Environment 2004

The Norwegian petroleum sector

Ministry of Petroleum and Energy

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Contents

Foreword

The Ministry of Petroleum and Energy produces an annual environmental review in cooperation with the Norwegian Petroleum Directorate. The purpose of this publication is threefold:

- to increase knowledge about the environmental aspects of Norwegian oil and gas activities
- to take a more detailed look at a specific topic which particularly concerns both the industry and the authorities, and identify the challenges and options faced
- to emphasise the government's goal of ensuring that Norway reconciles its role as a large energy producer with a pioneering position on environmental issues.

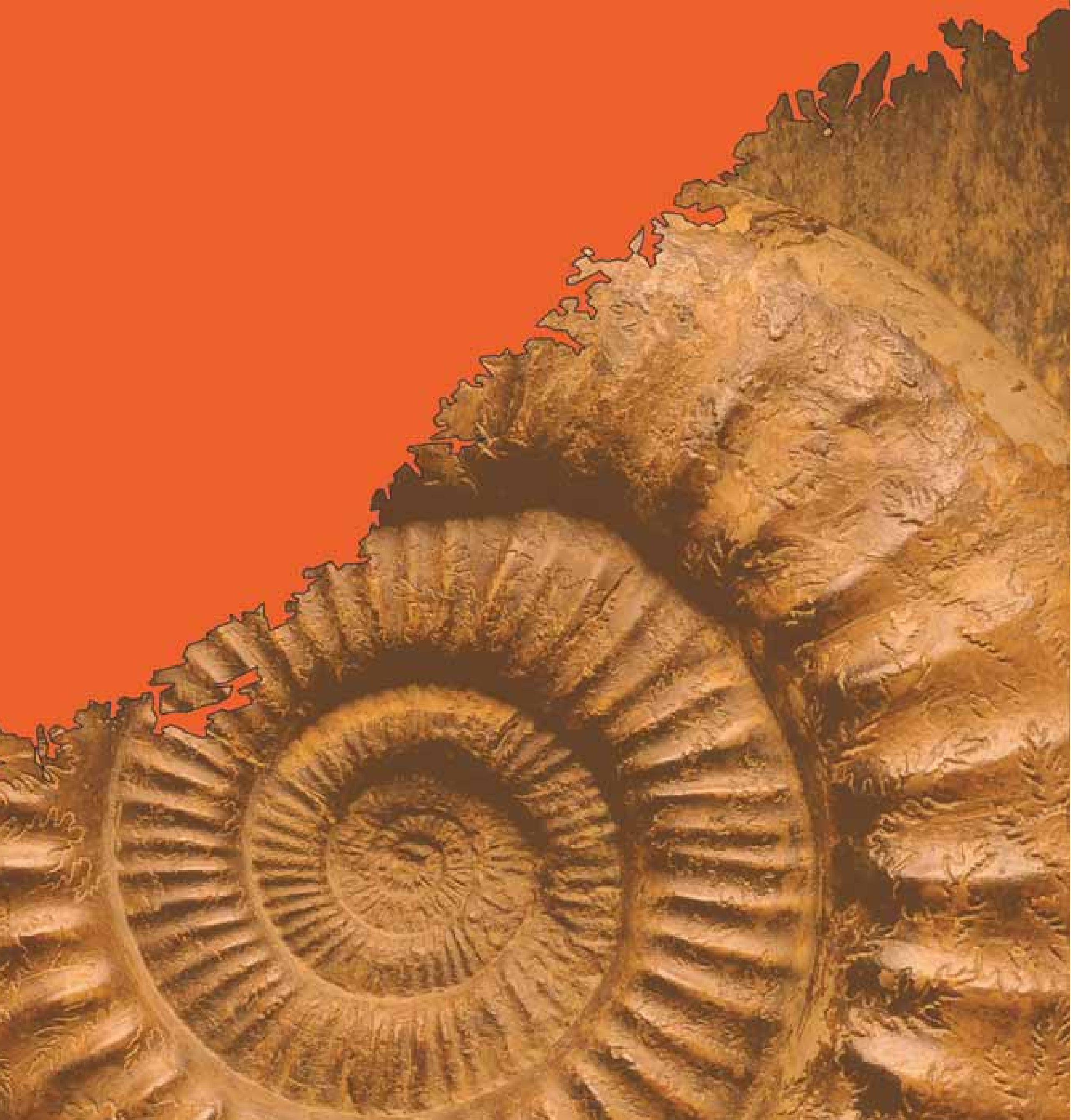
This year's edition focuses on the topic of produced water treatment techniques. It demonstrates that new Norwegian technology helps to limit the risk of environmental harm. New treatment techniques have been developed and adopted, but it can be difficult to understand why a specific solution is not applicable to every field.

Through the thematic section in part 2, we endeavour to explain why the choice of solution will vary from field to field, and how that reflects such considerations as technical reservoir conditions and costs. The strong focus on the environmental aspects of Norwegian oil and gas production has undoubtedly helped to make our petroleum sector a leader in this area. That reflects both the way the authorities have incorporated environmental considerations extensively into the industry's frame conditions, and from the commitment made by the industry itself.

Environment 2004 also incorporates a factual section, which covers the status of emissions/ discharges, environmental impacts, and measures to reduce discharges to the sea and emissions to the air from petroleum activities. The MPE hopes that a publication of this kind can help to enhance knowledge about petroleum activities and environmental issues.

Einar Steensnæs
Minister of Petroleum and Energy

Section 1
Facts



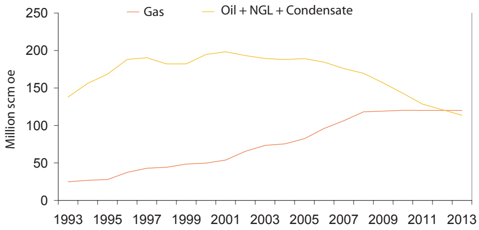


Figure 1 Production of oil, NGL and gas from the NCS
(Source: MPE/NPD)

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Petroleum activities in Norway

Facts about the petroleum sector

- Accounted in 2003 for 45.9 per cent of the value of Norwegian exports.
- Contributed about 24.8 per cent of overall government revenues in 2003 through:
  - revenues from the state's direct financial interest (SDFI)
  - taxes from the oil companies
  - dividends from Statoil.
- Gas is gaining increasing importance compared with oil.
- Remaining oil and gas resources on the Norwegian continental shelf (NCS) are substantial. Twenty-nine per cent of the original recoverable petroleum resources have been sold and delivered. Forty-one per cent lie in existing fields/discoveries and 26 per cent remain to be discovered. The rest of the resources relate to possible future measures to improve recovery.

Oil production from the NCS started on the Ekofisk field in 1971. Gas exports began from the same field in 1977. Bringing Draugen on stream in 1993 established the Norwegian Sea as a production province. Snøhvit was approved in 2002 as the first Barents Sea development.

Production from the NCS has generally grown year by year since activities began. See figure 1. Oil output averaged 3.3 mill barrels per day in 2003, and is expected to average 3.2 mill barrels per day for 2004 as a whole. This level is likely to be maintained over the next three years.

Gas production is expected to increase substantially from the present level of 73.4 bn scm per year to an annual total of 120 bn scm in 2010.

In addition to offshore developments, land-based facilities have been built at Kårstø, Kollsnes, Sture, Mongstad and Tjeldbergodden in order to bring oil and gas ashore and process them to a greater or lesser degree. Receiving terminals for natural gas from the NCS have been established at St Fergus in the UK, Emden and Dornum in Germany, Zeebrugge in Belgium and Dunkerque in France. A facility is also under construction at Melkøya outside Hammerfest to process gas and natural gas liquids (NGL) from Snøhvit. Plans call for production to begin during 2006.

Oil and gas are non-renewable resources, and their production often generates revenues in excess of those normally achieved in other industries. In Norway, much of these additional earnings accrue to the government through taxes and the SDFI. In addition, the government receives dividends from its holdings in Statoil and Norsk Hydro.

The Storting (parliament) resolved to restructure state participation in 2001. The government sold 21.5 per cent of the SDFI's portfolio during 2001 and 2002, with 15 per cent going to Statoil and 6.5 per cent to other companies. Two companies were also

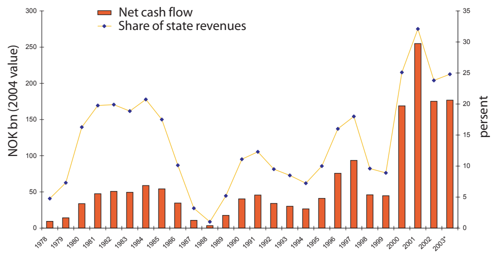

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Figure 2 Government's net cash flow from petroleum 1978–2003
*(Source: National accounts and state budget) *estimate*

founded in connection with the partial privatisation of Statoil – Petoro AS to manage the SDFI portfolio on behalf of the government and Gassco AS to serve as the neutral operator of the gas transport system.

Petroleum activities have contributed enormous revenues to Norwegian society. Total earnings from the sector have varied over time in line with changes in prices and production. See figure 2. Petroleum revenues are largely determined by world market prices for crude oil, the US dollar exchange rate and production costs.

Demand for goods and services generated by operations on the NCS has created major spin-offs for the mainland Norwegian community. A high percentage of the contracts for exploration, development, production, transport and removal of redundant equipment have been won against international competition by Norwegian companies. This has helped Norwegian offshore suppliers to become so strong in a number of areas that they have also gradually gained entry to the international market. Being competitive on the world market is vital for the industry's survival beyond the producing life of the NCS.

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Environmental protection by the authorities

To ensure that Norway can combine the role of a major energy producer with being a pioneer in environmental issues, an extensive set of instruments has been developed to take environmental considerations into account in all phases of petroleum activities.

The Norwegian authorities regard close cooperation with the industry as essential for achieving established environmental goals without imposing excessive economic costs on society. Miljøsok was established in 1995 in order to promote such collaboration in the petroleum industry. This cooperation has continued from 2001 through a new body, the Environmental Forum.

This initiative aims to strengthen and extend collaboration between the industry and the authorities in order to ensure that the Norwegian petroleum sector will remain among the front runners internationally for environment-friendly and cost-effective operation.

Exploration phase

The objective of opening new areas to petroleum operations is to find profitable resources for future development and production. The most important environmental impact of exploration work is the threat of acute discharges of oil, which are potentially dangerous to larvae, fish eggs, fish, seabirds, marine mammals and life along the shore. However, the likelihood of such spills is low. No major acute discharges have occurred over almost 40 years of exploration drilling on the NCS.

Before a new area of the NCS is opened for petroleum activities, detailed analyses are carried out on behalf of the government to assess the extent to which exploration could harm the environment. The obligation to carry out such impact assessments is laid down in the Petroleum Act. Studies are subject to public consultation and then presented to the Storting. Special impact assessments have been carried out for the Norwegian Sea, the Skagerrak and the southern Barents Sea.

The government also lays down specific requirements in opened areas which seek to lay the basis for coexistence between environmental, petroleum and fishing interests. These can include restrictions on when drilling is allowed to take place and the number of installations permitted in an area at the same time, limits on discharging drill cuttings, and specific emergency response requirements to curb damage from possible instances of acute pollution.

Once an area has been opened for petroleum activities, blocks in the area can be put on offer. Production licences are awarded to those companies which the government believes, after an overall evaluation, can best recover the predicted assets in the area.

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The Barents Sea is an important area for several reasons. It ranks as one of Norway's best fishing areas while probably also containing substantial oil and gas resources. Extensive impact assessments were carried out in connection with the opening of the southern Barents Sea in 1989 and ahead of the development of the Snøhvit gas field.

In addition, the Ministry of Petroleum and Energy (MPE) has been responsible for an impact assessment of year-round petroleum activities in the waters northwards from the Lofoten Islands, including the Barents Sea. This study aimed to present the most important issues relating to the environmental, fishing and social consequences of year-round petroleum operations in these waters.

The assessment was submitted on July 2003 and circulated for public consultation. In December 2003, the government resolved that the Nordland VI area off Lofoten would not be opened for further petroleum activities. This question will be assessed when the integrated management plan for the Barents Sea is presented. At the same time, the government resolved on a general opening of the previously-opened areas of Barents Sea South to continued year-round petroleum operations, with the exception of certain particularly valuable areas.

Development and production phase

Once commercially-viable discoveries have been made, the next phase covers development and operation to recover these assets.

Before the licensees can develop a discovery, the Petroleum Act requires that a plan for development and operation (PDO) be approved by the authorities. In addition, the licence partner must have permits for installation and operation (PIO) of possible associated facilities, as specified in section 4-3 of the Petroleum Act.

As part of the PDO/PIO process, the licensees must submit an impact assessment. This study will describe any environmental effects of emissions and discharges expected if the project goes ahead, and include a systematic review of costs and benefits of any mitigatory measures. Both the programme and the actual impact assessment are subject to public consultation.

Depending on the scope of the development, the PDO/PIO is considered by the King in Council or the Storting on the basis of an overall evaluation. Environmental protection represents one of the criteria applied in this evaluation.

In addition to the danger of acute discharges, the production phase involves continuous emissions to the air and discharges to the sea. These primarily include:

- discharges of water containing residual oil and chemicals
- emissions of carbon dioxide (CO_2) and nitrogen oxides (NO_x) from energy production and flaring
- emissions of non-methane volatile organic compounds (nmVOC) during offshore loading of oil.

Several policy instruments are deployed by the authorities to limit the environmental impact of emissions and discharges during the operating phase. These include conditions attached to plans for development and operation and installation and operation (PDO/PIO), carbon tax, and permits for flaring and emissions/discharges. These instruments vary from one kind of emission/ discharge to another.

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CO_2

With effect from 1 January 1991, the CO_2 Tax Act imposed a carbon tax on the use of gas, oil and diesel oil in petroleum activities on the NCS. This tax is levied on all combustion of fossil fuels – primarily natural gas and diesel – which emit CO_2. From 1 January 2004, the tax rate on the NCS is NOK 0.76 per litre of oil/scm of gas.

Gas flaring, other than volumes necessary for safety reasons during normal operation, is not permitted under the Petroleum Act without the approval of the MPE.

NO_x

NOx emissions are currently regulated on the NCS through possible requirements imposed during consideration of the PDO/PIO.

In 1999, Norway signed the Gothenburg protocol, which includes a requirement for a national reduction in NOx emissions of 29 per cent in 2010 compared with the 1990 level. Possible national instruments and requirements for different industries needed to meet this commitment are currently under consideration.

NmVOC

NmVOC emissions from offshore loading and storing crude oil have been subject since 2001 to emission permits issued under the authority of the Pollution Control Act.

Oil, organic compounds and chemicals

Companies must apply to the Norwegian Pollution Control Authority (SFT) for permits to discharge oil and chemicals to the sea. These permits are issued in accordance with the provisions of the Pollution Control Act.

This statute provides that operating companies have the responsibility and obligation to establish the necessary emergency response arrangements to deal with acute spills. Local and central government emergency response plans provide further protection.

Closing phase

Several Norwegian offshore fields have now ceased production or are nearing the end of their producing life. A total of 12 fields have been permanently shut in.

In 1998, the ministerial meeting of the convention for the protection of the marine environment of the north-east Atlantic (Ospar) approved a general prohibition on abandoning redundant offshore installations in the area covered by the convention. Exceptions can be made for concrete platforms, the bottom section of large steel structures, and other installations in the event of exceptional or unforeseen circumstances. Before a possible decision is taken on an exemption from the Ospar convention, the other parties to the convention must be consulted. The Ospar resolution is discussed in Proposition no 8 (1998-1999) to the Storting.

The Ospar resolution does not cover pipelines and cables. Report no 47 (1999-2000) to the Storting on disposing of redundant pipelines and cables, lays down general guidelines which specify that permission to leave such facilities in place should be granted when these do not cause any inconvenience to or safety risk for bottom fishing when compared with the cost of trenching, covering or removing.

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Status of emissions and discharges

The petroleum sector accounts for a substantial percentage of Norway's emissions of carbon dioxide (CO_2), nitrogen oxides (NOx) and non-methane volatile organic compounds (nmVOC). In addition, it generates minor emissions of methane (CH_4) and marginal emissions of sulphur dioxide (SO_2). Operations also cause discharges of oil and various chemicals into the sea.

The various emission components contribute to different environmental problems. In dealing with transnational pollution and emissions and discharges in common areas such as international waters, the countries involved must work together to achieve the desired environmental goals.

Several international agreements commit Norway to limit emissions of various substances. How this affects the petroleum sector depends on the terms of the specific agreement and how the requirements/ use of instruments are allocated sectorally in Norway. Those relating to emissions to the air usually specify ceilings for each country. The terms are crucial in determining whether obligatory emission curbs must be implemented entirely within a country or whether they can also be achieved in other countries where reduction costs may be lower. The costs of reducing emissions and discharges, both nationally and internationally, will be significant for determining the extent to which measures are imposed on the petroleum sector.

Global environmental problems

CO_2, CH_4, NO_x and nmVOC are greenhouse gases which contribute to global warming. They are regulated internationally through the UN framework convention on climate change. Norway's obligations under the Kyoto protocol mean that its average greenhouse gas emissions in 2008-2012 cannot be more than one per cent higher than in 1990. That involves a reduction of about six per cent from the current level.

This commitment can be met through reductions both nationally and partly in other countries through the use of the Kyoto mechanisms (international emission trading, the green development mechanism and joint implementation). In connection with its consideration of Report no 54 (2000-2001) on Norwegian climate policy, the Storting resolved that a broad national quota system for greenhouse gases should be established in Norway from 2008.

Regional environmental problems

NO_x, SO_2 and nmVOC contribute to regional transboundary environmental problems, such as acid rain, eutrophication (over-fertilisation) and ground-level ozone. They also cause certain local pollution problems. Emissions of these gases are regulated through various protocols under the convention on long-range transboundary air pollution (LRTAP).

Norway, other European countries, the USA and Canada signed the Gothenburg protocol in 1999. This seeks to solve the environmental problems represented by acidification, eutrophication and ground-level ozone. Under the protocol, Norway must cut its annual emissions of NOx to 156 000 tonnes by 2010. That represents a 29 per cent reduction from the 1990 level.

The commitment for nmVOC is virtually identical to the obligation accepted by Norway under the earlier Geneva protocol. This requires annual nmVOC emissions from mainland Norway and the Norwegian economic zone south of the 62nd parallel to be reduced by 30 per cent as soon as possible compared with 1989. Under the Gothenburg protocol, overall national emissions cannot exceed 195 000 tonnes per year by 2010.

Local environmental problems

Oil and chemical discharges from offshore installations may have local effects around their source and are regulated nationally by emission permits issued under the Pollution Control Act. In addition, such discharges are regulated by the Ospar convention because they take place in international waters and thus concern more than one country.

A recommended maximum oil content has been set internationally for discharges of water to the sea, and a recommendation for reducing total oil discharges from the offshore sector. Usage and discharge of chemicals are regulated internationally through requirements for risk assessment and categorisation of the inherent properties of each chemical.

EnvironmentalWeb

The Norwegian Oil Industry Association (OLF), the Norwegian Petroleum Directorate (NPD) and the Norwegian Pollution Control Authority (SFT) joined forces in 2003 to establish a common database for discharges to the sea and emissions to the air from the oil industry.

From 2004, all operators pursuing petroleum operations on the NCS must report emission/discharge data directly to the common database. This will make it easier for the operators and the authorities to analyse historical emissions/discharges in a more complete and consistent way than before.

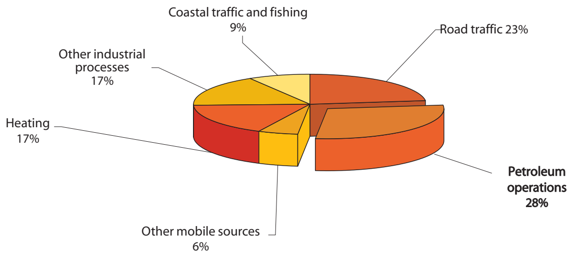

Figure 3 Sources of Norwegian CO_2 emissions, 2002
(Source: Statistics Norway/SFT)

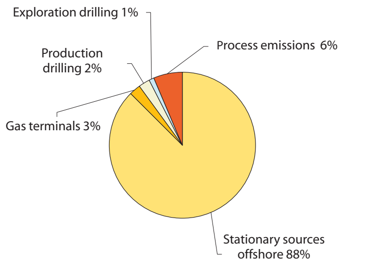

Figure 4 Taxed CO_2 emissions from petroleum operations by source, 2002
(Sources: MPE/NPD)

Carbon dioxide (CO_2)

CO_2 is the most important of the greenhouse gases. Emissions of CO_2 from human activities largely relate to the burning of fossil fuels.

Environmental impact of CO_2

Contributes to the greenhouse effect, which leads in turn to global warming.

Emissions from the petroleum sector

Petroleum activities account for about 28 per cent of Norwegian emissions of this gas (see figure 3), and this percentage is expected to increase to about 30 per cent in 2005-06 before starting to decline. The other major sources in Norway are road traffic and other mobile sources, heating, and various industrial processes.

As figure 4 shows, the bulk of CO_2 emissions by the petroleum sector derives from offshore installations. Other sources include gas receiving terminals on land and – indirectly – nmVOC emissions (process emissions). Virtually all CO_2 emissions from installations on the NCS derive from gas combustion in turbines and through flaring, and burning diesel oil. Natural gas releases the lowest volume of CO_2 per unit of energy of any fossil fuel.

Total CO_2 emissions from the sector have grown year by year, mainly as a result of increased activity. The trend in recent years and forecasts for the immediate future are shown in figure 6. Higher overall emissions do not mean there have been no environmental gains. However, improved energy utilisation and reduced flaring have not been enough to offset the rise in energy consumption to which increased activity has contributed.

One indication that operations have become more efficient is that CO_2 emissions per unit of oil equivalent produced declined by 23 per cent from 1990 to 2002 (see figure 7).

This can partly be attributed to:
- general improvements in technology
- measures to reduce emissions, partly prompted by the carbon tax imposed in 1991.

However, other factors – including a growing number of producing fields and the fact that key fields have reached a mature phase – could boost emissions.

Generally speaking, emissions from producing a unit of oil or gas vary both between fields and over a field's producing life. Reservoir conditions and transport distances to the gas market are factors which produce variations between fields in energy demand and consequently in emissions. Varying emissions over a field's producing life reflect the rising water cut (proportion of water in the wellstream) as production continues. Since energy requirements for processing are largely determined by the total volume of water, oil and gas in the wellstream, emissions per

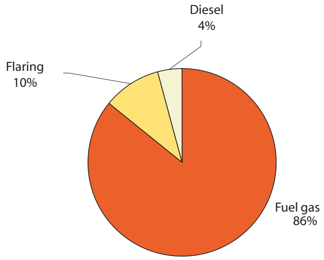

Figure 5 Taxed CO_2 emissions from oil and gas production by source, 2002

(Source: NPD)

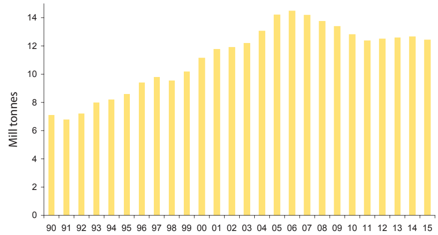

Figure 6 Total CO_2 emissions from the Norwegian petroleum sector

(Sources: MPE/NPD)

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unit produced will rise as a field ages. This is one reason for a slight increase in Norwegian emissions per unit produced in recent years.

The trend on the NCS towards more mature fields and the northward shift of activities encourage higher emissions per unit produced. 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.

This makes an important contribution to the development of the "CO_2 emissions per unit produced" indicator.

Preliminary figures from the NPD for 2003 show an increase of 2.5 per cent in overall CO_2 emissions by the offshore sector from 2002 to 2003.

Measures to reduce CO_2 emissions

The development of combined cycle solutions offshore, recycling of flare gas and injection of CO_2 from produced gas on Sleipner West help to show that Norway's offshore sector is well advanced in applying environmentally efficient technology.

Combined cycle power

Combined cycle systems, currently operational on Oseberg, Snorre and Eldfisk, involve using the waste heat in gas turbine exhaust fumes to produce steam for generating additional electricity. These units are unique in the world's offshore industry.

CO_2 storage

Instead of releasing the CO_2 separated from Sleipner West gas production to the air, it is injected in the Utsira sandstone formation 1 000 metres beneath the seabed. This is the first time CO_2 removed from natural gas production has been injected offshore in an sub-surface reservoir. A million tonnes of CO_2 per year have been stored in this way since 1996, and it is documented that the gas pumped into the Utsira formation stays there and does not leak out.

Norway will have good opportunities for future CO_2 storage because of access to natural formations and drained oil/gas reservoirs on the NCS. Storing CO_2 in drained reservoirs offers a good solution geologically, since such structures are very probably sealed because they have retained oil and gas over millions of years. Another advantage is that the extent and physical properties of these reservoirs have been surveyed in great detail. The NCS currently contains about 20 fields with a storage potential of roughly 1 000 mill tonnes of CO_2.

Using CO_2 to improve recovery

CO_2 can also be used on some fields to replace or supplement the injection of natural gas and water as pressure support to improve recovery. The NPD has estimated the technical potential for improved oil recovery (IOR) from using CO_2 in oil fields on the NCS at 240-320 mill scm.

Injecting CO_2 for IOR is effective because of the miscibility of this gas. It dissolves in the oil, causing it to expand and flow more easily. The expansion increases pressure in the reservoir, displacing the affected oil. CO_2 injection both stores the gas and generates revenues through IOR.

Using CO_2 for IOR on a field would mean a complete reorganisation of the field's recovery strategy, in addition to technological and cost

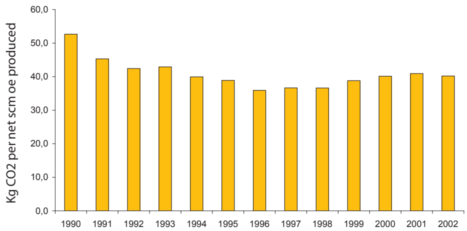

Figure 7 Emission of taxed CO_2 per unit produced
(Source: NPD)

challenges presented by modifications to installations, infrastructure for CO_2 transport and facilities for capturing the gas.

Sufficient quantities of pure CO_2 are unlikely to be available from point sources in Norway to meet the requirements for possible injection to achieve IOR on the NCS. Apart from Norwegian sources, supplies from other parts of the North Sea basin are being assessed.

An individual field is unlikely to find it commercially viable to use CO_2 for IOR, but it could prove socio-economically profitable when the environmental aspect is taken into account.

Flaring

The NPD has carried out an assessment of opportunities for achieving further reductions in greenhouse gas emissions from flaring. Important technical measures have largely been implemented. Further reductions in flaring can only be obtained through a stronger focus on operating routines at the companies and on production regularity.

Technology approved and implemented for reducing CO_2 emissions:

- CO_2 separation from the Sleipner West wellstream and subsequent deposition below ground
- utilising exhaust heat in the process system
- more efficient energy generation, such as the use of combined heat and power on Oseberg, Snorre and Eldfisk
- optimal dimensioning of pipelines
- replacing old installations, as on Ekofisk
- making greater use of more efficient gas engines in place of gas turbines
- optimising new fields for energy use and utilisation
- supplying electricity from land to Troll A
- recovering flare gas
- transferring power between Snorre A and B.

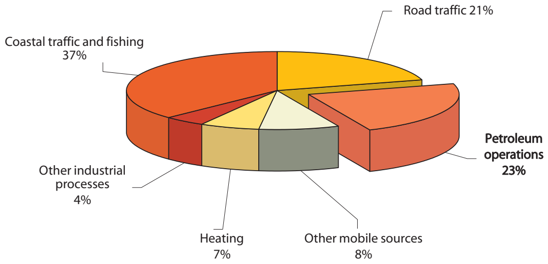

Figure 8 NO_x emission sources in Norway, 2002
(Source: Statistics Norway)

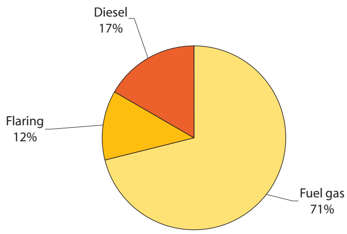

Figure 9 NO_x emissions from oil and gas production by source, 2002
(Source: NPD)

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Nitrogen oxides (NO_x)

NO_x are mainly formed by burning fossil fuels. Emission volumes depend on both combustion technology and fuel consumption. Gas turbines generate lower NOx emissions than diesel engines, for instance.

Environmental impact of NO_x

- Harm to fish and animal life through acidification of river systems and soils.
- Damage to buildings, stone and metals from acid precipitation.
- Eutrophication causing changes to the composition of the ecosystem.
- Damage to health, crops and building from the formation of ground-level ozone when NOx and nmVOC are exposed to sunlight.

Emissions from the petroleum sector

Mobile sources account for the bulk of Norwegian NOx emissions. See figure 8. The petroleum sector contributes 23 per cent. As with CO_2, turbines, flaring and diesel engines on installations represent major offshore sources. See figure 9. Some emissions will also relate to exploration and gas receiving terminals on land.

As figure 10 shows, emissions of NOx from the sector grew steadily from 1991. See figure 10. Emissions are expected to rise up to 2005, and then begin to decline. This is primarily because increased activity has boosted energy consumption and thereby volumes released. The change in emissions per unit produced provides an indication of offshore efficiency gains. Emissions per unit produced are shown in figure 11.

CO_2 and NOx emissions are closely linked, since both derive from the same principal sources. The most important exception is low NO_x burner technology for gas turbines, which can cut the release of these components by up to 90 per cent without affecting CO_2 emissions. In some cases, however, the amount of CO_2 given off can rise with this technology.

Measures for reducing NOx emissions

Most measures which reduce CO_2 emissions also help to cut the amount of NOx released from the petroleum sector. Other measures which can contribute to reducing NOx emissions are listed below:

- installing low NOx burners in new gas turbines
- catalytic cleaning
- steam/water injection in the combustion chamber.

Installing low NOx burners is regarded today as the most appropriate way to achieve substantial emission reductions from Norwegian offshore oil and gas

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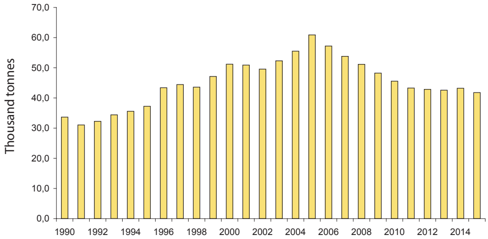

Figure 10 Total NO_x emissions from the Norwegian petroleum sector
(Sources: MPE/NPD)

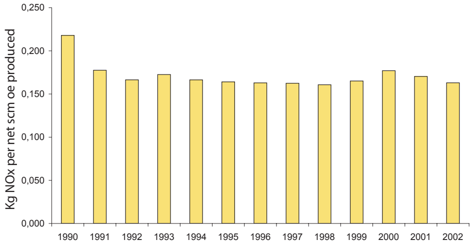

Figure 11 Discharges of NO_x per unit produced
(Sources: MPE/NPD)

activities. Such equipment is standard for new fields.

A study carried out by the NPD in 2001 with participation from the industry shows that the general cost of retrofitting such devices on existing installations is significantly higher than previously estimated. Both the cost and the environmental effect of retrofitting will vary significantly from machine to machine.

Costs associated with increased downtime on installations as a consequence of retrofitting low NO_x technology are an important consideration. Turbines with such burners also need more frequent and extensive maintenance than traditional machines. In a life-cycle perspective, this adds up to a substantial additional expenditure.

Generally speaking, low NOx technology on machines with high energy efficiency will yield a substantial environmental gain. Installing them on turbines running with low capacity utilisation will increase CO_2 emissions while failing to achieve the same NOx reductions obtained with high capacity utilisation.

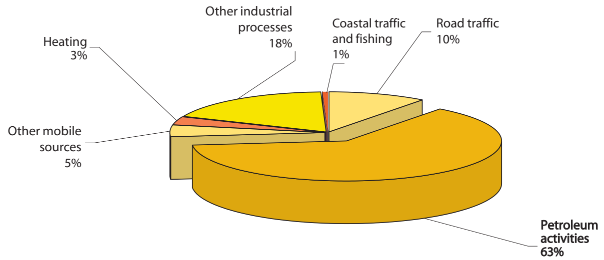

Figure 12 Sources of Norwegian nmVOC emissions, 2002

(Source: Statistics Norway)

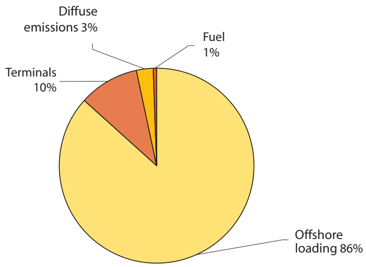

Figure 13 Sources of nmVOC emissions from the petroleum sector, 2002

(Source: NPD)

Non-methane volatile organic compounds (nmVOC)

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

Environmental effects of nmVOC

- Formation of ground-level ozone may damage human health as well as crops and buildings.
- Direct exposure may damage the respiratory system.
- Contributes indirectly to the greenhouse effect because CO_2 and ozone form when nmVOC reacts with air in the atmosphere.

Emissions from the petroleum sector

The petroleum sector is the main Norwegian source for emissions of nmVOC, with 63 per cent of the volume currently released in the country deriving from offshore storage and loading of crude. Figure 12 shows that other industrial processes and road traffic are also major sources.

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. Some emissions also occur at gas terminals and from minor leaks (see figure 13).

Emissions from loading a unit of oil vary widely between the various fields. Variations in the content of light components in the oil are one of the main reasons for this.

Several of Norway's new offshore developments utilise floating storage units. This kind of solution may release more nmVOC than fields such as Statfjord, Draugen and Gullfaks where crude is stored in the platform base. This is because emissions also occur from floating storage units when production is transferred to them.

NmVOC emission forecasts from the petroleum sector show a sharp decline over the next few years (see figure 14). This reflects both the installation of recovery technology in line with requirements imposed under the Pollution Act and an expected peaking in oil production within a few years. This will be crucial for Norway's observance of the Gothenburg protocol.

Measures for reducing nmVOC emissions

The release of nmVOC from offshore storage and loading of crude oil on the NCS is regulated through emission permits. These require that the oil must be

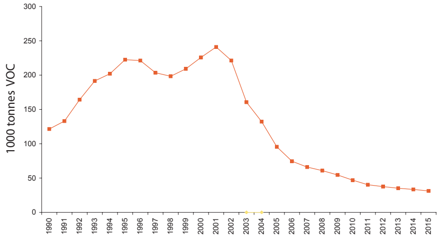

Figure 14 Total emissions of nmVOC from the petroleum sector, 2002

(Sources: MPE/NPD)

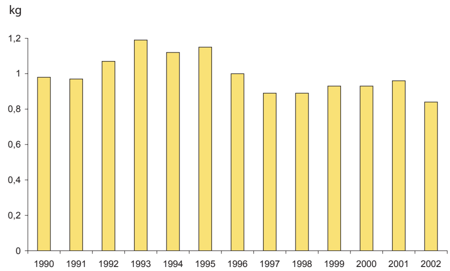

Figure 15 NmVOC emissions per unit produced

(Sources: MPE/NPD)

stored and loaded with the best available technology (BAT) for reducing emissions. Technologies which can satisfy this requirement are being phased in under a specified timetable up to the end of 2008.

The oil companies have been working for several years to make nmVOC recovery technology available for storage ships and shuttle tankers. Tested solutions are available which reduce emissions from a loading operation by about 70 per cent. A number of vessels have now been equipped with emission reducing technology.

Operators of Norwegian fields which use offshore loading have established an industrial collaboration to coordinate the introducing of these solutions and meet the requirements in an appropriate and cost-effective manner. This partnership lays the basis for exchanging experience about running the recovery plants.

An nmVOC recovery plant was commissioned for the crude oil terminal at Sture near Bergen in 1996. The plant is the first of its type to be installed at a crude oil terminal. To use it, tankers must be equipped with the appropriate connectors. All vessels must have installed nmVOC recovery systems from 1 January 2003, and are generally not admitted to the terminal without such equipment.

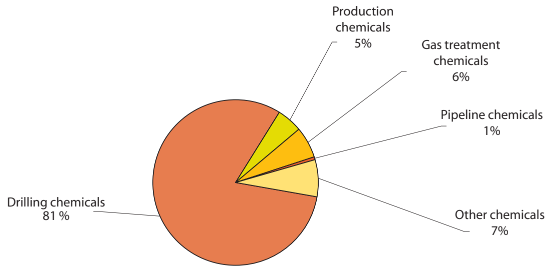

Figure 16 Chemical discharges on the NCS by activity, 2002

(Source: SFT)

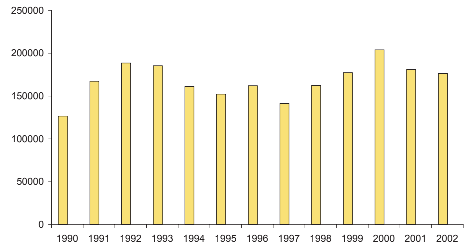

Figure 17 Total chemicals discharged from Norwegian petroleum operations

(Source: SFT)

Chemicals, oil and other naturally-occurring chemical substances

Chemicals are a generic term for all additives and other substances used for drilling and well operations and in oil and gas production. The main rule is that environmentally-hazardous substances must not be discharged, whether they are additives or naturally-occurring chemicals.

Environmental effects of discharging chemicals:

- Most of the chemicals used (more than 99 per cent) are assumed to have little or no environmental impact.
- Discharges embrace a variety of substances with very different potential effects on the environment.
- Little is still known about the possible long-term effects of chemical discharges.
- Several of the chemicals have some local toxic effect. Studies show they are diluted in the water column, and thereby do not represent a significant acute environmental hazard beyond the immediate vicinity of the discharge.
- Some of the chemical discharges could have extremely serious environmental consequences, including hormonal disturbances, and be bio-accumulative.

Environmental effects of discharging oil and other naturally-occurring chemical substances:

- Spills/acute discharges can harm fish, marine mammals, seabirds and shore zones.
- Considerable uncertainty exists about the environmental consequences of operational discharges. No environmental damage has yet been proven. Much research is under way, particularly into long-term effects.
- Great uncertainty also exists about the long-term effects of dissolved organic compounds, such as polycyclic aromatic hydrocarbons (PAH) and alkyl phenols. Considerable research is again being conducted in this area.

Discharges of chemicals

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

Various models are applied to ensure that environmental considerations are taken into account when the companies select chemicals. The Charm model has been developed by the nations involved in the Ospar collaboration. In Norway, Statoil has

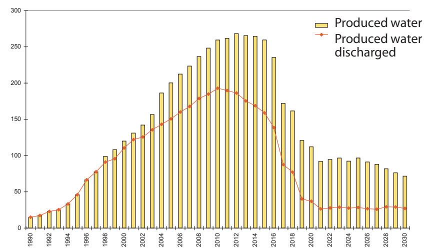

Figure 18 Volumes of produced water and produced water discharged, historical and forecast
(Source: NPD)

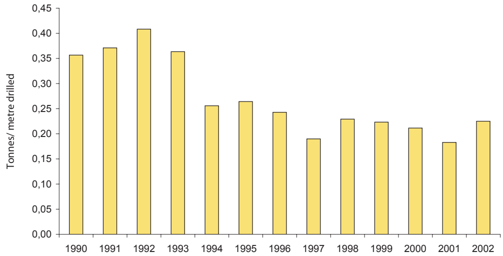

Figure 19 Discharges of drilling chemicals per metre drilled
(Sources: SFT/NPD)

developed the environmental impact factor (EIF), which has now been adopted by all operators on the NCS. Described in greater detail in part 2, this method is often used in combination with other models to achieve the best possible assessment of environmental impact.

In considering the environmental impact of chemical discharges, it is important to distinguish between:

- largely harmless and more harmful chemicals
- the quantities used and discharged
- where and under what conditions discharges are made, and conditions in the recipient.

More than 99 per cent of the chemicals used in Norwegian petroleum activities are thought to have little or no environmental impact (green and yellow chemicals in the SFT's classification). A large proportion exist naturally in seawater. The remainder are chemicals which are environmentally hazardous or whose potential effects have not been sufficiently well documented.

Of the chemicals used in 2002, 30.4 per cent were discharged to the sea – including the water in which these substances were dissolved. The figure for 1989 excluding the water was 64 per cent. Chemicals not discharged were dissolved in the oil, deposited below ground or treated as waste.

Discharges of oil and other organic compounds

Discharges from Norwegian petroleum activities are estimated to account for two per cent of the total oil entering the North Sea. The main sources are shipping and the mainland via rivers. Oil discharges from the petroleum sector derive almost entirely from ordinary operations, although acute spills do occur.

Produced water consists of injected seawater where this is used as well as formation water which has been in contact with the oil in the reservoir, and accordingly contains a number of organic compounds. The most important in an environmental perspective are PAH and alkyl phenols. Produced water can also contain residues of chemicals used in the process. This is described in more detail in part 2.

Discharge sources

Drilling and well operations

As figure 16 shows, 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 variations in the number of wells drilled.

Discharging oily drill cuttings has been prohibited on the NCS since 1991. This ban has contributed to a significant reduction in oil discharges from operations compared with the level if oily drill cuttings could still be discharged.

Combined with injection of cuttings below ground, new drilling methods and technology have helped to cut discharges per metre drilled in recent years (see figure 19).

As mentioned above, cuttings contaminated with oil-based mud are no longer discharged on the NCS. Recycling, underground injection and disposal on land are alternative ways of avoiding discharges from drilling.

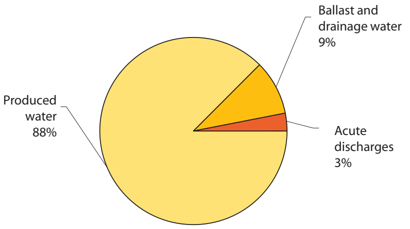

Figure 20 Oil discharges on the NCS by activity, 2002
(Source: SFT)

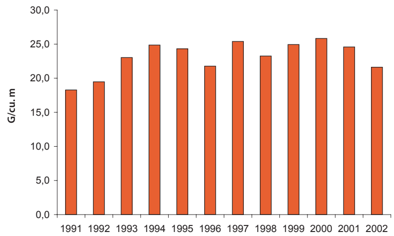

Figure 21 Discharges of oil per cubic metre of produced water
(Source: SFT)

Produced water

Water produced together with oil and gas is the main source of oil discharges to the sea from daily operations. See figure 20. Even if such water is carefully treated before discharge, it still contains residues of chemicals, oil and dissolved organic compounds.

The average concentration of oil in produced water on the NCS has been declining slightly. Under the Ospar convention, the content of dispersed oil in water discharged to the sea must not exceed 40 g/cu.m (milligrams per litre). Ospar has approved recommendations that this ceiling should be reduced to 30 g/cu.m from 2006, and that total oil discharges in produced water by member countries should be reduced by 15 per cent in the same year compared with the 2000 level. The annual average for Norwegian installations in 2002 was about 21.6 g/cu.m. This concentration has been fairly stable since 1990. See figure 21.

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 (see figure 18). Roughly 13 per cent of all produced water was injected in 2003.

Discharges of production and injection chemicals have risen in recent years, primarily reflecting increased use of subsea templates and more water injection. Such operations normally depend on chemicals. However, no clear trend can be discerned in the content of production chemicals in produced water. See figure 22.

Acute spills

Harm caused to the natural environment by acute oil spills depends on various factors which are more important than the size of the spill. Spill site, season, wind strength, current and the effectiveness of emergency response are crucial for the scope of any harm. Most serious acute Norwegian oil spills have involved ships close to the coast. Petroleum operations on the NCS have not been responsible for any major acute oil spills reaching the shore.

A relatively large number of acute oil spills have occurred on Norwegian offshore installations, but few of these are larger than one tonne. See figure 23. However, the total volume of oil involved in such spills is small compared with other sources.

In May 2003, a major acute spill occurred on the Draugen field in the Norwegian Sea. This caused a sharp rise in discharge figures for the year compared with 2002. Only about 180 cu.m of the roughly 750 cu.m spilt were recovered. Ranked as the third largest experienced on the NCS, the spill was caused by cracking in an end connection and consequent leakage after the installations had been shut down for a time. The relevant stretch of the mid-Norwegian coast was monitored, and none of the oil reached land. No damage to birds or fish was identified by the report from the commission of inquiry, even though only about 180 cu.m of oil was collected.

Zero discharge strategy at sea

The "zero discharge" concept was launched in Report no 58 (1996-1997) to the Storting on environmental policy for sustainable development. Since then, the authorities and the industry have worked together to refine the objective and to identify solutions for reaching it. The goals of the authorities are reflected

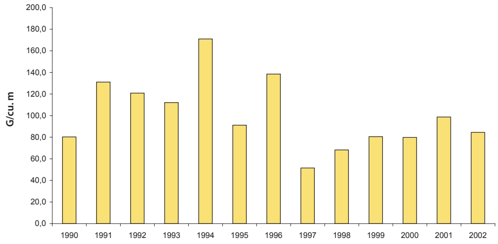

Figure 22 Content of production, injection and pipeline chemicals in produced water

(Source: SFT)

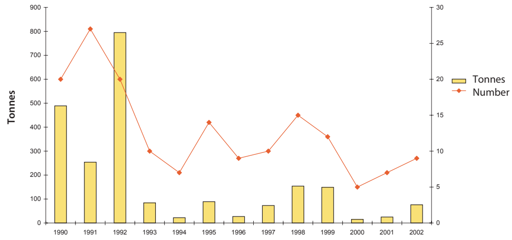

Figure 23 Acute oil spills over one tonne

(Source: SFT)

in Report no 25 (2002-2003) to the Storting on the government's environment policy and the state of the environment (see page 28).

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. Conditions on existing fields could be such that the level which is practical to achieve, based on an overall field-specific assessment, will be to minimise certain discharges.

Operators on the NCS are expected to be ambitious in their efforts to reach the target, and to be active in developing and adopting new techniques which can ensure that it is reached.

Reporting by the companies in 2003 shows that a large number of measures have been implemented, and that substantial environmental improvements have already been achieved. Providing the measures planned by the operators are implemented, they will come very close to achieving the target by the end of 2005.

Technological solutions

Developing new technology is important in meeting the zero discharge target. Solutions for separating or blocking water before it reaches the installation will be key elements. Separation can take place either downhole or on the seabed.

Because such solutions eliminate the need to pump water back to the platform, energy consumption and thereby emissions to the air can be reduced. At the same time, injection of water for pressure support can help to improve oil recovery. Where water injection is not the best solution, various types of treatment technology could help to achieve the zero discharge goal.

Technologies for eliminating or reducing discharges of environmentally-harmful compounds in produced water:

- full or partial injection below ground after topside separation
- mechanical or chemical shut-off of aquifers in wells
- separation downhole or on the seabed, followed by injection back below ground
- treatment of produced water on the field before discharge to the sea.

Technologies to avoid drilling fluid discharges:

- recycling
- collection and injection below ground
- collection and disposal on land.

Several of these technologies are already in place, due to be implemented, being tested or under assessment on a number of fields.

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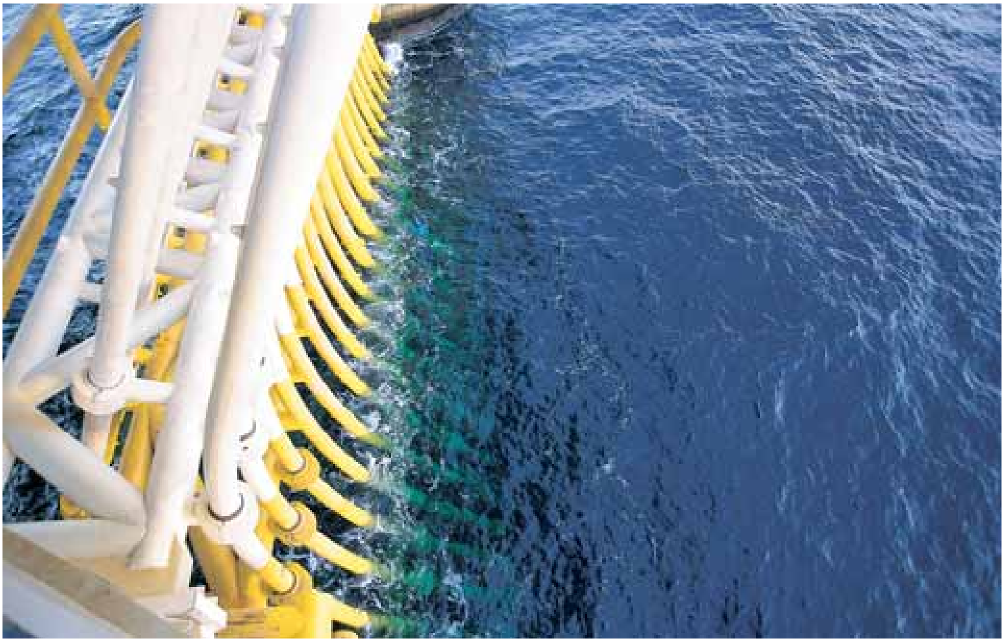
Full or partial injection has been adopted or planned on more than 20 Norwegian fields, and is also being assessed for a number of other installations. Various methods for shutting off aquifers have been adopted on many Norwegian offshore wells, and such solutions could find wider application as new or improved technology becomes available.

Subsea separation has so far been implemented only on Troll C, where a pilot plant is separating produced water from the rest of the wellstream in one of the production lines and then injecting the water.

Downhole separation has been tested on land, but trials in an offshore well will be needed before the technology can be adopted on a permanent basis.

Many different types of treatment technology are available for produced water. The ones used most frequently primarily separate out dispersed oil. Several newly developed treatment solutions which also remove dissolved components such as PAHs and alkyl phenols are now available and under testing offshore, or being developed. This work is described in more detail in part 2.



Zero discharges

1

Definition of zero discharges and zero discharge targets

Environmentally hazardous, environmentally-hazardous substances, environmentally-hazardous chemical substances, environmentally-hazardous components:
Substances or groups of substances with intrinsic properties such as toxicity, persistence (biodegradability), bioaccumulation potential and/or hormone disruption properties. The most dangerous of the environmentally-hazardous substances are called environmental toxins.
Environmentally harmful, environmentally-harmful discharges:
This term refers to the harm which discharges can cause, and depends on the volume discharged as well as the time and location of the discharges. An environmentally-harmful discharge can involve a hazardous substance, but can also be a substance without such intrinsic properties.

Zero discharge targets

Environmentally-hazardous substances

- No discharges or minimising of discharges of naturally-occurring environmental toxins ranked as priority 1 for chemicals hazardous to health and the environment. See the list for priority action in Report no 25 (2002-2003) to the Storting.
- No discharges of chemical additives in the SFT's black (basically prohibited for use or discharge) and red (high priority for phasing out through substitution) categories.

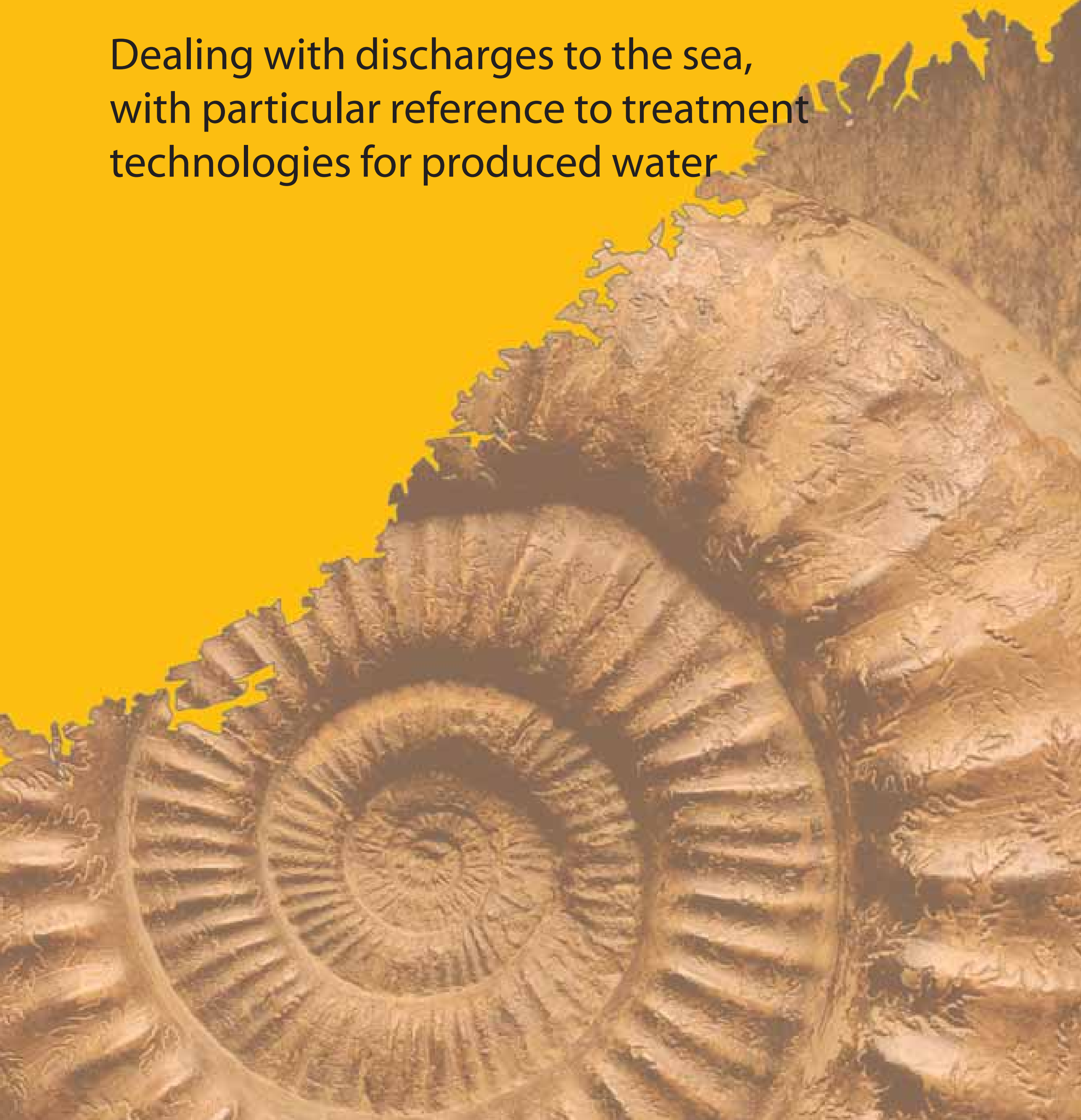
Other chemical substances:
No discharges or minimised discharges which could lead to environmental harm of:

- oil (components which are not environmentally hazardous)
- substances in the SFT's yellow and green categories
- drill cuttings
- other substances which could lead to environmental harm. See the regulations relating to the conduct of activities in petroleum activities (the activities regulations) of 3 September 2001.

Source: *Report no 25 (2002-2003) to the Storting on the government's environment policy and the state of the environment.*

Section 2
Special topic

Dealing with discharges to the sea, with particular reference to treatment technologies for produced water



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Introduction

An important challenge facing the petroleum industry is the discharge to the sea of substances which can harm the environment. As part of an overall approach to managing petroleum resources and the marine environment, the Storting has set a target of ceasing to discharge environmentally-hazardous compounds to the sea from offshore installations by the end of 2005. See the box in part 1 which provides a clear definition of the zero discharge concept and the zero discharge target.

To meet this objective, a number of new measures must be adopted on offshore installations. One relevant approach is to inject the water brought up in the wellstream from production wells (produced water) back below ground – either into the source reservoir or separate formations. Alternatively, environmentally-hazardous chemicals must be replaced with substances which have better environmental properties, usually in combination with treating produced water to a higher standard than today's.

The thematic section in Environment 2001 dealt with challenges and general solutions relating to discharges to the sea. A purposeful commitment to meeting the zero discharge target has yielded positive results in recent years, particularly in the development and use of new treatment technologies for produced water.

The global market for cost-efficient treatment technologies is expanding sharply as a result of stricter discharge standards. Norway's position as a pioneer in this development not only helps to solve national environmental challenges but also creates export opportunities for Norwegian industry. Various treatment technologies for produced water are accordingly addressed in this part of Environment 2004.

To put this presentation in its context, a brief initial description of the way oil, gas and water are handled on offshore installations is provided. The appropriate solution for dealing with produced water will vary from installation to installation. One purpose of this section is to explain the basis for the choices made on different installations.


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How a typical offshore installation works

On arrival topside, the wellstream normally comprises a mix of oil, natural gas and water under pressure. First-stage processing involves reducing the pressure through one or more stages to separate oil, water and gas.

Separated **natural gas** is dewatered and subjected to different forms of treatment before passing through various compressor stages to increase its pressure again.
Some of the gas is then used to generate power on the installation, with the rest either injected back into the reservoir for pressure support or piped to a receiving terminal on land. Valuable natural gas liquids (NGL) and condensate (light oil) are normally removed from the gas, either on the field or at the receiving terminal.

The oil is stabilised by removing the gas before being stored on the field and subsequently transported to land in shuttle tankers or a pipeline.

Water removed in the separators contains residues of oil and gas. The gas is stripped out and returned to the gas stream or flared. Further treatment of the water depends on whether it is to be discharged to the sea or pumped back below ground. Hydrocyclones (see the chapter on treatment technologies) are normally used to remove oil from the water before discharge to sea. This oil is returned to the oil stream.

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Environmental impact of discharges to the sea

Applying the precautionary principle

Laboratory trials have shown that certain substances in produced water can have adverse effects on the marine environment. Attention has focused recently on the possible negative impact of discharging dissolved organic compounds such as polyaromatic hydrocarbons (PAHs) and alkyl phenols.

How far the ecological system is affected depends on a number of factors. The composition and quantity of the discharges must be related to the environment's ability to dilute, break down, convert, absorb, accumulate or utilise these substances, for instance. In addition, different organisms vary greatly in their tolerance of pollution. How far they are affected can depend on temperature and season, which phase of their life cycle they are in and how long they are exposed.

Although no damage to the environment from discharging produced water has been demonstrated, broad agreement prevails that knowledge of long-term effects is deficient.

The industry and the authorities in Norway are collaborating through the Proof research programme on long-term effects of discharges to the sea from petroleum operations to enhance knowledge of the issues with the highest priority.

Administered by the Research Council of Norway, this programme began in 2002 and is due to continue until 2008 with an annual budget of about NOK 20 million provided jointly by industry and government.

In accordance with the precautionary principle, substantial steps are being taken on the NCS to reduce the risk of environmental harm. These measures, with the emphasis on treatment technologies for produced water, are covered in more detail in the following chapters.

Produced water

An oil reservoir always contains formation water. To maximise oil recovery, it is important to maintain reservoir pressure as the hydrocarbons are produced. Many Norwegian fields achieve such pressure maintenance by pumping down gas and/or seawater.

After a while, both injected and formation water will reach the production wells and flow up to the surface installation. This means that the volume of produced water increases as fields age. Towards the end of a field's producing life, the water proportion (cut) could be 90 per cent as against only 10 per cent oil.

Produced water contains oil droplets (dispersed oil), other organic components (including dissolved oil fractions), inorganic components (including heavy metals and natural low-level radioactive compounds) and chemical additives.

To ensure safe and stable operation of offshore installations, various chemical additives are required. These include:

- scale inhibitors to prevent salt scale in wells, equipment and piping
- corrosion inhibitors to prevent corrosion in piping and process equipment
- anti-foaming agents to reduce foaming in the production process
- biocides to reduce bacterial growth in the reservoir
- H_2S scavengers to remove toxic hydrogen sulphide gas

- hydrate inhibitors to prevent the formation of ice-like gas-water compounds (hydrate)
- flocculants to coalesce small oil droplets into larger drops which can be removed more easily from produced water.

When oil is separated from the produced water, the bulk of the water-soluble chemicals will normally remain with the latter while most of the oil-soluble chemicals stay with the oil fractions and are shipped ashore with the crude.

The chemical composition of produced water varies from field to field and over the production period, depending on what is found naturally in the reservoir and what is added. Generally speaking, an oil field produces much more water than a gas field. This is partly because water injection will not normally be used in the latter.

EIF – a new Norwegian tool for setting priorities

While produced water consists primarily of water, it also contains certain environmentally-harmful components. International attention has focused largely on reducing the content of (dispersed) oil in this water, but Norway also gives weight to reducing emissions of other environmentally-harmful

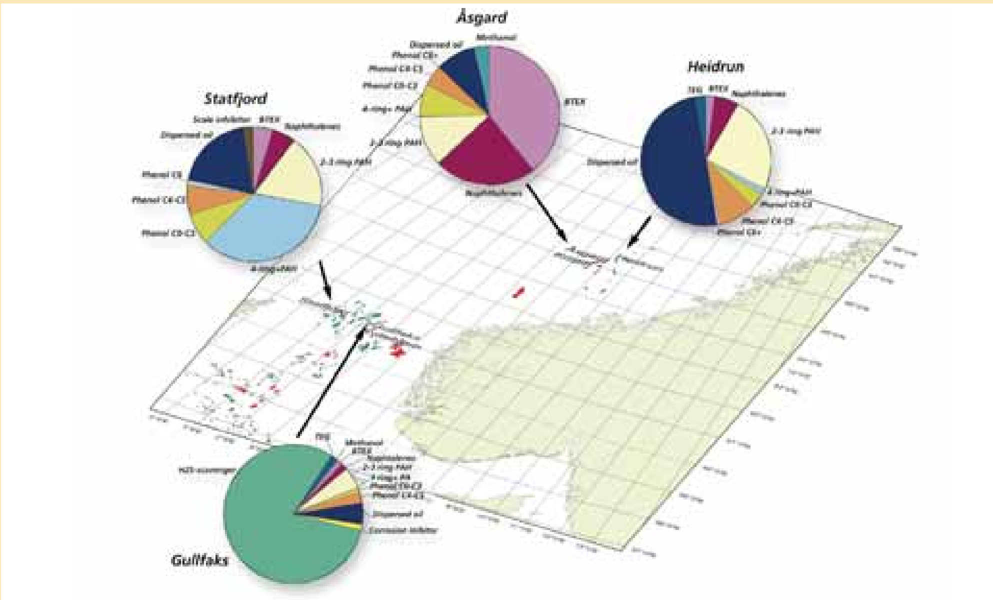

Figure 24 Contributors to the risk of environmental harm associated with discharges of produced water to the sea from four oil and gas fields.

(Source: Statoil)

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substances. A tool called the environmental impact factor (EIF) has been developed as part of the Norwegian work in order to calculate the risk of environmental harm when discharging produced water from a field.

The EIF for a field is calculated in part from the composition and quantity of produced water discharged and how discharges from a field disperse in the sea. This tool is used both by the authorities and by the oil companies for purposeful assessment of measures to treat produced water.

Figure 24 presents the various contributors to the total risk of environmental harm associated with discharges of produced water from four fields on the NCS. As can be seen, the principal challenges differ from field to field. This indicates that solutions for reducing environmental risk will also vary.

Produced water treatment techniques

Various measures and treatment technologies are available to limit the risk of environmental harm associated with water production on offshore fields. The choice of solutions for an individual field will depend on which substances contribute to the risk of environmental harm, which measures are suitable for removing these components and the cost of incorporating the necessary equipment on each installation.

Injecting produced water back into a reservoir is currently practised wholly or partly on more than 20 Norwegian offshore fields. About 13 per cent of produced water was injected in 2003. Installations with such injection will avoid discharges most of the time, depending on uptime for the plant. Combining several technologies, such as injection and Epcon (see below), can reduce residual discharges even further.

Injecting produced water on fields which require water for pressure support will replace seawater injection, and thereby involve only limited additional costs as well as no increase in emissions to the air. Not all fields require increased pressure support, and injecting produced water back into the oil reservoir will be inappropriate on these.

One drawback with produced water injection is that it introduces organic acids, which serve as very good nutrients for bacteria found in the reservoir. The problem is that these bacteria form H_2S as well as large quantities of biomass around the water injection wells. H_2S gas is very toxic to humans, and must be removed before natural gas can be sold. The biomass creates problems because it lowers the efficiency of injection for pressure support, and can thereby decrease oil recovery. Lost oil production will reduce revenues from offshore operations.

A number of measures are available for limiting the problems associated with H_2S formation and increased biomass in the reservoir, but these are expensive and can make it unprofitable to recover residual oil reserves.

An alternative to returning water to the producing formation is to inject it into a drained reservoir or a separate aquifer beneath the seabed. One drawback of such injection for storage is that dedicated wells must usually be drilled for this purpose, which is expensive. Injection also requires energy and could lead to higher emissions of CO_2 and NO_x.

Cutting the volume of water accompanying the wellstream from the reservoir to the surface offers another possibility for reducing the risk of

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environmental harm. Various methods for shutting off aquifers are applied in many wells on the NCS, and this approach could be widely applied as new or improved technologies become available.

The world's first plant for separating water on the seabed and injecting it back into the reservoir has been installed at the Troll C oil platform in the North Sea. Able to handle about 10 per cent of water produced from the field, this facility cost some NOK 550 million and has functioned well. Downhole separation has been tested on land, but is not yet in use on the NCS.

Chemical substitution involves replacing environmentally-hazardous chemicals with more environment-friendly substitutes. This work has been under way for a number of years to reach the government's target of phasing out the use of environmentally-hazardous chemicals by the end of 2005.

The challenge is to develop environment-friendly substitutes which function as well as the existing products. Plans drawn up by the operator companies indicate that it will by and large be possible to reach the goal of phasing out environmentally-hazardous additives discharged to the sea.

One remaining challenge is reducing discharges of the thread compounds used in drilling operations. Small quantities of copper and lead are added to these products, and these currently appears difficult to eliminate except at the expense of technical and safety considerations.

Treatment technologies for produced water can be an alternative or a supplement to the above-mentioned measures for treating produced water, and are described in more detail below.

Treatment technologies for produced water

Today's official requirement is that produced water discharged to the sea must contain no more than 40 milligrams per litre (mg/l) of dispersed oil.

The cost of installing one type of treatment technology will vary from installation to installation, with the volume of water involved influencing the size of the plant and thereby its price. Furthermore, some installations have spare space for new modules while others may require modifications and structural reinforcement before a treatment facility can be accommodated. A solution which functions well on one field will not necessarily do so on another.

A number of new treatment technologies have been developed and are currently being tested for use on the NCS. However, no single solution is well suited for reducing discharges of both dispersed oil and dissolved components on all types of oil and gas field.

Some relevant treatment technologies are assessed briefly below.

Traditional treatment technology

Traditional treatment primarily reduces the content of dispersed oil, and removes little of the dissolved components in produced water.

Hydrocyclones have so far been the most common treatment solution for produced water, and are used to meet official requirements for maximum discharges of dispersed oil.

These devices separate oil and water with the aid of centrifugal force. The produced water is rotated and differences in density cause oil and water to collect in different parts of the system, thereby separating them.

This technology normally removes 75-95 per cent of the oil droplets in produced water. Hydrocyclone

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efficiency increases with the size of the oil droplets, but these are smaller on gas and condensate fields. For this reason, hydrocyclones are more efficient on oil fields than on gas/condensate ones.

New treatment technology

When dispersed oil is removed, a number of the dissolved components accompany it. In line with the goal of eliminating the discharge of substances which pose a risk of environmental harm, considerable efforts have been made to develop and adopt new treatment solutions which remove dissolved components such as alkyl phenols and PAH compounds while also reducing the content of dispersed oil even further.

Epcon is a new Norwegian treatment technology which has attracted great attention recently from oil companies both in Norway and abroad. It will provide a better environmental and economic solution than traditional hydrocyclones on many fields, and requires little in terms of weight, space or maintenance.

The principle is that water flows into a large tank and rotates, so that the oil and gas becomes concentrated in the centre. Natural gas or gaseous nitrogen is added, and helps to raise the oil droplets to the surface while the water gets drained off from the bottom of the tank.

An Epcon plant with two tanks connected in series can reduce the oil content in produced water to almost 10 mg/l. In addition, it removes a good deal of the dissolved organic compounds which may be environmentally hazardous.

The technology has been tested in recent years on a number of installations, and is permanently installed on the Heidrun, Snorre and Brage fields and the Troll C platform.

CTour is a new treatment technology developed in Norway. It has a low weight, occupies little space and is well suited for fields producing a lot of water which also have access to condensate.

This ranks at present as one of the most promising treatment solutions. It has the potential to remove about 90 per cent of both dispersed oil and dissolved hydrocarbons (PAH and phenols). Tests show that it can also, in some cases, reduce the content of production chemicals.

The CTour process involves injecting condensate into the produced water before it enters the existing hydrocyclone facility. Condensate functions here as a solvent which shifts dissolved hydrocarbons from the water phase to the condensate phase (extraction). Small oil droplets coalesce into larger ones which can be removed in the hydrocyclones.

A number of the fields with a high water cut have no condensate of their own, however, particularly of the quantities and quality required by the CTour process. In such cases, it could be too expensive to transfer condensate from other fields and build a receiving plant on the installation to handle it.

CTour is at its most effective when the condensate consists primarily of light components, such as propane and butane. Adding a condensate with a high proportion of heavier components – benzene, toluene, ethyl benzene and xylene (BTEX) – could cause some of these components to remain in the water stream and be discharged to the sea.

It is possible to reduce BTEX discharges by installing a fractionation plant for the condensate, but this would require considerable space as well as significantly increasing the complexity and cost of the CTour process.

The technology has been tested on Statfjord, one of the largest fields on the NCS, and plans call for a

full-scale CTour plant to begin operating there in the spring of 2004. If this pilot facility proves successful, operator Statoil plans to install the technology on all three Statfjord platforms.

Macro porous polymer extraction (MPPE) has been developed in the Netherlands to remove dissolved organic components from water on gas/condensate fields with a relatively small water cut.

The principle is that produced water passes through a column packed with MPPE particles which remove the hydrocarbon components. Steam is then used to wash the hydrocarbons back into the process system. An MPPE installation must accordingly comprise one or more pairs of parallel columns.

MPPE is installed on three Dutch gas fields and has been undergoing long-term testing on the Åsgard field in the Norwegian Sea. Experience shows that this solution removes about 20-30 per cent of the dispersed oil and roughly 90 per cent of PAH and BTEX in produced water.

The technology operates best with low-volume streams, and is accordingly most suited for gas/condensate fields. It is also fairly energy-intensive as well as generating waste.

Cetco is an American treatment technology which uses a filter to reduce the content of environmentally-hazardous substances (PAH, BTEX and alkyl phenols/phenols), dispersed oil and heavy metals in various types of problematic water.

This solution operates best with low-volume streams, and is accordingly most suitable for gas/condensate fields. The technology is available, and has been used with well workovers on Heidrun, the Sleipner fields, Gullfaks and Jotun. A test on the Sleipner fields demonstrated that it can reduce the content of dispersed oil to 10 mg/l.

The drawback with a Cetco plants includes the generation of waste which must be transported away for destruction.

Coalescer technology has been developed to improve the removal of oil droplets from produced water. The principle is to encourage small droplets to coalesce into larger ones so that the hydrocyclones can remove them even more efficiently.

Examples of coalescer technology include:

Performance-enhancing coalescer technology - fibre (PECT-F) has been developed in the UK. It comprises a system of fibre materials which is placed in the hydrocyclone package's inlet chamber to help increase oil droplet size.

This technology has its greatest potential in those cases where a moderate increase in droplet size will yield a big improvement in hydrocyclone efficiency.

It has been tested on various types of field with good results. Hydrocyclone efficiency can be increased by up to 50 per cent with the aid of PECT-F.

The technology was installed on Draugen in the Norwegian Sea during 2001 on the basis of good test results. However, operating experience has proved less positive. Clogging can be a problem.

Mare's Tail is a new British treatment technology which resembles PECT-F. The principle is that one or two filters are placed ahead of the hydrocyclone to increase oil droplet size. One or two filter units in parallel allow possible replacements to be made much more quickly than with PECT-F's fibre material, which is inside the actual hydrocyclone column.

This technology has the potential to improve hydrocyclone efficiency by up to 50 per cent. It is best suited for gas/condensate fields.

The Hydrofloc process increases oil droplet size by treating produced water in a flocculation tank before hydrocyclone separation. In the tank, the droplets are subject to turbulence and a longer interval.

This system was originally developed for oil installations on Troll, and has been in operation there for several years with successful results. It has also been tested on Draugen, showing a very good performance for removing dispersed oil. However, a very large plant would be required for full-scale use on Draugen. That would involve extensive platform modifications.

Maximum environment for the money

Certain fields have small environmentally-harmful discharges, or have only a few years of producing life left. If environmental measures are so expensive that they shorten the time a field stays on stream, the government risks a substantial loss of revenues.

As a result, the Storting has provided that measures to fulfil the zero discharge philosophy should be subject to a cost-benefit analysis, and that minimising discharges can be sufficient if there are weighty arguments in favour.

An analysis is carried out in each case to determine how much a measure costs and what its environmental effect will be over the field's producing life. This makes it possible to choose the measures which provide the maximum environmental benefit for the money spent (cost efficiency).

Analysis of costs associated with the zero discharge target

As part of efforts to achieve zero discharges by the end of 2005, the operator companies have reported relevant measures with associated costs to the authorities. The NPD has analysed the cost and environmental effect of the measures assessed by the oil companies as relevant.

This analysis shows that a continued focus on substituting environmentally-hazardous chemicals in general will be a cost-effective measure. Similarly, injection of produced water on fields which need more water in any event for pressure support could also yield a substantial environmental effect for the money.

After that, a combination of treatment measures, process optimisation and produced water injection for pressure support or deposition will help to reduce the risk of environmental harm even further, but with a steady decline in the environmental effect achieved for the money spent.

Opportunities for emission reductions depend on new treatment technologies functioning in accordance with their test results. The cost of installing new treatment methods has still not been calculated with a high degree of accuracy, and this represents an uncertainty.

These opportunities also depend on the ability to replace all environmentally-hazardous chemicals with well-functioning environment-friendly substances. Considerable work remains to be done before full chemical substitution can be achieved.

The Norwegian authorities and the industry are now working to identify the best solutions which should be applied to achieve a practical level of zero risk for environmental harm from discharging produced water.