

# **Organising Innovation in North Sea Petroleum Industry: The Large Company and its Supplier Interface as an Environmental Innovation System<sup>1</sup>**

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The Norwegian Continental Shelf (NCS) has been an arena for extensive innovation in petroleum industry. Deep sea drilling was itself a major technological challenge at the start in the early 1970s, as drilling platforms representing some of the world's largest constructions were developed. Transition to subsea drilling in the 1990s and 2000s marked another major technological breakthrough based on a whole series of interlinked innovations ranging from modular subsea drilling units, autonomous underwater vehicles and seabed logging to carbon capture, with the North Sea again as a major innovation arena. Improved economic and functional performance very often went hand in hand with major advances in environmental performance.

What are the organisational formulae behind the combination of impressive technological breakthroughs and their operative implementation? Taking Statoil and its supplier network as a point of departure, this paper looks at the organisational architecture behind innovation in North Sea upstream petroleum industry.

While the substantive answer is itself of interest, given the scale and scope of the North Sea offshore industry, this case also provides valuable theoretical insights into how complex systemic creativity and interplay can be mobilised in targeted projects under advanced industrial regulation. A theoretical challenge posed by this case is to analytically bridge the system of innovation literature and the managerial theory of the innovative firm, (while also connecting to theory of regulation).

The Statoil case shows how outsourcing in value systems for static efficiency (transaction costs) potentially also establishes a broader platform for innovation when technological challenges proceed beyond technical capability of even large firms. The multiplier effects of competency recombination of the supplier system's joint capabilities, is immense. Furthermore, the core company, thereby also taps into capability/competency build-up derived from the supplier's engagement with other clients.

From a strategic point of view, however, it remains a puzzle how Statoil seemingly has managed to work out systemic or architectural innovation in the context of a supplier network, which is tied together neither by hierarchic governance nor by long-term alliances. The case study indicates that the answer may lie in the potential of other factors to serve as functional hierarchy-equivalents. Firstly, Statoil's privileged access to the licence apparently stabilises control in the supplier network. Secondly, the orchestration capability in the Statoil case may also reflect a more general "vanishing hand" effect to quote Langlois (2003), following improvements in coordination technology.

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<sup>1</sup> The paper is still at a very early draft stage, and the empirical details need further quality checks

However, the Statoil innovation case also highlights the significance of public regulation. The high tax rates and full cost deduction makes it cost-efficient to locate innovation on the Norwegian continental shelf. Furthermore, a consistent demand for impact assessments and state of the art technology to qualify for license, establishes an innovation pressure. In addition, comes, for the environmental innovation, also the adoption of strong zero emissions ambitions.

## **Theoretical Anchoring**

Given the complex organisation of upstream petroleum industry, with up to 80% of the cost structure outsourced, these innovations have been achieved with extensive input from the larger supply chain, involving interrelated processes throughout a large network of actors. Innovation thereby takes on a systemic character and an analysis of innovation in North Sea petroleum industry therefore calls for a system of innovation perspective as a central analytical point of departure.

### ***The systems of innovation perspective as a point of departure***

We find theoretical basis for such a broad analysis in the theory of innovation systems, which focuses on the systemic character and complex organisation of innovation. The Innovation systems concept was introduced in the late 1980's and established in the innovation literature as a result of the collaboration between Freeman, Nelson and Lundvall (Dosi 1988). Studies pursued by Freeman and his colleagues at SPRU in the beginning of the seventies (Rothwell and Zegweld 1985) gave strong support to the idea that success in innovation has to do with long-term relationships and close interaction with agents external to the firm. Closely related to this conceptual approach is also Michael Porter's influential work on industrial clusters (Porter 1990 and 1998), which may be seen as an important precedent to the innovation systems perspective.

Four central arguments are commonly made in support for taking a systemic approach to innovation, rather than focussing only on the individual firm:

- 1) a complementarities argument, pointing out the potential innovation synergies from matching capabilities across firm boundaries;
- 2) a positive externality argument, highlighting the extensive potential gains for the actors innovating together that are not incorporated in the accounting of the individual firm;
- 3) a flexibility argument, that points to the extensive potential for innovative recombination in a network as compared with recombination within a hierarchically organised firm;
- 4) a risk sharing argument, which highlights the economic consequences of tying up large investments in uncertain innovation projects in one single mono-purpose firm rather than in a multipurpose network of interacting firms.

## **Complementarities**

Following Stankiewicz (2001), the innovation potential of an innovation system lies in its clusters of complementary technical capabilities that allow multiple combinatorial designs. Innovation in such a system may take place by expansion of the design space through the addition of new capabilities or clusters of capabilities; progressive integration and structuring of the design spaces through the co-evolution of its various elements; or through accumulation of application-specific know-how linked to the evolutionary trajectories of particular artefacts.

This definition of technology highlights the combinatorial character of innovation, and Carlsson and Eliasson's argument that the growth and expansion of a design space and with it, of the technological opportunity set, usually requires that such novelties be integrated within a wider cluster of competencies. They also argue that as technical knowledge grows as the design spaces evolve.

## **Externalities**

A central reasoning behind the externalities argument of this perspective is that open network based innovation allows the parties to profit from the external capability of the entire system. These capabilities are necessarily larger than the internal capabilities even inside a large multinational firm. The Statoil-supplier network should therefore, in a systems of innovation perspective, allow Statoil to profit from extensive knowledge externalities.

As argued by Carlsson and Eliasson (2003) among others the basic attraction to all actors involved is that the business opportunities expand from being exploited through innovation. Similarly, Porter (1990, 1998) pointed out that the clustering process is critical to industrial dynamics by increasing the productivity of companies based in the area; by driving the direction and pace of innovation; and by stimulating the formation of new businesses. There is, in other words a collective gain to be harvested. Both the system of innovation and cluster perspectives, explore ways to unleash these externalities within environments rich in complementarities

## **Risk**

The central focus of the risk argument for systemic innovation is that the supply network represents a sharing of risk exposure from innovation, as well as a more flexible capability to recombine around promising configurations. The central motivation for this argument is the uncertainty following from the extreme quality variation characterises demand in a knowledge-based information economy. According to Eliasson (1992) this removes the theoretical possibility of both optimising and maintaining the assumption that *ext ante* plans equal *ex post* outcomes.

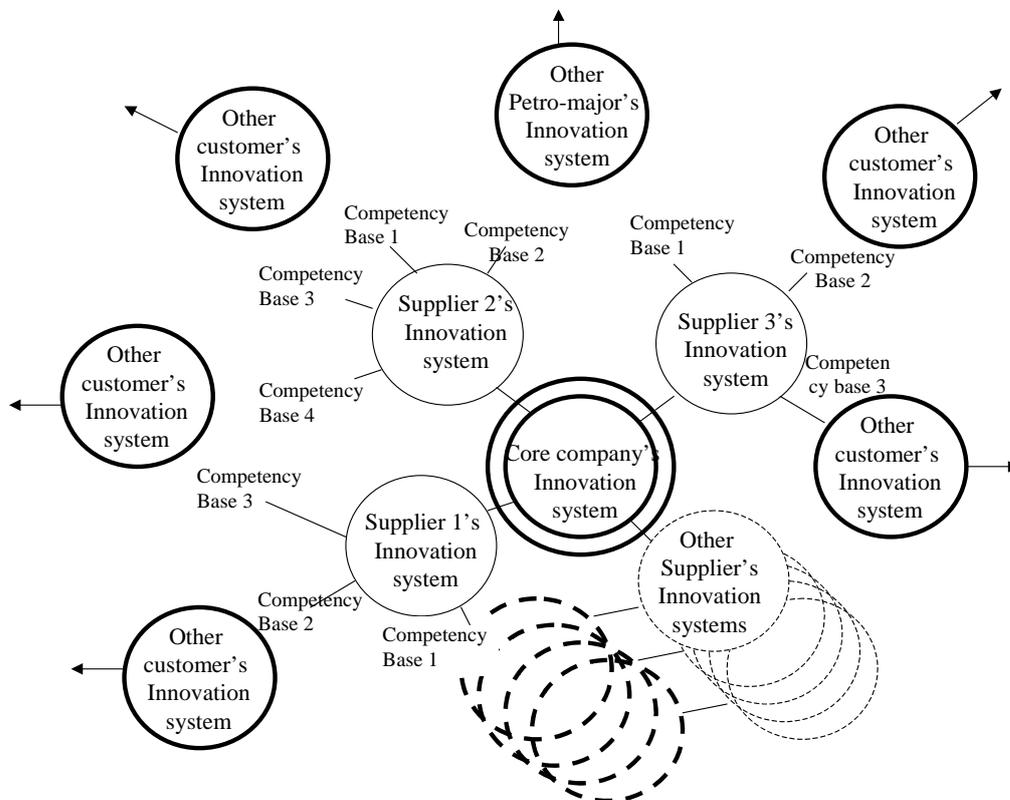
## Flexibility

The flexibility argument, in many ways, underlies most of the others. It is the recombinatorial dynamics that allows both the technological creativity and the sharing both of externalities and risk. Potential flexibility of re-combination of the system's total capabilities may meet a far wider opportunity set than one fixed combination. Multiple applications provide linkage possibilities for new technologies. However, flexibility is not a necessary characteristic of a network, but depends, fundamentally on the relational or contractual structures.

## Application to the Norwegian Continental Shelf (NCS)

Applied to the Statoil & supplier context, the systems of innovation perspective implies that Statoil can potentially mobilise broadly, not only their internal innovation system, but also the innovation systems of their suppliers (figure x), who are typically multi-technology actors with engagements in several related fields. These fields may range widely, from offshore and maritime competencies, robotics and control systems to biotechnology and pharmaceuticals.

Figure 1  
*The Supplier system as an innovation system*



One step further out, Statoil’s suppliers are engaged in innovation processes with other client firms or even client governments, as is typically the case with military technology. A range of basic technologies to the North Sea petroleum applications may thus be provided out of more generic products developed for other clients. Furthermore, suppliers are also engaged with their supplier’s innovation processes. The potential critical mass and diversity of innovation capabilities that may be mobilised in such a network is formidable!

***Managerial orchestration***

The systems of innovation literature successfully highlights the interfaces and the externalities involved in innovation and convincingly argues how innovation may be enhanced in larger interorganisational settings. However, it lacks guidance to managerial strategic organisation or how the potential positive externalities, complementarities, risk diversification and flexibility can be materialised. The need to stimulate creativity and develop new inventions needs, in other words, to be put into a viable business model to secure their commercial exploitation. In Utterback’s and Abernathy’s terms “The capabilities of a firm to innovate (and) to achieve efficient operations cannot be divorced from one another” (Uterback & Abernathy 1975/2000). Similarly, the March (1991) points out that “maintaining an appropriate balance between exploration and exploitation is a primary factor in system survival and prosperity” p 71.

While there is strong agreement on the need to link up innovation to efficient business models, there is considerable debate about how this should be done. Different literatures present elements of the organisational repertoire of innovation, but there is still no broad consensus on an over all framework that would allow design of an optimal fit between organisation and innovation. Furthermore, there is also extensive discussion as to the level of analysis when addressing extensive innovation in large-scale systems such as North Sea petroleum industry.

In an interesting attempt to address the strategic management of innovation from a transaction cost perspective, Teece (1996) points out that the managerial and coordination challenges vary extensively with technological characteristics and the distribution of competencies necessary for innovation (whether they exist inhouse or outside the focal firm) and the effects/implications of innovation (systemic or stand alone) (table1).

*Table 1: Innovation and organisational archetypes  
From Teece (1996)*

	<b><i>Type of Innovation</i></b>	
	<b><i>Autonomous</i></b>	<b><i>Systemic</i></b>
<b><i>Capabilities exist inhouse</i></b>	Silicon Valley type	Multiproduct integrated
<b><i>Capabilities exist outside</i></b>	Virtual (outsourcing)	Alliances
<b><i>Capabilities must be created</i></b>	Alliances Silicon Valley type	Silicon valley type

## **Autonomous Innovations**

When the technology can be sourced externally, and introduced without large repercussions throughout industry, Teece argues, alliances and virtual structures will work well. When technology can be sourced externally, there are no special hazards in contracting and adjustments to related technologies to realise the benefits of innovation are minimal, there is no need for large centralised bureaucratic structures to manage it.

When innovation remains autonomous, but exploitation requires the firm to access capabilities outside its boundaries, Teece argues that the innovating firm must craft virtual ties to the technology source. The technology's importance, being close to the core, and/or some element of "tailoring" presumably dictates more lasting relations rather than pure market transactions.

When innovation remains autonomous, but requires new capabilities to be created to exploit its potential, Teece argues, virtual structures are not quite enough, and internal development or alliances with equity are required to manage contractual problems between the parties.

## **Systemic Innovations**

By their nature, systemic innovations require coordinated adjustment throughout the system to realise the gains from innovation. To achieve this, Teece, following the late Schumpeter, argues that tight coordination is needed. He argues that successful development of systemic innovations need institutions, where information can be freely shared without worry of expropriation, where entities can commit themselves and not be exploited by that commitment, and where disputes can be monitored and resolved in a timely way. This is precisely what multiproduct integrated firms achieve.

Teece argues, however, that while systemic innovation favours integrated structures from a coordination perspective, alliances may be the best arrangement if relevant technological capabilities are resident in unaffiliated enterprises. Large firms may here mobilise links to smaller firms with necessary capabilities.

When systemic innovation requires entirely new capabilities in order for the innovation's potential to be realised, Teece argues for integrated firm structure of the Silicon Valley type. This, he points out, is the situation that Chandler (1990) describes in *Scale and Scope* for the leading industries of the late 19<sup>th</sup> and early 20<sup>th</sup> centuries. Teece (1993) argues that the winners were the companies that made major investments to shape the markets, and simply did not rely upon them.

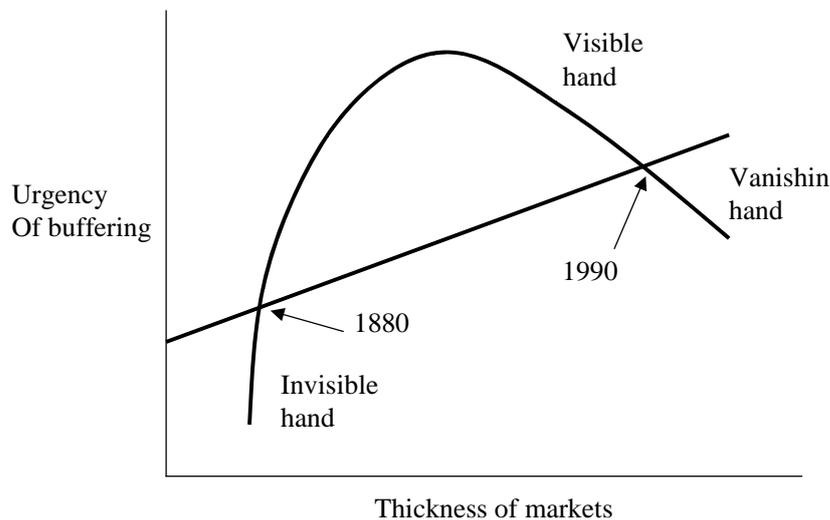
## **The evolving context**

Teece's functional argument for hierarchic integration is, however, met by a recent literature that points to a general evolution towards market-oriented governance. Langlois and other authors in this tradition see the buffering functions of management in the large corporation devolving towards the mechanisms of modularity and the market. They here point to mechanisms that we have previously discussed under the system of innovation heading like: informational decomposition, flexibility and risk spreading.

Langlois (2003) sums up this development in his “vanishing hand” thesis which, in shorthand formulation runs as follows: The factors shaping economic organisation of innovation may largely be summed up along two dimensions: the “thickness of the markets” and the “urgency of buffering”. By thickness of markets Langlois refers to such factors as the average income and the height of technological and political trade barriers, but also factors such as liquidity, transparency and capacity to handle financial risk. By “urgency of buffering” he refers to the degree to which the technology of production is complex, sequential and high-throughput.

Starting out towards the end of the 19<sup>th</sup> century, Langlois argues, markets were insufficiently thick to buffer product-flow uncertainty, just as they were initially too underdeveloped to handle financial risk (figure 2).

*Figure 2: Langlois’ vanishing hand hypothesis  
Langlois (2003)*



Over time, Langlois argues, markets get thicker and can thereby take on more of the governance previously retained by the firm (therefore the upward slope of the straight line). Secondly, the urgency of buffering levels off and then begins to decline because technological change begins to lower the minimum efficient scale of production. He also argues that urgency of buffering declines, because of improvements in coordination technology whether applied within a firm or across firms (and therefore the urgency) of buffering.

The term “vanishing hand”, of course, refers to Adam Smith’s famous metaphor of the “invisible hand” of market co-ordination and to the “visible hand” of the Chandlerian hierarchy, then followed by the more recent de-conglomeratisation and de-verticalisation that Langlois terms the “vanishing hand”.

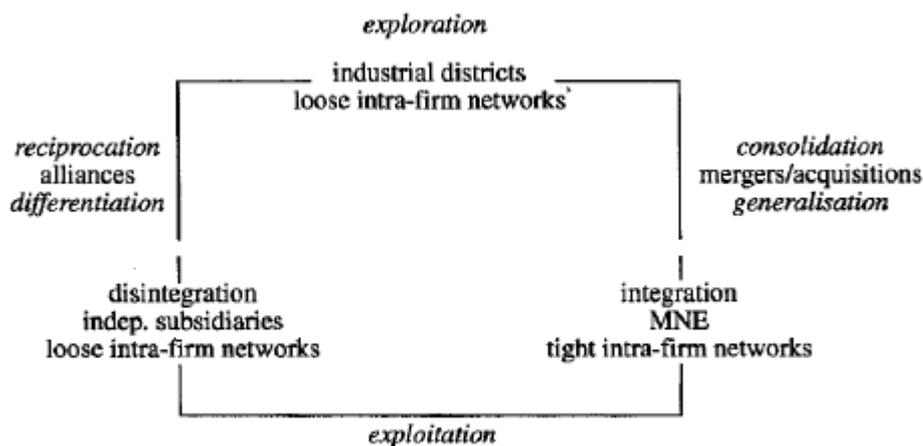
Langlois’ “vanishing hand” hypothesis thus, introduces a dynamic institutional contextualisation of Teece’s functional discussion of strategic organisation, envisaging that strategic orchestration is increasingly available outside hierarchies in more market-compatible forms. While Teece’s functional arguments may be basically sound, the general development pointed out by Langlois allows institutionalised market based orchestration of functions previously only open to hierarchic design.

## Dynamic organisation

Barth Nooteboom (1999) also introduces an important dynamic dimension to the organisation of innovation. However, unlike Langlois, his theory is dynamic in a cyclical and functional sense. In his dynamic theory of industrial organisation, Nooteboom allows several of Teece's managerial configurations to be sequenced over time, so as to strategically optimise management according to task structure in different phases of the innovation process.

Conceiving innovation as a learning and implementation process, Nooteboom notes that this process has both an exploration and an exploitation phase (figure 3). In the early invention/ exploration phase, the managerial design needs to be open and flexible - to allow novel combinations, while in the ensuing exploitation phase, the novelty needs to become standardised in a "dominant design" as Abernathy and Utterback (1978) have put it, indicating that at this stage what is needed is an organisational design aimed at consolidation.

*Figure 3: Nooteboom's Cyclical Theory of Industrial Organisation*  
From Nooteboom (1999)



Disintegrated constellations have a comparative advantage in the early stages of experimentation and invention, compared to the large firms. In the later stages of consolidation and generalisation, large firms have a comparative advantage, as winning designs may be integrated into more tightly governed contractual structures, or fully integrated hierarchy

To sum up Nooteboom's hypothesis: The cycle of learning and innovation generates a cycle of organisational integration and disintegration. For several reasons it is often loosely coupled systems that effect the novel combinations, while large firms (or tightly coupled systems) have comparative advantage in generalisation in a "dynamic complementarity" of loose and tight coupling. This resolves Schumpeter's ambiguity concerning the role of large versus small firms in innovation.

# Innovation in Petroleum Industry on the Norwegian Continental Shelf: The Case of Statoil and its Supplier System

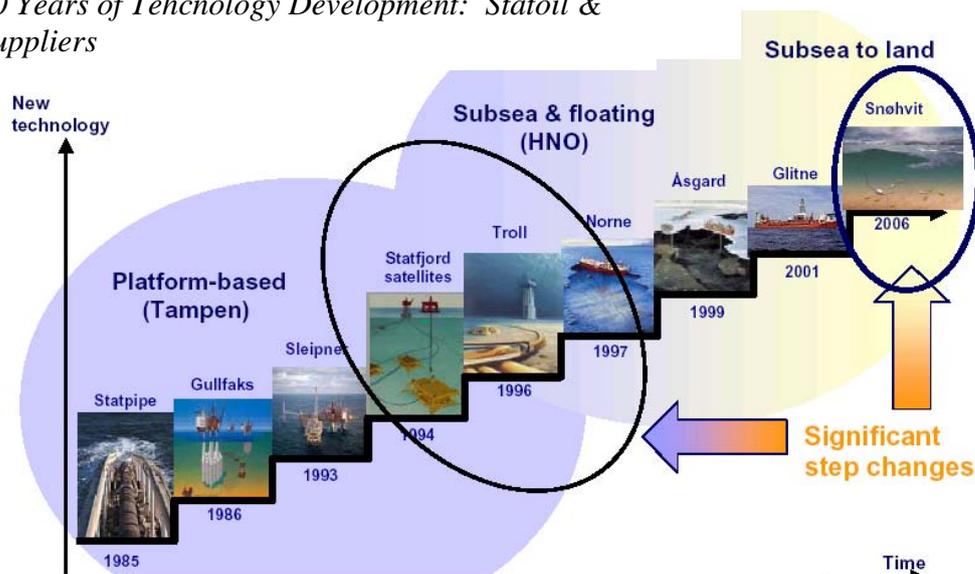
This section examines industrial organisation of innovation in oil production on the Norwegian Continental Shelf (NCS) against the theoretical background outlined above. The dominant petroleum company, Statoil and its supplier industry is taken as a focal example. A first section examines some of the general innovation achievements and explores the industrial organisation behind them. A second section specifically examines environmental performance as well as innovations by Statoil and its supplier system with a particular environmental focus. A final section discusses theoretical implications of the NCS case against the background spelled out above.

## *The Norwegian Continental Shelf as an Innovation Arena*

Given natural conditions such as harsh weather and deep water, the NCS right from the start became an arena for technological innovation as can be illustrated through the development of licences operated by the dominant actor, the state majority owned Statoil.

Since Statoil's operator- engagements in major North Sea projects the 1980's, the company and its supply network has undertaken major systemic innovations, moving from large seabed-platform based to subsea-based extraction, first in the form of subsea to floating ships and platforms, and currently projecting full offshore subsea to land extraction (figure 4).

*Figure 4:  
20 Years of Tehcnology Development: Statoil &  
Suppliers*

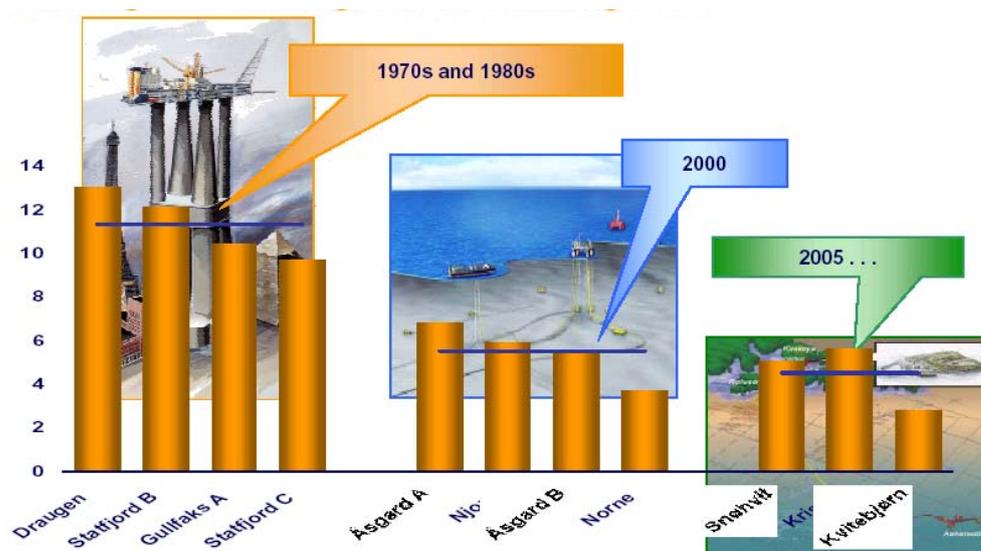


The oilfield developments here have gone from large platforms with enormous processing capabilities and excellent living conditions to a gradual move of processes to subsurface and subsea, and people to onshore. Complex, maturing fields and demands for increased productivity call for new technology.

Its most ambitious undertaking to date is the USD 6.3 billion Snow White gas and condensate development in the Barents Sea. This project includes the largest subsea production array to be remotely operated from a land facility. It also includes the longest subsea pipeline transporting unprocessed products to land injection equipment for carbon dioxide sequestration beneath the seabed, an environmental measure first applied on an industrial scale in Statoil's Sleipner field in the North Sea.

This development has come in response to several factors, such as the saturation of large fields and the need to proceed to extraction from so smaller so-called "tail fields", as well as the sharp drop in oil prices in the late 1990s. As indicated in figure 5, the cost reductions following the transfer to sub-sea technology was more than 50%.

*Figure 5*  
*Cost Reductions With Technology Development*  
*From Overvik 2004*



## **Innovation in Several Technological Fields Through systemic mobilisation<sup>2</sup>**

The "subsea-transition" has relied upon extensive innovations in several technological fields including subsea drilling; seismic mapping; subsea vehicles; intelligent fields, new pipeline technologies and an array of other innovative engineering and consulting

<sup>2</sup> Based on interviews with technology staff at Statoil, technology reports from the respective companies available on their websites.

services. Although many of the actors involved have a multinational field of operation, most of the innovations have a Norwegian base. According to Overvik (2004), about 80 percent of subsea technology deliverables are Norwegian.

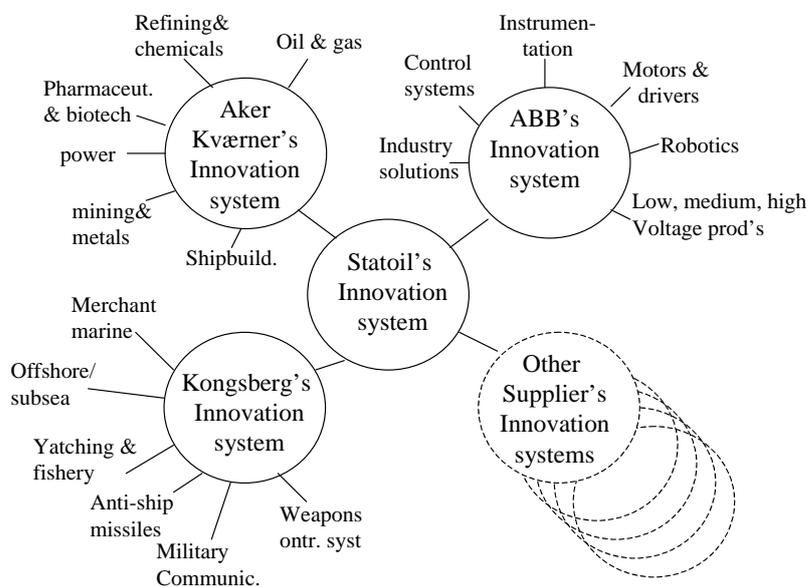
Given the complex organisation of upstream petroleum industry, with up to 80% of the cost structure outsourced, the technological achievements have only been possible through a mobilisation of joint innovation processes between Statoil and a host of suppliers and their skills and competencies.

The technological developments sketched above all illustrate the central arguments for systemic innovation including synergies from matching capabilities across firm boundaries. Most of the projects have also had clear positive externalities. Statoil has, in fact, generally taken a very open attitude to information sharing, and often involved other oil majors in the innovation, well knowing that the major economic effects come from increases in operative efficiency in petroleum exploration and production. Sharing of innovation costs also, obviously gives the company the benefits of sharing risk.

Several of the technical innovation projects also illustrate the flexibility of supplier-networks, when combined with the project-based nature of oil and gas production given the licensing rounds.

A brief glance at only the main Norwegian suppliers to Statoil illustrate the extensive industrial capabilities that can be mobilised (figure 6)

*Figure 6*  
*Statoil's large Norwegian Offshore Suppliers and their product-capabilities (indicated through their subdivision structure)<sup>3</sup>*



Through its supplier network, where we have only included some of the dominant core, Statoil is posed at the core of a broad set of industrial capabilities, branching into robotics, biotech, motors and weapon systems.

<sup>3</sup> Based on information from annual reports from the companies

Besides the oil and gas competence, Asea Brown Boveri, for instance, demonstrates capabilities in a broad range of fields such as control systems, instrumentation, motors and drivers, robotics low, medium and high voltage products and industry solutions, most of which may potentially provide useful complementary background for NCS offshore applications.

Aker Kværner, similarly can mobilise supplementary competencies to their oil and gas activities from shipbuilding, refining & chemicals, mining and metals, pharmaceuticals and biotech sections.

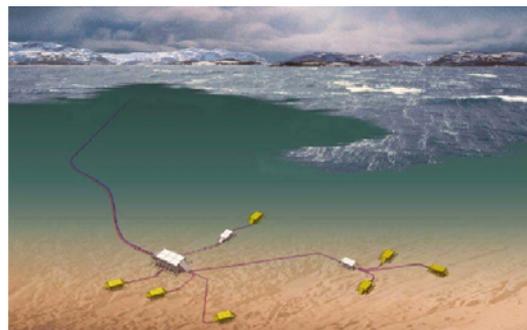
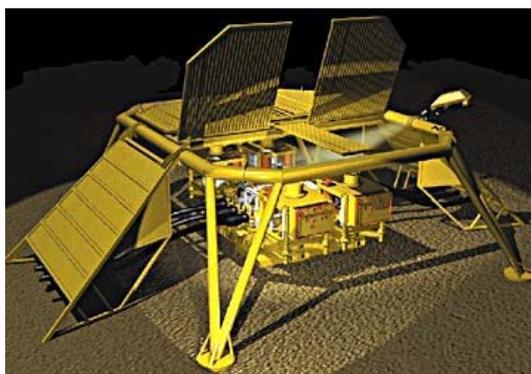
Another core supply partner, Kongsberg, is through the Kongsberg group involved in merchant marine, yatching & fishery, as well as a number of military applications in addition to its offshore, subsea activities.

For specialised innovation purposes, Statoils general innovation system is extended beyond the traditional partnerships to add on new experience and competencies. In this way, the Statoil supply system can tap into learning processes and project achievements far beyond its original competency based. The 2<sup>nd</sup> order networking approach rather than technology acquisition is vital to the fit between the new technological elements and the existing system.

## Subsea Dilling

As part of a move to cut costs in offshore petroleum production, Statoil has initiated the development a new generation modular subsea production systems, Hinge over Subsea Template (HOST) (figure 7). The Hinge may be installed at depths down to 2500 meters and is being used in several plased on the Norwegian continental shelf for the Gullfaks-field satellites, the HOST technology has implied savings of 50% compared to similar instalments in Statfjord satellites.

*Figure 7: Subsea production (From Kongsberg & Statoil)*

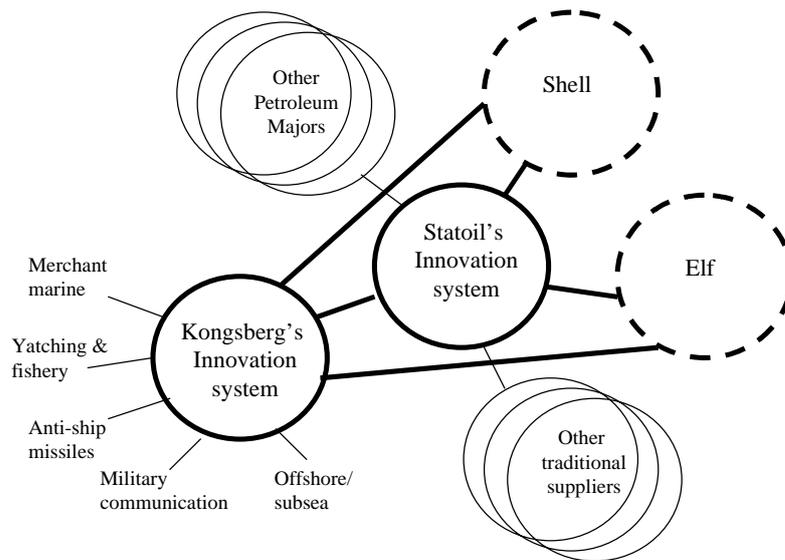


Primary operations targeted for the system are the deepwater guidelineless HOST being designed in a joint industry project; low-cost, low-function subsea installations To be cost-effective, it was necessary to produce a system that mobilizes to remote locations easily; operates with a standard remote operated vehicle system.

### *The Network*

The development HOST system has relied on extensive collaboration with one of the traditional suppliers, Kongsberg Offshore, but has also involved a partnership with some of the other oil majors operating on the NCS, Elf and Shell (figure 8).

*Figure y*  
*The innovation network for subsea drilling*

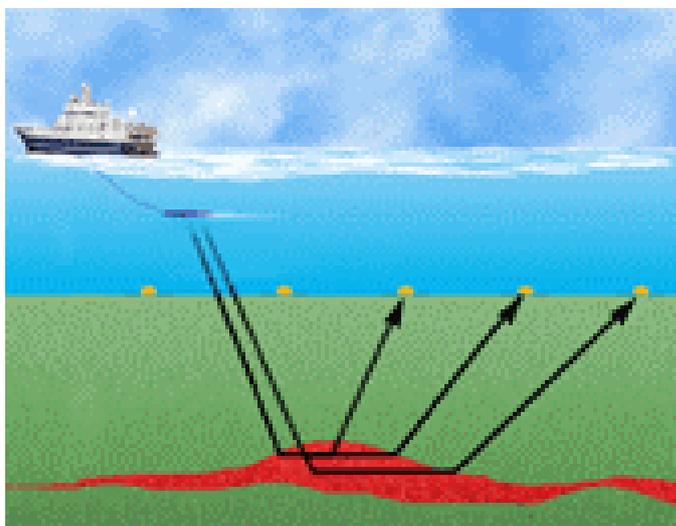


### **Improvements in Geological Mapping**

The new generation petroleum production has also relied on technological advances in geological mapping techniques, including Sea Bed Logging (SBL), which is an advanced new method for remote and direct identification of hydrocarbon filled layers in deep-water areas.

Modeling presented by Eidesmo et al. (2002) demonstrated that by using seabed logging (SBL), a special application of frequency domain controlled source electromagnetic (CSEM) sounding, the existence or otherwise of hydrocarbon bearing layers can be determined and their lateral extent and boundaries can be quantified. Such information provides valuable complementary constraints on reservoir geometry and characteristics obtained by seismic surveying (Ellingsrud et al 2002). While seismic surveying is based on sound waves and a proved method of defining structures and identifying possible reservoirs, SBL is based on electromagnetic waves and can determine whether the reservoir contains hydrocarbons or water (figure 9). As a result, the two technologies are complementary in the exploration phase.

*Figure 9*  
*Seabed Logging*  
*(from Statoil.com)*



#### *Network*

The SBL technique came out of research experiences Statoil had for quite some time conducted in the field of using electromagnetic waves in downhole tools to investigate reservoir properties, especially movement of water fronts. Information about a strong magnetic source triggered the idea of a possible direct Hydrocarbon indicator. From these discussions, the idea of "logging from the sea bed" by scaling up the distance, wavelength and power outputs was born, and is now contributing extensively to better reservoir identification and management (Marshall & Skitek 1990). During the development period, several patent applications were filed on this particular application of marine CSEM sounding<sup>4</sup>.

The idea of SBL was founded by Svein Ellingsrud and Terje Eidesmo then employees at Statoil R&D center during the autumn of 1997. Ståle Johansen, manager for exploration related research in Statoil at that time initiated the SBL project in 1997. Shortly after a cooperation was established with the Norwegian Geotechnical Institute (NGI) and Mylab (figure 10).

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<sup>4</sup> Published patent applications

1) Directed at general principles. Filed August 28, 1998. International publication date March 9, 2000, PCT application no WO200013046.

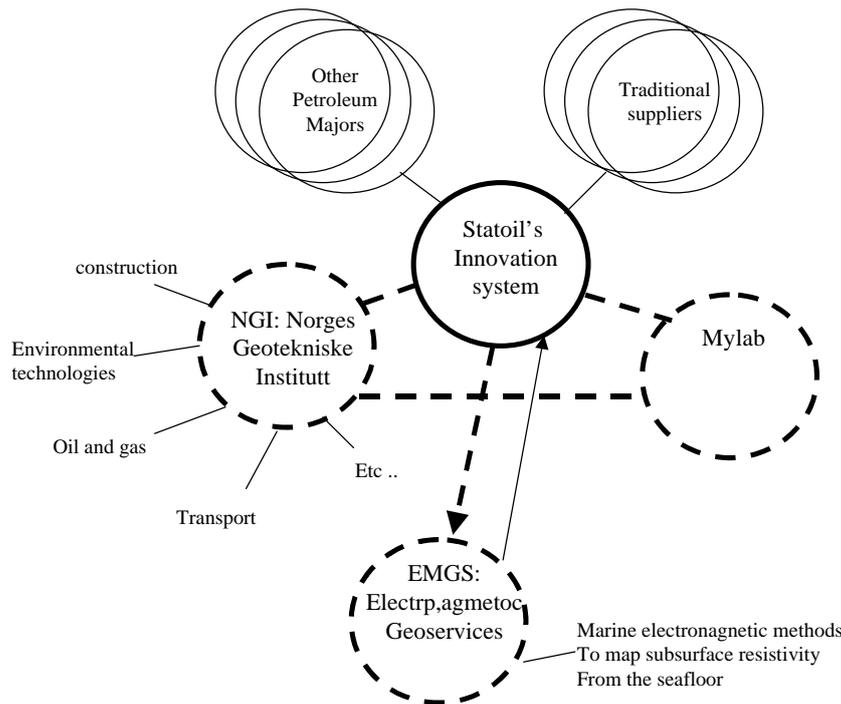
2) Directed at the wave guide effect directly by amplitude versus offset measurements. Filed February 2, 2000. International publication date August 2, 2001, PCT application no WO 200157555.

3) Directed at the effect of different antenna configuration. Filed August 14, 2000. International publication date February 21, 2002, PCT application no WO 200214906.

All patent applications are in the name of Statoil. emgs holds an exclusive license under the patent applications.

The spinout-company was established in 2002 by Statoil scientists, with the group as the majority shareholder and an annual turnover of roughly NOK 100 million. The solution developed by Statoil were licensed exclusively to EMGS. Originally applicable only in waters more than 500 metres deep, it can now be used in depths down to 300 metres.

*Figure 10  
Seabed logging network*



## Subsea Vehicles

Subsea drilling has necessitated subsea operative flexibility. Together with its suppliers, Statoil has, therefore, worked to develop an autonomous underwater vehicle for use in inspection, maintenance and repair of its subsea systems (figure 11). The target has been to design a vehicle that can perform the majority of the intervention repair and maintenance tasks associated with the production phase of the subsea field. The constraints were that this should be done while reducing the on site power requirements as well as the docking station's requirement, so that the vehicle could be incorporated directly into the subsea structure while rationalising the intervention interfaces.

Based on existing submarine vehicle technology, a first generation of subsea vehicles are already in operation. However, this field is under continuous development and it is anticipated that the innovation project will result in the design of a next generation vehicles that will ensure a seamless interface with the sub sea equipment, and provide even more cost effective intervention, maintenance and repair capability.

*Figure 11: Subsea Vehicle  
(From Cybernetix)*



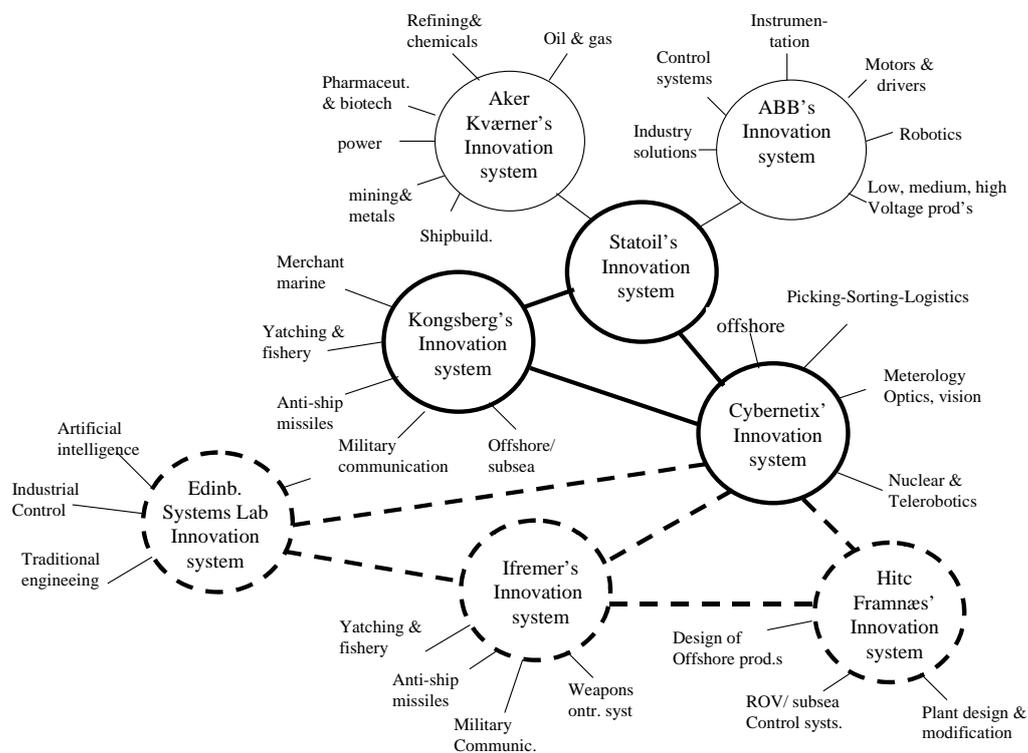
*The Extended Innovation system in the subsea vehicle case*

For the development of the Autonomous Underwater Vehicle development, Statoil was dependent not only on its traditional technology partner FMC Kongsberg in this case, but also on linking up with wider European competencies through the French company Cybernetics that combined competencies in subsea vehicles with disciplines such as microelectronics, and nuclear and telerobotics (figure 12).

Cybernetics, on its side, could draw on previous research with partners such as Ifremer, the French institute of research for the exploitation of the sea; Hitec Framnæs, a Norwegian design and engineering company operating in the oil & gas, marine and process industries and the System laboratory of Edinburgh University with a special competency in artificial intelligence and industrial control systems. In part sponsored by EU research grants, this group had developed the earlier generation of underwater vehicles, indirectly and through the Cybernetix connection Statoil could link up with wider European resources, which they could build upon in their development of the next generation vehicle.

Kongsberg and Statoil itself, in this case, presumably provides the link to fitting the vehicle technology to the modular subsea production system's interface.

Figure 12  
The Extended Innovation System in the Autonomous Underwater Vehicle Case



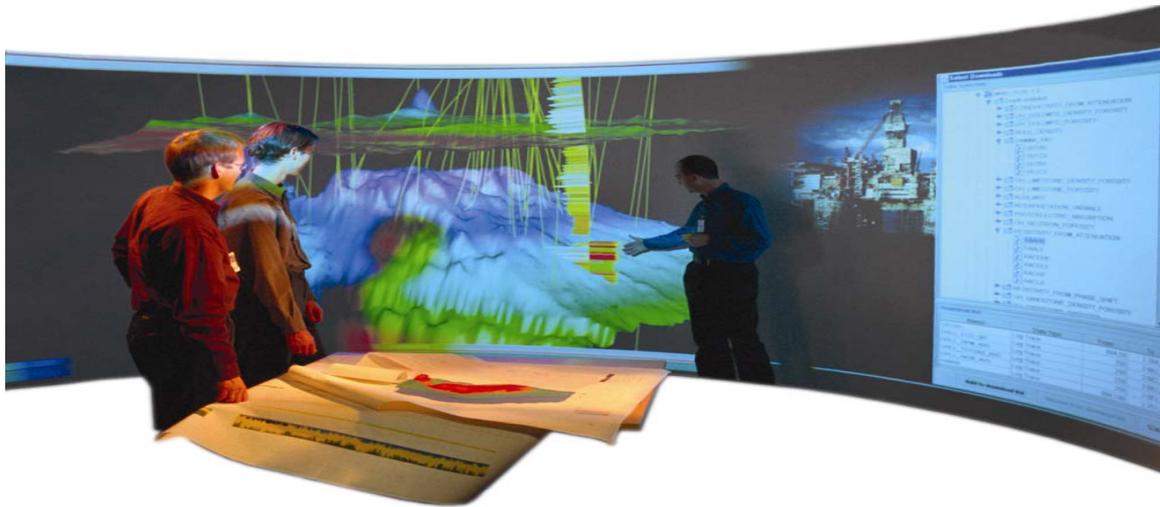
## Intelligent Fields

The coordination of several parts of the subsea endeavour has been operatively integrated by advanced IT solutions, under the concept of "Intelligent Fields". The new technology permits real-time interaction between offshore installations and land organisations over data, expertise and working process (Statoil.com). This technology is central to the move to the subsea – onshore controlled production system.

The system has evolved out of earlier initiatives, dating back in 1997, when Statoil's Research Centre started developing tools to help asset teams hit their reservoir targets more accurately. To avoid lock in to a singular supplier, Statoil decided to build a new system that could bring real-time data into a programme format that would allow participation from any service provider.

Having a single database and application suite has ensured consistency throughout well planning, drilling, evaluation and reporting and has given the wellsite geologists a better toolbox than before. Statoil has also seen potential cost savings through quicker decision making and improved communication with common access to real time data. However, the greatest potential value of this new approach is expected to come from increased production due to better well placement.

*Figure 13: Intelligent fields*

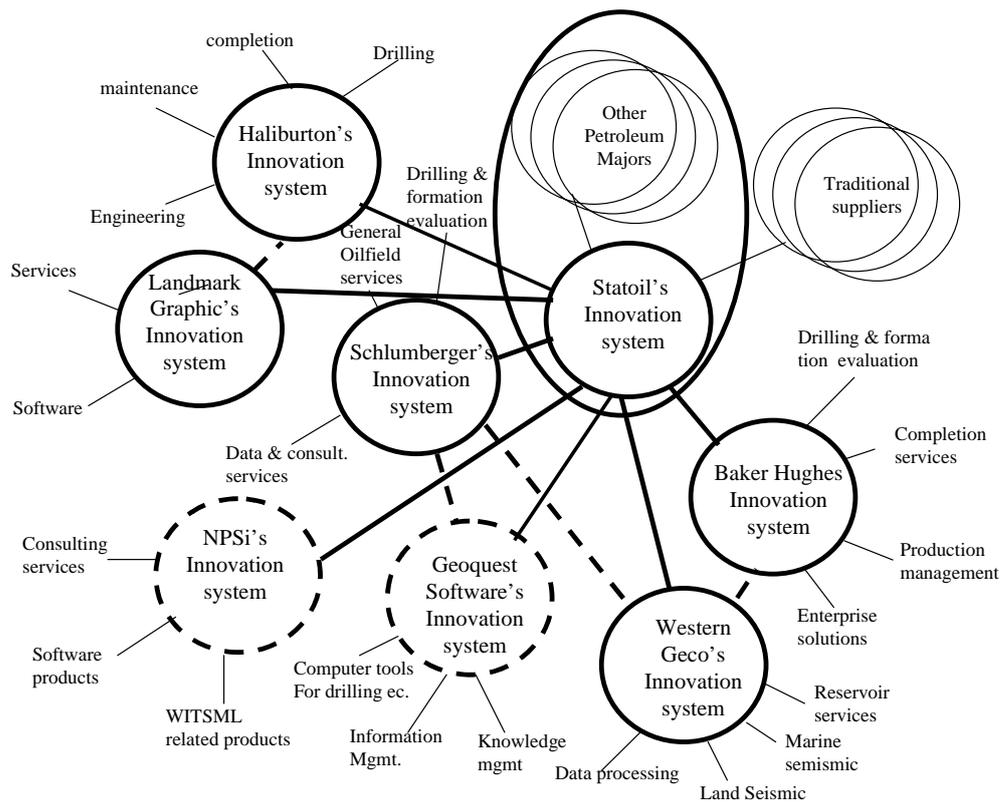


*The Extended Innovation System in the Intelligent Field Case*

The “intelligent field” is another case where the supplier network was extended to encompass new technological competencies. The “architectural” ambition to develop an open platform that could potentially become industrial standard in the outset dictated broad participation. Furthermore, the extensive interfaces between IT and various technology components demanded a wider set of competencies than those existing in the traditional supplier network. The open platform/ architecture ambition also dictated the alliance with other petroleum majors. Statoil here ventured far outside of its traditional Norwegian supplier network.

An important piece of the intelligent field concept, WITSML or “wellsite information transfer standard ML” was initially developed by the WITSML project, an oil industry initiative sponsored by Statoil, BP and later by Shell, as a new standard for drilling information transfer. Initial participation is from the major service companies Baker Hughes, GeoQuest, Halliburton, Landmark and Schlumberger (figure 14).

Figure 14: The Intelligent Field Innovation Network



## Regulation and Market Drivers

One core incentive and basis for strategic action lies in the licensing system. Production licenses are normally awarded by the Norwegian Government through licensing rounds. The government invites applications for a certain number of blocks. Companies can apply individually or in groups. On the basis of applications received, the Ministry of Petroleum and Energy puts together a group of companies for each license or can make adjustments to a group that has submitted a joint application and appoints an operator for this partnership, who is responsible for the daily conduct of operations in accordance with the terms of the license. A production license entails an exclusive right to explore for and produce petroleum within its specified geographical area and therefore gives the license holder a strategic asset that it may use to mobilise complementary competencies. Given the extensive super profits from oil exploration under the OPEC cartellisation, the licensee holds access to valuable resources. As major actors, and Statoil in particular, tends to win a stream of licenses on the NCS over time (Fact sheet 2004) the license stabilises the control structure and makes Statoil an attractive partner in long term relationships.

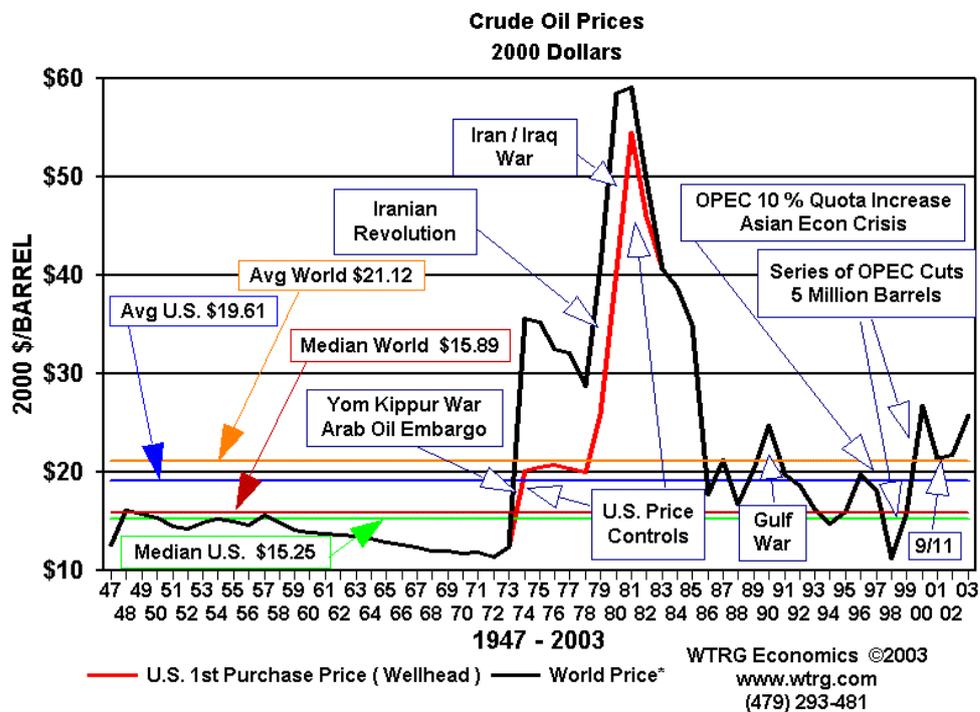
However, as new fields are opened and new licenses awarded, there is a renewed competition also for Statoil, where technological innovation and environmental performance are core evaluation criteria. Statoil and other petroleum majors that candidate for licenses, therefore have an interest in pushing technological frontiers, especially if this is also cost-efficient.

This creates a cycle of innovation and stabilisation, where each new licence is an innovation opportunity which then is stabilised into an efficient exploitation design

as the license turns into operative mode. The following new licence then takes innovation one step further. This resembles the cyclicity not unlike what is described in Nooteboom's strategic cycle of differentiation, accommodation, consolidation and generalisation. However, whereas Nooteboom assumed that the whole company might be going through the full cycle, the NCS petroleum model indicates that a large company may have projects which are at different stages at the same time. Admittedly, there will be cross-licence learning whenever possible, however each license will have a material structure inherited from its "generation" state of the art technology, which limits the transfer possibility.

The price fall in the late 1990s (fig 15) probably accentuated the innovative pressure. Low oil prices can make fields unprofitable and reduce exploration and investment opportunities for oil companies on the NCS. Norway experienced this from 1998 to 1999, when oil prices declined towards USD 10 per barrel. From 1997 to 2000, the number of exploration wells on the NCS was reduced by more than 50 per cent. There was also a dramatic decline in the number of new fields that licensees decided to develop during the period. This demonstrated that the oil companies responded quickly to low oil prices, and that these prices need not be depressed for long before the impact on exploration operations and new field developments is felt. (report 38 to the Storting, 2000-2001).

Figure 15  
Crude oil prices  
From WTRG Economics 2003



Further incentives to innovate on the NCS are given by the Norwegian petroleum taxation builds on the Norwegian rules for ordinary corporation tax, which is charged at 28 per cent both on land and offshore. Owing to the extraordinary profitability of petroleum production, a special tax of 50 per cent is also levied on this industry.

An uplift of 30 per cent of the investment – five per cent for the for six years from the date of the investment – protects the companies’ normal return from the special tax. However, companies can also deduct all relevant costs, including exploration and net financial expenses. In addition comes full consolidation for all fields. This creates an environment for NCS operations where the actors are motivated to locate relevant innovation projects in this area as the cost reduction from tax deduction is higher in the NCS than in other areas.

Further incentives to cost-reducing innovation came with a policy shift from Norwegian authorities in 2002 to allow smaller actors to take part in oil production from so-called marginal “tail” fields. A new company, Petra, thus became operator of the Varg field, on August 1st 2002, as the previous licence holders, Statoil and Norsk Hydro, were planning to shut the field down. During 2003, the company has drilled an exploration well and three new production wells on the field. If the approved enhanced oil recovery program is successful, production from Varg is expected to continue until 2007. Petra AS is a wholly-owned subsidiary of Petroleum Geo-Services, one of Statoil’s suppliers in the geo-services field. The company was formally approved as license holder and operator on the Norwegian Continental Shelf (NCS) in February, 2002.

### ***Environmental Innovation***

Does the innovation network also deliver on the environmental side?

The picture here is rather mixed and varies according to environmental indicators and which processes one examines:

On the negative side, the fact that many Norwegian oil fields are aging and that petroleum extraction on the NCS therefore relies more and more marginal resources, does in itself weaken the environmental performance. Energy requirements for processing are, for instance, largely determined by the total volume of water, oil and gas in the wellstream. As a field comes closer to depletion, the water content increases extensively.

Furthermore, as a gas takes a larger share of total production, this in itself also tends to weaken environmental performance. Treatment and transport of produced gas require more energy than liquids production, and the proportion of produced gas in total Norwegian output is steadily rising.

Also, the move toward subsea-drilling has had its environmental costs: Discharges of production and injection chemicals have risen in recent years, primarily reflecting increased use of subsea templates and more water injection, as such operations normally depend on chemicals.

On the positive side, technological achievements have been made in many operations with the effect of reducing environmental damage. Furthermore public policy and regulation is also becoming more and more demanding.

Based on a recently released Government report on environmental performance in the Norwegian petroleum sector, we shall briefly review some of the environmental performance on some key indicators: CO<sub>2</sub>, NO<sub>x</sub>, nmVOC and chemicals. Thereafter, we shall discuss the innovation processes behind CO<sub>2</sub> capture as an illustrative case.

## CO2

As can be seen from figure 6, total CO2 emissions from the petroleum sector have grown year by year, mainly as a result of increased activity (fig 16). There has, however been a certain improvement in emissions pr unit in the beginning of the 1990s, but this improvement has not persisted over time (figure 7)

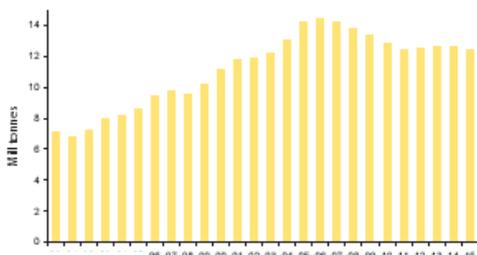


Fig 16 Total CO<sub>2</sub> emissions from the Norwegian petroleum sector (Sources: MPE/NPD)

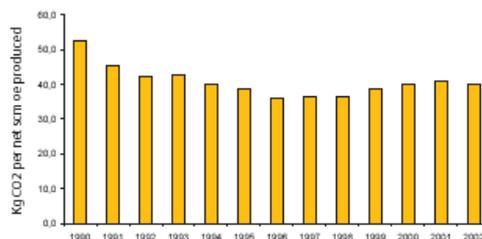


Fig 17 Emission of taxed CO<sub>2</sub> per unit produced (Source: NPD)

In spite of the largely unimpressive performance data, a number of technological measures have been taken to counteract CO2 emissions. This includes more efficient energy production, by combined cycle systems currently operational on Oseberg, Snorre and Eldfisk, using waste heat in gas turbine exhaust fumes to produce steam for generating additional electricity. It also includes experimentation with storage of CO2 separated from the Sleipner West gas production, which represents an innovative approach in this sector. Finally, recovering flare gas has now become the universal standard on the NCS, following new technological breakthroughs.

## NOX

The pattern of NOX emissions is not very different from that of CO2, reflecting that it comes out of much of the same sources, and that most measures which reduce CO2 emissions also help to cut the amount of NOX released from the petroleum sector.

As indicated in figure 18 the total emissions from Norwegian petroleum production have been rising and have peaked last year. However, NOX emissions are expected to decline more rapidly than CO2 emissions. Similar, also to the CO2, development, the emissions pr unit have dropped from 1990, but have then stabilised (figure 19).

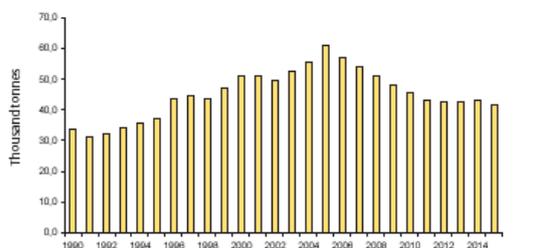


Fig 18 Total NO<sub>x</sub> emissions from the Norwegian petroleum sector (Sources: MPE/NPD)

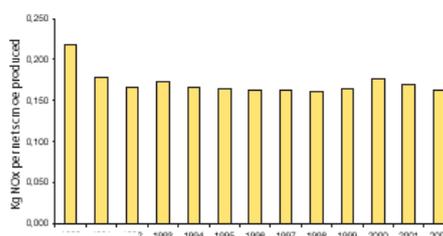


Fig 19 Discharges of NO<sub>x</sub> per unit produced (Sources: MPE/NPD)

As already mentioned, most of the measures which reduce CO<sub>2</sub> emissions also reduce NO<sub>x</sub>. In addition come the possibility of installing low No<sub>x</sub> burners in new gas turbines, catalytic cleaning and steam/water injection in the combustion chamber. According to the Norwegian Ministry of Petroleum and Energy, Installing low No<sub>x</sub> burners is regarded today as the most appropriate way to achieve substantial emission reductions from Norwegian offshore oil and gas activities, and such equipment is standard for new fields.

### Non-methane volatile organic compounds NmVOC

NmVOC is a general term used for volatile organic compounds other than methane, which vaporise from crude oil and other substances.

The petroleum sector is the main Norwegian source for emissions of nmVOC with 63% of total Norwegian emissions. The bulk of emissions in the petroleum sector derives from offshore storage and loading of crude oil and from receiving terminals on land. However, the share of the petroleum sector is declining as emission-reducing technology gets phased in (figure 20). As yet, however, the emissions pr unit have not declined dramatically (fig 21).

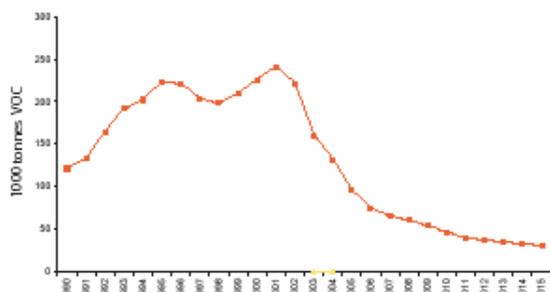


Fig 20 Total emissions of nmVOC from the petroleum sector, 2002  
(Sources: MPE/NPD)

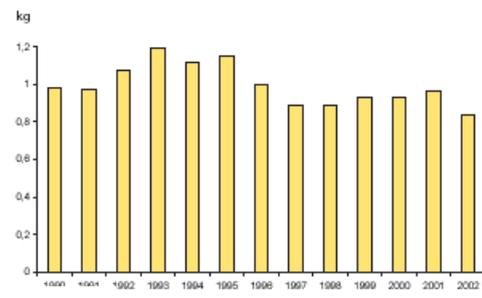


Fig 21 NmVOC emissions per unit produced  
(Sources: MPE/NPD)

### Chemicals, oil and other naturally-occurring chemical substances

An efficient oil and gas business would be impossible without chemicals. Substantial efforts are therefore being made to develop substances that cause the least possible harm to the environment when used.

Drilling and well operations clearly rank as the biggest source of chemical discharges on the NCS. Year-on-year changes in the overall figure for such discharges therefore relate largely to variation in the number of wells drilled (figure 22). Combined with injection of cuttings below ground, new drilling methods and technology have helped to cut discharges per meter drilled in recent years (see figure 23)

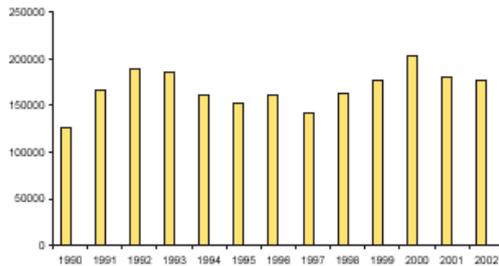


Fig 22 Total chemicals discharged from Norwegian petroleum operations  
(Source: SFT)

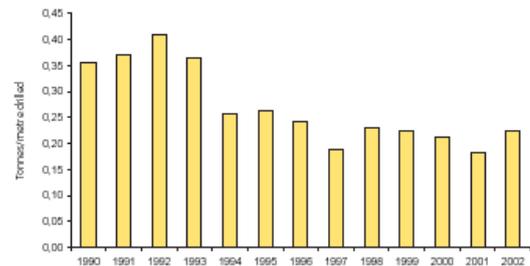


Fig 23 Discharges of drilling chemicals per metre drilled  
(Sources: SFT/NPD)

Several of Norway's largest fields have now reached such a mature phase that their water cut is higher than before, boosting the volume of produced water and thereby oil discharges. Injecting produced water below ground has started on a growing number of Norwegian fields and is expected to bring the volumes of produced water discharged down considerably (figure 24)

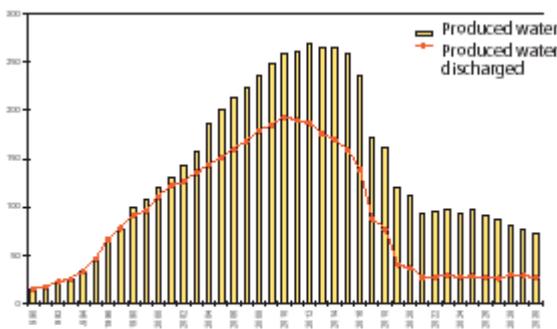


Fig 24 Volumes of produced water and produced water discharged, historical and forecast  
(Source: NPD)

A number of projects have been initiated to improve the environmental performance of the oil production on the NCS. Also in this field, we can observe that the oil majors are extensively dependent on external networks. However, the maturity of the technology varies, and we can observe the traditional supply networks supplemented by more research-oriented systems.

Limited space does again not allow us to explore the whole array of environmental innovation projects in further detail, and we have selected two: CO2 capture at the Sleipner field and the non-methane volatile organic compounds reduction as examples of a more research oriented project on the one hand, and a more industrially mature project on the other.

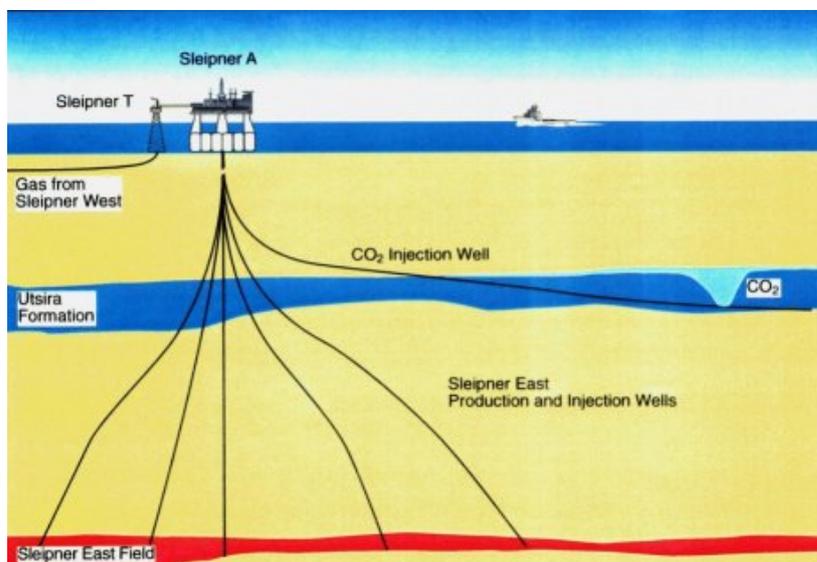
### ***The Case of CO2 Capture at Sleipner***

CO2 capture is still at the research/pioneering project state, but it is characteristic of the NCS context that the pioneering project has been undertaken under Statoil's leadership.

Statoil and license partners started in 1996 to inject 1 million tons of CO2 per year into sands of the Utsira Formation at the Sleipner field in the North Sea. This is

the first case of industrial scale CO<sub>2</sub> storage in the world. A special feature of the natural gas from the Sleipner West field is the high content of carbon dioxide (~ 9%), this being reduced via amine stripping towers to 2.5% prior to despatch. The CO<sub>2</sub> is then injected into a saline water-bearing structure, the Utsira formation, that comprise sands ~800 metres below the seabed. Production from the Sleipner West gas and condensate field began in August 1996. Treating carbon dioxide in this way almost entirely eliminates emissions to the atmosphere. This project marked a milestone in industrial history as this had never before been carried out on such a large scale (1 mt/a CO<sub>2</sub>). In addition, CO<sub>2</sub> had not been compressed and injected underground on an offshore platform before.

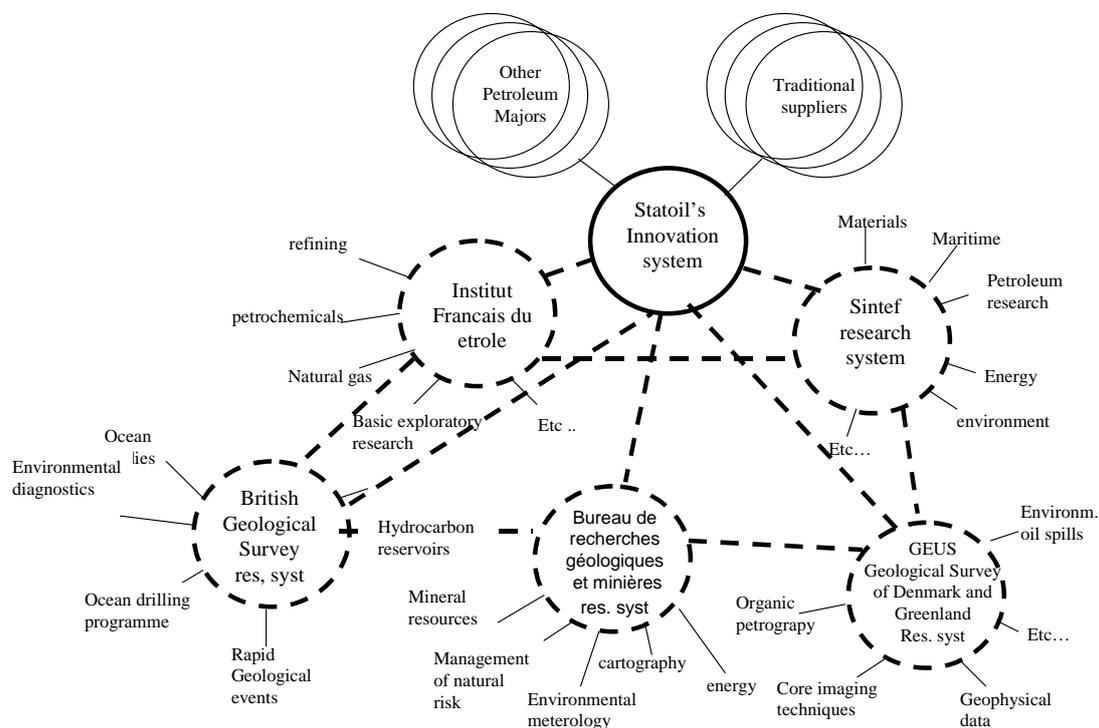
*Figure 25*  
*Oil capture at Sleipner*  
*From Sintef*



As part of the pioneering project Statoil also initiated and organized a following multinational and multidisciplinary research project to document and investigate CO<sub>2</sub> capture in saline aquifer reservoirs. The project serves as a test case for offshore underground CO<sub>2</sub>-disposal in general, and for possible future use of the wide-spread Utsira Formation in particular. According to the IEA, the monitoring project is confirming that CO<sub>2</sub> storage in deep saline reservoirs is a safe and reliable option and is supplying data to validate reservoir simulation models which will be essential in the planning of future CO<sub>2</sub> storage projects in other parts of the world. (IEA 2004)

The programme also mobilized a wide network of partners, including some of the oil companies operating on the Norwegian continental shelf, but also a section of geological and petroleum research institutions (figure 26:

Figure 26  
The industrial-research cluster involved in the project of CO<sub>2</sub> Capture at Sleipner



This network has been able to mobilise a number of capabilities within geology, environmental diagnostics, mineral resources, geophysical data and oceanographic knowledge that supplements the traditional industrial knowledge base of the industry. Furthermore, the scientific credentials have probably also been of importance in providing credibility to the public authorities and public at large on the sustainability of the CO<sub>2</sub> solution

### ***Strategic Drivers***

The regulatory context on the Norwegian Continental Shelf could in many ways be characterized as ambitious and includes a number of regulatory tools.

Firstly, the licensing procedure described in the preceding section for general innovation also applies to environmental innovation. Before a new area of the NCS is opened for petroleum activities, detailed analyses are carried out on behalf of government to assess the extent to which exploration could harm the environment.

As part of the licencing procedure the plan for development and operation, (PDO) must be approved by Government. In addition each licence partner must have permits for installation and operation (PIO) As part of the PDO/PIO process the licensees must submit an impact assessment, and environmental protection represents one of the criteria for the overall license evaluation.

In addition, Norwegian Government deploys several policy instruments to limit the environmental impact of emissions and discharges during the operation phase. This includes conditions attached to PDO and PIO, carbon tax and permits for

flaring and emissions/discharges. These instruments vary from one kind of emission/discharge to another. More specifically:

- With effect from 1991 a carbon tax on the use of gas, oil and diesel oil in petroleum activities on the NCS is imposed. January 2004 the tax rate is NOK 0.76 pr litre oil/scm of gas.
- Gas flaring, other than volumes necessary for safety reasons during normal operation is not permitted.
- NOX and NmVOC are subject to emission permits since 1999 and 2001.

The strong environmental engagement Norwegian authorities in environmental questions related to petroleum industry comes out of the fact that Norway is under pressure from international protocols: The Gothenburg protocol requires NOX emissions reduced by 29% compared to 1990. The North Atlantic Oskar convention sets a ceiling for 40 milligrams per litre of dispersed oil in water discharged to sea and recommends lowering to 30 milligrams in 2006. Norway is also committed to the Kyoto process of CO<sub>2</sub> reduction.

Given the industrial structure, with a traditional reliance on hydropower, Norway does not have any simple leeway to accommodate lavish emissions from its expanding petroleum sector. More recently, therefore a “zero discharge” concept has been launched by Government after consultations with industry ( Gvt Report no 25, 2002-2003).

Defined in accordance with the precautionary principle, the zero discharge goal aims to help ensure that discharges of oil and environmentally-hazardous substances to the sea do not cause unacceptable health or environmental damage. The main rule is that no environmentally harmful substances should be discharged, whether these are chemical additives or naturally-occurring chemical substances. This goal applies already for new stand-alone developments and by the end of 2005 for existing installations. It covers all offshore activities, including drilling and well operations, production and pipeline leaks. A stricter interpretation of the zero discharge concept will be applied in the vulnerable Lofoten- Barents Sea areas than on the rest of the NC. When choosing measures on each field, an overall assessment must be made of a number of factors, including environmental consequences, safety conditions, reservoir technology aspects and cost.

## **Final Reflection**

The NCS petroleum industry case clearly supports the arguments for a systemic perspective on innovation. Most of the innovation projects have drawn widely on complementary resources in the supply system. They have apparently had extensive positive externality effects throughout the supplier community and thus have provided Statoil with flexibility in re-combining competencies and resources that the company could never have achieved alone. The broad involvement also of the other petroleum majors have contributed extensively to risk sharing as well as collective momentum in establishing architectural innovation in certain projects, such as the intelligent field.

Where the innovation challenges went beyond the core competencies of the supplier network, such as in the CO<sub>2</sub> capture case, and also in the intelligent field case, the system has been capable of dynamic extensions. These extensions have supplemented the core competencies in the supply network in highly specialised

fields. However, the new specialised input has generally been tied closely in with the supply system to secure fit with existing technical system. The Kongsberg-Cybernetix is a case in point.

Outsourcing in value systems for static efficiency (transaction costs) in other words potentially also establishes a broader platform for innovation when technological challenges proceed beyond technical capability of even large firms. The multiplier effects of competency recombination of the supplier system's joint capabilities, is immense. Furthermore, the core company, thereby also taps into capability/competency build-up derived from the supplier's engagement with other clients.

The systemic nature of the extended supplier chain serves to explain much of the creativity that has been unleashed in many of the cases we have explored. However, it does not explain how the system could achieve strategic integration? We have previously pointed out that strategic integration has been poorly accounted for in the system of innovation literature, and have, therefore, supplemented the system of innovation perspective with a transaction cost based perspective on strategic organisation.

A central argument in the transaction cost perspective as presented by Teece is, as we remember, the argument that systemic innovation needs hierarchical governance. Nevertheless, Teece argues that while systemic innovation favours integrated structures from a coordination perspective, alliances may be the best arrangement if relevant technological capabilities are resident in unaffiliated enterprises. Large firms may here mobilise links to smaller firms with necessary capabilities. When systemic innovation requires entirely new capabilities in order for the innovation's potential to be realised, Teece has argued for integrated firm structure of the Silicon Valley type.

Taking the transaction cost perspective as a point of departure, it remains a puzzle how Statoil seemingly has managed to work out systemic or architectural innovation in the context of a supplier network which is not tied together neither by hierarchic governance nor by long term alliances. The cases indicate, however, that several factors nevertheless serve to consolidate strategic capability in the Statoil-supplier case.

Firstly, Statoil's, or the oil major's strategic position in the network is greatly strengthened by its privileged access to the licence. This stabilises control in the supplier network. Perceived ability to gain future access to new licences gives even more strategic power. From the licence address position, Statoil has been capable of executing considerable architectural/structuring power without hierarchic integration.

In project-based collaboration with other oil majors, Statoil has even been able to stage explicit architectural efforts on behalf of industry (ex intelligent fields) leading up to industrial standards. However, the allocation of tail production to small suppliers indicates that the period of exclusive access may easily be more challenged if the Statoil supply system is not able to operate with cost efficiency in marginal fields.

While the orchestration capability in the Statoil/ NCS case is to some extent anchored in specific factors, it may also reflect a more general "vanishing hand" effect. As complex technical economic systems proceed beyond technical capabilities of even large firms, there will be a strong pressure for governance and economic organisation to follow suit. We recall that Langlois explicitly pointed out improvements in coordination technology being one of the central factors behind the vanishing hand development.

Besides the long term dynamics pointed out by Langlois, the Statoil innovation cluster case also indicates the relevance of Notebooms shorter term cyclical model. In the NCS case, the licensing procedure provides such a cyclical regulation instrument, which constitutes opportunities for building new technological platforms.

However, the NCS case also highlights the significance of public regulation. The high tax rates and full cost deduction makes it cost-efficient to locate innovation on the NCS. Furthermore, a consistent demand for POD and state of the art technology to qualify for license, establishes an innovation pressure. In addition, comes for the environmental innovation, the adoption of zero emissions ambition

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