion is less but a patent is still valuable to avoid others blocking use of the technology via infringement claims.
- Wish to exert control over a third party likely to need the technology. Whether or not the technology is to be developed fully for use (internal or external), a patent can be used to block or frustrate rivals developing or accessing particular technology.
- Wish to signal (for internal and/or external purposes) strength in a particular area. This at least indicates where a firm believes its technological strengths are greatest. This is to gain advantage in winning access to oilfields, forming partnerships, raising capital and attracting talent, for example.
- Share information within and without the organisation.

It appears in upstream petroleum that high diffusion and limited shelf-life of technology mean that, normally, IOCs patent only where a technology is needed for internal use; to stop others blocking access. Where IOCs do patent, this is less concentrated in established technologies since there is competitive supply and lower potential for competitive advantage. IOCs most commonly patent where Frontier technologies are used in their own businesses, to secure ownership. There is limited availability of Frontier technologies from suppliers and the competitive advantage from Frontier technologies is potentially high, making it sensible for oil firms to own and control these.

The decision of whether to seek Intellectual Property Rights (IPR) for innovation or to rely on trade secrecy is complex. There is evidence that the decision is both situation- and firm-specific. It is, however, difficult to circumscribe a particular process or method (as opposed to product) using patents and fieldwork has not found any IOCs using patents in this way. Rather, if management does decide to patent, it is to secure access to a technology it intends to use, rather than to block others' access to the technology.

3.4.1. Variations in propensity to patent

Patenting activity categorised by upstream petroleum technology types is available (further detail is given in Table A1, Appendix A) so it is possible to seek explanations for patenting behaviour (and the differences in patenting between firms) from firms' upstream petroleum activities. According to Acha (2002), Shell demonstrates a strong performance throughout the period 1984 - 1997, which she ascribed to the technology being developed for the North Sea in the 1980s and later for the Gulf of Mexico, particularly the deepwater zones. Elf Aquitaine had been spending hugely on R&D, but patented little, and this is likely evidence of a decision to not disclose rather than a true indication of innovation activity or innovation success. Similarly, Total was a particularly weak patentee, despite being a moderate spender in upstream R&D, according to Acha's estimates. Conversely, the US firms Arco and Mobil patented much more than would have been anticipated from their R&D spending, which was relatively low.

There are systematic differences between companies, industries and countries in terms of propensity to patent. In this study, by focusing upon the most international firms in only the upstream oil and gas sector, the first two factors are minimised. A detailed study of country differences has not been done.

3.4.2. Worldwide patent data

Table 7 - Annual patents data, global, 1984 and 1996 (derived from Acha, 2002)

	1984	**1996**
Top ISCs*	234	415
Top 10 IOCs**	404	110
Sub-total	638	525
Top Research Institutes***	155	67
Top 10 Suppliers (non ISC)****	236	108
Total	1029	700

From Derwent Scientific and Patent Information, patent classes H01-A (Exploration), H01-B (Drilling), H01-C (Well completion, stimulating and servicing) and H01-D (Producing)
**The top 4, 5 and 6 ISCs (not specifically identified) are variously used in Acha's data*
***Exxon, Mobil, Chevron, Texaco, Amoco, Arco, British Petroleum, Shell, Total, Elf*
**** The top 6, 8, 9 and 10 Research Institutes are variously used, but are not identified specifically*
*****The companies are not identified*

Acha (2002) shows a general decline of 8% annually over the period 1984-1996 in patenting activity across the major oil companies, but with great differences between firms (see Figure A7, Appendix A). She ascribes the decline to three effects: changes in propensity to patent, changes in total underlying innovation activity (in the case where all categories follow the trend), changes in the technological requirements prevailing (in the case where individual patent categories move independently). Efficiency or productivity differences between R&D organisations, which could account for differences in output, have not been considered closely. These were not identified by any interviewee or prior literature as significant. A plausible explanation for the decline in operators' patenting, aside from their reduced R&D spends, is their progressive concentration upon exploration techniques and methods. These lend themselves less well toward being patented and there is less reason to patent these (lower observability(11), hence lower diffusion).

As Table 7 illustrates, overall patent activity for all four Derwent classes has fallen over the period 1984 - 1996. This is especially true for Production technologies, which declined by 80%, most of this due to the IOCs (this detail is revealed in Table A1, Appendix A). Producing technologies are more mature than the other classes of technology, hence offer less competitive advantage for vendors and users and attract less investment in innovation.

(11) Observability = to understand how a technology functions simply be observing its operation

Table 8 - Annual average number patents, global data, 1984 – 1997 (Derived from Acha, 2002)

	1984 - 1988	1989 – 1992	1993 - 1997
Top ISCs*	209	257	282
Top 10 IOCs**	387	295	159
Sub-total	596	552	441
Top Research Institutes***	138	202	81
Top 10 Suppliers (non ISC)****	228	136	96
Total	**962**	**890**	**618**

Data is for Derwent patent classes H01-A (Exploration), H01-B (Drilling), H01-C (Well completion, stimulating and servicing) and H01-D (Producing)
**The top 4, 5 and 6 ISCs (not specifically identified) are variously used in Acha's data*
***Exxon, Mobil, Chevron, Texaco, Amoco, Arco, British Petroleum, Shell, Total, Elf*
**** The top 6, 8, 9 and 10 Research Institutes are variously used in Acha's data, but are not specifically identified*
*****The companies are not identified*

The data in Table 7 is supported by the data in Table 8. Patenting activity has shifted to the ISCs but there has been a decline in overall patenting activity. The IOCs have steadily reduced their patenting throughout the period. There has been an apparent polarisation in patenting within the suppliers, with activity concentrating within the ISCs at the expense of the smaller suppliers.

3.4.3. US patents data

Table 9 - Patenting by major oil operators and major suppliers, US only, 1985 - 1998 (Source: Jacquier-Roux and Bourgeois, 2002)

	1986*	1989*	1992*	1995*	1998*
Oil operators	876	833	509	546	260
Oil suppliers	622	618	524	841	768
Total	**1498**	**1451**	**1033**	**1387**	**1028**

1986, 1989*, 1992* and 1995* represent the cumulative of 1985 through 1987, 1988 through 1990, 1991 through 1993 and 1994 through 1996 respectively. 1998* is the total of 1997 and 1998*
Oil operators is 18 oil companies, including the Top 10 IOCs. Oil suppliers is 28 suppliers, including the largest ISCs
Patent data is from Derwent, covering all oil and gas exploration and extraction classes, US patents only

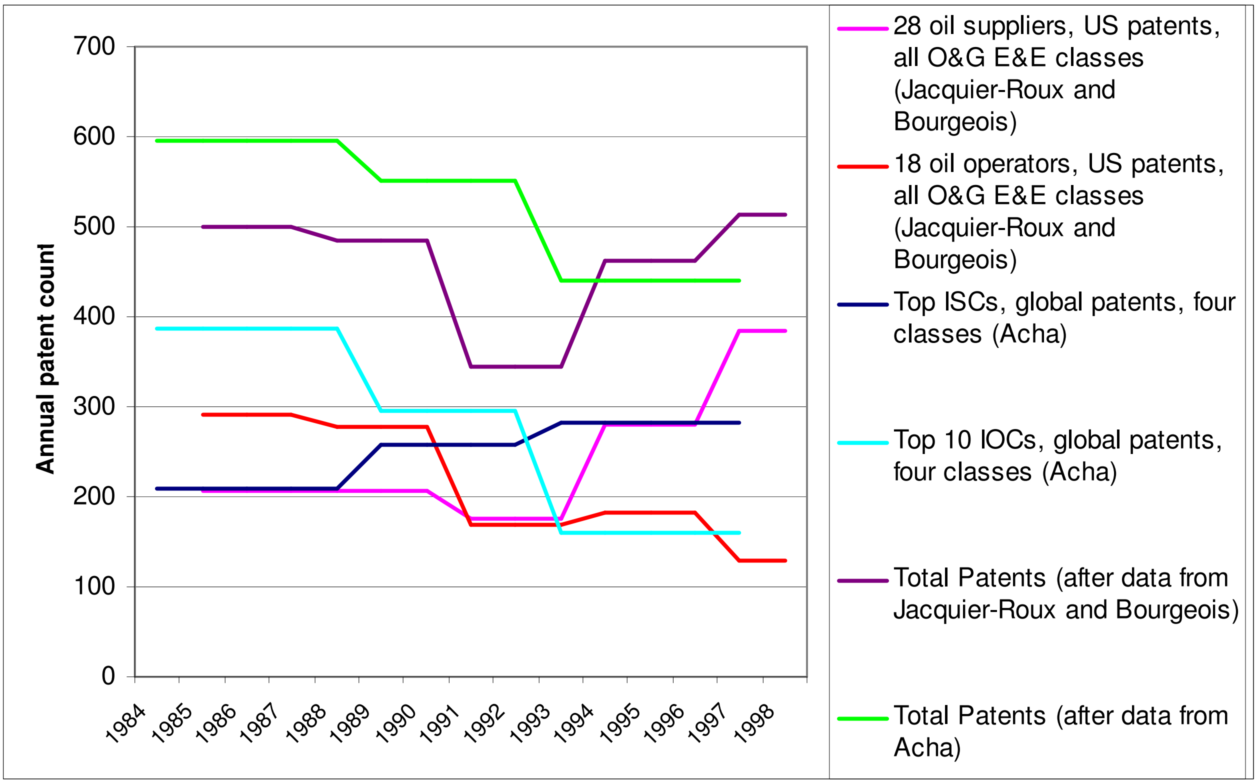
The number of patents granted to oil operators fell substantially over the periods in Table 9, while those granted to oil supply companies rose. Oil service companies over-took operators in patenting activity in the period 1991 to 1993.

The patent data for the major operators and suppliers from Table 8 and Table 9 is graphed in Figure 2. The US data shows the supply sector having replaced the oil companies in patenting activity. Patenting by supplier firms has risen consistently throughout the period. Oil company patenting has been, but for a slight recovery in 1994 to 1996, down markedly.

In terms of total patenting activity across IOCs and ISCs, data from Jacquier-Roux and Bourgeois shows US patenting having recovered to mid-1980s levels, but Acha's global data shows a steady fall. The combination of both the sample composition and patent classes being different in each case makes comparison difficult, but both data do confirm the divergence in patenting between oil companies and their suppliers and the concentration of IPR in the supply sector.

Jacquier-Roux and Bourgeois observed that the shift in patenting activity toward suppliers coincided with oil firms reducing their own technology development and then writing tenders in such a way as to put the onus for innovation on the suppliers. This led the suppliers to expand their technology development capabilities.

Figure 2 - Trends in patenting for suppliers and oil companies (from Table 8 and Table 9)



Note: O&G E&E is Oil & Gas Exploration & Extraction

3.4.4. Relation between ISC and IOC over technology IPR

The view expressed by a Total senior manager interviewed is to allow the service and supply companies to earn their income stream from selling technology (Mattenet, 2004). Where Total does transfer technology IPR to a supplier or develops something jointly with a supplier, Total may seek to secure preferential access terms (a favourable licence or certain rights over the licensing of technology to others, for example) but would not seek to retain any IPR necessarily.

Interviews confirmed that some industry insiders see technology innovation slowing; a somewhat separate issue to the number of patents being published. Qureshi (interview, 2003), while thinking that the innovation rate had held-up reasonably well until now, thought it could stall at some point. One view – expressed by Shell technology managers (Luca et al, 2003) – is that this is a natural consequence of the rising challenges faced by the industry; as technologies mature and it becomes harder to find and produce oil and gas. Innovation becomes more difficult, costly and may slow. An alterative explanation is that declining R&D funding and an increasingly short-term and problem-specific focus are at cause.

3.5. Presentation of Publishing data

Specialist abstracting services can provide data on what areas of technology oil companies, or their employees, have published in. Acha (2002) provides some aggregated data and this is discussed here. Table 10 is a summary of fuller publishing data shown in Figure A8, Appendix A.

Table 10 - Publishing data summary (derived from Acha, 2002)

	1984 - 1988	**1989 - 1992**	**1993 - 1997**
Total number of Upstream technology publications by the top 10 IOCs (average number annually within range)	**1314**	**2008**	**2016**

Publications data is a poor proxy for technological activity except as an indicator of scope. Acha concludes that publications (books, articles and conference papers, relevant to upstream petroleum technologies) by employees of major oil firms indicate little else than the general scope of the technologies being pursued, and say little about scale. The rising number of publications could be a consequence of the increasing collaboration in the industry, which likely gives rise to greater cross-fertilisation of ideas and stronger motivation to publish. As Acha notes, "IPR is heavily controlled and [diffusion] resisted, but joint papers are encouraged" (p. 171).

It is important to note that, generally, propensities to patent and to publish have not converged. Within IOCs, the trend of rising numbers of publications is counter to the falling R&D spending and patent counts for the period 1984 to 1997. There is also increasing divergence between firms, with, for example, Shell's publications increasing at a faster rate than Total's. Shell has shown consistently a strong publication record and Total has always published little. Acha, however, does not read too much into this data, since publication is often done on the employees' own initiative – perhaps following a publishers' or conference organisers' invitation - and largely in their own time. Publication can form part of the process of employee job-performance evaluation.

3.6. Other information disclosures

Disclosures relating to technology or technology strategy in corporate communications and elsewhere are a further source of insight. Acha (2002) has, for example, analysed disclosures (financial and non-financial) in IOC annual reports. This information can be particularly timely and can often complement other data to produce a clearer view of a company's technology strategy.

It is evident from literature and interview that companies in upstream petroleum, oil companies especially, are circumspect in what information they disclose externally. Interview with managers in Total (Préel, 2003) and Gaz de France (Nabil, 2004) confirmed that there are limits to what information will be shared with external technology partners or disclosed at all, based on what is strategically important. Keeping secret sensitive technologies while also sharing information with various partners is nothing new for oil companies, of course, but the distinction between the two sets of information is hardening. As IOCs divest non-core technological activities and collaborative networks gain favour, the oil firms are sharing more and more information with external partners, but at the same time are being increasingly careful to guard the remaining core technology items. Literature suggests that keeping secrets appears to be increasingly the exception, but some clearly defined limits to this are in evidence. Firms may proscribe altogether communication related to sensitive technology items.

3.7. Shell. The exception?

Suppliers' active participation in working with the oil operators to develop standardised, low cost designs has become more usual, ever since the operators themselves withdrew from many development activities. Shell has, however, withdrawn to a lesser extent and Acha (2002) reports that Shell's business model includes benefiting from all stages of the technology value chain, not only the application stage. Interview with Shell (Luca et al, 2003) found another explanation: Shell regards technology similarly to the other major oil firms – something to be implemented, not owned or treated as a commercial enterprise – but will intervene (i.e. invest its own funds or resources) in order to have certain technologies commercialised quicker, for more rapid deployment in its operations. The service companies offer generally a faster route to implementation. In this light, Shell's view of technology is not far removed from its peers, and it was Shell that made public the technology behind the now ubiquitous Semi-Submersible drilling rig, which it developed, in order to not retard commercialisation (Acha, 2002). Producing oil & gas, not technology, is Shell's source of profit.

It seems reasonable for a company to treat technology that is important to its interests as a special case, particularly where it is embryonic (for example, Frontier technology) and to devote internal resources to influence and speed its development to commercialisation. Most of the major oil companies continue to commercialise technology to some degree (interview with Qureshi, 2003). It is our view that Shell is not so very different from the other major oil companies in these respects.

3.8. A closer look at the evidence on technology organisation within Shell and Total

Throughout this section on proxy data we have referred often to these two companies. The proxy data and fieldwork provide a picture of two different approaches to managing technology.

The relative publishing performances of Shell and Total do fit a wider pattern. Acha (2002) showed that Shell was technologically consistently strong (high patenting and high estimated upstream R&D) and Total consistently weak (low patenting and low estimated upstream R&D). Therefore, Total may have the lower-key technology organisation, one that publishes less and is approached to publish less (the dominance of the English language may be an issue here). These comments must be tempered by observing that companies will not be uniformly strong or weak technologically, but will focus their resources where they are most required. However, interview with both Shell and Total (Luca et al, 2003 and Préel, 2003) confirmed the view that Shell makes technology a more explicit element of business strategy and more rigorously plans its technology investments.

4 - R&D NETWORKS

The trend of recent years has been for IOCs to reduce their technological activities (evidenced by less R&D spending and less patenting) and for the major suppliers to increase theirs. There is strong evidence that these changes have happened within a context of growing use of innovation networks. Here, we look more precisely at how the different actors have collaborated together.

Vertical integration is a response principally to high transaction costs (for example, in the specification and purchase of items from supply companies) and information asymmetry (Oster, 1999). Historically, these costs and asymmetries arose in upstream petroleum because of the difficulty of co-ordinating the different functions and the uncertainty inherent in E&P activities. However, with technologies of co-ordination (computing and communications) it has become possible for distinct functions within the supply chain - previously integrated - to separate. A factor tending to force the user function apart from the supplier function is the need for each to specialise, in order to manage increasing underlying uncertainty and challenge in the business and technology environments.

Collaborative networks are examples of partial vertical integration: they are 'organised markets`, not governed by the open market. Many investments made by supply firms are transaction-specific and some information asymmetries remain, hence to avoid bargaining problems and opportunistic behaviour, the relationship between user and supplier must be regulated somehow. Transaction-specific investments are common in upstream petroleum because of the asset-specific nature of much of the technology.

In Frontier situations there is a case for IOCs to keep the creation of technology internalised (effectively, integrating backwards into the supply function) owing to the lack of competitive supply and the prospect of competitive advantage from controlling Frontier technology.

4.1. Collaborative networks

Jaquier-Roux and Bourgeois (2002) contend that in the energy sector two styles of R&D have dominated: up to the mid-1980s a vertically integrated organisation (classical, First Generation, in-house R&D) was the norm. Since then firm-networks based on collaboration of one form or another have proliferated. The computing and telecom revolutions have made possible the necessary co-ordination between functions outside of the close integration within a single firm. The enlarging group of companies involved in oilfield developments as a consequence of this "deconstruction of the oil industry's integrated value chain" (Bresser et al, 2000, p 4) demands a greater degree of synchronisation and new organisational forms become necessary. For the upstream petroleum sector, the oil price crash of 1985 provided the necessary crisis for operators to begin implementing new strategies and reforming their organisations. Reform has become now semi-continuous.

Several authors have stressed the increasing importance of collaborative networks in the process of innovation. An editorial in GasTIPS, the Gas Technology Institute journal, stated that "Such consortiums are providing an increasingly large share of the industry's overall E&P research investment" (GasTIPS, 2002) and the Energy Information Administration's website (Dooley, last updated 2003) describes that "firms are increasingly turning to collaborative R&D".

Collaborative networks are useful in technological innovation as they provide interaction and exchange between parties; traditional vertical integration in the same company and in arms-length contracting with external firms both limit such transactions. As competition for fresh reserves rises and those reserves become more difficult to exploit, instability and change will become ever-stronger features in upstream petroleum. Under these conditions of rising uncertainty and reducing windows of opportunity, the collaborative model becomes more useful, since the number and quality (the amount and type of information exchanged) of transactions increases.

Bourgeois (1999) ascribed the proliferation of networks between oil companies and their contractors to the shortening "shelf life" (p. 774) of technology, the acceleration of diffusion of competitive technologies and the impossibility for any one company to control the increasing breadth and depth (specialisation) of technology. A Chevron manager is quoted as putting the shelf life for even breakthroughs at just 2-3 years.

Collaboration between different actors within the context of networks for technological innovation has several dimensions:

- Degree of Influence versus Control sought by the IOC (high control implies low collaboration)
- Extent to which external partners are used in creating technology (high utilisation of external partners implies high collaboration)
- Financial leverage achieved by IOCs by distributing costs among partners (high leverage implies high collaboration)
- Number of external partners involved in a project (few partners would tend to imply low collaboration)
- Type of external partners involved in a project (collaborative or protective, functioned on the behaviour adopted by partners)

Some comment is required on the last two dimensions: number and type of partners. Having fewer partners means a larger share of value for each, but the total value could be less, execution could be slower and the risk of failure may be higher. Collaborating with research institutes rather than, for example, supply companies can provide extra confidentiality (Nabil, 2004). The situation depends a lot on which (as well as how many) partners are involved.

Such collaboration can achieve substantial leverage of R&D spending. One oil company manager interviewed for this report estimated the leverage effect of collaborating with external technology specialists at about 3:1 (i.e. by collaborating, the oil company spends one third of what it would if it acted alone).

Jacquier-Roux and Bourgeois (2002) hold that the networks that have been formed between operators and their suppliers are essentially dynamic. The firms involved and the relationships between them can adjust depending upon the specific project under consideration. Therefore, networks might continue from one project into the next and have the ability to adjust to the new requirements.

4.2. Joint Industry Projects

Joint Industry Projects (JIPs) date from the early 1970s, so are not unique to the collaborative network model, which dates from the mid-1980s. Sharing of tasks on substantial technological projects is not a new feature of the industry. One of the largest upstream petroleum JIPs now is DeepStar, formed in 1991 to pursue technology for Gulf of Mexico deepwater. It has 63 member firms (48 suppliers and 15 oil companies) (GasTIPS, 2002). And JIPs are not popular only with private firms, but with governments also, for example Norway's State Research Council helps finance a Statoil / Shell / Halliburton / Petrotech[(12)] JIP.
Where the cost of developing a technology is high, the risk is large or the technology diverse or complex then it is normal to form a JIP, involving service companies and operators. These syndicate the investments and pool a wider body of skills. For these reasons, JIPs are especially popular with smaller oil firms. Acha (2002) points out that oil firms' "preference to syndicate" (p. 97) their investments in oilfields might influence the forming of collaborative relationships around technology. However, such syndication is not common among the ISCs, who tend to develop technology separately of other suppliers whenever they have the capability to do so.

Interview confirmed that the relatively low costs to an oil operator of joining many JIPs and the limited commitment required mean that the larger operators can afford to participate in many projects. Each of the oil companies interviewed explained that the costs of participating in a JIP are sufficiently low, such that wherever they have an interest in the topic they will participate, "just to see what happens" being a common view. Consequently, a strategic approach and careful selection of JIPs is not universal. Sanderson (2002),

(12) Statoil is Norway's state-owned oil company, Petrotech is a supply company

however, in reviewing BP's approach to membership and formation of certain JIPs outlines a more structured approach. Such an approach may also be true for operators with more limited R&D budgets.

It is recognised (Acha, 2002 and Jacquier-Roux and Bourgeois, 2002) that negotiations over IPR ownership are often the most complex element in establishing any JIP. However, as Acha points out, who shares in the knowledge (a separate issue from ownership of it) is equally important but is rarely controlled to any extent.

4.3. Practical experience of collaborative models

Interviews with technology managers in oil operators and supply companies provided some insights into how collaboration works in practice. There is consensus that external networks for technology innovation are advantageous and are being used increasingly, but also that some problems remain.

The majority of interviewees reported on going and unresolved difficulties in working with different partners. Attempts at creating partnerships were often described as "experimental" and the results "mixed".

4.3.1. Collaboration with suppliers has produced results, but expect adjustments

The ISCs would be expected to be organised better for innovation and more productive innovators for each R&D dollar spent. The Schlumberger manager interviewed for our research agreed with this analysis and clearly saw Schlumberger's differentiation and competitive advantage based upon technology and having unique products to offer (Montaron, 2003). Producing and commercialising innovations is closer to both an ISC's core competence (product development) and competitive position (maintained through defending its products) and ISC patenting activity has certainly been strong in the last 10 years. Qureshi (2003) also felt that ISCs could be shown to be more productive patentees per R&D $ than oil firms. The three Shell managers interviewed (Luca et al, 2003), however, did not perceive any large efficiency gain when R&D is outsourced and the EIA's website (Dooley, last updated 2003) notes that "No data to support or refute the 'increases in Energy R&D efficiency hypothesis' has been found".

There is circumstantial evidence that the cycle time for innovation has shrunk, and Luca et al (2003) ascribed this to increased collaboration in networks, but also saw limits to how far outsourcing can go. Operators may in fact take some technology tasks back just as others continue to be outsourced, in a dynamic equilibrium, with differentiation being made between technologies.

4.3.2. Different partnership models

Several interviewees described that although collaboration was increasingly how innovation was managed, there were many false starts in the process and various models of co-working, with different roles for the partners (both IOC and ISC) in evidence. Whether these are durable, with deep partnerships being formed, is uncertain. Shell's position (from interview with Luca et al, 2003) is usually to simply adopt the fastest or most profitable way to implement any technology, but bilateral relationships were highlighted as a particularly durable partnership model.

Halliburton Energy Services (HES), part of the Halliburton Company, points out that oil firms' rate of adoption of novel technology is a significant challenge for the whole industry (Halliburton Energy Services, 2003). While HES perceives that much of the burden of conceiving and commercialising oilfield technology rests with the large service companies, it seeks to have direct client involvement in its product development as a means of attracting interest and having clients commit to field trials. Schlumberger, on the other hand, while working with selected clients to field-test items, develops technology alone (Montaron, 2003). Thus, it should not be assumed that all suppliers are equally open to collaborating, even with key clients.

4.3.3. Price pressure

ISCs seek to be close to their clients (i.e. regulated transactions and richer interactions, unlike an open market) and seek price advantage. Some operators welcome collaboration (for richer interaction, a supplier who better understands the assets, less asymmetry of information, less opportunistic behaviour), but continue to want lowest (open market) costs. Thus, there is potential for conflict.

There is a history of suppliers trying to “value price” their products and services to oil firms (Charles River Associates, 2003). All of these attempts have been resisted successfully since no supplier has sufficient control over any technology to threaten the oil firms. The IOCs seek to remain in full control of pricing. One perspective on these tensions, identified by Luca et al (2003), is that suppliers try to offer solutions (that carry a price premium, sold on their “value”) while operators continue to seek products (lower price, bought on their “cost”).

There is asymmetry of bargaining power between suppliers and buyers. The Upstream-related businesses of even the largest service firms are dependant on just a few oil operators for their revenues (this is revealed in company annual accounts). These clients are mostly much larger than the suppliers. Even Schlumberger, the largest ISC by market capitalisation, is much smaller than the major oil firms (refer back to the market capitalisation values on pages 10 and 11).

4.3.4. Acquiring knowledge for commercial gain

One oil company interviewee pointed out that operators were frequently wary of entering into collaboration with certain supply firms. The risk is that the information transmitted during collaboration (e.g. operating expertise, design data) is repackaged or incorporated into an innovation and then offered for sale back to the originating company or commercialised and sold to others with the originator not benefiting. In this regard, certain suppliers can be especially acquisitive of information.

4.3.5. Bargaining problems and the funding of R&D

The transaction-specific nature of investments in upstream petroleum creates difficulties between the suppliers that invest in technology development and the oil companies that may ultimately buy the technology. Often, IOCs are unwilling to make the commitment to buy or give the financial assistance that the supply firm seeks. This view was expressed by the supply firms interviewed and tacitly acknowledged by the operators as an obstacle to co-operation. Suppliers have often invested heavily in innovation, only to be disappointed by clients wary of non-proven technology, who place a low value on the innovation or who bargain over price (bargaining problems as part of opportunistic behaviour).

4.3.6. Collaboration works best where there is high technology content in the product or service

Collaboration is most concentrated in a few areas of the upstream petroleum industry, according to fieldwork for this study. It is strong in the development of technologies related to reservoir appraisal but is found rarely in development of, for example, production technologies or drilling and construction services. Interviews, for example, with managers in two suppliers with contract drilling businesses, ENSCO and Saipem, suggest that the low technology content of a drilling rig means there is no reason for operators to treat drilling contractors at all collaboratively (Wilson, 2003 and Valenchon, 2003).

This reflects the pattern of what technology is core and non-core for oil operators and also the distinction between Frontier and established technologies. There must be a high content of technology in the product or service to persuade the oil company to adopt a collaborative, rather then market-based, relationship with the supplier. High technology content reflects rapid innovation and change, which is a response to a dynamic and uncertain business environment.

However, even where there is technology within the products or services, the competitive position of the supplier is not always sustained easily. Saipem, for example, invests in items with a high technology component (in LNG and deepwater facilities) but the Saipem manager interviewed perceived little and only temporary differentiation, hence brief competitive advantage, from these (Valenchon, 2003). Innovation within service companies brings only brief competitive advantage (expressed as premium pricing or higher market share) since new designs become standardised quickly. Six companies compete for business in the integrated service and supply sector and competition is high.

4.4. Position of the IOCs: Systems integrators and Heads of technology networks

We think of an oilfield development in technological terms as relying upon a large number of technology networks to create the necessary products and services. Thus, the IOC will be the Architect in charge of the development and will also be the Head of a number of technology networks.

- **IOC as Systems Integrator**

As IOCs have reduced their involvement in technology creation, they have become integrators increasingly of others' technology to occupy a system integrator role (often called an Architect role). In the literature, however, this term has differing definitions. Here, the term is used to describe an IOC that works neither exclusively itself on technology nor simply buys technology from suppliers, but that actively collaborates within external networks to assemble or integrate technologies for an oilfield development. The systems integrator remains engaged in actual technology creation and actively collaborates with others. The systems integrator outsources innovation according to strategic criteria but does not loose influence over and capability in a wide range of oilfield technologies. This enables the systems integrator to assemble technologies for an oilfield, seeking an optimal technical and economic solution.

The oil company, as the oilfield operator, is entirely responsible for the oilfield development. This legal responsibility – which for the major oil companies applies in each of the many fields which they operate - means that the operator should remain in control of the system of innovation. The success or failure of technology when applied in the field is the responsibility of the operator primarily, not the technology provider.

A systems integrator role seems to have been adopted also by at least the largest supply companies, the ISCs. Increasingly, these firms are taking charge of entire sub-systems and hence are integrators at least at the sub-system level.

- **Head of the technology network**

Networks are important for the creation of innovative technologies and IOCs must be involved in these to ensure that the technologies developed are appropriate for the operating assets. Further, for any IOC to be able to make a technology somehow exclusive to just its assets, and hence difficult for others to use, is clearly an advantage worth investigating.

Even though oil operators have reduced their own innovation activities, they remain firmly at the head of certain networks (i.e. they ultimately control or influence the direction of particular technologies). In these cases, the user may outsource some or much of the innovation, but retains control over the specification of standards, performance requirements and the co-ordination of tasks. The operator may take the initiative in technology development.

According to Jacquier-Roux and Bourgeois (2002) suppliers no longer have "capacities of initiative" (p. 414) to conceive genuinely innovative solutions, but are, rather, motivated by profit to focus on cost efficiencies of increasingly standardised approaches. However, there has been an increasing number of such oilfield technology networks that suppliers have become the head of and Bourgeois (1999) suggests that it is the suppliers who are now in control of and expert in many technologies. The buyers – the oil companies – have merely become adept at writing tender documents and subsequently contracts to translate business requirements into technological terms.

We argue here that both suppliers and the IOCs control technology networks and have capacity and initiative around innovation. IOCs should and do retain control over particular technology networks where that technology is critical within the portfolio of assets (in Frontier situations, for example). Otherwise, the technology should be managed from the supply sector. In this way, each technology network has the appropriate player at its head.

4.5. Collaboration between Suppliers

These relations are much more restricted than those between oil companies. They do happen – Schlumberger and Baker Hughes, for example, have a joint-venture seismic business, despite being competitors in some markets - but the fact that suppliers compete with each other over the ownership of technology restricts such collaboration. Where supply firms do collaborate with other technology suppliers, this is more likely to be with universities or specialist research institutes.

4.6. Comparison with another set of operators: the electricity generators

Jacquier-Roux and Bourgeois (2002) studied the development of strategy in oil firms and electricity generators and of their respective supply chains. They used a “firm network” model to analyse the two industries and used data covering the period 1985 to 1998. Deregulation has brought about convergences in financial and energy markets(13) since the 1980s and both oil firms and electricity generators were forced to improve earnings and react to rising competition. It is relevant to consider how each altered their technology strategies. Technology has evolved faster and with a greater intensity in upstream petroleum than in electricity generation and the alleged wrong decisions made by the electricity generators are instructive for the oil operators.

The evolution of technology strategy in upstream petroleum, where technological capability is retained by both operators and suppliers, contrasts with a more polarised picture in the electricity generation sector. Vertical, inter-company (between supplier and user) relations have benefited and deteriorated respectively, according to Jacquier-Roux and Bourgeois, in the upstream petroleum and electricity generation industries. In the electricity generation sector, the supply firms have been granted substantially more patents than the generators in every year since at least 1985 and the gap opened ever wider up to 1998. The electricity generators have never been strong patentees.

While petroleum firms – both oil companies and their suppliers – came together to form innovation networks with the oil companies remaining at the head of many of these, generators and suppliers in the electricity industry moved apart. The generators unloaded most of their cognitive capacity relating to technology, beginning in the mid-1980s, and developed instead cognitive ability in energy markets and financial assets, in response to their new regulatory environment. There was an almost total withdrawal from technological activities and control of technology shifted toward the supply sector. Largely, the generators are now limited to specifying to suppliers functional performance based upon financial objectives. This was not always the case: generators used to be central to technological activity in their sector.

Many generators are now not concerned with developing technical knowledge of their operations or developing new technology, despite continuing to be responsible for the operations. And yet the generation industry faces huge and immediate technological challenges, some at a societal level (supply being stretched by demand, need for more robust supply infrastructure, ecological issues such as converting to cleaner technologies and renewable sources, etc.). Withdrawal from innovation activities leaves the generators with a declining and ageing cognitive base, increasingly reliant on suppliers to operate and maintain their facilities. It is now the suppliers who are in a position to learn about the technology, and put that knowledge to profitable use. “Learning through operating” is an essential function within the supply chain, so if not done by the operator then the supplier must do it.

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(13) It is noted that this deregulation of energy markets was concerned mostly with the transmission and sale of gas and electricity and had little impact on E&P activities directly

Generators’ capacity to absorb novel technology is seriously reduced and they are exposed to the risk of changes in the environment that require a technological response, for example increase in the oil or gas price or a new entrant with some disruptive technology. By contrast, in upstream petroleum it is normally the case that the operator is at least closely involved in all operations, if not almost entirely involved.

4.7. The sustainability of collaborative networks

In the time that collaborative networks have flourished and operator profits have reached higher levels, the profitability of oil supply firms has declined. The financial health of oil firms is described as being at its best in 20 years (Salomon Smith Barney, 2001), following their most recent mega-mergers. As suppliers have increased their technology activities (or had their burden of technology increased, to express this another way), their profitability has declined, coinciding with higher marketing commitments (Gaddy, 1999). This is one reason for the uncertainty over the sustainability of relations between suppliers and operators around technology development. New business models, which provide adequate profitability for suppliers, may be needed and some anticipate further consolidation in the service sector, to cut costs and readdress the competitive balance with the IOCs. However, it is clear that it is the suppliers that are best positioned to manage the risks associated with the creation of many technologies – wherever they have the expertise - and therefore it is how the transactions are conducted that is under question, not the outsourcing of innovation itself.

The decline in large supply firm profits is not due solely to negative effects like pricing pressure, rising R&D and marketing expenses or cost overruns in working with oil companies. Halliburton, for example, has suffered asbestos-related costs in its construction division and Schlumberger has borne the costs of the merger with Sema and the slow-down in Sema`s IT services business. This complicates analysis of ISC business performance.

5 - TECHNOLOGY STRATEGY

The IOCs must decide which technologies should be continued to be developed in-house and which must be outsourced to the supply community and to what extent these can be outsourced, to retain appropriate influence or control. The parameters within these decisions are discussed here.

Traditionally, what has been thought of as technology strategy has focused upon 'high' technology and on product development. A great deal of the strategy literature that touches upon technology strategy (Oster, 1999 and Bresser et al, 2000 are recent examples) is concerned with science- and product-driven industries (for example, biotechnology, pharmaceuticals, computing or consumer electronics). Upstream petroleum companies, like many primary manufacturers, are not strongly either of these. Many of the IOCs do perform or closely assist in product development, but are concerned primarily with innovation of processes in what might be described as medium- or low-technologies (Petersen, 1980). The IOCs compete largely on the basis of their processes to find, produce and deliver to market commodity oil and gas. Consequently, the prior literature dealing with technology strategy (even specifically like Porter, 1985) does not cover in depth some of the important factors in oil company technology strategy formulation and implementation:

- Process, not product, innovation
- Emphasis on utilisation or application of technologies considered established in other fields
- The high uncertainty inherent in mineral exploration and production
- E&P technologies are often highly asset-specific owing to the unique nature of most oilfields, making copying or imitating others' innovations difficult or necessitating further investment
- The higher complexity and lower observability of process technologies, vis-à-vis products, which slows diffusion
- Profits are made by the application rather than ownership of technology
- In many industries the best technology will be the latest one. In E&P, however, the best technology to use is context-dependant, so the process in use is a poor proxy for how technologically advanced a firm is.

The oil and supply companies are incentivised differently in terms of investing in technology. Each has reasons to both stick with existing technology and hasten the adoption of the new. The oil company, as the purchaser increasingly of technology solutions, is motivated to get the innovations that respond to its needs with the lowest unit production costs, reduce risks and open up new opportunities. Innovation is necessary to meet, first, changes in the portfolio of assets (reservoir conditions change with time and new oilfields are brought into production) and, second, changes in the business environment (changing demand for crude oil and natural gas, new environmental regulations, rising costs, earnings pressures, etc.). However, the oil company may be restrained due to the uncertainty inherent in new technology.

The supply company is motivated to realise the greatest value from existing technology, and this is a brake on investment in new technology, while also seeking to compete with other suppliers by offering differentiated products. We discuss first the decisions from the IOC point of view and then from the ISC point of view.

5.1. Influences on technology strategy of the IOCs

By the early 1990s the major oil companies had refreshed their attitude to technology. The new position was increasingly that technology is to be applied in order to realise opportunities, not necessarily owned or developed in-house. This new thinking is summarised in Table 11.

Table 11 - Old and new paradigms of the US major oil companies (14) (source: translated from the table in Bourgeois, 1999, p. 775)

	Old paradigm	New paradigm
Source of technological creation	Internal	Influence and collaboration
Priority orientation of the project	Technology for its own sake, directed by technological opportunities	Technology subjugated by business needs
Motive	Private control of technology	Application of technology

Acha (2002) suggested that the innovation strategy within an oil firm is functioned upon three sets of factors:

1. the nature of the firm, including the preferences of management
2. the nature of the technologies concerned
3. the stage of development of these technologies (within and without the firm)

We now study each of these sets of factors.

5.1.1. The nature of the firm, including the preferences of management

Here we examine the different factors within the company that may explain the attitude toward technology and how it is managed and funded.

- **Implicit or Explicit role of technology**

Acha (2002) has defined two kinds of IOC, those that hold an Implicit or Explicit view of the role of technology within the organisation. These two types have the following characteristics:

Implicit: technology is not specifically identified as a strategic advantage, but is employed only to meet specific and identified needs. Technology is dictated to by other strategic considerations, never the other way round, and is problem-solving, never opportunity-making. Emphasis is placed on short-term R&D projects and providing technical service, to address only those technological issues most immediate in the current asset portfolio.

Explicit: the company positions itself as technologically oriented, and technology as something that creates opportunities and hence drives other elements of firm strategy. R&D projects will include medium- and long-term items and will encompass a range of technologies wider than necessary to service the present needs of operating assets. Future technology needs are anticipated.

Acha investigated these characteristics and attempted to find correlations. She defined an oil company as Explicit where technology was given prominence (such as in corporate publications, R&D spending and executive representation). This is the opposite of Implicit, where technology gets little priority.

She has shown that Explicit firms spend more on R&D as a % of total Capex and those with an Implicit view less. Critically, however, Acha notes that this does not mean necessarily that Implicit firms engage in less innovation or have lower technological capabilities, but only that they have different policies of allocating technological expenditure to R&D budget codes (rather than to other budget codes), different positions on whether to patent or not and different attitudes toward publishing.

(14) Table 11 is taken from a 1995 National Petroleum Council report, based upon a survey of USD oil companies. While it reflects neither observved behaviour nor the views of the supply sector, it does indicate a clear shift in thinking around technology creation.

None of the oil companies that we consider here conform to these models entirely, but rather exhibit traits of both, with one dominating. For example, Shell demonstrates Explicit qualities most strongly.

- **Business strategy: growth and efficiency**

We categorise business strategies into two types: Growth and Efficiency. Both regimes involve adding to reserves (as production depletes these) but under a Growth regime, reserves additions are made at a faster rate, to achieve aggressive growth – a costly and high-risk strategy. An Efficiency approach seeks a cautious – lower risk and cost efficient – route that targets specific opportunities, for more modest growth. The difference between the two strategy types is the tolerance of risk and this influences the criteria that IOCs use to evaluate projects. In the period to the early 1980s many upstream petroleum firms followed a Growth strategy, thanks to the elevated oil prices seen since the early 1970s. In Growth periods the primary focus is exploring for and acquiring new reserves (both long-term debt and Upstream R&D rise), not management of earnings. Acha (2002) has confirmed this from a study of E&P expenditure data: in periods of tight supply/high prices, spending is sensitive to the availability of good prospects, consistent with a Growth strategy. Otherwise, spending is sensitive to operating cash flow, typical of an Efficiency strategy. With declining oil prices from 1981 came a period where many IOCs switched to an Efficiency strategy and Acha observes this happening in the period 1984 to 1997. Many IOCs appear to have moved from Growth to Efficiency when they concluded that depressed oil prices and rising finding and developing costs would persist for the foreseeable future. Tecnomare (First Break, 1997) reported in 1996 that Efficiency strategies dominated in all oil companies.

We have not investigated in any detail the present tendencies of IOC business strategies. Tight supply and high prices have now returned but the poor availability of good prospects limits Growth options. Qureshi (interviewed in November 2003) thought that Efficiency strategies continued to dominate. In any case, IOC business strategies are not tightly synchronised since their underlying asset portfolios and reserves depletion rates – both important factors for business strategy – vary between companies.

- **Organisation of R&D**

Amoco and Arco were early adopters of newer R&D organisational models. In the early 1990s, Amoco decentralised decisions and funding of R&D to business units. This was later modified to return longer-term R&D projects – which, presumably, business units focused on short-term results were neglecting - to centralised control and funding. Since 1982 Arco has pursued a "pyramid style" (Acha, 2002, p146) technology strategy, balancing technical service with short-, medium- and long-term research projects while also differentiating between what technologies to be leader in, in which to be a fast follower and in which to just keep pace.

Acha concludes that BPAmoco acquired Arco in 2000 as much for its technological skills – notably in difficult Alaskan operations – as for its profitable assets. Thus, M&A has been another means for companies to acquire technology and technological capability.

- **Inertia in R&D spending**

Schlumberger's Montaron (interview, 2003) commented that there is much inertia in R&D spending and Jacquier-Roux and Bourgeois (2002) note that R&D costs tend to be inflexible due to a high staff cost component. Total's philosophy (Préel, 2003) is to maintain a similar R&D budget from one year to the next since the activities are medium- to long-term. It can be appreciated clearly that there are risks involved in cutting or expanding knowledge-based organisations through, in the first case, loss of skills and, in the second, integration of new people and skills. Hence, disclosed R&D spending figures at least tend to be quite stable over time.

- **Human Capital and organisational design**

Ability to integrate technologies is fundamental for successful exploration and production of hydrocarbons. Thus, the oil operator must be a systems integrator and this requires a high level of technological capability. The operator must be competent in the technologies involved in E&P, most concentrated and developed for core technologies (i.e. those most important to the asset portfolio). Internal problems demand internal competences for a solution and it is not possible to simply transplant knowledge into an organisation previously lacking in it. These competences are expensive to create and maintain, but are a necessary part of keeping control of the direction of costs and having a capability to respond to competitive threats, such as disruptive technologies or new business conditions.

Any intensification of R&D represents an increase in cognitive resources and absorptive capability and if the firm is to follow a research-intensive strategy then the necessary managerial structure must be in place. In the case of acquiring technology and competences via M&A, the process of educating the organisation will take time. Vertical integration between R&D and other functions (such as operations and engineering) is an important component in the dynamics of the creation of knowledge.

Major oil companies may have outsourced certain technological functions, but this does not imply outsourcing of the capability behind that technology. In Total's case, for example, a significant part of the upstream R&D budget is spent on co-ordination and liaison tasks (Préel, 2003). Total has maintained capabilities in-house that are necessary to manage and collaborate with external technology providers. Of course, the degree to which an oil company maintains in-house skills varies from technology to technology, driven by the needs of the present and future asset portfolio.

Jacquier-Roux and Bourgeois (2002) observe that how large organisations – including the big energy companies – manage labour and productivity often damages their innovation capabilities, particularly in the case of lay-off of skilled people. The major challenge for firms is not that the knowledge will then diffuse, and with it any related competitive advantage, but that they then lack the cognitive capacity to innovate and to absorb innovation. The reorganisations (examples include the move to asset-based organisations and the outsourcing of engineering functions) have shifted skilled people out of IOCs and often out of the upstream petroleum sector entirely (Loth et al, 1999). Acha (2002) is not alone in noting the negative effects of the changes (cost cutting, reorganisation, job outsourcing and severances) on oil firms' human capital that came as a consequence of the new environment.

Human capital within networks of collaboration between firms must also be managed. It is vital that the network retains its skills and knowledge (much of these embedded in the people) in order to grow the shared cognitive resource. Thus, technology strategy both informs and relies upon human resource strategy.

- **Management: attitudes and motivations**

In her analysis of proxy data, Acha (2002) concludes that the preferences of oil company management count a great deal toward the level of R&D spending and the propensity to patent and publish. Thus, traditionally, the attitudes of management have influenced technology strategy.

An essential but difficult to manage step in commercialising innovations is proving the technology in the field. The oil firm business units responsible for production are wary of introducing anything new (a design, method or chemical, for example) to a producing asset; the commercial downside of reducing or halting production, if the technology disappoints or fails, is large, however small the risk. The cost of even conducting a field trial can be high. This issue is complicated as major oil companies are now arranged into asset-based units, each a profit centre where the management are often incentivised on short-term performance. In these cases, the long-term strategy held by the corporate centre (which may be more motivated by longer-term and larger gains) is at odds with local management. Interview confirmed that local management is often a brake on innovation, which means that only technologies likely to yield benefits quickly, coupled with low failure risk, will get to a field-proving stage. The exception would be for assets that are explicitly experimental, for example certain Frontier projects (e.g. deepwater or heavy crude oilfields). The managers of such projects would be motivated according to different criteria.

5.1.2. The nature of the technologies concerned

Many authors describe the technologies that produced great advances in E&P as breakthroughs. 3D seismic and MWD (the enabling technology behind directional drilling) are quoted often. But, the basic elements of such technologies had often existed and been applied occasionally for many years. For example, directional drilling had been done on a number of occasions from the mid-20th century onwards. What helped technologies like MWD to become technically and economically feasible on a wide scale was something external to upstream petroleum, namely the computing revolution, begun in the late 1970s, which made processing of large volumes of data possible.

Table 12 presents one way of categorising the different technologies used in upstream petroleum. Our study is interested particularly in the Specific Technologies category, since this is where E&P technology networks concentrate. Many JIPs, like DeepStar quoted earlier, are engaged in the creation of Specific Technologies. However, this is not to overlook the efforts necessary to bring Adapted Technologies and even Generic Technologies into use in upstream petroleum.

The most important categories of Specific Technologies in E&P are shown in Table 13. It is clear that differentiation between IOCs and ISCs continues to be prominent. The oil operators have reduced their involvement in certain technologies, well completion for example, allowing the suppliers to have fuller autonomy, but have strengthened in other areas, in exploration for example.

Thus, the IOCs have withdrawn from many traditional items, such as oilfield equipment. With the strengthening of knowledge in reservoir technologies (exploration and reservoir engineering in Table 13), the type of innovation carried out by oil companies has become increasingly intangible in nature (for example, the software used to interpret reservoir data). The ISCs have increased their technological activities across the board, but with emphasis on those areas vacated by the IOCs.

Table 12 - Different kinds of technologies (derived from J F Giannesini, IFP)

- Generic Technologies: Computers (explosion of computing power ➨ 3D seismic), IT (e-world), Metallurgy, Molecular Biology (enhanced recovery) etc.
  - not born in the E&P world, but used by the E&P players
  - accessible to everybody
  - not a competitive edge

  It is important to never miss these external innovations and to transplant them into own businesses

- Adapted Technologies: sensors, shipbuilding, corrosion prevention, etc.
  - born outside, adapted and mastered by the E&P world
  - not accessible to everybody (for a limited period of time)
  - can be a competitive edge (for a limited period of time)

  Expertise is needed to adapt to own application, then protect and defend them

- Specific Technologies: 3D seismic interpretation, horizontal drilling, flexible risers, basin modeling, etc.
  - born in the E&P world: generated by the E&P players, Oil companies or Service companies
  - not accessible to everybody (for a limited period of time)
  - can be a competitive edge (for a limited period of time)

  Select and develop these technologies, then protect and defend them

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- **The asset-specific nature of technology**

Oil company R&D is focused upon technical support and short- and medium-term research and development, all directed toward identified technology issues with present or future assets. This strong focus upon assets reflects the high asset-specificity of technology in upstream petroleum. This specificity tends to restrict diffusion and standardisation of technology and diffusion is further slowed by the low observability of process technology.

The larger the company and more diverse its asset base, the greater its technology needs, but this does not mean that the largest oil firms will be capable across all technologies. Oil companies must specialise in certain technologies according to the challenges presented by their asset bases. For example, Acha (2002) quotes a BP executive as believing "that a successful exploration effort requires being in the right basins; building a No 1 or No 2 position in those basins" (p. 151). The implication of this is that strength technologically in all oilfield types is not an appropriate strategy, even for IOCs. Firms must specialise.

5.1.3. The stage of development of technologies (within and without the firm)

The business strategies of the major oil firms used to be based on a geological advantage, specifically access to low-cost reserves. Following the nationalisations of many oil industries in the 1960s and 1970s, business strategy for the IOCs, now denied access to many of these reserves, came to depend on a more complex situation where having access to cheap oil was no longer sufficient. Items like financial economies of scale, technological innovation, product differentiation, internationalisation of activities and strategic alliances all became more important. Technological innovation became necessary to explore for and produce oil outside of the established areas.

- **The change in the basis of competitive advantage from geology toward technology**

Up to the 1960s the low price of crude and its easy availability meant that upstream businesses were only moderately profitable and strategically unimportant to oil firms. From the beginnings of the modern oil industry in the 1850s up to the 1940s development focused on the transport and storage of oil. During and after the Second World War up to 1960s investment concentrated in developing refining capacity. From the 1960s, however, the major private oil firms began to react to the threat of being excluded from many traditional production areas.

Oil was discovered in Alaska in 1968 and one year later in the North Sea. These investments in Frontier areas were small at first but rose hugely after the Arab Oil Embargo of 1972-1973 (see Figure A4, Appendix A, OECD member state oil & gas R&D). The increased oil price and the reduced availability of easy reserves switched management's attention to technology and to upstream businesses. Upstream technology became an important component and a boom in technology spending in a wide range of technologies, fuelled by the high oil price, ensued. By being able to explore for and produce oil outside of the traditional production areas, the IOCs offered diversification of both source and product to customers. Maintaining technological capability and high entry barriers through advanced technology became an important element of competitive advantage.

Oil prices peaked in real terms during 1981 and then began to fall. Following the price collapse of 1985-1986 the R&D expenditures of the major oil companies began a steady decline. These firms were forced to concentrate on production areas and technology projects compatible with this low oil price environment and the need to evaluate R&D investments much more carefully began to be important. Arco introduced differential investing around 1982 (identifying the technologies to lead, follow or lag in and invest accordingly) and British Petroleum began using sophisticated technology planning from the late 1980s (Kostoff, 1997).

Table 13 - Categories of technology and the positions of IOCs and ISCs (Derived from fieldwork and literature)

Oil and Gas technology types (based on major patent classes)	**IOCs**	**ISCs**
Exploration (including Geology, geophysics, geochemistry)	All IOCs strengthening in this area. Strong historical publication record (their biggest topic area). Patent record declining, inline with overall reduction in patents. ***Strong and strengthening***	Not ISCs largest area of patenting, but over-took the IOCs in terms of patenting around 1989. Have been strong in publishing (their 2nd or 3rd biggest area of publication). ***Maintaining a good position***
Well completion, Stimulating, Servicing	Little publishing activity and moderate patenting. Patents much declined since their peak in 1994. ***Weak and withdrawing***	ISCs traditionally strong patenting activity here. Routinely their 1st or 2nd patent class. Strongest area of publishing activity. ***Maintaining a lead position***
Drilling	Most operators are reducing strength in this area. Only ever moderate publishing here. Overall patenting activity has fallen steadily. Many oil firms do prioritise drilling technology, owing to its high cost, but tend to collaborate in any work. ***Withdrawing. Switching to collaboration***	ISCs show moderate but consistently strengthening publishing activity here. Consistently their 1st or 2nd patenting area. Over-took the IOCs in terms of patenting around 1992. ***Strong and strengthening***
Production	Operators involved in mature provinces (eg continental US fields) continue, but most are withdrawing from this area. Marked reduction in patenting since at least mid-1980s. Minor publishing continues. ***Weak and withdrawing***	Small publishing and patenting activities, but withdrawal of others (notably oil firms and research institutes) from this area leaves ISCs in a relatively strong position. ***Potential for strength***
Reservoir engineering	Strong publishing activity here, second only to Exploration. ***Area of strength***	Steady, moderate publishing. ***Maintaining position***
Well logging	Small but steady publishing. ***Non-priority area***	2nd or 3rd area of publishing in recent years. ***Maintaining a good position***
Pipelines	Small but steady publishing. ***Non-priority area***	Very small publishing activity. ***Non-priority area***

- **Effect of evolution of technology on attitudes to IPR**

The area of technological focus for the IOCs is moving up the value chain, concentrating around exploration and reservoir interpretation/management skills. These technologies are more intangible (they are based on software and methods) and hence they are both less easy to protect via patents and their diffusion is slowed by their lower observability. This weakens the case for oil firms to protect innovation through IPR, even in the areas where they remain active innovators.

- **Outsourcing from IOC to ISC, with the Frontier a special case**

The division of tasks between the oil companies and the supply firms continues to be dynamic. The trend that has developed is for the suppliers to assume ever more the development of technology, with the oil companies just guiding technology creation. The exception is where a Frontier area of production (whether a province or reservoir type) is under development. In this case, the oil company needs to be more involved in the development and specification of the technology in order to advance and protect its competitive position. Interview confirmed that IOC R&D spending favours Frontier technologies strongly over established ones. The greater uncertainty in Frontier situations and the fact that technology development is necessary to exploit these means that the operator must take a more direct role in innovation.

5.2. A technology strategy framework for IOCs

Table 14 – Revealed Technology Strategy Environment (derived from fieldwork and literature)

Business Strategy prevailing	Responding Technology Strategy	Comments
Growth	Explicit	• Supports high R&D spend • High patent count • High exploration activity • High FDC tolerated
Efficiency	Implicit	• Reduced spending • Fewer patents generated • Less exploration activity

Table 14 illustrates the main features of the technology strategy that prevailed in the period studied, as evidenced from literature and fieldwork. These links are, like the relationship of R&D spending to business performance, not easily discovered.

It is evident from IOC behaviour that a Growth business strategy has traditionally paired with an Explicit technology strategy, and an Efficiency business strategy with an Implicit technology strategy. However, for an Efficiency strategy to be pursued for any period of time requires sufficient ongoing investment in technology to sustain the rate of reserves additions. Affording R&D during periods of Efficiency is thus a challenge for managers not reflected in Table 14. We conclude that an Explicit technology strategy should be followed at all times, regardless of business conditions prevailing, in order to realise fully the cost, risk and opportunity benefits of technology.

The recent historical trends are of falling patenting and declining R&D spending by the major oil companies, with an apparent increased collaboration with and reliance upon suppliers for technology. Thus, it appears that the description of oil company behaviour shown in Table 14 does not account for the collaborative models that have become popular or of the distinction to be made between Frontier and established technologies. To take these three factors into account, we propose a development of the model described in Table 14, with the following features added:

- a collaboration dimension, expressed in terms of the influence or control over the innovation process
- an uncertainty dimension, expressed in terms of the uncertainty underlying the technology being considered
- technology strategy type as a dependant variable is removed; Explicit is now prescribed throughout

The proposed framework is outlined in Table 15 and, for simplicity, presents two technology cases: Established and Frontier. In the first case where the technology under consideration is for a well-understood application in a low-uncertainty environment, such as with finding and developing reserves in known zones, there is no reason for the oil firm to be involved to any great extent in creating that technology. In this case, R&D spending should be low and the development of the technology should be influenced via the external network. In the second case, of technology for a poorly understood application in a high uncertainty environment, such as for Frontier E&P, closer involvement and greater control become appropriate. Such a strategy incurs higher R&D costs and involves the oil company acquiring IPR.

Table 15 - Proposed Technology Strategy Environment

Business Strategy prevailing	**Low uncertainty (Established)** Low R&D and influencing technology creation via collaboration, IPR sought rarely	**High uncertainty (Frontier)** High R&D and controlling of technology creation (more in-house, less collaboration), IPR sought routinely
Growth	Innovation necessary to access growth opportunities	Emphasis on creation and control of technology
Efficiency	Innovation necessary to achieve cost efficiency and manage risk	Limited activity, due to high implied costs of developing the Frontier while in Efficiency

In essence, an IOC requires only to influence technology in low-uncertainty situations and requires more control as uncertainty rises. Clearly, the many different technologies being pursued by an IOC at any time will occupy positions across the uncertainty dimension, so IOC technology strategy will be at many positions across Table 15 simultaneously. An important feature of the proposed framework is that an Explicit approach to technology strategy is required under both Growth and Efficiency business strategies.

5.3. Technology strategy of the ISCs

Internationalisation of IOC purchasing strategies and a weakening of preference for home-country suppliers led to sharply increased competition in the service sector. Thus, supply firms suffered greater revenue volatility and price pressure just as they were being subject to the same financial pressure as their clients. The suppliers were also incentivised (forced would be how others see it) to widen their range of goods and services and to strengthen their own R&D as operators outsourced functions evaluated to be non-core and shifted increasingly from technical to functional specifications in their tenders.

The ENSCO manager interviewed (Wilson, 2003) saw very little value in investing in technology for drilling rigs. High diffusion of knowledge and buyer bargaining power ensure that innovation is quickly standardised; thus construction and drilling service companies like Saipem and ENSCO do not need the intensive R&D strategies of firms like Schlumberger. Competitive strategy for construction and drilling service companies is based largely on cost-parity and differentiation of execution, with limited scope for product differentiation (in Saipem's case in Deepwater and LNG applications, for example).

Supply firms are most likely to patent technologies they intend to commercialise for external application, not rely on trade secrecy. Unlike oil companies, supplier firms are also likely to patent for the sake of interrupting competitors' access to a technology (Montaron, 2003). It is more rational for technology and product centric companies to behave in this way, and patents provide better protection for products than for processes.

For Schlumberger, continuous research – a calculated mixture of applied research to address specific problems plus more fundamental research – is essential to cope with the uncertainty inherent in minerals exploration and production (Montaron, 2003). One of the largest suppliers in upstream petroleum, Schlumberger now outspends all other companies in the sector on R&D. And Montaron affirmed that Schlumberger has always been pro-active about R&D, not just filling in for retreating operator budgets. Qureshi (2003) described Schlumberger as having taken the lead in using technology as a competitive differentiator to support premium pricing and gain market share.

6 - CONCLUSION

This report discusses how technology strategy is described in literature and by interviewees and evidenced by available proxy data. The present and likely future trends in technology strategies and the upstream petroleum business environment are reviewed and the prevailing framework for technology strategy within upstream oil companies is described. Critically, the framework does not reflect the collaborative models that have gained popularity.

A revised framework is proposed. This concentrates on leveraging R&D spending via collaboration with selected external partners, so acquiring competence, access to and influence over technologies but without seeking ownership necessarily. The most established technologies should be outsourced and influenced via the procurement process, while higher uncertainty categories of technology should be managed in closer collaboration. The degree of collaboration should be functioned upon uncertainty, hence Frontier technologies dictate less collaboration and more control to secure the additional competitive advantage of these situations. Thus, if an IOC develops technology in-house at all this should be only for the most sensitive categories. Rigorous planning processes, careful categorisation of technologies and an explicit approach to technology strategy are required in all cases. Each oil firm has, however, a distinct set of assets and will make maximum use of inherited in-house capabilities and resources and hence differences in precisely how the system is implemented are to be expected.

A possible reversal of the R&D spending trends of 1995 to 2002 is observed in the most recent data for Shell and Schlumberger. The reasons for this and the strength of the reversal are not obvious. The total R&D budget for each of the major upstream petroleum companies is influenced by much more than just the technology strategy in upstream business units. The change may signal reduced R&D spending by suppliers (as they address earnings concerns, for example) and a reversal of the R&D cuts made by operators (as, for example, they address technology short-falls). Equally, the change could indicate business environment changes. It does demonstrate that technology budgets and how tasks distribute between users and suppliers are dynamic and not bound to follow any trend for long.

It is not easy to forecast the direction of R&D spends and distribution of tasks since the structure of the supply chain will continue to be dynamic. There are a number of tasks (conceiving innovation, commercialising innovation, learning the application of technology, etc.) that must be performed within this 'innovation system', and the issue here is how these essential tasks distribute throughout the supply chain.

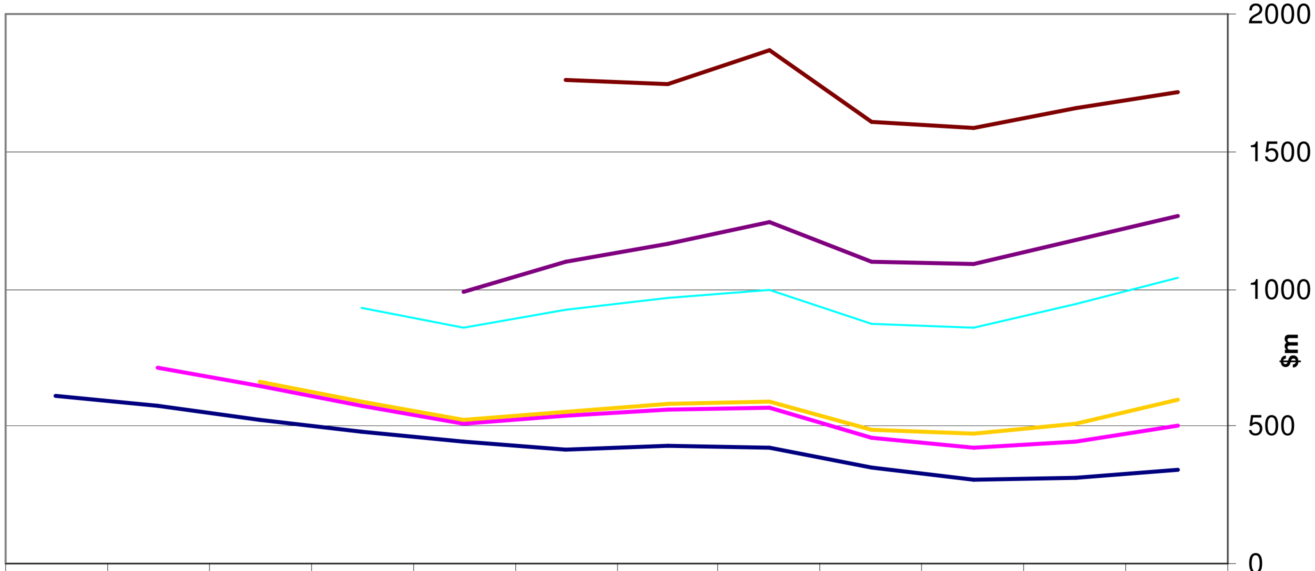
For oil firms, just as for their suppliers, technology must be treated as an explicit element of business strategy. An oil company must have a clear vision of what direction it is taking technologically, be aware of the competitive role of technologies (sensitive to the business strategy prevailing) and appreciate the value of each of the numerous technologies used within its operating assets.

Appendix A – Additional data

Table A1 - Analysis of Annual Leading 30 Patentees (derived from Acha, 2002)

Patents in Well Completion and Services	**1984 - 1988**	**1989 - 1992**	**1993 - 1997**
Top 6 ISS	81	87	101
Top 10 Oil Majors	59	66	53
Research Institutes (Top 8)	34	54	17
Suppliers (Top 10)	68	50	9
Patents in Exploration Technologies	**1984 - 1988**	**1989 - 1992**	**1993 - 1996**
Top 4 ISS	50	91	60
Top 10 oil majors	67	64	22
Research Institutes (Top 9)	15	10	7
Suppliers (Top 10)	13	17	23
Patents in Drilling Technologies	**1984 - 1988**	**1989 - 1992**	**1993 - 1997**
Top 4 ISS	62	69	108
Top 10 oil majors	103	72	50
Research Institutes (Top 6)	54	91	31
Suppliers (Top 10)	103	54	60
Patents in Production Technologies	**1984 - 1988**	**1989 - 1992**	**1993 - 1997**
Top 5 ISS	16	10	13
All 10 Oil Majors	158	93	34
Research Institutes (Top 10)	35	47	26
Suppliers (Top 10)	44	15	4

Figure A1 - Upstream R&D Spending for ISCs and IOCs combined (corrected to 2002 dollars)

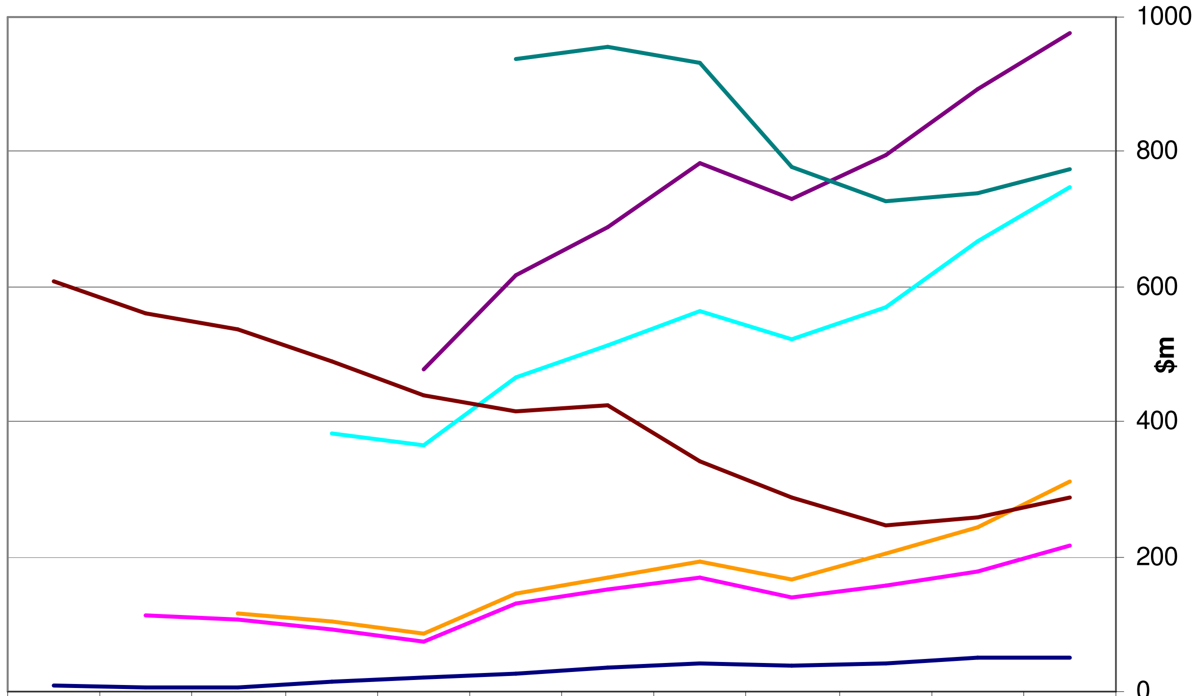


	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Exxon+SII+Chevron+Texaco+Phillips+Mobil	608,8	574,4	524,5	480,2	446,9	417,0	428,1	422,8	351,5	302,4	315,3	338,9
Exxon+SII+Chevron+Texaco+Phillips+Mobil+BHI		709,9	648,5	574,7	509,6	536,8	560,8	564,5	459,0	423,9	446,6	504,4
Exxon+SII+Chevron+Texaco+Phillips+Mobil+BHI+WFT+BJS			661,1	588,3	523,7	553,5	580,8	589,5	489,4	473,0	511,1	598,5
Exxon+SII+Chevron+Texaco+Phillips+Mobil+BHI+WFT+BJS+SLB				928,2	855,3	925,8	970,0	999,1	872,8	856,5	946,7	1036,5
Exxon+SII+Chevron+Texaco+Phillips+Mobil+BHI+WFT+BJS+SLB+HAL					988,0	1099,8	1166,8	1241,9	1095,7	1091,8	1178,4	1264,5
Exxon+SII+Chevron+Texaco+Phillips+Mobil+BHI+WFT+BJS+SLB+HAL+Total+Fina+Elf+BP+Conoco+Shell						1760,9	1746,9	1872,4	1607,5	1585,7	1659,0	1716,6

Figure A2 - Upstream R&D spending for ISCs and IOCs seperately (uncorrected for inflation)

Notes

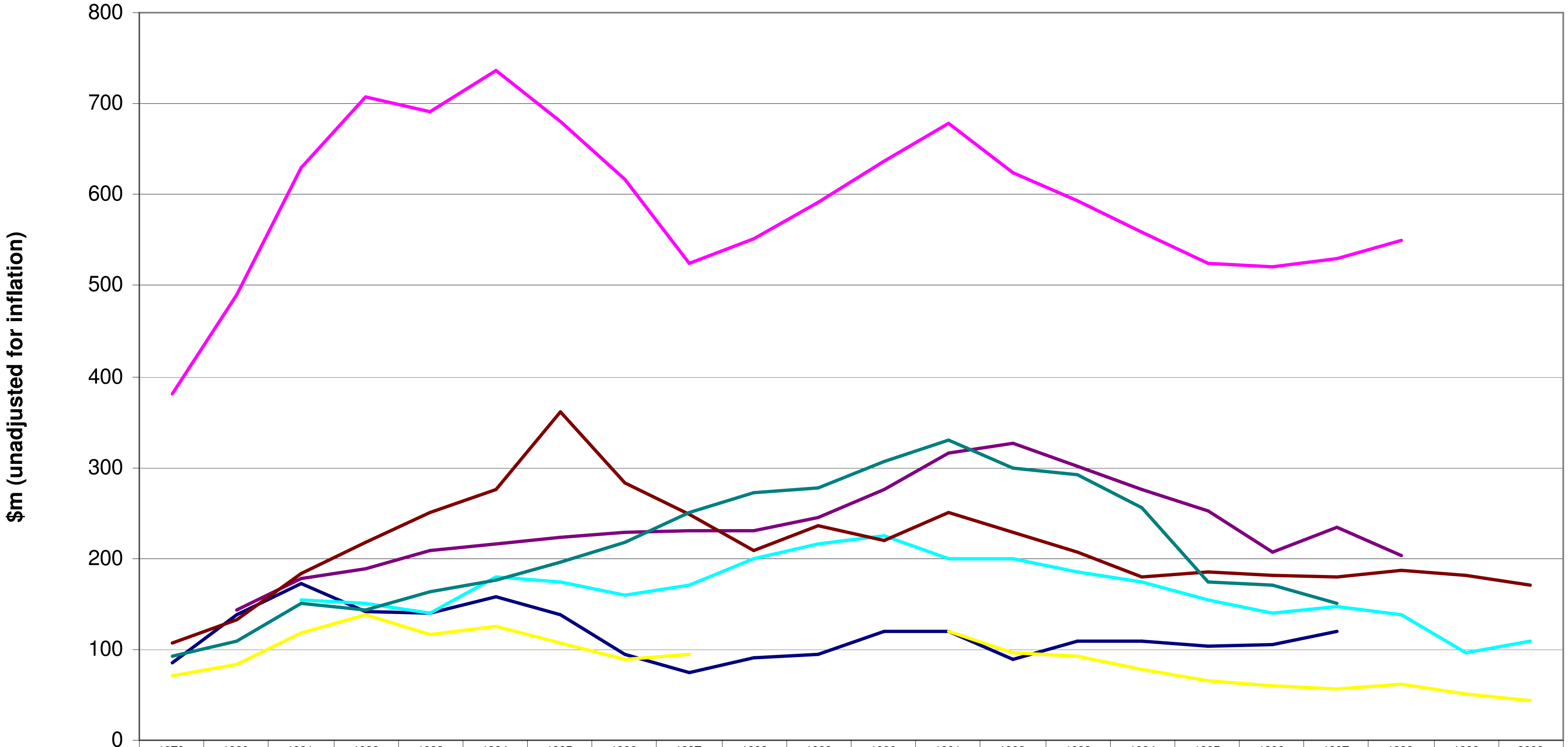
R&D expenditures from SEC 10K and 20F annual filings or Annual Accounts for each company in each year. HAL, SII and SLB disclose R&D dedicated to Upstream. Most BHI, BJS and WTF R&D is Upstream, according to company disclosures. IOC Upstream R&D is assumed to be 30% of total disclosed R&D (after Acha, 2002).



	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
SII	8,9	6,2	6,6	14,6	21,4	27,8	34,9	41,0	39,0	42,4	50,8	50,6
SII+BHI		112,1	105,9	92,2	74,2	131,1	152,1	169,4	138,8	158,1	178,9	216,1
SII+BHI+BJS+WTF			116,0	103,3	86,0	145,5	169,8	192,1	167,1	204,8	241,9	310,2
SII+BHI+BJS+WTF+SLB				382,3	365,0	466,5	513,8	563,1	523,1	569,8	666,9	748,2
SII+BHI+BJS+WTF+SLB+HAL					476,6	616,6	687,8	783,1	730,1	793,8	892,9	976,2
Exxon+Mobil+Chevron+Texaco+Phillips+Arco +Amoco	609,0	561,3	536,7	488,7	438,3	414,9	424,8	342,0	287,4	245,4	256,8	288,3
Exxon+Mobil+Chevron+Texaco+Phillips+Arco +Amoco+Total+Fina+Elf+Shell+BP+Conoco						939,0	954,3	931,8	777,6	728,4	738,9	773,1

Figure A3 - US oil majors R&D spending 1979-2000

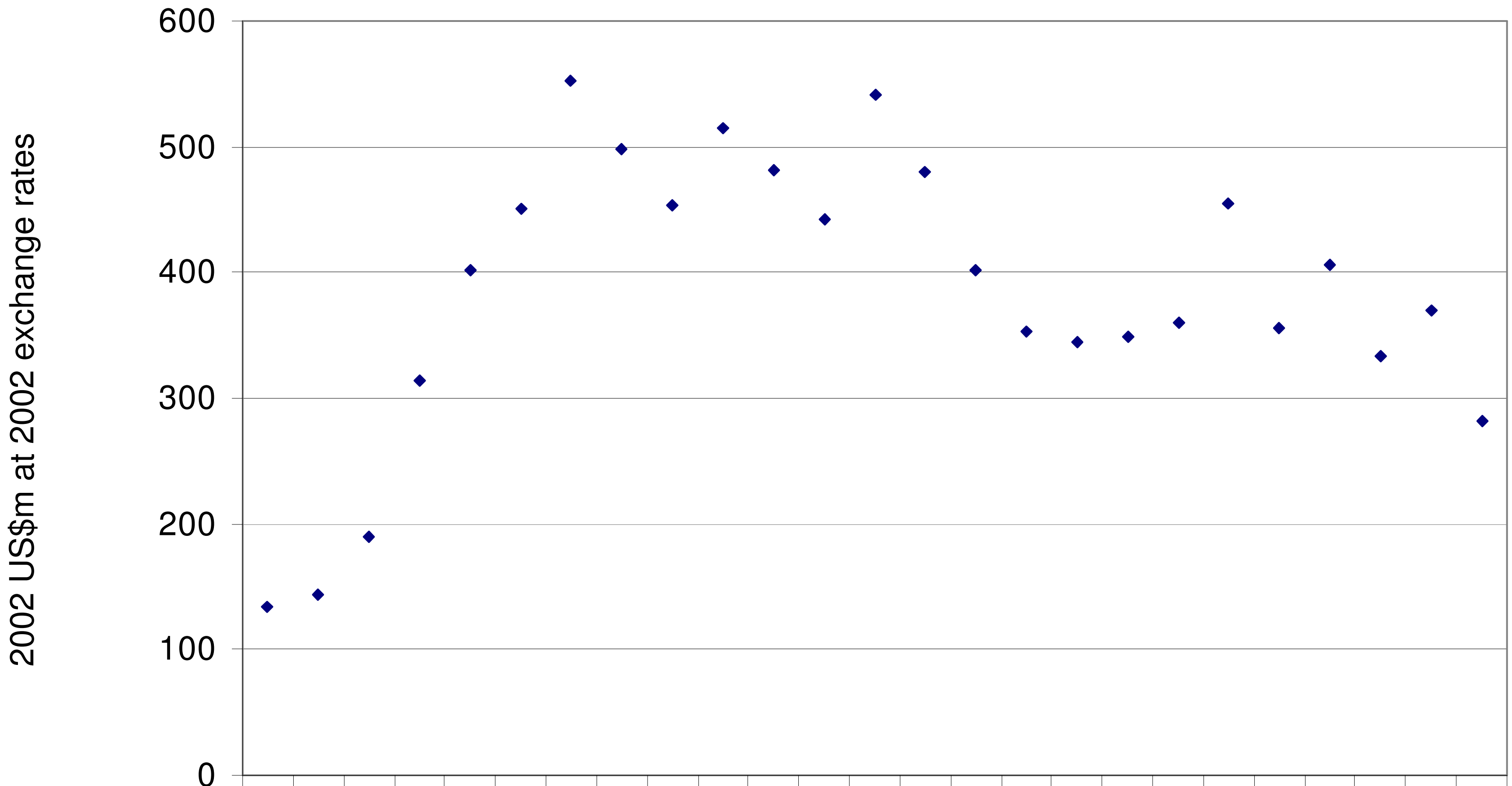
Sources: Company annual 10K filings, from Business Week R&D Scoreboard and SEC Edgar database



	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Arco	85,8	138,3	172,6	141,0	140,0	157,0	138,0	94,0	75,0	91	95	120	119,0	89,0	109,0	109,0	104,0	106,0	120,0			
Exxon	381,0	489,0	630,0	707,0	692,0	736,0	681,0	616,0	524,0	551	592	637	679,0	624,0	593,0	558,0	525,0	520,0	529,0	549,0		
Phillips	70,3	84,3	118,0	138,0	116,0	125,0	107,0	89,0	94,0				119,0	96,0	93,0	78,0	66,0	59,0	56,0	62,0	50,0	43,0
Texaco	61,0		155,0	150,0	140,0	180,0	175,0	160,0	170,0	200	215	225	200,0	200,0	185,0	175,0	154,0	139,0	147,0	138,0	96,0	108,0
Mobil		143,0	178,0	188,0	209,0	215,0	224,0	229,0	231,0	230	244	276	316	326,0	301,0	275,0	252,0	206,0	234,0	204,0		
Chevron	107,1	132,5	182,9	218,3	250,6	276,0	361,0	283,0	249,0	208	236	219	250,0	229,0	206,0	179,0	185,0	182,0	179,0	187,0	182,0	171,0
Amoco	93,4	108,3	150,0	143,3	164,0	176,0	196,0	217,0	251,0	272	278	307	330	300	292	255,0	175,0	171,0	151,0			

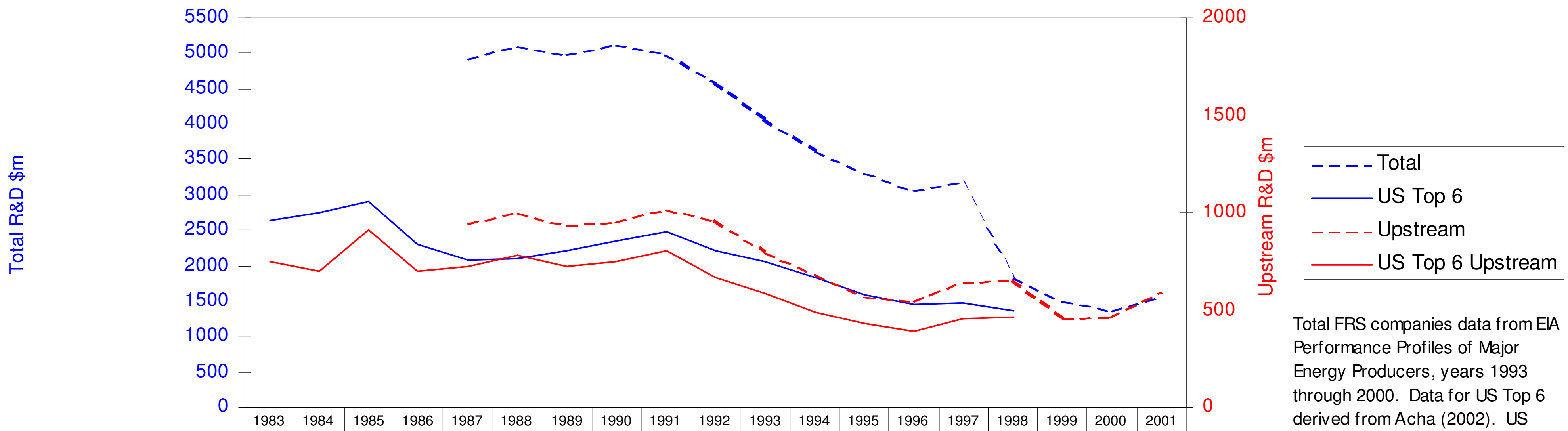
Figure A4 - IEA member state energy technology R&D for Oil & Gas, 1974 to 1998

Source: IEA R&D database



	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
Governments budgets	135	143	190	314	401	451	552	498	453	515	481	442	542	481	402	352	345	349	361	454,6	356	406	333	370	282

Figure A5 - FRS Companies R&D spending, Total and Upstream (Year 2001 dollars)

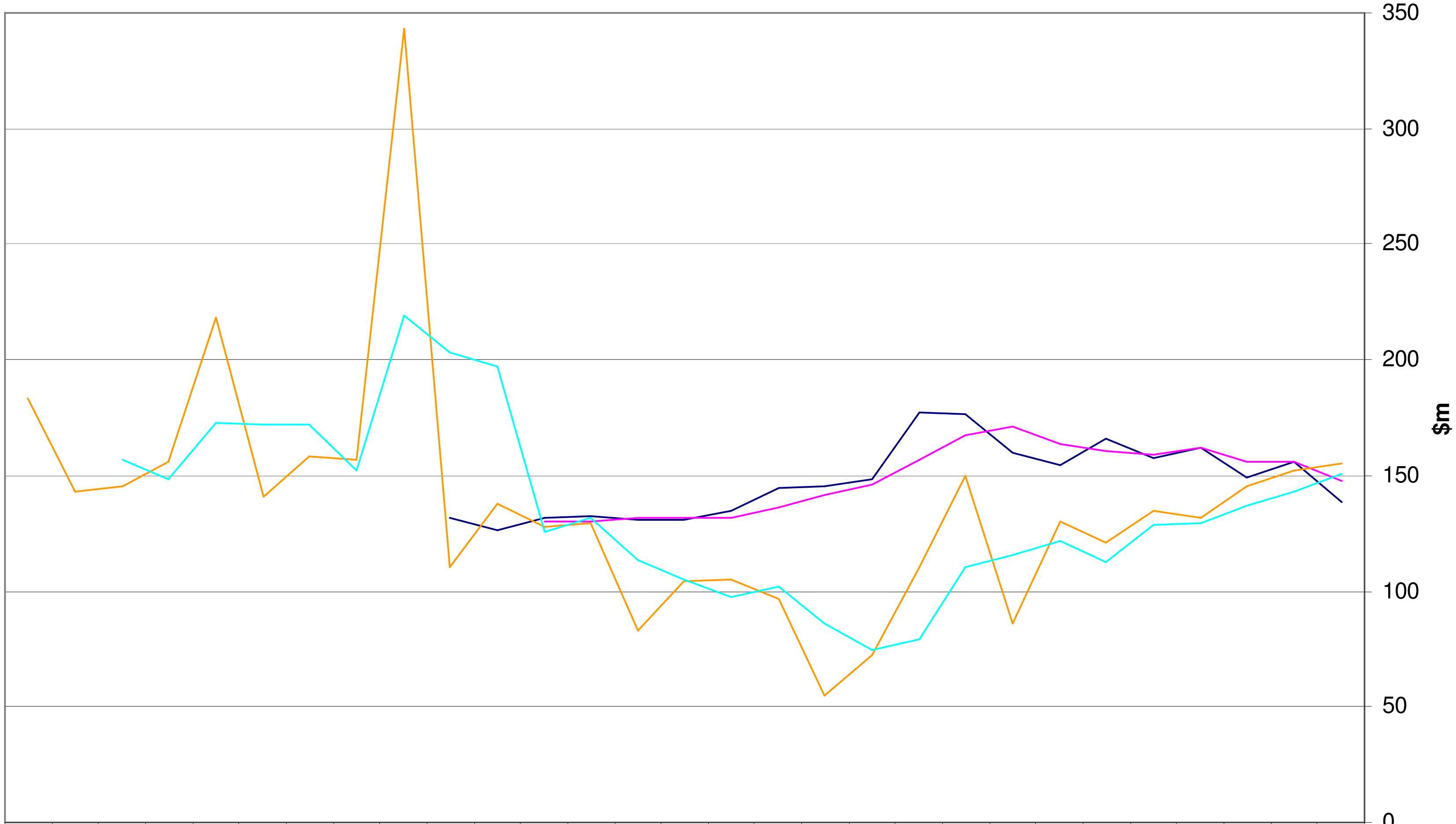


	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
Total					4928,5	5099,1	4980,1	5121,1	4994,9	4585,8	4063,4	3625,5	3317,9	3074,0	3184,5	1838,3	1496,1	1359,2	1570,0
US Top 6	2634,8	2759,6	2898,4	2304,1	2079,9	2100,9	2202,9	2340,8	2480,8	2223,0	2054,2	1834,1	1591,1	1448,2	1468,1	1354,7			
Upstream					941,0	1000,8	933,4	953,9	1016,4	959,1	799,3	679,9	572,9	545,3	645,7	652,6	451,8	464,3	592,0
US Top 6 Upstream	744,5	702,3	909,4	702,9	722,0	777,5	724,9	745,3	803,9	666,9	586,1	490,9	429,1	390,3	455,9	460,9			

Total FRS companies data from EIA Performance Profiles of Major Energy Producers, years 1993 through 2000. Data for US Top 6 derived from Acha (2002). US inflation of 2.5% used throughout.

Figure A6 - Shell (RD/STT) and Schlumberger (SLB) quarterly disclosed total R&D

(sources: company quarterly financial statements, not corrected for inflation)



	1996 Q4	1997 Q1	1997 Q2	1997 Q3	1997 Q4	1998 Q1	1998 Q2	1998 Q3	1998 Q4	1999 Q1	1999 Q2	1999 Q3	1999 Q4	2000 Q1
SLB Qtr R&D										131,8	126,4	131,3	132,7	131,0
3pt MA												129,8	130,1	131,7
RD/STT Qtr R&D	183,0	143,0	145,0	156,0	218,0	141,0	158,0	157,0	343,0	110,0	138,0	128,0	129,0	83,0
3pt MA			157,0	148,0	173,0	171,7	172,3	152,0	219,3	203,3	197,0	125,3	131,7	113,3

	2000 Q2	2000 Q3	2000 Q4	2001 Q1	2001 Q2	2001 Q3	2001 Q4	2002 Q1	2002 Q2	2002 Q3	2002 Q4	2003 Q1	2003 Q2	2003 Q3	2003 Q4
SLB Qtr R&D	130,7	134,3	144,6	145,6	148,2	177,3	176,8	159,7	154,6	166,2	157,2	162,4	149,1	156,2	138,3
3pt MA	131,5	132,0	136,5	141,5	146,1	157,0	167,5	171,3	163,7	160,2	159,4	161,9	156,2	155,9	147,8
RD/STT Qtr R&D	104,0	105,0	97,0	55,0	72,0	110,0	150,0	86,0	130,0	121,0	135,0	132,0	145,0	152,0	155,0
3pt MA	105,3	97,3	102,0	85,7	74,7	79,0	110,7	115,3	122,0	112,3	128,7	129,3	137,3	143,0	150,7

Figure A7 - Patents related to Upstream Technologies by Company, 1984 to 1997 (reproduced from Acha, 2002)

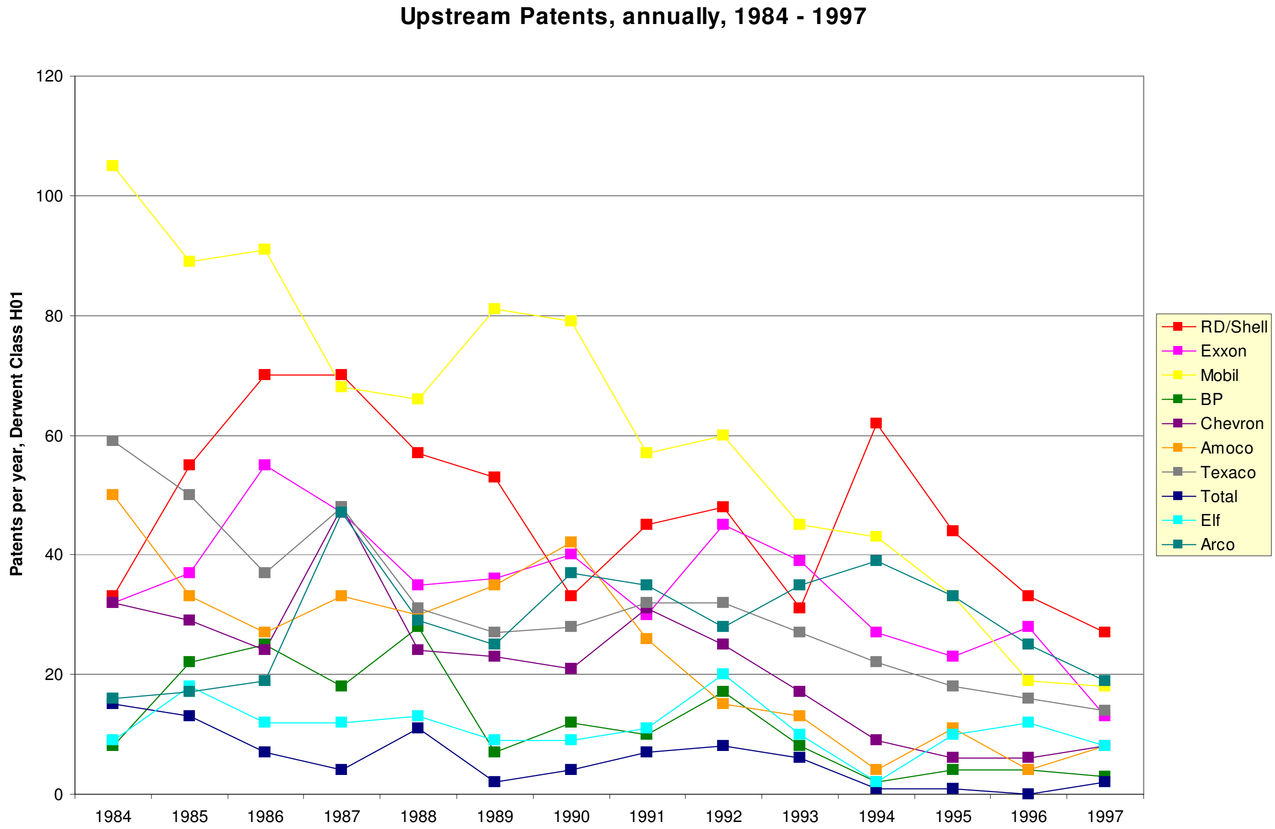
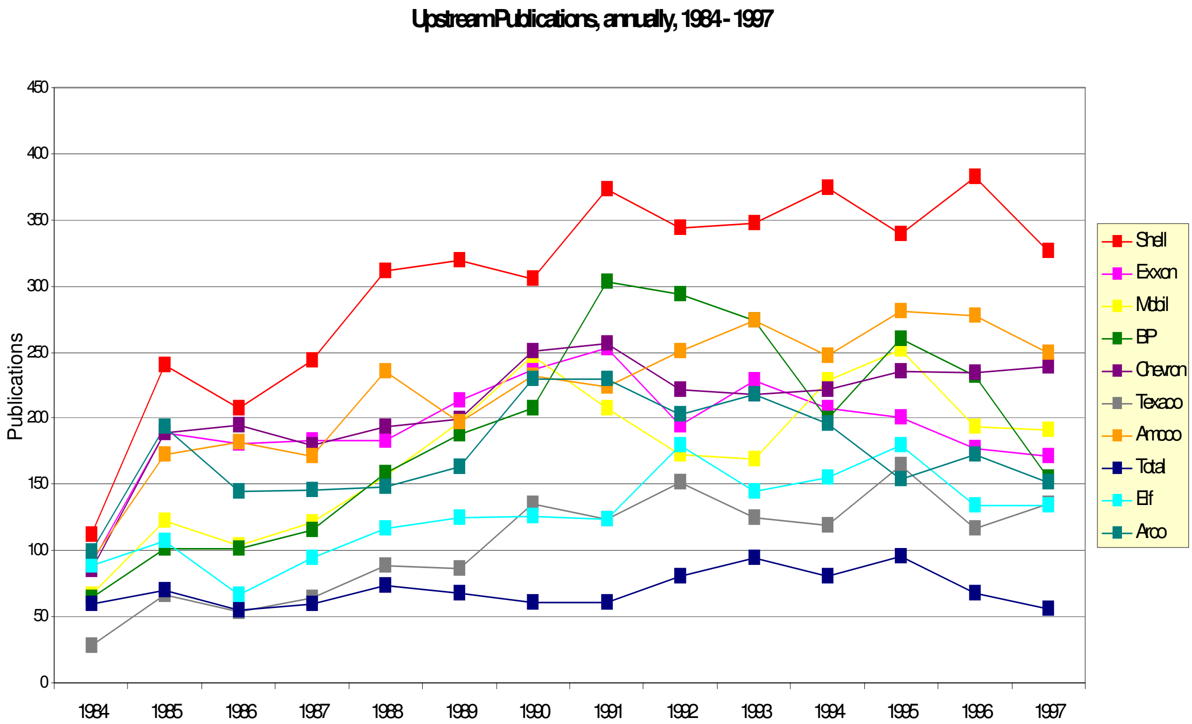


Figure A8 - Publications related to Upstream Technologies by Company, 1984 to 1997 (reproduced from Acha, 2002)



Appendix B – Terminology and abbreviations

3D seismic – This is a remote-sensing technique that allows a computer model in 3D to be made of the reservoir and permits significantly better appraisal of the characteristics of the reservoir. A development of 3D seismic is 4D seismic, which combines successive 3D images to show the dynamic (in time) behaviour of fluids within the reservoir.

Basin – This term refers to a sedimentary basin, where a number of reservoirs may occur. Typically, oilfields together in the same basin will share similar characteristics (similar reservoir rocks, oil and gas fluids, water depth, etc.), so it would be expected that similar technology could be used throughout.

BOE, **Barrel oil equivalent** – It is common to add volumes of oil and gas together, to arrive at a single number that represents the total hydrocarbon volume. Finding and development costs (FDC) and reserves additions costs for example can then be expressed as a ratio using the BOE figure. BOE is calculated by dividing the volume of gas by a factor and adding the result to the volume of oil.

CAPEX – In oil company financial statements, this is Capital and Exploration Expense.

CRINE – Cost Reduction In the New Era. A UK government-led initiative, comprising a number of expert work groups, tasked with reporting on opportunities to raise the profitability of UK oil sector firms operating on the UK's continental shelf and hence to extend the viability of the oil industry there. The "new era" refers to the post-1985 period of low oil prices and the increasingly marginal economics of many UK oil fields.

Deepwater – Most offshore oil and gas production takes place on the continental shelf where water depth rarely exceeds 500m. Operating in deep water beyond the shelf may involve significantly different technology for oil and gas exploration and production. Definitions for Deepwater vary but +500m water depth is a conservative guide. Some literature discusses Ultra-Deepwater, usually for water depths below 2000m. Presently, oil production has been achieved in around 2000m of water and exploration has been carried out at around 3000m.

Directional drilling – this makes it possible for difficult to get at "targets" (i.e. the part of the reservoir that the drill should reach) and for multiple targets to be reached by the one well. Thus, previously inaccessible parts of the reservoir can be drained and the number of wells for production reduced. Directional drilling has produced benefits in terms of better reservoir management (more optimal extraction of oil and gas) and lower costs.

E&P – Exploration and Production. These are two of the principal activities conducted in the Upstream petroleum sector. The terms E&P and Upstream are often used synonymously.

EIA – Energy Information Administration, an agency of the US Department of Energy

Extra heavy oil and Oil sands – This is one of a group of oils, collectively termed Non-Conventional. Very different technology, much of it still in early development, is required to extract these oils.

FDC – Finding and Development Costs

Frontier and **Established** – In this report, new operating environments – geographic and reservoir – are termed Frontier. Environments that are already developed are termed Established.

FRS – Financial Reporting System, operated by the EIA, into which the largest US-based oil and gas producers report detailed financial and other data on a regular basis. The FRS R&D data used here is reported annually.

IEA – International Energy Agency

IOC – International Oil Company. There are the largest private integrated oil companies that operate internationally, so participate in exploration and production activities worldwide, without geographical constraints. They deal with the widest range of E&P technologies, hence should have a broad technology strategy. The six oil companies defined as IOC for this report are: ExxonMobil, Shell (Royal Dutch/Shell Transport and Trading), BP, Total, ChevronTexaco and ConocoPhillips.

IPR - Intellectual Property Rights. IPR include patents, trademarks and copyrights. This report discusses patents only.

ISC – Integrated Service and Supply Company. These are the firms that service the IOCs globally. The six companies defined as ISC for this report are: Schlumberger (NYSE ticker symbol SLB), Baker Hughes (BHI), Halliburton Company (HAL), Smith International (SII), Weatherford International (WFT) and BJ Services (BJS).

JIP – Joint Industry Project

M&A – Merger and Acquisition

MWD – Measurement-while-drilling. This is the enabling technology behind directional drilling.

NOC – National Oil Company

OECD – Organisation for Economic Cooperation and Development

Oilfield or **Field** – This includes the reservoir plus all the sub-surface and above-surface fixed equipment and facilities used to produce and transport the oil and/or gas. In this report the term describes both oil and gas producing fields.

OPEC – Organisation of Petroleum Exporting Countries, formed in 1960

PPP – Purchasing Power Parity

R&D – Research and Development

Reserves – In this paper, this is taken to mean proven reserves. Proven reserves are the volume of oil and gas which has been reasonably proven to be producible. The oil and gas has been found and its volume ascertained, the technology exists to bring the oil and gas to market and the forecast economic conditions make the operation acceptably profitable. Significantly, this means that the proven reserves figure is subject to management judgement and as technology improves and economic conditions (e.g. long-term forecasts of price, cost of capital, operating costs, etc.) change, then the proven reserves value for the same reservoir can be revised. Changes in the estimated volume of the oil and gas in place, or indeed the discovery of a new reservoir, are therefore not the only factors contributing to changes to the proven reserves figure. Reserves must be disclosed in financial statements (see FASB, 1982).

Reservoir – This is the volume of rock sub-surface (commonly several thousand feet below ground or below the seabed) that contains the oil and gas. It is not unusual for the oil and gas to be divided among several compartments in the one reservoir.

Appendix C - References

1. Fieldwork

Interviews (some by telephone) and extended personal communication were held with the following technology professionals and researchers in the upstream petroleum sector or research functions.

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