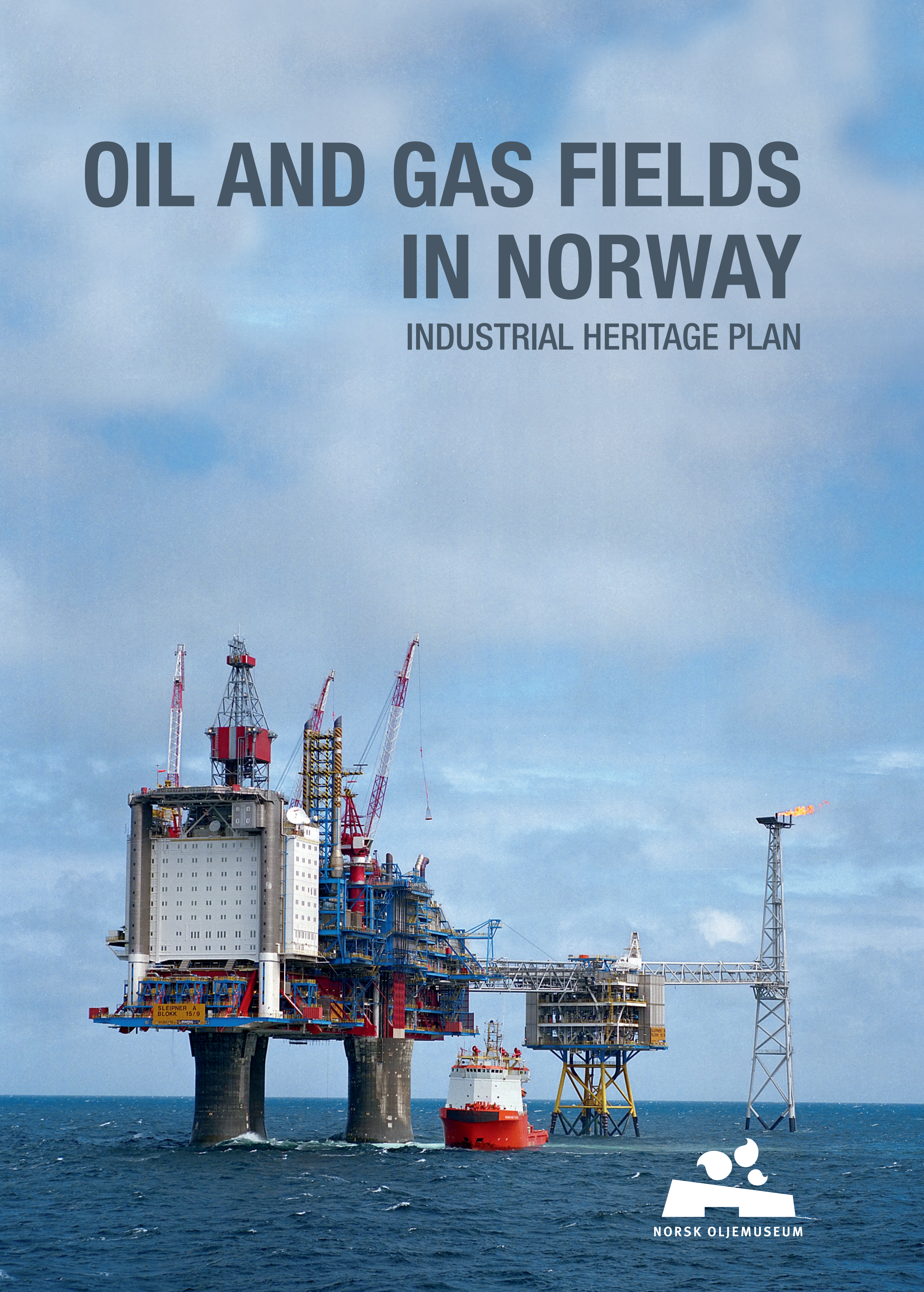
OIL AND GAS FIELDS IN NORWAY

INDUSTRIAL HERITAGE PLAN



NORSK OLJEMUSEUM

DEVELOPMENTS ON THE NCS

Political guidelines and technological choices

Troll A is towed out to the field in 1995. Photo: Leif Berge/Statoil

This article describes developments on the NCS in terms of the conditions underpinning Norway's emergence as an oil and gas nation, the role of government and the rapid technological progress made. An approach has been chosen which illustrates various eras and development features in relation to government administration and development of the oil and gas fields on the NCS.

Various factors have determined the choice of development solution. The government's political goals have varied between one period and another, from encouraging the import of foreign expertise and technology, via national management and control, to liberalisation and a focus on improved resource utilisation. Technological progress has been a continuous process, which has eventually made it possible to develop ever more demanding fields. Substantial design differences accordingly exist in terms of size, complexity, technical solutions and architecture.

The start-up period

During the early years of oil activity on the NCS, the government was concerned to attract multinational companies. Norway depended on their specialist expertise and their technical and financial capacity to get started in an acceptable manner. Few Norwegians were involved in the industry, and few domestic companies sought to win deliveries.

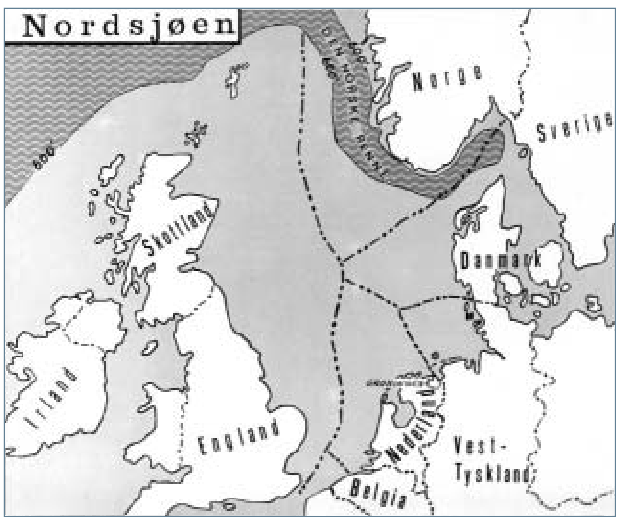
Natural basis for oil activity

Geology

The Groningen field in the Netherlands was discovered in 1959. This aroused the interest of the big international oil companies, which sought permission to conduct seismic surveys in the North Sea off the UK and Norway. The thick sedimentary strata on the British and Norwegian sides of the North Sea proved to offer very favourable conditions for petroleum accumulations.

Norwegian continental shelf (NCS)

Negotiations were pursued in the early 1960s over jurisdiction in the North Sea. The legal status of the continental shelf had not been clarified at this point, and it was by no means certain that the Norwegian state had the proprietary right to possible discoveries. Norway declared its sovereignty over the continental shelf in 1963, giving it jurisdiction over all exploration and exploitation of submarine natural resources. However, Britain, Norway and Denmark did not reach agreement until 1965 on where the boundaries between their sectors should be drawn in accordance with the median line principle.



North Sea boundaries in 1965. From a brochure published by Esso Norge

Commercial basis for oil activity

Little expertise was available in Norway at the beginning of the 1960s on exploring for, producing or processing petroleum. No education was provided in this area, no government bodies or institutions worked with oil and gas, and no legislation or other regulations specifically addressed petroleum activity. To some extent, people were familiar with building large structures such as dams, bridges and ships, but oil operations were unknown. During the initial period, therefore, attention was focused on learning to adapt solutions developed abroad.

The maritime expertise acquired by Norwegians over generations was a big advantage when oil exploration and production began. Many seafarers accustomed to working far from home for long periods were recruited by the petroleum industry. Seagoing experience from the sea and great adaptability were important in an international business like oil. Norwegian shipowners also had experience of operating internationally, and already had contacts in the oil industry. Many of them were well capitalised and accustomed to making big and fairly risky investments. A number of shipyards large and small engaged in newbuilding and repair were strung out along the Norwegian coast. These had little involvement in platform building during the early years, but a number adapted quickly to the offshore sector after the sharp rise in crude prices in the 1973 oil crisis and a series of discoveries on the NCS. They built drilling rigs, production platforms, and supply and support ships.

International expertise

The government saw that the big oil companies had both the technological expertise and the capital required to find and exploit possible petroleum resources. Norway accordingly depended on these multinationals during the early years to exploit its oil and gas. Government policy focused on attracting international oil companies and technology.

Foreign suppliers therefore dominated initially in every area. The technology and development solutions imported in this period were regarded as the best in the world, but were not necessarily adapted to North Sea conditions. That left room for improvement, where Norwegian industry was quick to become involved. The structure of Norway's shipbuilding sector, with many small and dispersed units, meant that big jobs had to be split between a number of yards. Sharing work in this way permitted quick delivery while allowing local yards and engineering works to benefit from the expertise.

Esso was the first company to gather geophysical data on the NCS, starting as early as 1962 in Norway's North Sea sector. These surveys provided indications that oil exploration was worth pursuing. A number of companies became involved in this activity during 1964. When the Ministry of Industry put most of the blocks on the NCS south of the 62nd parallel on offer in 1965, 11 applicants indicated their interest. Nine industrial groupings received production licences for a total of 74 blocks.

Drilling

Drilling for oil has been an industry for more than 150 years, with the rotary method first adopted in the early 20th century. From today's perspective, this technology remained at an early stage when operations began in the North Sea despite the many improvements already made. While drilling exploration wells is relatively simple, those for production are more demanding. When oil drilling began on the NCS, opportunities to angle a well away from the vertical were fairly restricted. That meant a number of wellhead platforms were required, and reservoir utilisation was relatively low. The latter only improved when deviated, horizontal and multilateral (sidetrack) drilling techniques were developed.

The oil companies outsourced much of the practical work in exploration drilling to various contractors, who largely hailed from the USA (Sedco, Odeco and Zapata Offshore).

Exploration drilling from semi-submersibles

The idea of drilling from a floating unit emerged in 1947 when barges were used for this purpose in the Louisiana swamps. Such vessels were also needed in deeper water, however and Bluewater I was built in 1961 as the first semi-submersible. This was followed by a number of new designs – Ocean Drilling (Odeco) in 1963, Sedco 135 (Friede & Goldman) in 1965 and Pentagone 81 (Neptune) in 1969.

Ocean Traveler being towed from New Orleans to Stavanger. Photo: Norwegian Petroleum Museum archive

Semi-submersibles proved to be well adapted for drilling in the North Sea. Such units float on pontoons, and their deck height above the sea is adjusted with the aid of ballast tanks.

Odeco's fifth drilling rig, Ocean Traveler, was delivered during 1966 from a yard in New Orleans and towed to Stavanger that June. Esso used this vessel to initiate drilling on the NCS in June 1966. An accident a few months later showed that the design was not strong enough for North Sea weather conditions, and Norwegian shipbuilding expertise was

The Grane platform stands on a steel jacket. Photo: Norsk Hydro

mobilised to improve the rig.

The first Norwegian rig was built in 1966 on the basis of US technology. Ocean Viking was a sister vessel to Ocean Traveler, and based on the Odeco design. Half the substructure and pontoons were built at Rosenberg Mekaniske Verksted in Stavanger. The other section, identical but a mirror image, came from Burmeister & Wain in Copenhagen. Both components were towed in June 1966 to the Akers Mekaniske Verksted yard in Oslo and welded together. The topside was mated with the substructure by submerging the latter – an approach which was to become standard when building concrete production platforms a few years later.

Fixed steel production platforms

Technology for building offshore production platforms was first developed in the Gulf of Mexico and Venezuela just after the Second World War. The first prefabricated unit of this kind, supported on a steel jacket, was installed in 1947. It proved a big success, and the Gulf of Mexico had more than 1 000 such platforms by 1963. The first of them stood in shallow water, but the technology was further developed to permit installation in ever deeper water. Constructed in 1988, the largest steel platform of this type stands in 412 metres of water in the Gulf.

Units supported by steel jackets represented the best available technology, and such platforms accordingly dominated on the NCS during the early years. Of the 32 installations associated with the Ekofisk development, 31 have steel jackets. A total of 63 such platforms have been positioned on the NCS. This was an efficient and well-tested technology, which functioned well in the shallower parts of the North Sea.

After the jacket had been installed, the topside had to be lifted into place. Major advances had also been made with crane ships. Their maximum lifting capacity in 1945 was 75 tonnes. That had reached 300 tonnes in 1962 and Chocktaw lifted 800 tonnes on delivery in 1968. The latter vessel was used to position the Ekofisk and Frigg installations. Considerably larger units arrived in the 1980s, and the biggest today can lift more than 14 000 tonnes.

Gulftide in production on Ekofisk in 1971. Photo: Norwegian Petroleum Museum archive

Jack-up rigs

In 1950, Magnolia Petroleum Company adopted the jack-up platform technique which had been used by shipyards, among others, for decades. This concept was developed from 1953 into the type of jack-up rig familiar today. The first production unit on the NCS was *Gulftide*, a converted jack-up drilling rig, which produced the first oil from Ekofisk in the summer of 1971.

National control and the development of Norwegian industry

Many discoveries, and particularly the start to production from the Ekofisk field in 1971, made it clear that the NCS contained substantial assets. The government accordingly wanted stronger ownership and greater national supervision and control. Building up a new industry and ensuring good resource utilisation were important goals. As far as possible, the oil companies were to use Norwegian suppliers.

The creation of Statoil and the Norwegian Petroleum Directorate (NPD) in 1972-73, and the development of Norsk Hydro and Saga Petroleum, were important elements in creating a Norwegian industrial community in the petroleum sector. Expertise was built up in oil, shipping and engineering companies, shipyards, seismic survey contractors, government, and eventually also in research and development. Progress was fastest in those areas which could exploit established Norwegian expertise and combine this with specialist know-how from foreign companies.

Role of government

The standing committee on industry in the Storting (parliament) presented a recommendation in 1971 which helped to lay the basis for an integrated Norwegian oil policy, formulated as the 10 "oil commandments". Ensuring national supervision and control of all operations on the NCS was the most important goal. Emphasis was also given in the commandments to developing new industrial activity, safeguarding the environment and taking account of regional policy interests. The oil would be the property of the state and benefit the whole community. Norway would become independent of oil imports and, to ensure this, the petroleum was to be landed in the country. New industrial activity based on oil and gas was also to be created, and the government would support an integrated Norwegian oil community. A state-owned Norwegian oil company was to be created to look after the government's commercial interests.

Increased taxes

In the wake of 1973's sharp increase in crude prices and the consequent boost in oil company profits, the government resolved in 1974 to introduce a special tax of 25 per cent on net income from oil operations.

Prices were driven up by the international oil crisis associated with the Yom Kippur war of 1973, and the decision by the Organisation of Petroleum Exporting Countries (Opec) to use oil for the first time as an instrument for applying political pressure. The USA and other countries supporting Israel in the war were subject to an oil boycott, and the reduction in supplies forced up the price. It rose 400 per cent in three months to top USD 11 per barrel just before Christmas 1973. Production cuts reduced world trade

The 10 "oil commandments"

1. National supervision and control must be ensured for all operations on the NCS.
2. Petroleum discoveries must be exploited in a way which makes Norway as independent as possible of others for its supplies of crude oil.
3. New industry will be developed on the basis of petroleum.
4. The development of an oil industry must take necessary account of existing industrial activities and the protection of nature and the environment.
5. Flaring of exploitable gas on the NCS must not be accepted except during brief periods of testing.
6. Petroleum from the NCS must as a general rule be landed in Norway, except in those cases where socio-political considerations dictate a different solution.
7. The state must become involved at all appropriate levels and contribute to a coordination of Norwegian interests in Norway's petroleum industry as well as the creation of an integrated oil community which sets its sights both nationally and internationally.
8. A state oil company will be established which can look after the government's commercial interests and pursue appropriate collaboration with domestic and foreign oil interests.
9. A pattern of activities must be selected north of the 62nd parallel which reflects the special socio-political conditions prevailing in that part of the country.
10. Large Norwegian petroleum discoveries could present new tasks for Norway's foreign policy.

in oil, and a lot of tankers had to be laid up. A number of well-known Norwegian shipowners went into liquidation, and many shipyards experienced a dearth in orders. Encouraging new results from the North Sea, such as the discovery of Frigg in 1971 and Statfjord in 1973, were important in this perspective. Most Norwegian shipyards converted quickly to offshore fabrication, and shipowners turned their attention from tankers to petroleum-related vessels.

Norway's tripartite petroleum model

The Storting resolved in 1972 that state involvement in the petroleum sector should be divided into political, administrative and commercial segments.

Political responsibility for oil and gas was assigned to a dedicated department of the Ministry of Industry, with a separate Ministry of Petroleum and Energy (MPE) established in 1978.

The NPD was established to be responsible for resource management and safety regulation. This agency accordingly collected and processed geological and geophysical information from the NCS, checked that the oil industry complied with legal and regulatory requirements, and monitored offshore safety and the working environment. These roles were separated in 2004, when the Petroleum Safety Authority Norway (PSA) was created to regulate health, safety and environmental issues on the NCS and at land-based plants involved in petroleum processing and export. The NPD retained resource management. These two institutions collaborate and still share the same office building.

State oil company Statoil was created to manage the government's commercial interests.

The PSA

The safety and resource management divisions of the old NPD reported to different ministries, but the MPE nevertheless had an overall responsibility. That changed when the PSA was demerged as a separate regulator.

In 1976, the NPD's safety division halted the construction of the planned Statfjord B platform on safety grounds. Statfjord A had been built in such a way that the living quarters and helicopter deck sat on top of the production and processing equipment, where oil and gas were under high pressure. The NPD now wanted a separate quarters platform. Operator Mobil and the other licensees opposed the construction of additional installations, and studies were launched to see whether it was possible to increase the distance between accommodation and production on the B structure. To meet the NPD's safety requirements, the living quarters were positioned as far as possible from areas with a potential for explosion.

Statfjord B. Photo: Øyvind Hagen/Statoil

Statfjord B was built with a large, open deck which reduced risk in the event of possible oil and gas leaks. This platform accordingly became the first in the world to be built after a risk analysis had been carried out. That helped to form the basis for a new regulatory approach, which builds in Norway on the principle of self-regulation. Players are required to document that they comply with the regulations. Risk analyses are expected to be done, with requirements for continuous improvement and the application of new technology where necessary.

The PSA supervises compliance with the regulations by auditing all the players, and coordinates the necessary collaboration with other regulators. This means that the oil companies avoid having to deal with many agencies which have specialist responsibilities relating to petroleum activities.

Statfjord A. Photo: Solstadcrew

The NPD

Oljedirektoratet er statens fagorgan med mye av den The NPD is the government's specialist agency, with much the same technical expertise as the companies. Together with the MPE, its job is to ensure the highest possible net value creation from oil and gas operations on the NCS.

Thanks to the tax system, the government covers more than 78 per cent of all expenses in the oil sector but receives a corresponding proportion of net income from the business.

Such a system calls for a high level of professional expertise in order to ensure that society's assets are managed in line with the intentions of legislation and statutory regulations, and in accordance with on-going political decisions.

Short-term optimisation of cash flow is not compatible with Norway's petroleum legislation, but the government cannot demand that the companies implement projects which do not profit their shareholders. The Norwegian authorities have accordingly found solutions for many big projects which meet the interests of everyone concerned. Specialist expertise in the NPD has been useful in such contexts. Examples include Troll Oseberg gas injection (Togi), Troll Oil, Ekofisk II, Snøhvit LNG and Valhall water injection – major projects involving high risk and big investment, which have all generated additional revenue for the government and the companies.

Three Norwegian oil companies

Statoil and Norsk Hydro, owned 100 and 50 per cent respectively by the government, were also supplemented by private interests. The Norwegian Oil Consortium (Noco) was established by 20 large companies in 1965 and joined forces in that year with US major Amoco to create the Amoco-Noco group. Noco was the forerunner of Saga Petroleum, which was founded in 1972 with the bulk of its shareholders from Norway's shipping and industrial sectors.

Building up Norwegian companies

In order to manage the state's commercial interests, Statoil was awarded 50 per cent or more in all new production licences – starting with the grant of the Statfjord blocks in 1973. The other licensees were also required to pay Statoil's share of exploration costs (known as carried interest). Were a discovery developed, however, Statoil paid its share of the costs. In 1974, after the first oil price surge, new provisions gave the government the right to an even larger stake. A sliding scale was introduced to increase state participation in line with the size of production. Licences also included terms which allowed the government to change the operator if one company discovered a disproportionate number of fields.

In subsequent licensing rounds, Statoil received holdings in most of the blocks – including those considered the best. The most promising prospects, such as Statfjord and Gullfaks, were moreover awarded outside the regular licensing rounds. During the third and fourth rounds, Norwegian companies received holdings of more than 50 per cent in every block awarded.

Oil and gas were proven in virtually all the acreage awarded in the fourth licensing round of 1979. Some of these discoveries – Troll, Oseberg, Gullfaks and Snorre – proved very large. The proven resource base doubled in a short time. That led to increased activity, and the build-up of a Norwegian oil industry continued.

Technology agreements

In connection with the fourth round, the government expressed a clear desire to ensure the transfer of expertise to Norwegian research teams and industrial companies. "Technology agreements" were concluded between the government and foreign oil companies to achieve this goal. The aim was to encourage Norwegian industry and expand domestic expertise. The foreign companies contributed money and know-how to develop technology in Norway. That gave Norwegian scientists and companies access to petroleum-related research. These agreements rank as one of the most significant and extensive technology policy initiatives ever taken in Norway.

SDFI established

Statoil expanded quickly and acquired a very dominant position. Its cash flow had become substantial in relation to Norway's gross domestic product. A

The Ullrigg Drilling and Well Centre is a world-class laboratory in its field. It offers the industry a full-scale test facility for verification of new technology. Built during 1985, Ullrigg has been utilised in a number of projects, including intelligent well solutions for new field developments. Photo: Iris

process was initiated by the Conservative Willoch government in 1981 to change this position. The solution was to separate the commercial from the administrative, with Statoil's cash flow split into company and state shares. That gave the government direct control of a substantial proportion of the on-going revenues and expenses. To achieve this, the state's direct financial interest (SDFI) was established under Statoil's management. The latter was left with more commerce and less politics.

New technology

A number of large fields were discovered in this period. Deeper water and tougher weather called for substantial technological advances before these discoveries could be developed. Active industrial policies by the government and a big commitment by the companies meant that expertise and new enterprises were rapidly built up in such areas as seismic surveying, drilling, construction of supply ships, rigs and platforms, and research and education.

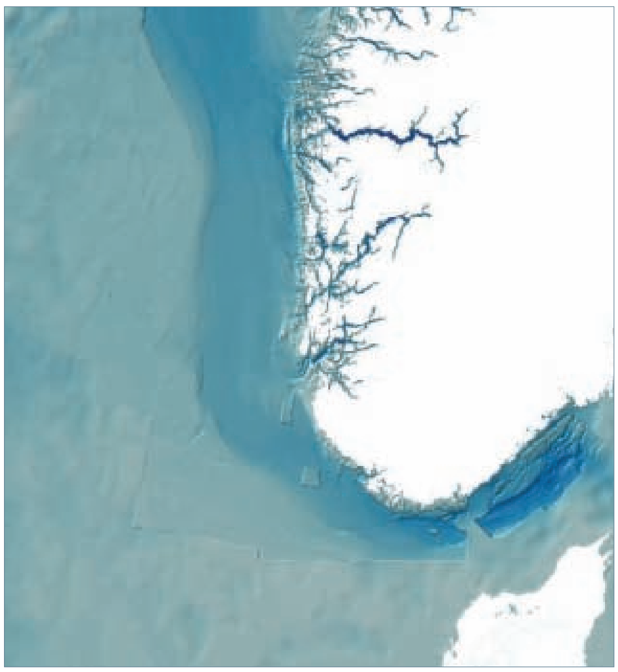
Pipelines

Ekofisk, in 70 metres of water, was at the limits of the industry's production capabilities in the 1960s. New discoveries further north were in deeper water – 150 metres in the Statfjord area, for instance, and more than 300 on Troll.

The latter lies in the Norwegian Trench, a submarine valley which runs along the west Norwegian coast from the Oslo Fjord to Stadlandet in Sogn og Fjordane. It represented a barrier for landing oil and gas by pipeline in the early years, and new technology had to be developed before this could be surmounted.

Assessments in the 1970s for landing gas from Ekofisk and Frigg concluded that it was neither technically nor economically feasible to bring these resources ashore in Norway through a pipeline across the Norwegian Trench. Ekofisk's oil was piped to Teesside in England and its gas to Emden in Germany, while Frigg gas was carried in two pipelines to St Fergus in Scotland.

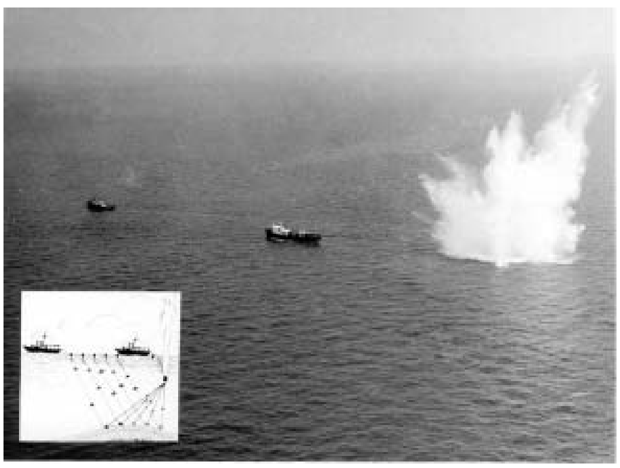
A decade of extensive research and development work allowed Statoil to lay the Statpipe line from the Statfjord and Gullfaks fields across the Norwegian Trench to Kårstø north of Stavanger. From there, the gas was piped on to European markets. Further south in the North Sea, Elf had found Heimdal in the mid-1970s. Gas from this field was not enough to justify a dedicated pipeline, but it could be tied into the Statpipe system.



The Norwegian Trench runs along Norway's west coast. Map: Mareano

Pipelines on the NCS. Map: NPD

Norway's network of pipelines from the fields to land has been constructed in step with developments on the NCS. These oil and gas lines run to Tjeldbergodden, Nyhamna, Mongstad, Sture, Kollsnes and Kårstø in Norway as well as to Teesside, Easington, St Fergus and Cruden Bay in the UK, Dornum and Emden in Germany, Zeebrugge in Belgium and Dunkerque in France.



Marine seismic surveying in 1966. Dynamite as a sound source was replaced in the late 1960s by airguns. From a brochure published by Esso Norge.

As Norway's gas resources grew, the need to coordinate their export steadily increased. After sales contracts for gas from the huge Troll field had been concluded, the Norwegian government established a Gas Negotiating Committee (GFU) in 1986. Comprising domestic oil companies Statoil, Hydro and Saga, this body was responsible for the marketing and sale of all Norwegian gas. Neither its members nor other oil companies were permitted to sell their own gas. Commercial contracts negotiated by the GFU had to be approved by the MPE.

This gas coordination model was expanded in 1993 with the creation of the Gas Supply Committee (FU) to serve as an advisory body for the GFU and the MPE. All oil companies owning gas on the NCS were represented.

When the European Union adopted its gas market directive in 2000, the Norwegian model had to change. The GFU was dissolved, and each gas owner has been responsible for the sale and transport of its own production since 2002.

Seismic surveying

Seismic surveys are an important tool in the hunt for oil and gas. The technology was very advanced when petroleum operations began on the NCS, and Norwegian companies quickly became key players in its further development and adaptation for offshore use. Norwegian factory trawlers proved very suitable for conversion to seismic vessels and were quickly adapted to this role. The former crew stayed with the ships, providing the geophysicists and engineers with valuable knowledge about handling equipment derived from the fishing fleet. Synergies between fishing and seismic surveying mean that Norway has played a key role in this discipline since the early 1970s. Beginning with the creation of Computas and Geoteam, that involvement continued through the emergence of Geco and PGS as world leaders in the seismic survey market.

Aker H3

The Aker engineering group spent the autumn of 1969 analysing known semi-submersible drilling rigs with a view to finding better and more competitive solutions. Particular emphasis was placed on seaworthiness. The new design had to cope with wave heights of 30 metres, as well as offering improved mobility, maximum strength combined with reduced steel weight, a bigger payload and lower

Deep Sea Driller was the first Aker H3 rig. Photo: Norwegian Petroleum Museum/Aker Collection

construction costs. Designated the Aker H3, this solution placed the drilling derrick in the centre of the topside. It also featured eight support columns attached to two pontoons aligned in the direction of travel. Deep Sea Driller, the first rig of this type, was built for the Odfjell group and became operational in February 1974.

With crude prices quadrupled following the 1973-74 crisis, finding oil in the North Sea had become even more profitable. This area also offered the benefit of lying in northern Europe, a politically stable region. The North Sea would provide Europe with oil even if another crisis arose in the Middle East. Twenty-five H3 rigs were on order before the first had been delivered.

The H3 concept was developed further with the H3.2, H4.2, H5.2 and H6. A number of yards around the world have built rigs of these types on licence from Aker, and many of the H3 rigs have later been upgraded and modernised. They have been provided with equipment for drilling in ever deeper waters, and the H6 – regarded as a sixth-generation rig – can work in 3 000 metres..

Concrete

When development of Ekofisk began in the early 1970s, no pipeline infrastructure existed to take oil and gas to market. Offshore loading was the only way to export oil, and a form of intermediate storage had to be installed in order to be able to maintain production regardless of weather conditions. Discussion focused initially on a steel tank, but the final choice fell on a concrete version presented by

The Ekofisk tank is towed to the field.
Photo: Norwegian Petroleum Museum/Aker Collection

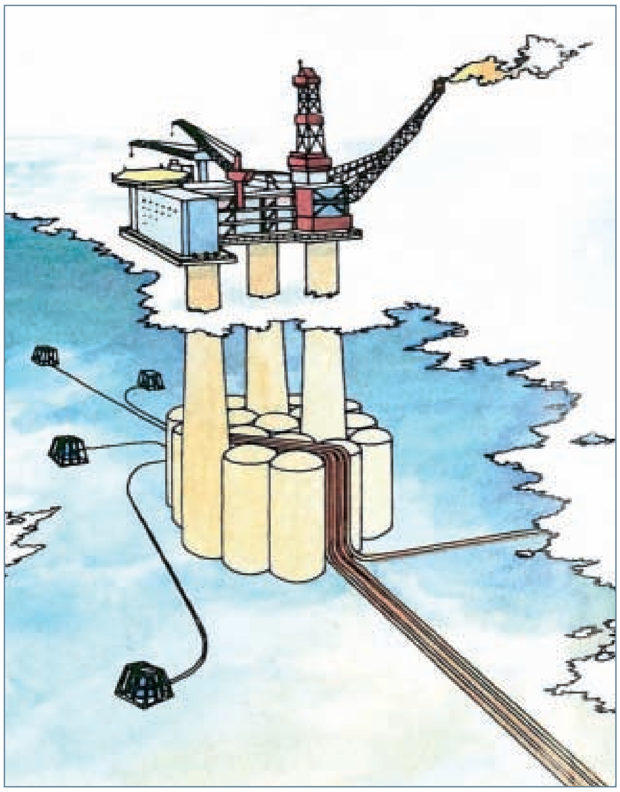
Statfjord C. Photo: Harald Pettersen/Statoil

French company C G Doris. This structure comprised a base section, a store for one million barrels of oil, a breakwater and a top plate. The job of building it was given to a joint venture of Norway's Selmer and Høyer-Ellefsen construction companies, with Jåttåvågen outside Stavanger chosen as the building site.

The Ekofisk tank proved a success, and marked a breakthrough for offshore concrete structures. This technology was further developed by a number of companies, and the Norwegian contribution was named the Concrete Deepwater Structure – abbreviated to Condeep.

A few weeks after the Ekofisk tank had been towed out and installed on the field, the first production platform with a Condeep support structure was ordered by Mobil. This contract went to a joint venture between Høyer-Ellefsen, Selmer and Furuholmen called Norwegian Contractors (NC), and the platform was intended for Britain's Beryl field. The Condeep became a popular design, and NC had no less than six of these "gravity base structures" (GBSs) under construction at Jåttåvågen by the end of 1974.

Statfjord A was the first Condeep to be delivered for the NCS, and development of this field marked the breakthrough for Norwegian companies and platform solutions. Statoil's key role in this and other fields allowed it to ensure that domestic bidders won contracts. The requirement for a high level of Norwegian participation and the limited number of companies able to accept such assignments meant that many of the players were the same from



Gullfaks B. Illustration: Statoil

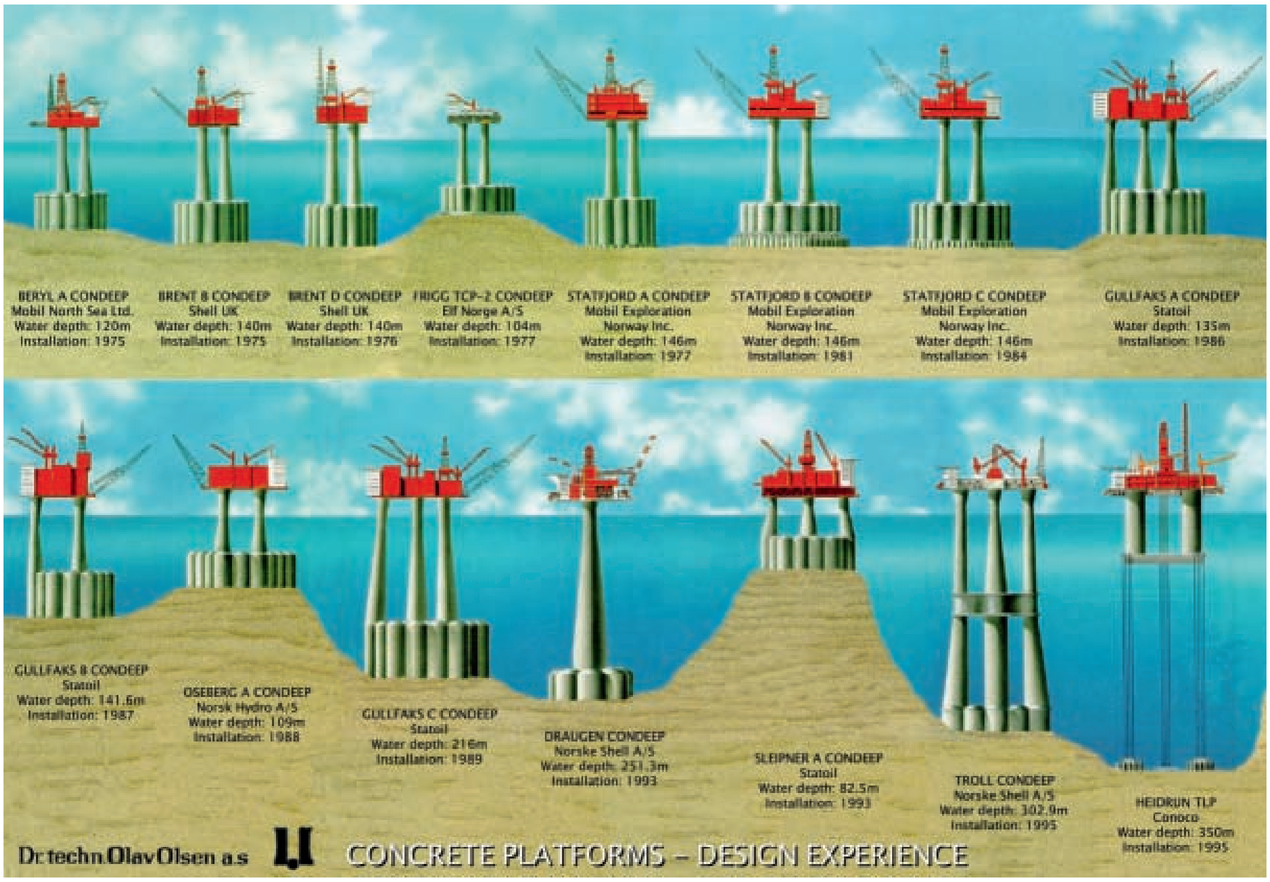


Illustration: Dr.techn Olav Olsen AS

one project to another. These suppliers eventually developed expertise with the type of platform used to develop Statfjord and frequently selected for subsequent projects. This large fixed unit featured an integrated topside, modularised so that fabrication contracts could be split up. Changes to development solutions largely took the form of step-by-step adjustments within the same overall thinking. Technological progress consisted of identifying techniques which made it possible to build ever better versions of roughly the same kind of platform.

Concrete installations were more expensive to build than steel structures, but the fact that the topside with all production facilities could be installed before tow-out to the field eliminated the need for expensive offshore lifting. The GBS could also carry the heavier load of processing equipment required on fields with a high level of output. Most of the concrete platforms were built as integrated production, drilling and quarters (PDQ) structures.

In the late 1970s and for much of the 1980s, the concrete platform more or less ruled the roost. These massive installations, crowned with their characteristic steel topside, were produced almost in series. The bottom cells in a Condeep could store oil and be combined with offshore loading and transport by shuttle tankers. Seven of 12 concrete platforms on the NCS were built with a view to such oil storage.

The difficulty faced by other solutions in winning acceptance are illustrated by Gullfaks, the first all-Norwegian development project. As operator, Statoil opted to build on experience gained from Statfjord by choosing a concrete GBS for all three Gullfaks platforms. With hindsight, however, it is hard to understand why Statoil decided on a more expensive GBS for the B installation. This platform has a simplified process plant, with only first-stage separation and water injection equipment. Oil and gas are transferred to the A or C platforms for further processing and storage. Topside weight is therefore not particularly high, and a steel jacket would have been sufficient. The platform stands moreover in just 141 metres of water, and the GBS cells are not used to store oil.

In addition to the Ekofisk tank, a total of 18 concrete platforms were built in Norway – 15 in Stavanger, two in Åndalsnes and one at Hanøytangen outside Bergen.

Cost reductions and new development solutions

The oil price slumps of 1986 and 1998 called for drastic cost reductions. At the same time, the big North Sea fields faced declining output, and improved resource utilisation became more important. Smaller discoveries and deeper water demanded new development solutions.

Oil prices slump

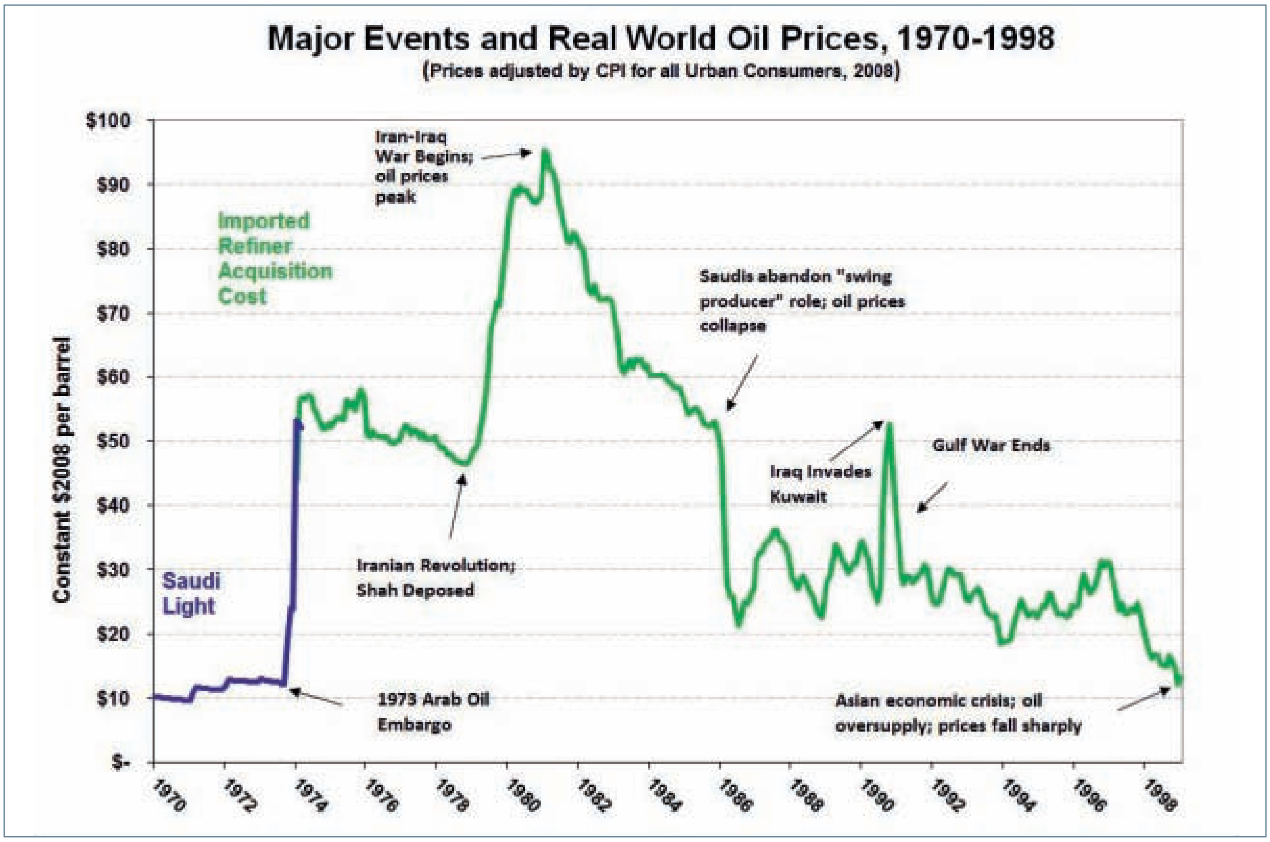
Most producing countries developed and exported as much crude as they could while prices were high. The result was over-production and a collapse in oil prices during 1986 to less than USD 10 per barrel. Adapting to this change proved painful, not least for Norway. Costs had to be cut.

New frame conditions

The price slump led to reduced activity. In response, the government moderated its terms. From 1 January 1987, for instance, the carried interest scheme – whereby foreign companies paid the state's share of exploration costs – was terminated. The companies were also allowed to charge depreciation from the first year of investment, rather than when production began. Royalty was terminated for new fields in 1988. These measures had an immediate effect, and fears of an investment drought turned within a couple of years to worries about excessive capital spending. That prompted the institution of a queuing system for new projects. Terms were further eased in the 1990s. The sliding scale, which allowed the government to increase state participation, was abolished in 1992. And the requirement that the state and Statoil should have at least 50 per cent in each licence ended in 1994.

Restructuring and mergers

Over-production and lower crude prices returned in 1998. The decline in demand was closely related to the economic crisis which hit Asia in that year. An unusually mild winter in 1997-98 in Europe, Japan and North America, with little demand for heating oil, also hit the oil market. In addition, Iraq returned to the market as a result of the UN's "oil for food" programme. The result was that oil prices fell for a short time below USD 10 per barrel, lower in real terms than in 1986.



Source: US Energy Information Administration (EIA)

This decline caused great nervousness in the oil industry. Much uncertainty prevailed about the future, and the oil companies entered a phase of major restructuring. They became fewer and bigger. BP merged with Amoco, Exxon with Mobil, Texaco with Chevron, and Conoco with Phillips Petroleum. While Shell acquired Enterprise Oil, Total joined forces with Belgium's Petrofina and Elf Aquitaine. In Norway, Saga was taken over by Hydro.

Statoil acquired a stock market listing in 2001, but the government secured its rights by retaining a majority shareholding. As a consequence of this partial privatisation, it was resolved to create a new state-owned company, Petoro AS, to manage the SDFI. It serves as the licensee with voting rights and obligations on a par with the other companies on the NCS. The government sold a number of holdings in connection with the establishment of Petoro. Roughly 15 per cent went to Statoil and five per cent to Hydro. Gassco was also established as a wholly state-owned company to serve as operator for the gas pipeline network and the most important land-based gas plants. Although oil prices rose to record levels, the integration process in the Norwegian oil industry continued. Statoil merged with Hydro's oil and energy division in 2007. After a brief period when it was known as StatoilHydro, the company changed its name back to Statoil in 2009. It dominates the NCS as an operator and licensee, and is also active internationally with a presence in all parts of the world.

Cost cuts and improved recovery

With the 1986 price slump, profitability was more important than ever in new development projects. Less expensive solutions were required.

A joint project on the competitive position of the NCS (Norsok) was established in 1993 to strengthen competitiveness in an international perspective. This had been prompted by government and industry concern over the high level of Norwegian costs and reduced profits. Execution time and bills for developing and operating installations on the NCS were to be cut. Norsok became very significant for the further development of Norway's offshore industry, and was a prime mover in the introduction of engineering, procurement and construction (EPC) contracts.

These meant in practice that main contractors such as Aker, Kværner, the Umoe group and ABB Offshore took over a much larger share of developments from the oil companies. New frame conditions, combined with support and pressure from the government, also led to a new commitment to better resource utilisation and a higher recovery factor. New techniques for improved oil recovery (IOR), such as horizontal and multilateral drilling, three- and four-dimensional seismic surveys and many different injection methods, boosted reservoir utilisation on most Norwegian offshore fields and thereby extended their producing life.

New development solutions

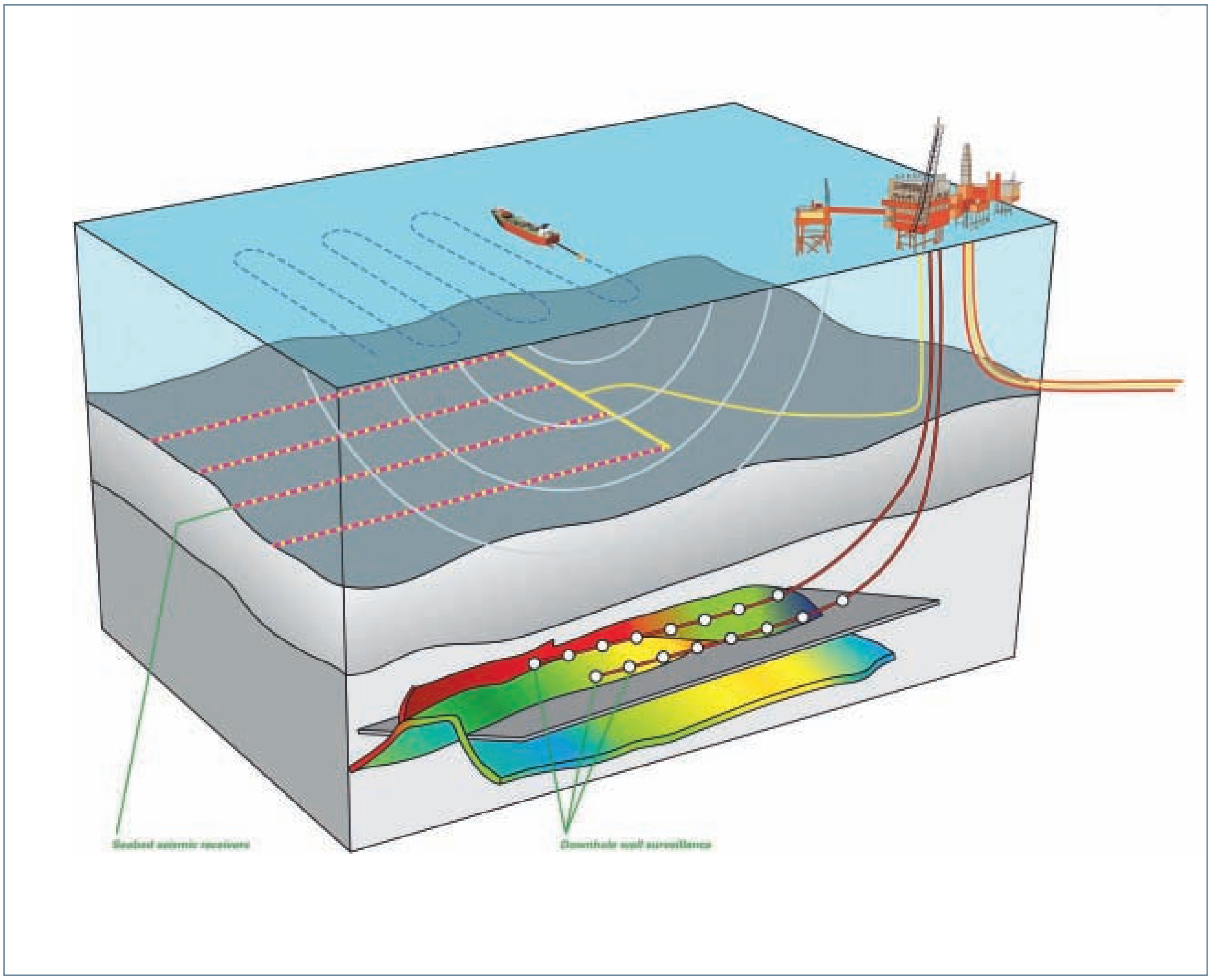
A technological shift occurred at the start of the 1990s, when the big integrated concrete structures were replaced by subsea facilities tied back to existing fixed installations, floating units, production ships or simple unstaffed platforms.

By the end of the 1980s, the North Sea was becoming a mature oil province – in other words, the biggest fields had been found and had reached their plateau production. New discoveries were generally smaller and located further north in a tougher climate, and many lay in deeper water. A lack of infrastructure around a number of the new discoveries called for the installation of additional pipelines to bring oil and gas ashore. These finds required production solutions which differed from the familiar concrete platforms. Developing and adopting new technology were once again necessary to bring fields on stream safely and profitably.

Seismic surveying

One requirement for better resource utilisation is good knowledge of the reservoir's extent. Developments in seismic surveying have accordingly been crucial.

The Ramform Explorer seismic survey vessel.
Photo: Petroleum Geo-Services



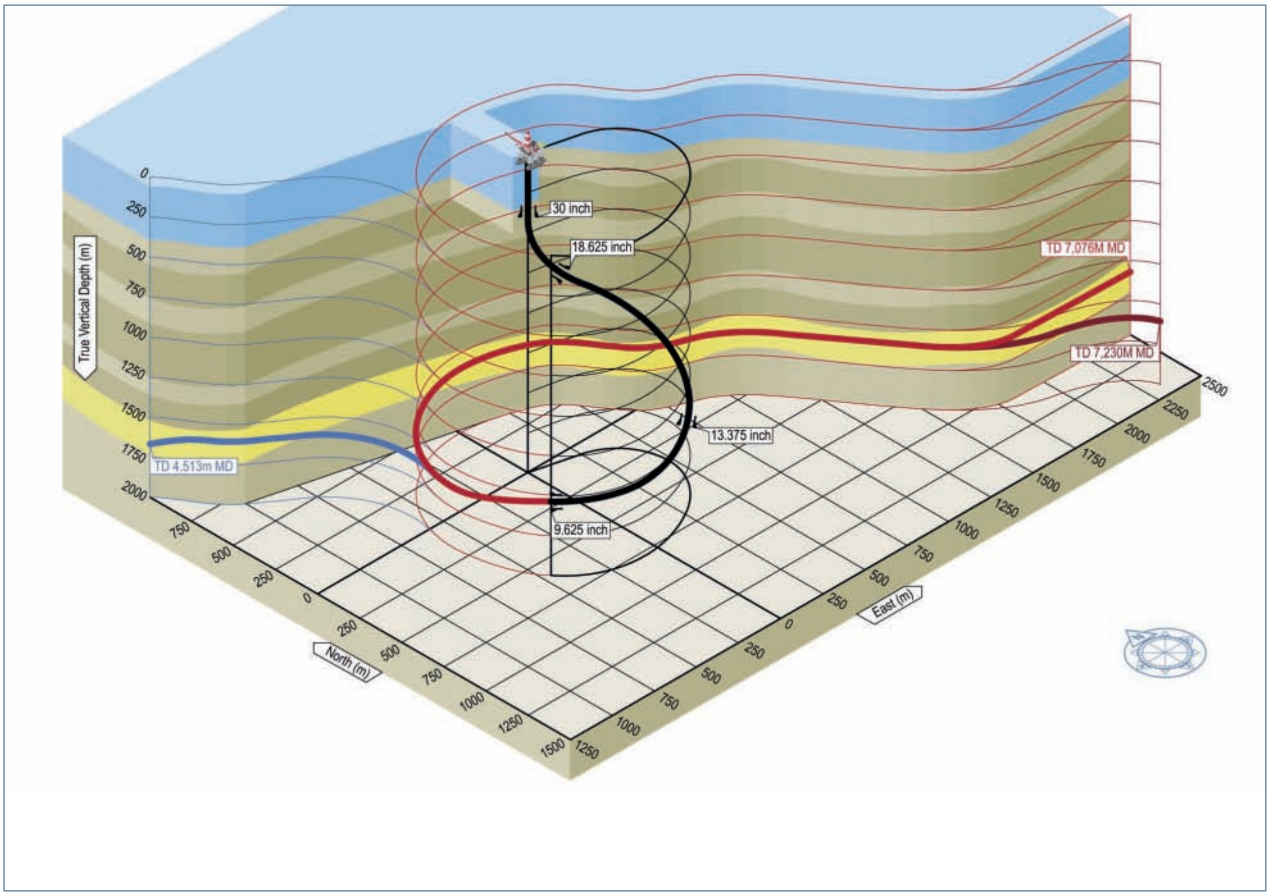
Seabed seismic surveying in the Valhall field. Illustration: BP Norge

Two-dimensional seismic data were gathered during the early years using a single sound source and a cable (streamer) equipped with hydrophones, both towed behind the survey vessel. From the late 1970s, three-dimensional surveying was gradually adopted. This technique is regarded as a milestone in the development of seismic data gathering for detailed mapping of the sub-surface. 3-D surveying developed rapidly, from being shot with a single source and streamer, via multi-vessel operations, to the current solution with up to 18 streamers towed by a single ship. Efficiency has thereby increased markedly. The distance between the data gathered by the 3-D technique is much smaller than for 2-D, typically 25 metres.

Introduced from the mid-1990s, the four-dimensional solution represents a 3-D survey repeated a number of times. Its main purpose is to map changes in the distribution of oil, gas and water in a reservoir over time as a result of production or injection.

Seabed seismic surveying was also introduced in the 1990s. Data are gathered here by one or more cables carrying hydrophones and geophones laid on the seabed, while the same sound source used in conventional surveys is towed behind a vessel on the surface. This technique provides a better image of the sub-surface. Other, more specialised methods include passive surveys, where no active source is used. Complementary geophysical methods have also been developed in recent years to supplement the information obtained from seismic surveys.

Today's geophysical industry is characterised by a large number of new companies in addition to the big established players. Very many of these enterprises are rooted in Norway's big geophysical community. Demand for seismic survey capacity has been high in recent years, opening opportunities for new participants in the market.



Horizontal and multilateral wells. Illustration: Baker Hughes

Drilling

Horizontal, multilateral and subsea-completed wells marked the crucial leap to drilling more efficient producers. These techniques have made it possible to recover more from fields with a minimum of wells and platforms. As well as allowing a larger part of the reservoir to be produced in an economic manner, they have helped to turn discoveries earlier regarded as non-commercial into profitable fields.

A good example is Troll Oil. When planning began for a Troll development in the early 1980s, technology to recover the oil in this field profitably was only in its infancy in a few countries. Troll's oil lies in thin but very extensive zones. To make a development economic, long horizontal wells had to be drilled with great precision just above the oil/water contact. Hydro completed the first such well in 1989. With the aid of advanced horizontal drilling and new technological solutions, a discovery initially described only as a gas field became one of the biggest oil producers on the NCS with a plateau production of more than 400 000 barrels per day.

The Troll Oil project has also occupied a key place in the development of multilateral (sidetrack) wells which make it possible to reach more of the reservoir at a lower cost. Roughly half of all the advanced sidetracks in the world have been drilled on Troll. Technological progress has occurred in an interaction between various players. Almost all technology and product development associated with the development was pursued by Norwegian suppliers, or at local subsidiaries or branches of international contractors. Virtually all subsequent field developments have been based on concepts which utilise this type of well.

A further advance is the "intelligent" well. With the aid of downhole instrumentation, valves in the well can be remotely operated to increase oil output and reduce water production. Should too much gas enter a multilateral, for instance, one of the sidetracks can be shut down while another continues to produce. Pressure can also be regulated. The outcome is increased petroleum production and less need for expensive well workovers.

Multiphase flow transport

Traditionally, oil, gas and water are separated on a platform close to the wellhead for onward transport. Dewatered gas gets piped to the market, while oil is either loaded onto a shuttle tanker or sent through its own pipeline. This requires platforms with processing equipment to be installed on each field. Research has been under way in Norway since 1980 to find ways to eliminate such surface installations, with unprocessed wellstreams piped to platforms some distance away or directly to terminals on land. Such solutions depend on oil, gas and water being transported in the same pipeline – known as multiphase flow.

Active use of multiphase flow represented an important watershed in developments both on the NCS and internationally. It permitted the harnessing of small satellites close to existing platforms. A crucial breakthrough for this technology was the Troll Oseberg gas injection (Togi) project.

The original development plan for Troll A was based on an integrated PDQ platform, but it became clear that this structure would be too heavy and have such a deep draught that it could not be towed from its Norwegian construction site to the field. The solution was to transfer the processing facilities to land and build a gas treatment plant at Kollsnes near Bergen. However, that required further advances in multiphase flow.

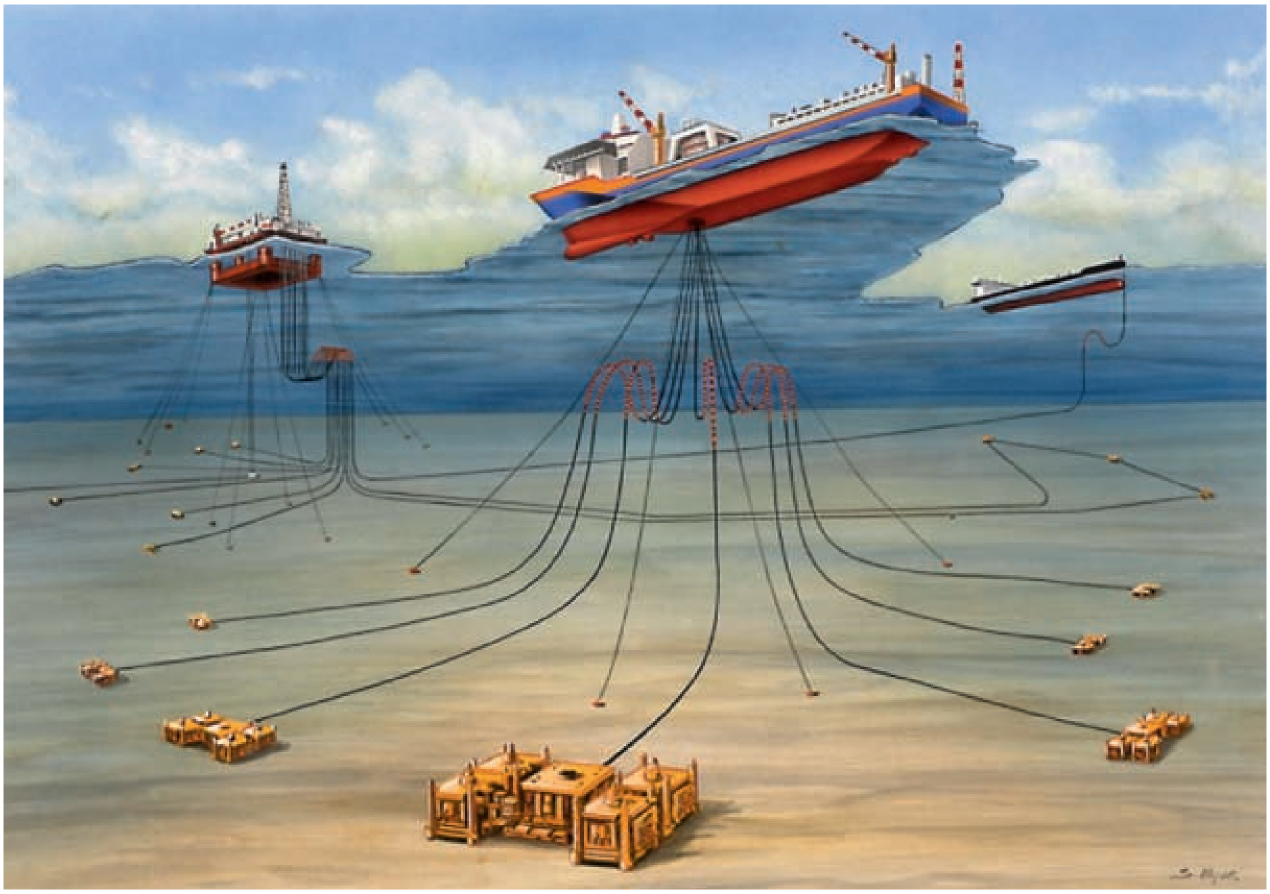
Ormen Lange is a gas field which also contains condensate (light oil). Special studies were carried out to prevent ice and hydrates (ice-like hydrocarbons) from plugging the 120-kilometre pipeline to the receiving terminal at Nyhamna in Møre og Romsdal.

Multiphase flow technology was also crucial for developing Snøhvit. The multiphase pipeline linking the subsea installations on this Barents Sea field with the gas liquefaction plant at Melkøya outside Hammerfest is 143 kilometres long.

The multiphase flow test plant at Tiller/Sintef. Photo: Sintef

Subsea installations

North-East Frigg was equipped with the North Sea's first remotely operated subsea production facility in 1981, involving a six-well template in 102 metres of water 18 kilometres from Frigg. East Frigg was also remotely operated from the main field, and the first field developed without the use of divers. Its installations were developed through the Skuld project and positioned during 1988 in 110 metres of water. Togi, installed in 1991 on Troll to supply Oseberg with injection gas, was a major new step in technological terms. The water depth was 300 metres, and the Oseberg platform stood no less than 48 kilometres away. That presented new challenges with regard to components for the remote operation system, which had to cope with the increased water pressure, and to the transport of unprocessed gas over such distances. Progress has continued, with seabed processing facilities installed on such facilities as the Troll pilot, Tordis, Snøhvit and Ormen Lange in depths of 300-1 100 metres.



Subsea installations on Åsgard. Illustration: Svein Bjur/Statoil

A template for Ormen Lange. Photo: Tor Alvseike/Statoil

Production floaters

Floating production installations provide great flexibility, not least with regard to water depth, rapid installation, an early start to output, re-use and removal.

One concept is the tension-leg platform (TLP), where the floating steel or concrete support structure is attached to the seabed by rigid tethers. This solution was first tested on Hutton in the UK sector during 1984, and introduced to Norway by Saga on Snorre in 1992. The latter lies 150 kilometres west of Florø, in 300-350 metres of water. Oil and gas from the Snorre A TLP are piped to Statfjord for final processing, storage and export. Heidrun, the last concrete platform built on NCS so far, is the world's largest TLP with a hull in this material.

A number of semi-submersible platforms with a catenary mooring system can be found in the northern North Sea and on the Halten Bank. Of these, Troll B has a concrete hull while Troll C, Snorre B, Visund, Åsgard B, Njord A and Kristin are in steel.

Production ships

Production ships are designed to weathervane around a central turret held in place by a catenary mooring system, so that they are always bows-on to wind and waves. Oil is transferred from seabed templates through flexible risers to the ship for processing, storage and export via shuttle tankers. This approach can in principle be applied for production in the deepest waters.

Petrojarl I was the first purpose-built production ship on the NCS. It produced initially from only one well at a time, and was accordingly used largely for early production before a field was fully developed.

Permanent floating production, storage and offloading (FPSO) units able to produce and process oil and gas from up to 20 wells began to be needed from the mid-1980s. Esso Norge pursued the turret-moored production ship (Tumops) project with Norway's Tentech to find a solution for Balder. Based on this concept, Tentech built a production ship in

The Snorre A TLP. Illustration: Saga Petroleum

Troll B . Foto: Helge Hansen/Statoil

Petrojarl I on Glitne. Photo: Bent Sørensen/Statoil

Spain which was sold to Kerr McGee. Used to produce Britain's Griffin field, it was the first vessel of its kind in the world. Seven production ships are currently on stream on the NCS today, including Petrojarl I.

The Balder floating production unit (FPU). Photo: ExxonMobil Norge

More efficient field operation

As the NCS has matured, a larger proportion of investment, costs and other inputs has been devoted to operation, maintenance and modification of fields and installations. A concentration on efficient operation has thereby also become more important. The companies have recently been particularly concerned to adopt integrated operation (IO). The Norwegian Oil Industry Association (OLF) has calculated that full implementation of IO could boost value creation from the NCS by up to NOK 300 billion, equivalent to a large new petroleum field.

This new way of working is based on laying fibreoptic cables between land facilities and offshore installations. That permits rapid transfer to land of large volumes of data supplied by instruments throughout the production chain, from the reservoir, via wells and the process plant to the operation room. New opportunities are thereby provided for efficient management and optimisation of field operation because different groups of specialists at the operator on land, on the offshore field and at contractors and other partners worldwide can observe and manage the same equipment or process in real time. They can then collaborate on solving problems and taking better and faster decisions, and so cut costs and boost revenues.

Concern for the environment

The petroleum sector is often presented in the media and by environmental organisations as an industry with a high risk of causing serious harm to the environment. This thinking was boosted by the Ekofisk Bravo blow-out in 1977. However, no acute discharge causing serious environmental damage has occurred in 40 years of production on the NCS, from either the offshore industry or its associated transport and land-based facilities. According to the Norwegian Coastal Administration, most of the well-known major oil discharges along the Norwegian coast derive from ships. In addition come an unknown number of illegal oil discharges from ships and fishing vessels which are not reported.

Through management and increased understanding, risk can be influenced by preventive and impact-reducing activities. Within the framework set by government regulations, developers affect risk through technology development, the choice of development and operating concepts, and organisational measures.

Planned emissions/discharges

Ordinary operation involves planned emissions to the air and discharges to the sea. These can only be made with a permit from the Norwegian Climate and Pollution Agency (Klif). The biggest discharges occur during the drilling phase, in those cases where drill cuttings and chemicals are discarded to the sea and seabed. General targets for zero petroleum-industry discharges were first set by Report no 58 (1996-97) to the Storting, and have later been tightened up several times.

The Norwegian oil and gas industry is subject to one of the strictest environmental regimes in the world. Standards for emissions/discharges are generally tough. Special requirements for zero discharges apply to both exploration and production on the northern NCS.

Environmental conditions on the seabed and in sediments have been monitored since 1973, and on a regular basis since 1982. Historically, sediment monitoring has revealed effects from the discharge of oily drill cuttings. Discharging oil-based drilling mud was banned in the early 1990s, and the area affected by drill cuttings has since declined by about 90 per cent. Discharges of cuttings coated with water-based mud do not have a similar impact on the seabed environment. The environmental monitoring has not documented any substantial harm to the seabed.

Produced water has been in contact with the subsurface geological formations for millions of years, and can contain inorganic salts, heavy metals and organic substances. Despite being treated before discharge, it will retain small residues of oil/condensate as well as dissolved materials. As fields on the NCS mature, the proportion (cut) of water produced together with the oil increases. Produced water can be injected back below ground, but this calls for substantial amounts of energy which in turn increases emissions. This makes it important to apply measures where the environmental effect is greatest, while achieving a sensible balance between cost, benefit and overall environmental impact.

Flaring has been controlled on the NCS since 1971, and this regulation was incorporated in the Petroleum Activities Act in 1985. Norwegian petroleum legislation now prohibits flaring except on safety grounds. When considering development plans submitted by the companies, the NPD also assesses the design of the proposed facilities in terms of flaring requirements, and flaring permits are linked to production permits. These strict controls help to keep the level of flaring on the NCS low compared with other nations.

Together with flaring, burning natural gas or diesel oil to generate power on the installations is the main source of carbon dioxide and nitrogen oxide emissions. Production installations have a number of functions which need power, and their consumption will vary with the type of hydrocarbon, production profile, pressure development in each reservoir, reservoir composition, number of wells, need for water and/or gas injection, and time of year. The most power-intensive processes on a platform are compressing gas for transport, injecting water and gas for pressure support, and pumping of oil/condensate. Energy for these processes is largely provided by gas turbines or engines.

Three types of energy are produced on installations.

- Electricity is largely generated by gas turbines driving generators. In some cases, diesel engines are used as the driver. Three NCS installations also use steam turbines fuelled by exhaust fumes from gas turbines.
- Mechanical energy from gas turbines driving compressors and, in some cases, pumps.
- Heat, which is largely recovered from gas turbine exhaust fumes. On a number of older platforms, it is produced by gas-fired boilers.

Energy efficiency

The Norwegian petroleum industry has long worked to reduce carbon emissions. A number of measures have been adopted, with new technology developed and implemented since Norway's carbon tax was introduced in 1991.

With a substantial potential for helping to cut greenhouse gas emissions, enhancing energy efficiency can be achieved in principle by making production more efficient or reducing consumption. Opportunities for such measures will be determined to a great extent by the installation's characteristics, such as age, remaining production life, and space and weight constraints.

Existing facilities vary greatly in terms of the technology they employ and the opportunities offered for enhancing energy use. Age and remaining production life are important in this context. Prospects for adopting new technology are limited in many cases by weight and available space for installing equipment. Major conversion projects are generally pursued on large fields with a long remaining production life. That provides openings for more extensive energy efficiencies.

Power from shore

Transmitting power from shore to Norwegian offshore installations is a regular topic of discussion as a way of reducing carbon emissions from the petroleum industry. Turbines driving equipment directly can only be replaced by power from shore if they are swapped for electric motors. That would be a very large and expensive change. Electrical equipment accounts for only 45 per cent of installed output today, which makes it difficult to convert a whole installation to electric operation. A partial conversion involves replacing gas-fired power stations with alternative electricity supplies, while directly-driven compressors and large pumps are not replaced. This approach is not as extensive because it requires less modification work and smaller transmission systems, and because the transformer stations can be dimensioned for a lower load and will thereby cost less.

Much greater freedom in choosing the power source is available when designing new installations. In most cases, the cost of driving them entirely by electricity will be smaller than on existing facilities. Power from shore must now be assessed and costed in the final plan for development and operation (PDO) of all new fields. Troll A has been fully electrified from the start in 1966, and the whole of Valhall is being converted to take electricity by cable from Lista in southern Norway. Similarly, the Gjøa platform due to come on stream in 2010 will be fully electrified.

Carbon capture and storage (CCS)

With the political decisions on CCS for the gas-fired power stations at Mongstad and Kårstø, Norway has opted to be a technological innovator in securing the necessary progress required for full-scale domestic projects in this area. Such development will be crucial if CCS is to be adopted extensively on a global scale.

Three main types of CCS technologies are available – carbon capture from natural gas, carbon separation before combustion, and carbon separation from flue gases after combustion.

CCS from flue gases is an immature technology today, but is expected to be crucial in reducing emissions from large land-based sources in the future.

Capturing carbon dioxide from natural gas on Sleipner East and storing it in the Utsira formation has attracted much positive attention internationally. A similar CCS project on Snøhvit before gas liquefaction at Melkøya builds on the same principles.

If CCS is to help combat climate change, it must be secure against leaks over a long period. Subsurface containment in reservoir-quality sediments seems to be the only real option for carbon management on a substantial scale within the next decade.

A number of studies have been carried out on carbon injection for IOR in various fields, most recently a joint Shell-Statoil project from Draugen and Heidrun on the Halten Bank.

Similar major studies have also been conducted for such fields as Gullfaks, Volve, Brage and Oseberg East in the North Sea.

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