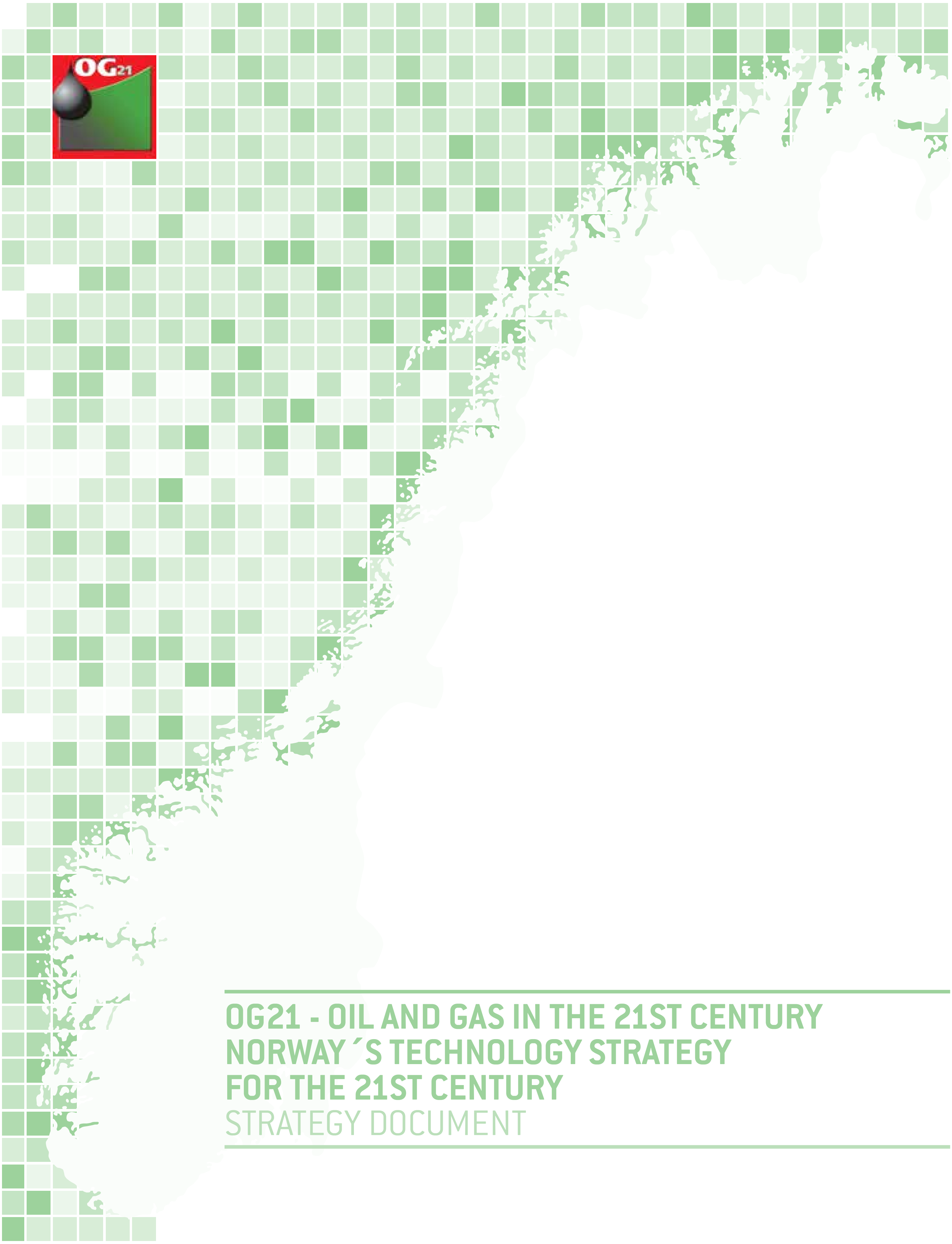

OG21 - OIL AND GAS IN THE 21ST CENTURY
NORWAY´S TECHNOLOGY STRATEGY FOR THE 21ST CENTURY

STRATEGY DOCUMENT

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CONTENT

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OG21 – OIL AND GAS IN THE 21ST CENTURY NORWAY´S TECHNOLOGY STRATEGY FOR THE 21ST CENTURY

CONTENT EXECUTIVE SUMMARY

INTRODUCTION

"The petroleum industry is norway's leading industry and the largest contributor to the economy"

During the last 40 years, the Norwegian petroleum industry has created value from the Norwegian Continental Shelf (NCS) totaling more than NO K 9000 billion measured in 2012 monetary value (ref. Facts 2012 by NPD). By the end of 2011, the NCS had produced 36 billion boe (5.7 bn Sm3 oe) so far and proven but not yet produced are 31 bn boe (4,9 bn Sm3 oe). So far 44 % of expected Norwegian resources have been produced. The basis for this enormous value creation has been a long series of world class technological breakthroughs.

The petroleum industry is Norway's leading industry and the largest contributor to the economy with 26 % of government income, 47 % of all exports and 21 % of GDP. The remaining potential resources, especially on gas and new discoveries, indicate that the industry still has a growth potential and a long-term future on the NCS.

Demand for oil, gas and coal grows in absolute terms through 2035. Fossil fuels remain the principal sources of energy worldwide. Growth in oil consumption in emerging economies, particularly for transport in China, India and the Middle East, more than outweighs reduced demand in the OECD, pushing global oil use steadily higher. Taking all new developments and policies into account, the world is still failing to put the global energy system onto a more sustainable path (IEA, World Energy Outlook 2012). Activities on R&D must therefore continue, to manage the balance between the need for more energy and the environmental focus.

On the NCS , most of the "easily" recoverable resources have been produced. The remaining resources are more challenging and require further technology development. In addition, discoveries are smaller. The activity moves into new areas with new challenges i.e. developments that are closer to the coast and vulnerable areas, deeper waters and arctic conditions much further away from infrastructure. These challenges require further emphasis on R&D. This OG21 Strategy addresses these evolving challenges in the petroleum industry. Focus is on the strategic technology themes for adding reserves and maximizing production, achieving cleaner and more energy efficient production and maximizing value creation through exporting technology.

The Norwegian petroleum sector has adopted a policy with strong social responsibility and has developed the field of Health, Safety and Environment (HSE) to high industrial standards. Still there are HSE challenges in the petroleum sector, especially in relation to environmental challenges in sensitive areas.

THE ROLE OF TECHNOLOGY ON THE NORWEGIAN CONTINENTAL SHELF

Technology has been essential for the development of Norway as a leading petroleum-producing nation. The Government recognized this by placing considerable emphasis to motivate and support R&D. The result has been the creation of the world's cleanest petroleum industry and significant value creation.

Most of the "easy oil" has been found; hence technology will be essential in the future. The market alone will not secure the technologies that are required to sustain production and discover new resources on the NCS. To maintain Norway's position as a technology leader, Government funding will stimulate the availability of needed technologies. OG21 is an enabler for continued technology success and for realization of the value of Norwegian oil and gas resources. The impact of Norwegian petroleum technology so far The willingness to invest in R&D has been a key success factor for the development of the Norwegian petroleum industry since the very beginning (Box 2.1).

NCS operators have pioneered innovative technology such as horizontal drilling, time lapse seismic surveying (4D) and subsea technology. The development of horizontal drilling and multilateral wells on Troll, and the subsea developments with multiphase transport directly to shore on Snohvit and Ormen Lange are examples of Norwegian technological excellence. On Troll, new technology enabled the development of the oil rim, which released reserves worth more than NO K 500 bn that would otherwise have been left in the ground. Global companies have used the NCS as a testing ground for new technology which can also be applied elsewhere. Therefore exports of advanced technology solutions have prospered. Norwegian petroleum technology has also had a positive effect on the environment. As an example restrictions and new technologies, have reduced CO_2 emissions by 40 mn tonnes since 1994 (Konkraft Report No.5). The enabling technologies for lower emissions have since been implemented in many locations around the world.

THE FUTURE

New and improved technology will continue to be an enabler for the Norwegian petroleum industry. The Norwegian Petroleum Directorate (NPD) estimates that there is between 33 and 75 bn boe remaining on the NCS and therefore there is a considerable potential for further value creation. Realizing this potential depends on continued willingness to invest in R&D. The overall rewards of R&D by far outweigh the initial investment and effort required, and the benefits spread far beyond the initial application.

KARL JOHNNY HERSVIK
BOARD CHAIR

BOX 2.1: EXAMPLES OF VALUE CREATION BY NEW TECHNOLOGIES

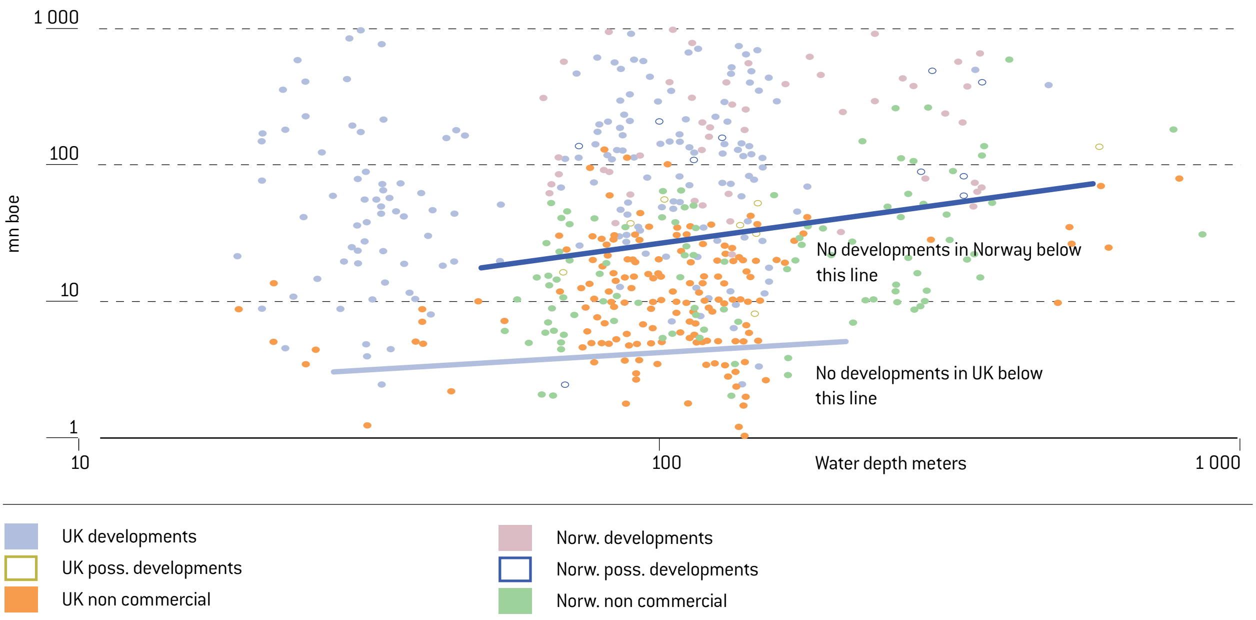
Value creation on the NCS has dependent on development, qualification and implementation of new technologies. The NCS has a reputation for being one of the most innovative petroleum regions in the world:

- Crossing the Norwegian Trench in 1985 to allow gas exports to Emden from Statfjord and also bringing gas to the Norwegian continent allowing value creation in Norway (Kårstø)
- Troll started production in 1996 from the largest structure that has been moved on earth, the 472 m high Troll A concrete platform. Troll developed horizontal precision drilling to produce the 11-13 m thin oil layer underneath the gas, giving an additional NOK 500 bn of value.
- Ekofisk, Statfjord, Oseberg and Gullfaks have prolonged and increased production considerably due to world class IOR with extensive infill drilling, water and gas injection, time lapse seismic (4D) and reservoir characterization.
- Sleipner started the first offshore Carbon Capture and Storage (CCS) in 1998 and deposited 1 million tonnes CO2 per year to reduce the CO2 content from 9% to 2.5% sales specification.
- Development of analytical tools for multiphase flow has made it possible to have long reach subsea wells and subsea to beach solutions.
- Subsea separation pilot at Troll, and later subsea platform (subsea separation, boosting and water injection) at Tordis.
- Ormen Lange started production in 2007 and had to overcome the extreme challenges of steep subsea slopes through the Storegga submarine landslide trench down to 800–1100 m water depth and has the world's longest subsea gas trunk line 1,200 km from Aukra to Easington, UK.
- Norway has the lowest emission to air per produced unit in the world.

The NCS resources could not be developed without a long series of world class technological breakthroughs.

CHALLENGES FOR THE NORWEGIAN PETROLEUM CLUSTER

FIG 3.1: DISTRIBUTION OF MARGINAL FIELDS AND THE DIFFERENT ECONOMIC THRESHOLDS BETWEEN NORWAY AND THE UK



Source: WoodMackenzie data

Large areas of the NCS can be considered to be mature. The remaining developments are mostly satellites and redevelopment of producing fields. The brown field phase introduces new challenges if production is to be sustained. Fig. 3.1 indicates that there is a potential to further reduce the minimum threshold size to make more Norwegian discoveries profitable.

3.1 PRODUCTION AND RESERVE REPLACEMENT

There are substantial resources remaining in the NCS. The large potential comes from increased recovery rate from existing fields and from undiscovered resources. Focus on cost effective technological developments and implementing new technologies are vital topics in how this potential can be realized. This requires substantial effort. In addition large areas are still not available for exploitation.

The North Sea, Norwegian Sea and Barents Sea all have similar expected resource base with increasing upside potential and uncertainty in the northern areas (Fig. 3.2).

- In certain sectors of the NCS the remaining volumes will require more effort in order to be found, developed and produced. The following challenges have been identified:

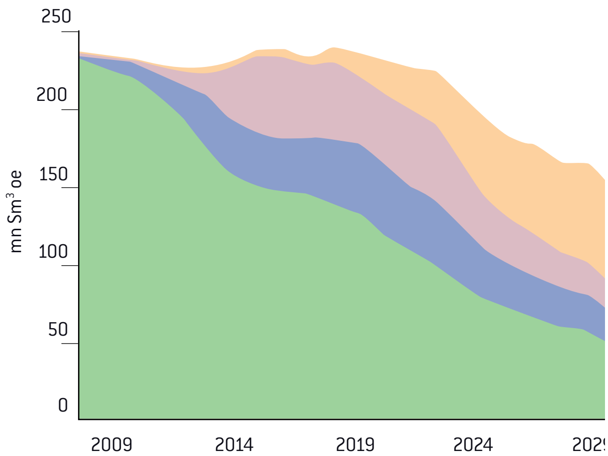
- There are several unexplored areas with potential for new large discoveries, also in areas that are not yet opened like the Barents Sea. It requires more knowledge and technological development to find and make these accessible.

- Technologies that make small discoveries economically viable are a key factor. Several of these minor discoveries depend on an ageing infrastructure approaching decommissioning. This gives a narrow window of opportunity.

- There are more challenging reservoirs (tighter, faulted, multiple zone reservoirs, high temperature and pressure, high CO2 content etc.) remaining – most of the "easy barrels" have been produced. New technologies to tackle these challenges are needed.

- Due to smaller field developments it is harder to obtain pilot testing of new technologies and implementation of improved oil recovery (IOR) technologies within a single licence.

FIG 3.2: REMAINING POTENTIAL NCS INCLUDING UNDISCOVERED RESOURCES



Source: Norwegian Petroleum Directorate

- Smaller discoveries depend on cost effective solutions, which can be achieved through focus on standardization and by clustering of several developments to ensure sustainable volumes. Optimal technology for use across many opportunities must be found.

The industry's willingness to develop and deploy new technologies to meet these challenges will be essential for realizing this potential both in the mature and frontier areas. Several challenges with potential to lead to technological solutions have been highlighted, however, there is an important timing dimension associated with these challenges.

ENERGY EFFICIENT AND CLEANER PRODUCTION

It is now more important than ever for Norway to focus on cleaner and more energy efficient production. The petroleum industry is responsible for more than a quarter of the national CO2 emissions. There is decreasing tolerance for greenhouse gas emissions and discharges to sea. Further reduction will require more engagement and will be more challenging. Two factors have been instrumental:

- a comprehensive and strict regulatory framework and policy instruments
- innovation and deployment of new technologies

The petroleum industry in Norway as well as globally has to look to new areas for exploration to replace reserves and production. As petroleum exploration and production move into frontier areas, it becomes vital to ensure that there is minimum impact on the environment, and that the petroleum industry can coexist with other industries (e.g. fisheries). This requires continued efforts to make improvements that provide safeguards against emissions to air and discharges to water. The main challenges to the petroleum cluster are:

- Focus on energy efficiency has great potential and will contribute to a further reduction of the environmental footprint.
- Further reduction of emissions to air (CO2, NOx, SOx).
- The industry must assess and calculate the risks of unforeseen incidents and then establish technical and operational solutions to reduce these. The ability to have continued safe operations will be a prerequisite for opening frontier areas.
- There is a need to introduce new environmentally friendly chemicals for both enhanced oil recovery (EOR) and oil spill technology.

EXPORT OF TECHNOLOGY

New technologies that create value on the NCS often have export potential. It is therefore important to focus on win-win opportunities for both increased production/reserve replacement on the NCS and maximizing value creation through export.

The participation of the larger international oil companies in R&D activities in Norway has been important. This has contributed both to the funding of R&D and enhanced the global marketing opportunities for Norwegian suppliers. Future government funding and the tax regime should support the continued attractiveness of Norway as an oil and gas R&D nation. There is a need for a fiscal instrument that covers the risks the supplier companies have when prototyping and executing deployment tests of new technology. Likewise, operators need to be bolder with respect to piloting and putting new technology into use. It is not only large contractors that operate internationally today. Small and medium size companies are also active in niches. The global players can provide the international network that small companies need in return for new ideas and technology.

EMPLOYMENT AND COMPETENCE DEVELOPMENT

The increasing complexity to discover and produce hydrocarbons requires more "knowledge" per produced unit. The need for highly educated personnel will therefore continue to increase. It is of vital importance to maintain the high level of competence in the universities and research institutes. In order to recruit young talent to the industry, it is paramount that there is a positive perception of the long-term outlook of the industry. Oil and gas is not in the sunset phase but has a 100 year perspective. Maintaining leading edge capabilities and workforce, requires continuous challenging projects also on the NCS. Active international collaboration between Norwegian and international universities to exchange ideas, create new solutions, etc., must be stimulated.

"The willingness to invest in R&D has been a key success factor for the development of the norwegian petroleum industry since the very beginning"

OG21 TARGETS

VALUE CREATION THROUGH PRODUCTION AND RESERVE REPLACEMENT

To be able to keep Norwegian production at today's level, new reserves must be discovered and developed. OG21's target is to realize NPD's goal for reserve growth:
800 mn Sm3 oil (5 bn boe) before 2015 (Fig. 4.1).
Approximately 75% of this has to come from fields in production (Fig. 3.2). The results so far are that the reserve replacement is behind the planned schedule for reserve growth. The target for reserve growth is still valid.

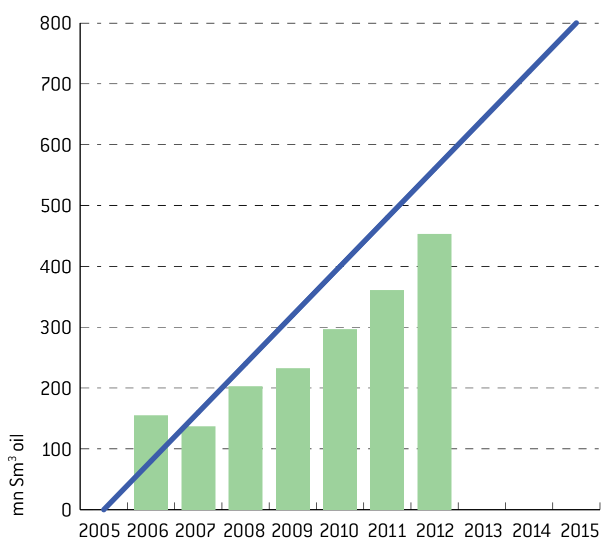
ENERGY EFFICIENCY AND CLEANER PRODUCTION

In a global context, the NCS is one of the leaders in clean and energy efficient production (Fig. 4.2). The goal is to maintain this global position as the oil and gas province with one of the highest energy efficiency, lowest level of emissions to air, and lowest harmful discharge to sea per produced unit.

VALUE CREATION THROUGH EXPORT OF TECHNOLOGY

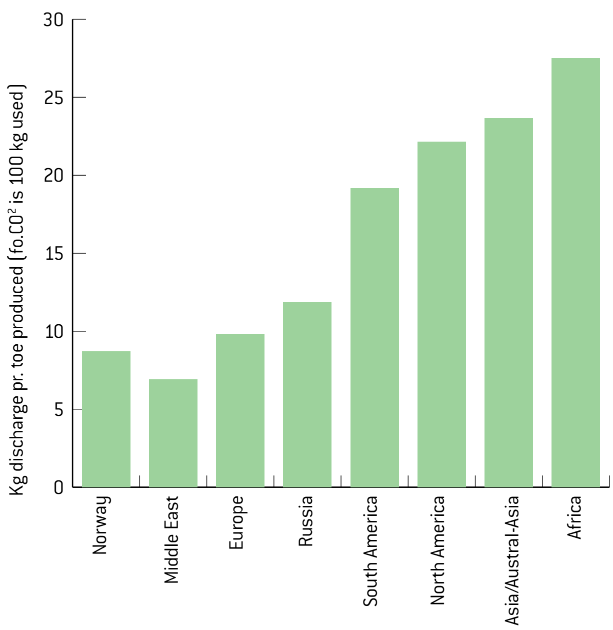
Growth in oil and gas technology sales from companies in Norway to international markets has been a success and has increased from NOK 15 bn/year in 1995 to NOK 120 bn/year in 2012. This has developed into an important export element and will secure employment and income even with declining production on the NCS. OG21's target is to realize the goal of NOK 120 bn/year by 2012 set by Intsok.

FIG 4.1: TREND IN THE ANNUAL GROWTH IN OIL RESERVES COMPARED WITH THE NPD TARGET



Source: Norwegian Petroleum Directorate

FIG 4.2: GREENHOUSE GAS EMISSIONS PER UNIT PRODUCED IN DIFFERENT PETROLEUM PROVINCES KG OF CARBON EQUIVALENT PER BOE PRODUCED (2011)



Sources: OGP and Environment Web

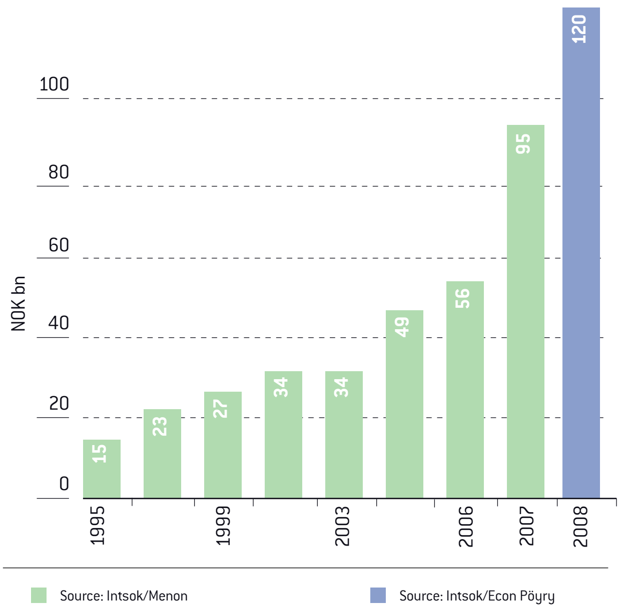
VALUE CREATION THROUGH EMPLOYMENT AND COMPETENCE DEVELOPMENT

The oil and gas sector is the largest industry in Norway employing 250,000 people directly and indirectly. It is necessary to have a significant and stable home market, and maintain and further develop the technology and competence of the Norwegian oil and gas cluster, i.e. oil companies, suppliers, financial institutions, research institutes and higher educational institutions. OG21's goal is that the Norwegian Cluster develops and delivers competitive and high tech solutions also in the future. This is the foundation to further develop the successful Norwegian oil and gas technology cluster.

The Norwegian oil and gas cluster's technological competence and the revenue generated from the oil and gas production will be critical for the development, deployment and operation of marine renewable energies like wave- and windpower and may also have application to other renewable energy technologies.

"OG21's goal is that the Norwegian cluster develops and delivers competitive and high tech solutions also in the future"

FIG 4.3: GROWTH IN OIL AND GAS TECHNOLOGY SALES FROM NORWAY



STRATEGIC RECOMMENDATIONS

In order to meet the targets outlined in the previous section, the OG21's strategy is that the research and technology developments should focus on:

- Adding reserves and maximizing production
- Cleaner and more energy efficient production

Successful cooperation between all parties in the Norwegian petroleum cluster (sometimes referred to as the "Norwegian Model") has been the foundation for the results from the NCS. To continue this and even improve it, will be a success factor in the future. Expert groups from the industry called Technology Target Areas (TTA) have defined the technological needs and priorities outlined in section 5.1–5.4

Value creation through production and reserve replacement
There are four areas of prioritized technology activities in both new and existing fields, which will increase production:

1 Exploration and increased recovery

a) Play analysis for new exploration models (geology)
b) Geophysical imaging and interpretation (subsalt, sub-basalt, deep and complex reservoirs, fluid identification)
c) EOR methods including low energy methods
d) Reservoir characterization

2 Cost-effective drilling and intervention

a) Low cost drilling and increased drilling efficiency
b) Light (rigless) well intervention
c) Technology for production from discoveries with low permeability and hydrostatic pressure.
d) Low cost drainage points, including advanced well construction.

3 Subsea production, processing and transportation

a) Low pressure production: subsea boosting, compression, separation, subsea produced water reinjection, and downhole artificial lift
b) Long-distance multiphase transport

4 Enabling commercial development of marginal resources, through cost-effective development solutions on the NCS

a) Develop modular technology solutions and standardized interfaces between tools, equipment and software across the industry
b) Products and subassemblies optimized for easy installation
c) Re-use of products and solutions
d) Standardization in administration, e.g. formats for pre-qualification and tenders, consistent use of standards and specifications

ENERGY EFFICIENT AND CLEANER PRODUCTION

The objective is to reduce the environmental footprint of existing fields and minimize the footprint for new exploration and development on the NCS. These goals are particularly relevant for environmentally sensitive areas, as well as areas where the petroleum industry coexists with other industries. There are three areas of prioritized technology activities, which will reduce the environmental footprint.

1 Reduce emissions of CO2

a) Development and qualification of well technology, pipelines and injection strategies for safe transportation and storage of CO2
b) Development of cost-effective ways of increasing the share of renewable energy supply and infrastructure to existing and future petroleum developments

2 Energy efficient production

a) Improve and optimize energy use (hardware, software and processes), in particular for offshore power generation
b) Reduce energy consumption in gas transportation and processing.
c) Subsea or downhole processing

3 Reducing the environmental risk from operational and accidental discharges to sea

a) Rapid detection systems and oil spill response for coastal areas
b) New drilling technologies that increase the available time-window for exploration drilling in sensitive areas
c) New technology to avoid or reduce the discharge of produced water. Develop greener alternative products to replace existing hazardous chemicals (e.g. hydraulic fluids, process chemicals, all-electric subsea systems)
d) Development of a holistic eco-system approach towards environmental risk assessment and monitoring
e) Develop better risk assessment approaches that address the complex interfaces between people, technology and organizations involved in avoiding accidental discharge

VALUE CREATION THROUGH EXPORT OF TECHNOLOGY

Increased challenges for international exploration and production create new and growing opportunities for the export of technology from Norway. This will have a positive impact on skills, competence and the level of employment in Norway. International experience and success in broader technology markets will contribute to drive down the unit costs and enable lower cost for redeployment on the NCS.

OG21 will promote strong focus on technologies with significant export potential as well as high potential for increased production or replacement of reserves or cleaner and more energy efficient production on the NCS.

VALUE CREATION THROUGH EMPLOYMENT AND COMPETENCE DEVELOPMENT

OG21 will contribute to the understanding of the contribution from the petroleum industry to economic development with challenging jobs to be filled in a 100 year perspective. After 40 years of growth the petroleum cluster in Norway now has an aging work force. It will need to train and develop highly skilled and well educated engineers and natural scientists. There is and will be a large need for more staff particularly at MSc and PhD levels for many years to come. There is a concern that too few students in secondary school study mathematics and physics. It is also a concern that the number of Norwegian applicants to PhD studies is at an extremely low level.

Competence is developed through challenges and high activity both in R&D and field development. It is therefore important that recruitment to R&D and the level of R&D are strengthened. A high level of activity on the NCS will contribute to develop the industry.

"The objective is to reduce the environmental footprint of existing fields and to minimize footprint for new exploration and development on the NCS"

IMPLEMENTING THE STRATEGY

The purpose of the OG21 strategy is to align the various stakeholders to a common direction and understanding regarding technological challenges as well as technological opportunities. This will ensure a coordinated national effort in research, development, demonstration and commerciali-zation.

The Role of OG21

- OG21 acts as a catalyst for change and cooperation between key stakeholders
- OG21 consist of a board established by the MPE and a secretariat reporting to the board OG21 monitors and highlights new industry trends and swiftly brings them to the attention of its participants
- OG21 influences the allocation of resources by advising the MPE who in turn use the Research Council of Norway's petroleum related R&D programmes to implement the technology strategy. This model secures a link between basic and applied research, via pilot demonstration and qualification to commercialized products
- OG21 stimulates technological collaboration across the whole petroleum industry.

The Technology Target Area (TTA) recommendations remain as a key enabler in the implementation of the OG21 strategy. Based upon this strategy, OG21 has revised the TTA structure and focus on the following four themes:

1. Energy efficient and environmentally sustainable technologies
2. Exploration and increased recovery
3. Cost-effective drilling and intervention
4. Future technologies for production, processing and transportation

The establishment of a holistic strategy for Carbon Capture and Storage is to be done in cooperation with Energy21.

Implementing the OG21 strategy will depend on cooperation with relevant organizations such as Norwegian Oil and Gas Association, Federation of Norwegian Industries, Intsok, the Research Council of Norway and Innovation Norway. The main instrument to present the strategy to the different parties will be the OG21 Forum which brings together operators, researchers and the authorities to meet and discuss technological challenges. OG21 is also arranging seminars for discussion of the strategy and how to close identified gaps. OG21 is also playing an active role in promoting awareness of the types of education needed in the industry.

The Technology Target Area details the OG21 strategy into sub-strategies that give clear prioritizing of technology needs. Each Technology Target Areas addresses the whole value chain, from education to R&D, incl. piloting.

Each TTA is based on the strategy themes and the priorities that OG21 has developed to identify gaps that need to be closed. The TTA define sub-strategies within the overall focus areas. Special emphasis will be placed on cooperation between the TTAs to develop integrated solutions. This will require enhanced inter-disciplinary communication.

The role of the Government

Public funding should primarily focus on education, basic science, long-term technology development and the stimulation of technology pilots. Short-term challenges will to a larger extent be the responsibility of the industry. The funding should focus on the fundamental research element of the value chain and provide risk reductions for important technologies that otherwise might not be developed and matured.

Governmental engagement is important to stimulate research and develop high levels of competence is executed in Norway. Without incentives the industry may go abroad with their research activities. Increasing international competition makes it necessary for the Government to show a long-term commitment and through that, provide support to the supplier industry based in Norway.

The role of the Research Council of Norway (RCN)

The Research Council of Norway serves as a national strategic body for research, as a research funding agency and a bridge between Norwegian and international research. The RCN is responsible for research of national importance such as the oil and gas sector. The financial instruments of the RCN are the main sources for Governmental R&D funding to this sector and cover basic and applied science as well as innovation and demonstration projects. The large-scale strategic programme PETROMAKS 2, the demonstration programme DEMO 2000 and several Centres of Excellence and Centres of Innovation are set up to address the challenges and potentials within the Norwegian oil and gas sector. The profile of the strategic research funded by the RCN mirrors the priorities of the OG21 strategy and ensures a coordinated effort between universities, the research institutes and the industry. In addition, the RCN 's funding of long-term basic science, infrastructure for science and PhD and post.doc positions are key building blocks with significant impact for developing petroleum-related products, processes and services. R&D within fields like materials and nanotechnology, maritime technology, mathematics, geophysics, geology and chemical technology are examples of this.

The RCN -funded activities will follow-up OG21's strategy as follows:

- Provide input to the Government on the profile and structure of R&D to meet the OG21 goals
- Give advice to the Government on funding needs for basic research, applied research, innovation and demonstration activities
- Ensure focus at the universities on recruitment and high quality long-term basic science of relevance to the oil and gas sector
- Ensure focus at the research institutes on applied science and cooperation with the industry.
- Provide support to industry-driven projects
- Facilitate cooperation between Norwegian and international research
- Ensure cooperation and coordination among various stakeholders involved in petroleum R&D.
- Provide statistics and analysis of R&D in the oil and gas sector

The role of the Research Institutes and Universities

Research institutes and universities are an important part of the Norwegian petroleum cluster. The institutes have a special focus on research for the medium and long-term needs of the industry, while the universities have the main responsibility for education and basic research. In order to respond to the OG21 challenges it is important to focus on:

- Education and recruitment of petroleum research scientists
- Build strong national research teams that are internationally competitive
- Build, upgrade and maintain a world class research infrastructure
- Cooperation with industry in competence programmes and applied research as well as testing and piloting

A prerequisite to enable the research institutes and universities to carry out world class research and educate and train petroleum personnel is that the Government provides predictable funding and framework conditions. The Norwegian cooperation model is widely recognized, but we can gain even more through closer cooperation between the institutes and universities. Centres for Research-based Innovation (SFI) and Norwegian Centres of Excellence (SFF) are examples of strong national teams, but further funding is required in order to maintain, strengthen and build up groups that are able to develop new technology in cooperation with oil companies and the supplier industry. Access to world class research infrastructure is important for developments in all the Technology Target Areas, and the cooperative use of large scale infrastructure is important to secure cost efficient and innovative research.

Oil companies and suppliers will only carry out their research and development in Norway as long as they benefit from well-equipped and strong research organizations, highly educated personnel and sound governmental research funding. In order to keep world class research institutions, Norway must maintain competitive funding models.

The role of industry

To achieve OG21's strategic goals an active participation from the industry is needed. There are four areas of particular importance:

- Using the OG21 strategy as a reference document for internal company technology strategy
- Willingness to actively contribute in the TTA work
- Willingness to provide pilot opportunities/sites
- Pro-actively seek technology collaboration opportunities between oil companies, suppliers and research institutes/ universities

This will ensure that efforts in the oil and gas cluster are concentrated to close the technology gaps identified, and should result in business opportunities both short and long term.

FINANCE

RESEARCH AND DEVELOPMENT

On the NCS, the petroleum industry's ability to meet its challenges and deliver pioneering technology within the new OG21 strategy themes will depend on a predictable, long-term commitment from the whole petroleum cluster. Historically the Norwegian Government's long-standing commitment and emphasis on running R&D activity in Norway has given a corresponding willingness by the Norwegian petroleum industry to invest in and test new technology. Public R&D funding is a precondition to attract international capital and international oil companies to execute R&D in Norway. Figure 7.1 shows the public funding of petroleum-related R&D since 2000. OG21 has previously recommended an increase to NOK 600 - 800 mn/year. This is approximately NOK 250 mn higher than today's level. Compared to the state revenue of NOK 290 bn (2009 estimate, Ministry of Finance) annually from the oil and gas sector NOK 350 mn/year, represents as little as 0.1 percent. To increase the R&D funding and increase the industrial engagement, OG21 also recommends that the R&D (FoT) percentages/bands as defined in the licence accounting agreement are increased. In a global context there will be increasing focus on national competence development, and OG21 recommends that public funding of higher education and basic research is increased.

PILOTING

It is believed that most of the giant fields on the NCS have been developed. Until recently these fields have carried much of the larger successful piloting of new technologies. The current portfolio of many small discoveries requires a new model for technology maturation. Technology development outside large development projects needs to be stimulated using public incentives. Companies will perform technology development where the framework conditions are considered to be the best. Norway has enjoyed internationally competitive incentives and financial tools for demonstration programmes (e.g. DEMO2000) which has attracted competence and private capital to address and solve NCS challenges. This has resulted in new technology which has greatly increased the recovery of hydrocarbons on the NCS, and in addition there has been considerable value creation in Norwegian companies through the export of technology. Today the frame work conditions are far less attractive. Not only because it is difficult to get financing through projects (small fields), but more due to the fact that public funding is very low. This means that private capital and competence (which is scarce) are prioritized elsewhere, delaying solutions which would benefit increased production on the NCS .This may result in lost reserves due to factors such as aging infrastructure (ref Konkraft report no. 2).

OG21 recommends that governmental funding to demonstrate prototypes and execute pilots is greatly increased to a level of NOK 150–200 mn. It is vital that this increased effort does not make a negative impact on the governmental funding of research.

An alternative proposal is capital funding support systems, like the GIEK model (Guarantee Institute for Export Credits) as used in Norway or the establishment of similar incentives, e.g. financial mechanisms made available to companies for the execution of piloting. If the technology becomes a success, the support is paid back while it is deductible in case of failure. This could reduce the risks, especially for small and medium-sized suppliers.

Another possibility is to establish a mechanism to stimulate piloting in the different licences like the R&D (FOT) in the licence accounting agreement or other mechanisms. OG21 recommends that the different alternatives are further evaluated by the Government.

"The current portfolio of many small discoveries requires a new model for technology maturation.

Technology development outside large development projects needs to be stimulated by using public incentives"

EXECUTIVE SUMMARY

OG21 was established by the Ministry of Petroleum and Energy MPE) in 2001.

The Board of OG21 is responsible for developing a National Technology Strategy for the Norwegian petroleum industry, and also to serving as an advisor to the authorities and industry at large.

The previous OG 21 strategy is perceived to have successfully aligned the various stakeholders towards a common direction and ambition regarding technology challenges as well as technological opportunities. The strategy has also resulted in coordinated national efforts in research, development, demonstration and commercialization.
A revision of the OG21 strategy has been necessary for the following reasons:

Main Challenges

- The focus on climate change from the authorities, industry and society at large has intensified the drive to find, develop and produce oil and gas resources in a cleaner and more energy-efficient manner.
- The mature part of the Norwegian Continental Shelf (NCS) requires acceleration of efforts to find, develop and produce oil and gas resources to sustain societal value creation.
- The situation on the NCS in 2012 has radically changed compared to 2000. Historically, larger developments have carried significant technology development and deployment responsibilities. The current portfolio of smaller discoveries and developments is unable to provide capital for technology advancements, which must be supported by other means.
- Both the Norwegian Sea and the Barents Sea now appear more than before, to be areas with significant potential, although with increasing upside and uncertainty in the northern areas.

In the short term perspective it is important to convert existing resources into reserves and in the long term perspective finding new resources is essential.

The key strategic goals are:

- *Value creation through production and reserve replacement*: Reserve growth of 5 bn boe before 2015.
- *Energy efficient and cleaner production*: Maintain the Norwegian position as the oil and gas province with the highest energy efficiency, the lowest level of emissions to air, and lowest harmful discharges to sea per produced unit.
- *Value creation through increased export of technology*: Continue the current growth path with annual oil and gas technology sales above NOK 120.
- *Value creation through employment and competence development*: Sustain and further develop Norway's position as a leading and competitive oil and gas technology cluster.

The key means for implementation of the revised strategy of 2010 for OG21 strategy are:

To arrange forums and meeting places to create awareness and common understanding of the challenges and opportunities within the Norwegian oil and gas environment.

To establish and develop Technology Target Areas (TTA) within:

1] Energy efficient and environmentally sustainable technologies;
2] Exploration and increased recovery;
3] Cost-efficient drilling and intervention;
4] Future technologies for production, processing and transportation.

OG21 strategy is a framework and source of input for:

– Government funding related to Research and Development (R&D)
– Specific governmental funded R&D programmes like PETROMAKS and DEMO 2000
– Companies, higher education institutions and research bodies targeting the oil and gas industry
– Companies, higher education institutions and research bodies targeting renewable energies, Carbon Capture and Storage (CCS) and potential spin-offs to other industries where oil and gas industry competence and resources can be applied.

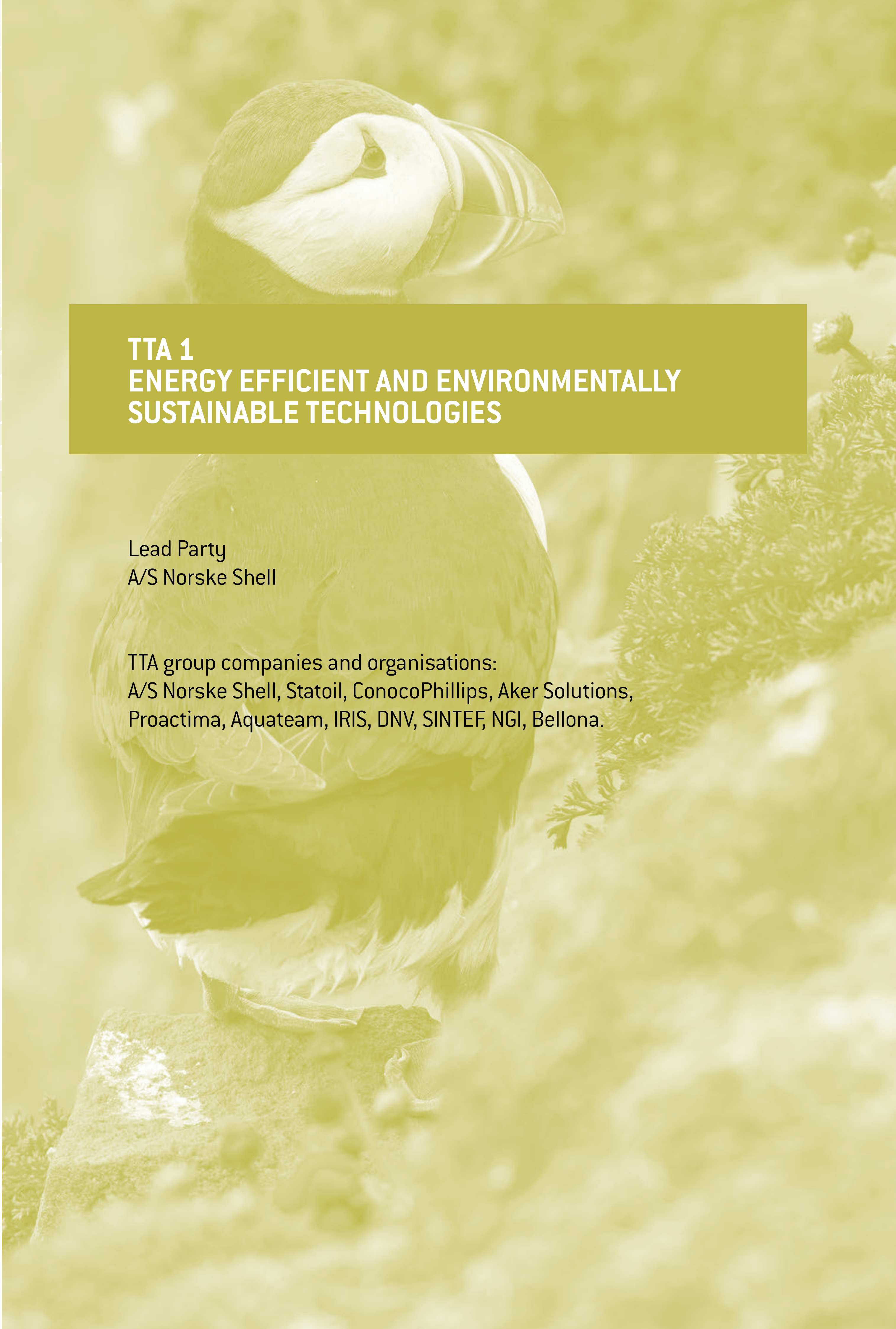
In order to implement the strategy, OG21 recommends that Government funding of at least NOK 600-800 million/year is allocated to oil and gas R&D. In addition, clear signals must be sent to companies that Norway is an attractive place to carry out R&D. This calls for incentives that allow equipment suppliers and contractor companies to undertake research, development, prototyping and deployment tests of new technologies at an attractive risk level.

The Government's petroleum R&D funding should be stable over time and give priority to:

1. Energy efficient technologies to further reduce emissions to air and discharges to sea
2. Solutions and services for increased oil recovery to maximize recovery rates from mature assets within the lifespan of the existing infrastructure
3. Drilling technologies to reduce cost and environmental impact
4. Stimulate advanced subsea systems to maximize value creation in Norwegian offshore assets
5. Develop long-distance subsea multiphase transportation technologies to meet challenges in remote areas and enable the utilization of existing processing facilities
6. Develop incentives for piloting new technologies to reduce uncertainty for small and medium-sized companies
7. Higher education to secure high levels of oil and gas competence in Norway

The OG21 strategy is designed to guide the governmental funding and be used as input to technology strategies in the oil and gas industry.

"The OG21 strategy should guide the governmental funding and be used as input to technology strategies in the oil & gas industry"



TTA 1
ENERGY EFFICIENT AND ENVIRONMENTALLY SUSTAINABLE TECHNOLOGIES

Lead Party
A/S Norske Shell

TTA group companies and organisations:
A/S Norske Shell, Statoil, ConocoPhillips, Aker Solutions, Proactima, Aquateam, IRIS, DNV, SINTEF, NGI, Bellona.

CONTENT TTA 1

EXECUTIVE SUMMARY TTA 1

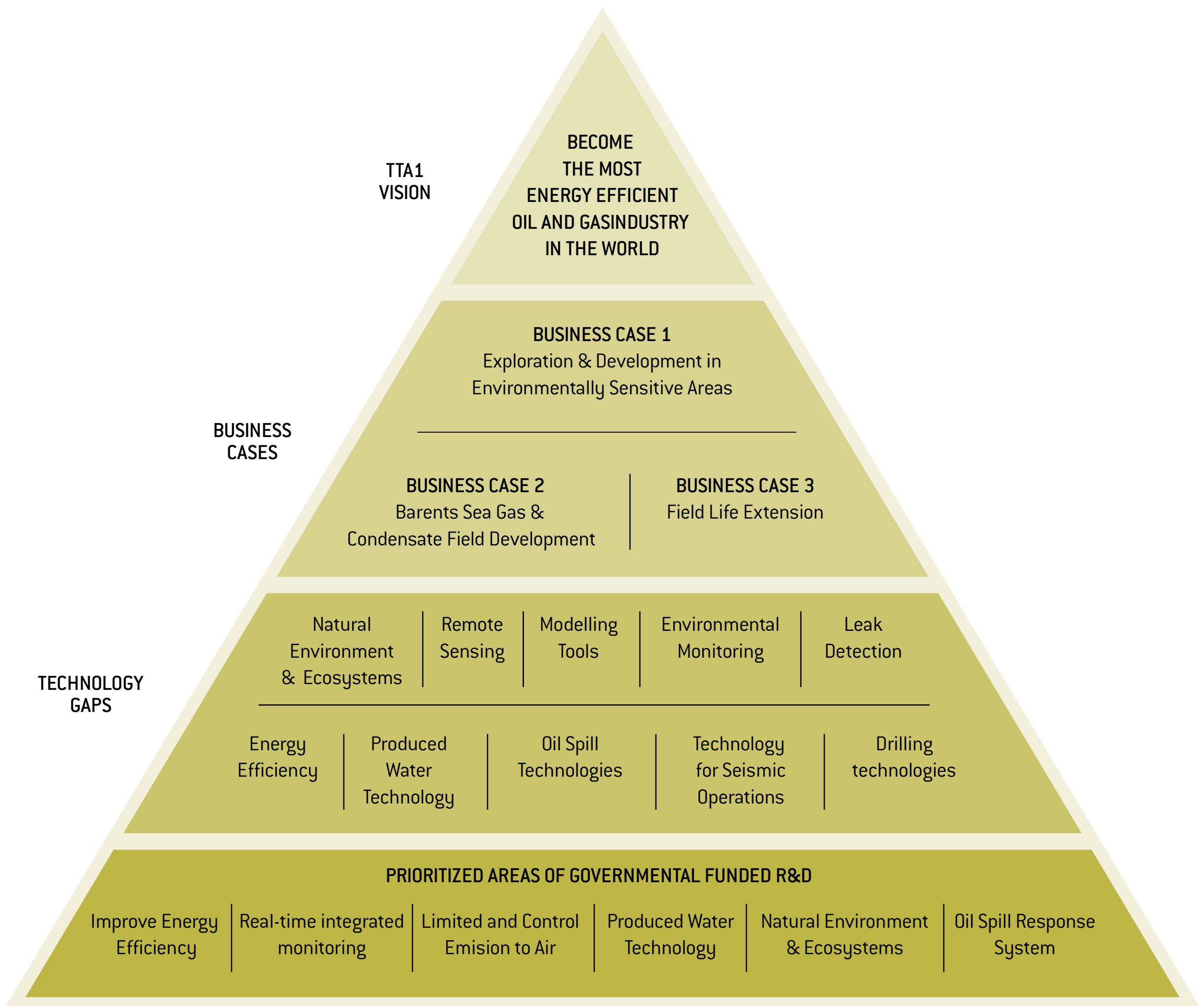


FIG ES2: VISION, BUSINESS CASES, TECHNOLOGY AND COMPETENCE AREAS, AND PRIORITISED AREAS FOR GOVERNMENTAL FUNDING OF OG21 TTA1

The main objective and strategy of the TTA "Energy efficient and environmentally sustainable technologies" (hereafter named TTA1) is to ensure that the operators on the Norwegian Continental Shelf (NCS) remain in a leading position with respect to environmental performance, whilst contributing to safe and optimised resource recovery, and value creation.

The maritime sector and the energy sector have similar strategic organisations; Maritim21 and Energi21. Both organisations have TTAs linked to their sectors discussing the importance of energy efficient and environmentally sustainable technologies. OG21 and Energy21 have jointly addressed Carbon Capture and Storage (CCS), and a joint CCS strategy report has been prepared by CLIMIT.(1) Therefore technologies related to CCS have not been included in this report.

Some areas of the NCS face challenges related to ageing facilities, tie-ins of marginal fields to existing infrastructure, and tail-end production; activities all of which rapidly increase the produced water- and gas production rates. This calls for improved water treatment technologies and increased energy efficiency. Energi21 covers the development of new and alternative energy sources, thus these has been omitted here.

The TTA1 strategy focuses on environmental technology and competence necessary to:

- Attain the society's acceptance for continued growth and development of the oil and gas industry
- Reduce the environmental footprint of existing fields, and minimise the footprint of exploration and development in environmentally sensitive areas
- Enhance the energy efficiency of exploration and production (E&P) related work
- Reduce the environmental risk and improve the preventive measures to avoid accidental oil spills, and minimise the damage if they occur

TTA1 has identified technology gaps and research needs that need to be met in order to combat the challenges related to further development of oil and gas activities on the NCS.

The TTA1 vision is to support the Norwegian industry to become the most energy efficient oil and gas industry in the world.

The current, and the future, business challenges on the NCS have been evaluated from a TTA1 perspective. The three most relevant business cases are considered to be:

1) Exploration & Development in Environmentally Sensitive Areas
2) Barents Sea Gas & Condensate Field Development
3) Field Life Extension

For each of these business cases technology gaps and detailed technology needs have been identified. The value potentials have not been identified, however the implementation of energy efficient and environmentally sustainable technologies as outlined herein is a critical step in order to obtain "license to operate", after which the value potential may be realised. For each of the technology needs, the time perspective, cost level, time criticality, market value, fulfilment of OG21 strategic goals and main barriers for success have been outlined. For ease of understanding, the technology gaps have been summarised into the following thematic areas:

1. Understanding the natural environment and the ecosystems
2. Remote sensing technologies
3. Modelling tools
4. Environmental monitoring
5. Leak detection
6. Energy efficiency
7. Produced water technology
8. Oil spill response technologies
9. Technology for seismic operations
10. Drilling technologies

Furthermore, a second list of TTAs has been identified; a prioritised list of important industry needs independent of governmental funding:

1. Improved energy efficiency
2. Real time integrated monitoring
3. Limit and control emission to air
4. Produced water technology
5. Natural environment and ecosystems
6. Oil spill response systems

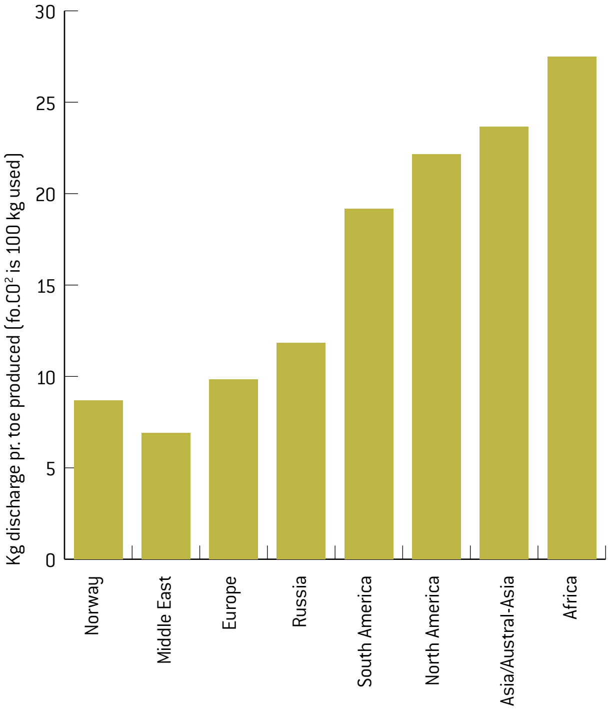
In line with the overall strategic goals of OG21, development of the technologies outlined within the aforementioned focus areas will contribute to increased safety, and help minimise the environmental impacts associated with operation on the NCS. It is also expected that enhanced R&D in these areas will contribute to increased energy efficiency in the oil and gas production from the NCS, which again will lead directly to a decreased environmental impact through reduced greenhouse gases emissions.

Governmental funding should primarily focus on education, basic science, long-term technology development and the stimulation of technology pilots. The funding should focus on the fundamental research elements of the value chain, and provide risk reductions for important technologies that otherwise might not be developed and/or matured. Governmental engagement should also stimulate research to continue to secure a high level of competence in Norway, since without incentives the industry will perform its research abroad. Increasing international competition makes it necessary for the government to show a long term commitment and provide support to the supplier industries that are based in Norway. This is particularly important for developing the competence and technologies needed to become the most energy efficient and environmentally friendly oil and gas industry in the world and contribute significantly towards meeting Norways climate goals. In a global context, the NCS has been the world leader in clean and energy efficient production for many years, but has now been surpassed by the Middle East region (Figure ES1).

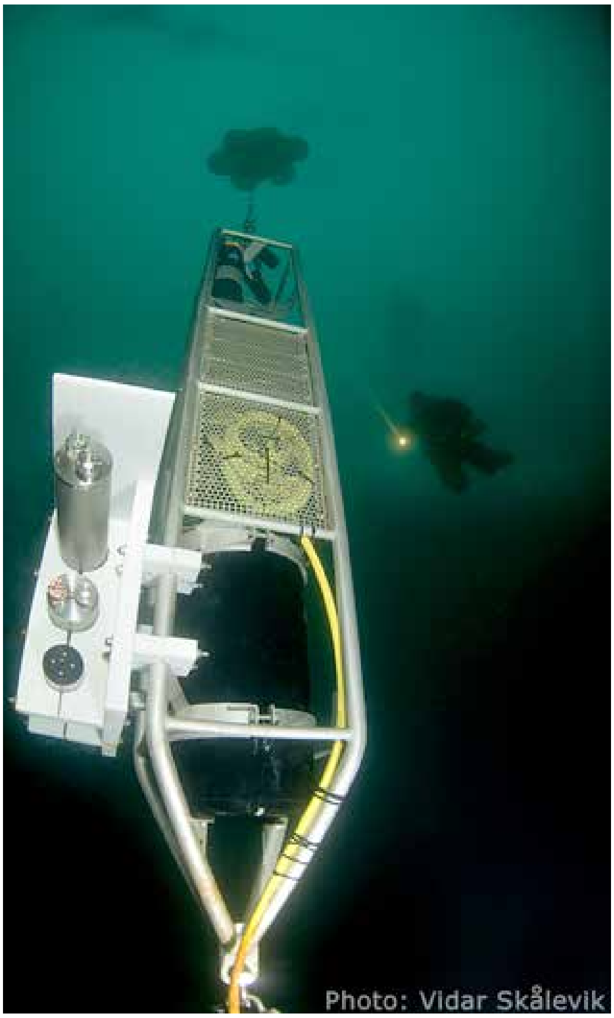
With these considerations in mind, the following is a prioritised list of areas needing governmental funding:

1. Develop methods to improve the energy efficiency of offshore operations as well as transport and processing of oil and gas
2. Improve knowledge of real-time integrated monitoring and modelling systems
3. Systems to limit and control emissions to air
4. Increase the fundamental understanding of the fate and effects of EOR/IOR chemicals, including produced water treatment
5. Improve knowledge and understanding of the natural environment and the ecosystems
6. Develop new and continue to improve oil spill response systems
7. Improve systems for leak detection, including real time monitoring and remote control systems for pipelines, risers, subsea and surface equipment

FIG ES1: KG CO2 EQUIVALENT PER PRODUCED BARREL OIL EQUIVALENT. (SOURCE OLF MILJØRAPPORT 2011)



Sources: OGP and Environment Web



Technology developed for real-time hydrocarbon leak detection/monitoring. BiotaGuard AS.

Figure ES2 shows the vision, business cases, technology and competence areas, and prioritized areas for governmental funding for OG21 TTA1.

The funding from the Research Council of Norway (RCN) should reflect these prioritised areas, as there is currently a lack of support to some areas; particularly the areas of improved energy efficiency, and emission control must be given higher priority in the future. There should be a focus on programs that promote implementation of the technologies within the next 5-7 years in order to contribute significantly to meeting Norway's climate goals by 2020. Recent events related to acute spills also show the importance of, and need for, improved spill response systems. Promptly addressing the emissions and spill issues will make it easier for the industry to obtain future licenses to operate.

For RCN projects the current distribution of funding is 50 % to competence building (FP and KMB), 15 % to applied research (BIP) and 35 % to demonstration activities (Demo2000). This illustrates a lack of funding for applied research projects.

The current PETROMAKS funding of TTA1 related projects is low. The volume of annual funding of TTA1 related technologies is proposed to be in line with the other TTAs, considering that the international supplier industry has established departments in Norway based on the competence and experience in Norwegian industry clusters. These clusters are fed by a knowledge economy and continuous R&D activities. The governmental support towards education and research is essential to maintain a competitive Norwegian industry, and to attract international companies.

VISION AND GOALS

The TTA1 vision is to support the Norwegian industry to become the most energy efficient oil and gas industry in the world. For Norway this means to continue to be the province with the highest energy efficiency, lowest levels of harmful emissions to air, discharges to sea and sediments, and exposures to workers per produced oil and gas unit. The vision also includes increased attention to technologies that assist in reducing the environmental impact from accidental oil spills to sea.

The business challenges on the NCS, both currently and in the future, have been evaluated, and the following three business cases have been viewed as the most important seen from a TTA1 perspective:

1) Exploration & Development in Environmentally Sensitive Areas
2) Barents Sea Gas & Condensate Field Development
3) Field Life Extension

The TTA1 strategy focuses on environmental technology and competence necessary to:

- Attain the society's acceptance for continued growth and development of the oil and gas industry
- Reduce the environmental footprint of existing fields, and minimise the footprint of exploration and development in environmentally sensitive areas
- Enhance the energy efficiency of E&P related work
- Reduce the environmental risk and improve the preventive measures to avoid accidental oil spills, and minimise the damage if they occur

TTA1 has identified technology gaps and research needs that need to be met in order to combat the challenges related to further development of oil and gas activities on the NCS.

The TTA1 vision is to support the Norwegian industry to become the most energy efficient oil and gas industry in the world.

For each of the aforementioned challenges, R&D needs have been identified. And, correspondingly, the time perspective, cost level, criticality, and market value have been recognised for each of the R&D needs.

"The TTA1 vision is to support the Norwegian industry to become the most energy efficient oil and gas industry in the world"

BUSINESS CASE 1: EXPLORATION & DEVELOPMENT IN ENVIRONMENTALLY SENSITIVE AREAS

OVERVIEW

On the NCS several restrictions apply to exploration activities, especially exploration drilling, in areas defined as environmentally sensitive(3)(4). Environmentally sensitive areas are often characterised by having high biological activity and diversity, being close to shore, important areas for fishing and fish reproduction, and contain vulnerable marine ecosystems (e.g. coral reefs). Areas having high touristic value (scenery) are also included in the definition. Unopened areas such as Lofoten, Vesterålen, Jan Mayen, and the northern and eastern parts of the Barents Sea; ice edge locations; and a few already opened areas are examples of such sensitive areas.

These environmentally sensitive areas are also considered to hold a large proportion of the yet to find oil and gas reserves on the NCS. A report discussing the possible opening of the unopened areas in the northern part of the Norwegian Sea (the areas off Lofoten, Vesterålen and Senja) indicates that these areas could hold 202 million Sm^3 oe. (approximately 1.4 billion barrels) (5).

In order to be able to explore and develop these sensitive areas it is imperative to develop energy efficient and sustainable technologies as recommended in this TTA.

A balance between oil and gas activities, and actions protecting the environment, is required during development and operation in environmentally sensitive areas. Actions protecting the environment would encompass the local industries' needs, lifestyles and communities. Environmental protection and management requires special emphasis on technological solutions that eliminate or reduce the potential risk and impacts posed by the petroleum activities. Technology in this context means hardware, methods, software and knowledge. As the challenges and conditions from one sensitive ecosystem to another differ, technical solutions and decision support tools should be developed for, or adapted to, specific areas and/or environments.

FIG 1: ERIK RAUDE, A 5TH GENERATION DRILLING RIG FOR ARCTIC AND ENVIRONMENTALLY SENSITIVE AREAS (LEFT); AND NORDLAND, A TYPICAL AREA CHARACTERISED AS HAVING A PARTICULARLY SENSITIVE ENVIRONMENT (RIGHT).

FUTURE CHALLENGES AND TECHNOLOGY GAPS

General challenges

Exploration and development in sensitive areas may reveal new technical, environmental and logistic challenges (e.g. deep water, subsea operation, harsh climate, remoteness, seasonal darkness and/or the presence of ice). Historical baseline information for physical, chemical and biological variables as well as knowledge about sensitive ecosystems may be scarce in some areas, but is crucial in order to understand the natural variations within these environments. Collection of such data is an ongoing process that has taken place through a number of industry and/or government programmes. For example, significant progress has been made in closing the knowledge gaps with respect to seabed mapping, seabirds and biodiversity. However, more effort is still required in order to understand the consequences of, and reduce the environmental risk from, operational and accidental discharges to sea.

There is also a need for real-time mapping of important biological resources and their movements in environmentally sensitive areas. Either through real-time monitoring, or monitoring adapted to their activity schedule; e.g. fish spawning migration, seabird aggregations at sea, seabird breeding and overwintering migration, marine mammal and polar bear migration, etc. Attention should be given to satellite technologies, airborne mapping using computerised image recognition and/or unmanned aircrafts, and remote and in situ sensors. Please refer to the Barents Watch project.

Existing methods for assessing environmental risk are to a large extent restricted to separate human activities, selected species and/or limited compartments of the marine environment. Techniques that provide a holistic overview of the ecosystem taking natural variation/background load into account are currently not available. However work is ongoing. The methods and tools to analyse environmental impact and risk should be subject to continuous development, and be able to understand ecological interaction between species.

Ecological and ecosystem based assessments that focus on the prediction of potential impacts, and simulate the structural and functional changes in the marine environment should be developed and used instead of worst-case risk assessments. In order to improve in this area, it is necessary to integrate expert knowledge, models and decision support tools, site specific data, local information, and knowledge of natural and seasonal variations.

In order to reduce the environmental risk from operational and accidental discharges to sea, environmental monitoring methods and technologies should be integrated into the industries' day-to-day operations (e.g. multi-sensor data captured from several sensors and platforms, communication infrastructure, analysis, and interface).

Prevention of well incidents, intervention, and oil spill response capability is critical to address in any operation, but will be even more important in environmentally sensitive areas.

Responding to oil spills in new frontier areas (e.g. the Arctic, deep waters and/or close to shore) present new challenges that need to be addressed. New solutions should be able to operate under rougher weather conditions, under lower temperatures, and in ice infested areas.

In the event of an oil spill, response managers must quickly select the most appropriate response tactic(s) (e.g. biodegradation, mechanical recovery, in situ burning, and/or chemical dispersion). The choice to implement a particular response strategy in a specific area should be based on the efficiency and environmental effects of that particular response option under the prevailing conditions. Therefore an information base outlining the contingency system producing the lowest environmental impact is essential. It is thus important that the information base includes the capability of the response tactics in various situations; e.g. weather conditions, presence of sensitive ecosystems, high touristic places, etc.

To be able to convey to the stakeholders that the industry is capable to respond to oil spills under various conditions, and possesses the technological advances to detect, contain and clean up spills, more innovative solutions needs to be presented. Oil spill contingency plans including chemical dispersants and in situ burning are already in use, but should be developed further.

Exploration

Both during seismic operation and exploration drilling, safe and efficient information gathering should be in focus to minimise the environmental risk. Gravimetric and electro-magnetic imaging, combined with acoustic based seismic, and the development of new innovative technologies, should be improved in order to verify the presence and migration of oil and gas, and marine mammals; e.g. via satellite tracking and acoustic sensoring.

New well drilling methods in order to perform safer and more energy efficient drilling activities should also be developed. Such technologies are also addressed by TTA3 (Cost-efficient drilling and intervention); examples include:

- Technology and methods to produce slender wells (reduced the hole diameter) to reduce the requirements for rig size, energy consumption, and minimise the cuttings volume and chemical usage. This implies reduced environmental footprint and a more energy efficient drilling technology.
- Improve blowout prevention – implement Best Available Technology and Best Available Practice in well engineering design and well operation management to reduce the likelihood of future incidents.
- Develop new extended-reach technologies to reduce the need for rigs to be situated close to sensitive areas (e.g. deepwater corals, spawning and fishing areas).
- Develop new cuttings disposal technologies that allow safe disposal in locations away from vulnerable seabed habitats.

Involved personnel should receive continuous training in critical drilling operation scenarios using realistic drilling simulations. Integrated operations using parallel control rooms connecting the drilling rig and the onshore operation centre could also reduce the likelihood, impact, and extent of a well incident. Forecasting simulations based on well responses whilst drilling could be a tool for early identification of well problems. Real-time information systems should have high reliability to secure adequate and sufficient guidance and support from company specialists on onshore locations.

New and innovative solutions to minimise the likelihood, impact and extent of well incidents such as well kicks and blowouts should be developed (suggested by TTA3). Additionally, new rig fluid handling systems that implement the use of efficient and effective chemicals should be developed so that these can operate in an environmentally friendly way.

Prevention of lost well control incidents will be one of the top priorities for the industry, therefore capping and containment systems should be developed, and made available as a contingency system if needed.

Development

Technology advancements for surface and subsea leak detection, including leak detection from pipelines, injection wells and surrounding areas is critical. Ongoing work includes the development of methods/technologies for integrated environmental monitoring, which will enable flexible solutions (long-term and/or real-time) aligning environmental monitoring with the industries' day-to-day operations. Although many subsea installations have sensor systems for leak detection, the reliability and robustness of these is not adequate. Furthermore, there is presently no qualified technology for leak detection from injection wells available.

Improved systems for mud and cutting handlings on site should be developed as an alternative to transportation to shore. This will improve the energy efficiency of the drilling operations. Therefore, new and improved technologies for the re-use of mud and the injection of cuttings into subsea disposal wells are needed. Alternatively, methods for safe disposal of cuttings away from vulnerable habitats are needed.

Re-injection of operational discharges (i.e. produced water) is not always an option. Therefore work is needed on developing zero harmful discharge systems. Examples of new risk reducing technologies expected to be implemented are secondary containment systems (i.e. pipe-in-pipe solutions), leakage detection systems, and integrity monitoring and assessment systems. It is further expected that technologies such as subsea processing and ultra long distance well construction could reduce the risk for discharges to sea significantly. Technologies that allow for economical and safe field development in subsea tunnels and cavities up to approximately 50 km from shore, exist today, but should be further developed.

FIG 2: TECHNOLOGY DEVELOPED FOR REAL-TIME HYDROCARBON LEAK DETECTION/MONITORING.

R&D NEEDS

The following R&D needs have been grouped according to the challenges and technology gaps identified.

General R&D needs

Understanding the natural environment and the ecosystems

- Improve knowledge of biological diversity and natural and seasonal variations in specific environments, including ecosystem function and species' interactions.
- Improve knowledge of the environmental effects of operational and acute discharges to sea.

Remote sensing technologies

- Develop remote sensing technologies for real-time mapping of biological resources such as movements and/or migrations using e.g. satellite technologies, airborne computerised image recognition and/or unmanned aircrafts, remote and in situ sensors.

Modelling tools

- Develop ecological based tools to predict the potential impacts, and to simulate the structural, functional, and cumulative impacts in the marine ecosystems (moving from species to an ecosystem level).
- Develop models and decision support tools that integrate expert knowledge, online monitoring systems, site specific data, and local information on natural and seasonal variations.
- Continue to improve and integrate modelling tools for oil spills, species migration, ecosystems, meteorology, oceanography and biological impacts.

Environmental monitoring

- Develop methods and technologies for integrated environmental monitoring, which will enable flexible solutions (long-term and/or real-time) aligning environmental monitoring with the industries' day-to-day operations (e.g. multi-sensor data captured from several sensors and platforms, communication infrastructure, analysis, and interface).
- Improve the robustness and reliability of real-time biological and environmental monitoring technologies, including systems for interpretations and integrations of online data into working processes linked to risk and impact modelling.

Oil spill technologies

- Develop new, and continue to improve, current oil spill response systems addressing technology challenges when operating in: reduced visibility conditions (including darkness), strong currents and high sea states, areas with limited infrastructure, cold temperatures, and near-shore areas.
- Develop innovative solutions to detect, contain and clean up spills (mechanical recovery, chemical dispersants and in situ burning).
- Improved knowledge of the efficiency and environmental effects of the various response options under the prevailing conditions.

R&D needs for Exploration

Technology for seismic operations

- Develop new technologies for gravimetric and electro-magnetic imaging, and acoustic based seismic technologies to verify the presence and migration of oil and gas.
- Develop new, and improve existing, methods and tools to monitor the presence and migration of marine mammals in relation to seismic activities, e.g. via satellite tracking and acoustic sensoring.

Drilling technologies

- Develop technologies to reduce the hole diameter (i.e. drill slender wells) to reduce the requirements for rig size, improve energy efficiency of drilling, minimise the cuttings volume and the use and discharge of chemicals.
- Improve and develop new systems for cutting handling as an alternative to transportation to shore, e.g. technologies for injection of cuttings into a subsea disposal well or for safe disposal away from vulnerable habitats.
- Improve existing and develop new technologies for integrated operations using parallel control rooms connecting the drilling rig and the onshore operation centre.
- Develop forecasting simulation tools based on well responses whilst drilling. This could be a tool for early identification and mitigation of well problems.
- Develop and implement new risk reducing technologies such as secondary containment systems (i.e. pipe-in-pipe solutions), leakage detection at the well head, and integrity monitoring.
- Improve, develop and implement new intervention capabilities through a contingency system for capping and containment (including subsea dispersant hardware). Such systems should be rapidly available at locations near the exploration areas.

R&D needs for Development

Environmental monitoring

- Develop real-time integrated onshore/offshore monitoring and modelling to minimise effect of regular operational discharges.

Leak detection

- Improve systems for leak detection, including real-time monitoring and remote control systems for pipelines, risers, subsea and surface equipment.

BUSINESS CASE 2: BARENTS SEA GAS & CONDENSATE FIELD DEVELOPMENT

OVERVIEW

At present time, the Barents Sea gas field development does not include tie-backs to existing export pipeline infrastructure, hence near future developments will aim to produce and transport liquefied natural gas (LNG), or compressed natural gas (CNG). A typical LNG production/transportation scenario includes gas treatment onshore, with storage and transportation similar to that of the Snøhvit/Melkøya development, except with an extended step-out to the offshore field.

This business case postulates that up to 150-300 km of wet gas may be transported between subsea templates and onshore facilities, with the main technology gap related to the extended step-out. Offshore floating, and/or LNG and CNG processing, may be alternatives to wet gas transport to shore for remote fields.

The Norwegian Petroleum Directory (NPD) has estimated the total gas condensate reserves in the Barents Sea to be approximately 800 BSm^3. Environmental regulations may require improved and/or new technical solutions to enable development of these reserves and acquire society's acceptance of the operations.

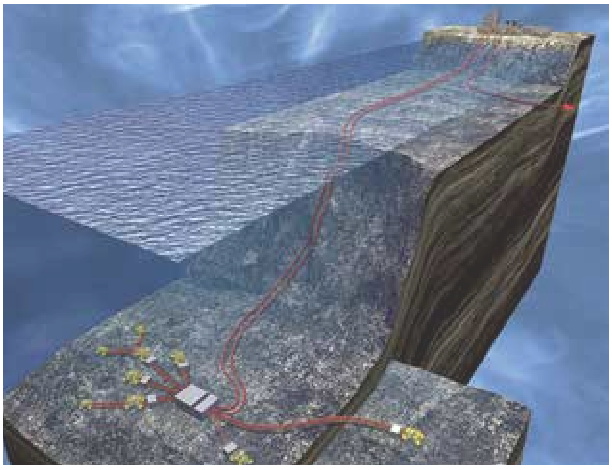
FUTURE CHALLENGES AND TECHNOLOGY GAPS

Gas condensate development in the Barents Sea calls for a common scientific, industrial and public understanding of the development in this region; and one that is energy and environmentally sustainable. This requires a holistic understanding of emissions and discharges from all activities from well start-up through to production.

Developing safe operations in frontier areas with rough climate and low temperature is likely to include subsea processing, long distance transport in pipelines and partial processing of fluids and gas offshore. This requires contingency plans to limit and handle potential gas condensate leakages. Real time leakage and performance control is also needed, as well as "fast" responding systems for leakages, and spill control of chemicals, gas and condensate. It also calls for better energy efficiency for the gas compression trains due to gas transport in longer pipelines which will increase CO_2 emissions per BOE.

FIG 3: HAMMERFEST LNG PLANT ON MELKØYA WHEN RECEIVING ITS FIRST LNG-SHIP IN DEC 2006.

FIG 4: TYPICAL SUBSEA TIE-BACK TO SHORE.



R&D NEEDS

The R&D needs have been grouped thematically, according to the challenges and technology gaps identified:

Understanding the natural environment and the ecosystems

- Develop methods and tools for a holistic understanding of emissions and discharges from all activities.
- Develop methods and tools to illustrate the accumulated effects of different environmental stresses on the ecosystem.

Leak detection

- Develop leak control systems for gas, condensate and chemicals for long step-outs offshore, subsea and downhole hydrocarbon processing.

Oil spill technologies

- Develop safe, robust and fast responding systems for controlling chemical, gas and condensate spill.

Environmental monitoring

- Improve systems to limit and control emissions to air (e.g. CO_2, NO_x, nmVOC).
- Improve condensate and water management systems to enable subsea and offshore processing of gas, condensate and chemicals.

Energy efficiency

- Develop and Promote Rapid Implementation of energy efficient systems for transporting gas and condensate on NCS before 2020.

BUSINESS CASE 3:
FIELD LIFE EXTENSION

OVERVIEW

According to the Ministry of Petroleum and Energy (6) there will be a drive to increase the recovery from Norwegian oil fields. This will require a combination of EOR/IOR measures on existing fields as well as tying in adjacent, smaller fields.

Some of the installations are of considerable age, and are in many cases limited by processing capacity, i.e. water and gas handling capacity. This implies a need to develop adjacent fields quickly whilst maintaining compatibility with existing process equipment. This is to ensure that the integrity of the installations, process equipment and transport facilities is unduly affected by operation too far beyond their intended lifetime. By adding new production to the diminishing volumes of older fields, the older fields will be able to increase their recovery in a profitable manner.

FUTURE CHALLENGES AND TECHNOLOGY GAPS

Remaining water handling capacity available for tie-ins from new fields is typically limited on most installations, but the benefit of dry production from early removal of produced water from the new production can greatly increase the chance for early tie-in. These benefits include cost sharing and increased recovery factors on both fields. Common issues associated with adding new production from adjacent fields to existing production facilities include the ability to extend operation of plant and equipment beyond its original design life and design capacity. This can result in increased use of chemicals (for example to safeguard plant integrity), and increased discharges of oil and chemicals to sea during normal operational conditions.

Fluid compatibility issues when different production streams (including oils, water and chemicals) are mixed are not uncommon. These can lead to reduced separation efficiency

FIG 5: VALHALL, OPERATED BY BP, IS BEING DEVELOPED IN ORDER TO INCREASE THE FIELD'S LIFETIME BEYOND THE PLANNED DESIGN. THE FIELD WAS ORIGINALLY BUILT WITH THREE PLATFORMS, BUT TODAY THE PLATFORM HAS EIGHT PLATFORMS IN TOTAL.

[6] *"Økt utvinning på norsk kontinentalsokkel", a report provided by the Ministry of Oil and Energy 2010. http://www.regjeringen.no/upload/OED/pdf%20filer/Oktutvinning.pdf*

and solid deposition. Variable flow rates also provide separation challenges. These separation challenges can in turn lead to difficulties in meeting existing discharge levels of both hydrocarbons and chemicals. Other challenges include obtaining agreements between different license partners within timeframes acceptable to utilise the resources in existing structures, and improve systems for leak detection.

IOR/EOR is needed to enhance the oil recovery. This includes the use of polymers, surfactants and other chemicals. Currently such systems create separation challenges not yet fully addressed in the offshore environment. An understanding of the environmental impacts these systems will generate needs to be in place before the decisions for allowing the use of such chemicals can be made. Development of environmentally acceptable production and treatment systems is required through a holistic environment management system including resource recovery and energy use.

The energy efficiency of existing facilities generally decreases with increasing facility lifespan, creating an increase in CO_2 emissions per unit of hydrocarbons produced. Total energy use on a platform generally decreases as production rates decrease, resulting in power generation facilities (sized for peak loads in early field life) operating at part load. This is considerably less efficient than full load operation. Modern facilities are also typically much less efficient than comparable onshore facilities, as technologies which enable efficient power generation, such as bottoming cycles, are not well suited to the offshore environment due to size and weight restrictions.

R&D NEEDS

The R&D needs have been grouped thematically, according to the challenges and technology gaps identified:

Produced water systems
- Develop a fundamental understanding of the fate and effects of EOR/IOR chemicals; their interactions with water, oil, reservoir, and the environment when discharged with produced water.
- Develop improved understanding of fluids characteristics and compatibility to enable optimisation of logistics in separation and PWT systems.
- Improve PWT and the operational flexibility of the PWT operation to handle variable flow rates, oil/water emulsions, solids and chemicals as seen in field life extension projects.

Modelling tools
- Improve reservoir souring modelling and integration with facility design, operation and health safety control.

Leak detection
- Improve systems for leak detection, including real-time monitoring and remote control systems for pipelines, risers, subsea and surface equipment.

Energy efficiency
- Develop energy efficient and environmentally sustainable water treatment solutions to treat produced water containing polymers and surfactants, to meet acceptable discharge and reinjection quality
- Develop energy efficient systems for transporting and processing gas and condensate such as compact waste heat recovery unit for the gas compression train
- Improve existing equipment to be able to extend their lifetime and performance, for example by developing:
- compact bottoming cycles (cycle that uses waste heat from the primary generation cycle, i.e. a gas turbine, to generate further electricity) to more efficiently generate electricity
- compact heat exchanger technology to improve heat integration opportunities (including the use of lower temperature heat sources for electricity generation)
- systems to generate power efficiently as both full and part load (i.e. turbine cycles that still operate efficiently when generating significantly less than their designed power output)

Electrification
- Electrification from shore will reduce Norway's CO2 emissions. Electrification of oil producing platforms, however, there would be a need to investigate the most energy efficient ways to produce heat for the platform's oil processing.

R&D PRIORITIES, TIME FRAME AND FUNDING FOR THE MOST IMPORTANT AREAS FOR VALUE CREATION ON THE NCS

The R&D needs identified have all been integrated into separate tables presented in this chapter. For each of the thematic R&D areas, one table have been generated. Each row represents one of the identified R&D needs, although the text has been shortened, and if the same R&D need has been identified more than once, they have been merged into one row. Please refer to chapters 3-5 for description of the R&D needs.

In the tables, the estimated time needed for technology development, the assumed R&D costs, a criticality evaluation, an estimated market potential, the OG21 strategic goals covered, barriers for the technology realisation and the priorities for industry and public funding have been indicated. Below can be found an explanation to the various terms:

The priority for industry public funding has been assembled by leading experts from O&G companies, manufactures and R&D institutes/universities.

Their experience and expertise secures the relevance and prioritized order of the list.

Term	*Definition*
Cost	The total cost of development from idea to qualified technology
Criticality	The need for addressing the technology gap in order to realise the business case
Market value	The possibility of a global market for the technology gap
OG21 strategic goal	Defined in the OG21 strategy document, where: 1) Value creation through production and reserve replacement with a reserve growth of 5 bn boe before 2015. 2) Energy efficient and cleaner production: become the oil and gas province with the highest energy efficiency, the lowest level of emissions to air, and lowest harmful discharges to sea per produced unit. 3) Value creation through increased export of technology: Continue the current growth path with annual oil and gas technology sales of NOK 120 bn by 2012. 4) Value creation through employment and competence development: Sustain and further develop Norway's position as a leading and competitive oil and gas technology cluster.
Barrier	The obstacles to realise the technology and bring it into application, where: I = innovation C = competence D = demonstration P = piloting

TABLE 1: UNDERSTANDING THE NATURAL ENVIRONMENT AND THE ECOSYSTEMS

Identified R&D need / Technology Gap	*Business Case*	*R&D time*	*Cost (MNOK)*	*Criticality*	*Market value*	*OG21 strategic goal*	*Barriers*	*Priority for industry funding*	*Priority for public funding*
Biological diversity, seasonal variation, ecosystem function and species interaction	1	10	500	High	Low	2,4	C/D	3	1
Environmental effects of operational and acute discharges	1,2	10	250	High	Low	2,4	C/D	1	1
Methods for holistic understanding of emissions and discharges	1,2,3	10	100	Low	Medium	2,4	C/D	3	2
Methods and tools to assess accumulated effects of different stress-ors on the ecosystem	1,2,3	15	100	Medium	Medium	2,4	C/D	2	2

TABLE 2: REMOTE SENSING TECHNOLOGIES

Identified R&D need / Technology Gap	*Business Case*	*R&D time*	*Criticality*	*Market value*	*OG21 strategic goal*	*Barriers*	*Priority for industry funding*	*Priority for public funding*
Real time mapping of biological resources, satellite technologies, airborne image recognition, remote and in situ sensors	1,3	10	Medium	High	2,3,4	C/D/P	2	2

TABLE 3: MODELLING TOOLS

Identified R&D need / Technology Gap	Business Case	R&D time	Costs (MNOK)	Criticality	Market-value	OG21 strategic goal	Barriers	Priority for industry funding	Priority for public funding
Ecological based tools to predict and simulate structural and functional changes and cumulative impacts to the ecosystem	1,3	5	100	High	Medium	2,4,3	C/I/D	1	2
Decision support tools integrating expert knowledge, online monitoring systems and site specific information	1,2,3	5	100	Medium	Medium	2,4	C/I/D	2	2
Oil spill and biological mobility models	1,3	5	100	Medium	Medium	2,4,3	C/I/D	2	2
Reservoir souring models	3	10	500	High	High	1,2,4,3	C/I/D	1	2

TABLE 4: ENVIRONMENTAL MONITORING

Identified R&D need / Technology Gap	*Business Case*	*R&D time*	*Costs (MNOK)*	*Criticality*	*Market value*	*OG21 strategic goal*	*Barriers*	*Priority for industry funding*	*Priority for public funding*
Operation integrated environmental monitoring technolo-gies (e.g. multi-sen-sor data, communica-tion infrastructure, and interface)	1,2,3	10	500	High	Medium	2,4	C/I/D	1	2
Real-time integrated monitoring and modelling systems to minimise effect of operational discharg-es.	1,3	5	100	High	Medium	2,4	C/I/D	1	1
Improved systems to limit and control emission to air	1,3	15+	5000	High	High	2,1,4,3	C/I/D/P	1	1

TABLE 5: LEAK DETECTION

Identified R&D need / Technology Gap	*Business Case*	*R&D time*	*Costs (MNOK)*	*Criticality*	*Market value*	*OG21 strategic goal*	*Barriers*	*Priority for industry funding*	*Priority for public funding*
Systems for remote leak detection, real time monitoring and control of pipelines risers, injection wells, subsea and surface equipment.	1,3	10	1000	High	High	2,3,4	C/I/D	1	1
Leakage control systems for gas, condensate and chemicals for long distance, subsea and downhole processing	2	10	500	High	Medium	2,3,4	C/I/D	2	2

TABLE 6: ENERGY EFFICIENCY

Identified R&D need / Technology Gap	*Business Case*	*R&D time*	*Costs* (MNOK)	*Criticality*	*Market* value	*OG21 strategic goal*	*Barriers*	*Priority for industry funding*	*Priority for public funding*
Technologies for more energy efficient transport and processing of gas and condensate	2	10	1000	High	Medium	3,2,4	C/I/D	1	1
More energy efficient water treatment systems	3	5	500	Medium	Medium	2,3,4	C/I/D	2	2
Improve existing equipment to enable lifetime extension	3	5	100	High	Medium	1,3,4	C/D	1	2
Production methods to improve energy efficiency	3	5	100	High	Medium	2,3,4	C/D	1	2
Compact bottoming cycles for electricity generation	3	5	100	High	Medium	3,2,4	C/D	1	2
Compact heat exchange technology for electricity generation	3	5	500	Medium	Medium	3,2,4	C/I/D	3	3
Systems for flexible power generation	3	5	100	High	Medium	3,2,4	C/I/D	1	2

TABLE 7: PRODUCED WATER TECHNOLOGY

Identified R&D need / Technology Gap	*Business Case*	*R&D time*	*Costs* (MNOK)	*Criticality*	*Market value*	*OG21 strategic goal*	*Barriers*	*Priority for industry funding*	*Priority for public funding*
Fate and effect of EOR/IOR chemicals	3	5	100	High	Medium	1,2,4,3	C/I/D	2	1
Fluid characteristics and compatibility in PWT systems	3	5	50	High	Medium	1,2,4	C/D	1	2
Flexible produced water treatment technologies	3	10	500	Medium	Medium	1,3,2,4	C/I/D	2	3
Improved condensate and water manage-ment technology and systems.	1,2,3	10	1000	High	Medium	2,4,3	C/I/D/P	1	2

TABLE 8: OIL SPILL RESPONSE TECHNOLOGIES

Identified R&D need / Technology Gap	*Business Case*	*R&D time*	Costs (MNOK)	*Criticality*	*Market value*	*OG21 strategic goal*	*Barriers*	*Priority for industry funding*	*Priority for public funding*
Improve existing oil spill response systems for various conditions	1,2,3	5	500	Medium	High	2,1,3,4	C/I/D/P	2	2
New solutions to detect, contain and clean up spills	1,2,3	10	1000	High	High	2,1,3,4	C/I/D/P	1	1
Efficiency & environmental effects of the various response options	1,2,3	5	500	High	Medium	2,3,4	C/I/D	1	2
Safe, robust and fast responding systems to control chemical, gas and condensate spills.	2	10	250	Medium	Medium	2,4,3	C/I	2	2

TABLE 9: TECHNOLOGY FOR SEISMIC OPERATIONS

Identified R&D need / Technology Gap	*Business Case*	*R&D time*	Costs (MNOK)	*Criticality*	*Market value*	*OG21 strategic goal*	*Barriers*	*Priority for industry funding*	*Priority for public funding*
Gravimetric and electromagnetic imaging, acoustic based seismic acquisition	1	10	500	High	Medium	1,3,4,2	C/I/D	1	2
Technologies to monitor marine mammals	1,2	10	500	Medium	Medium	2,3,4	C/I/D	2	2

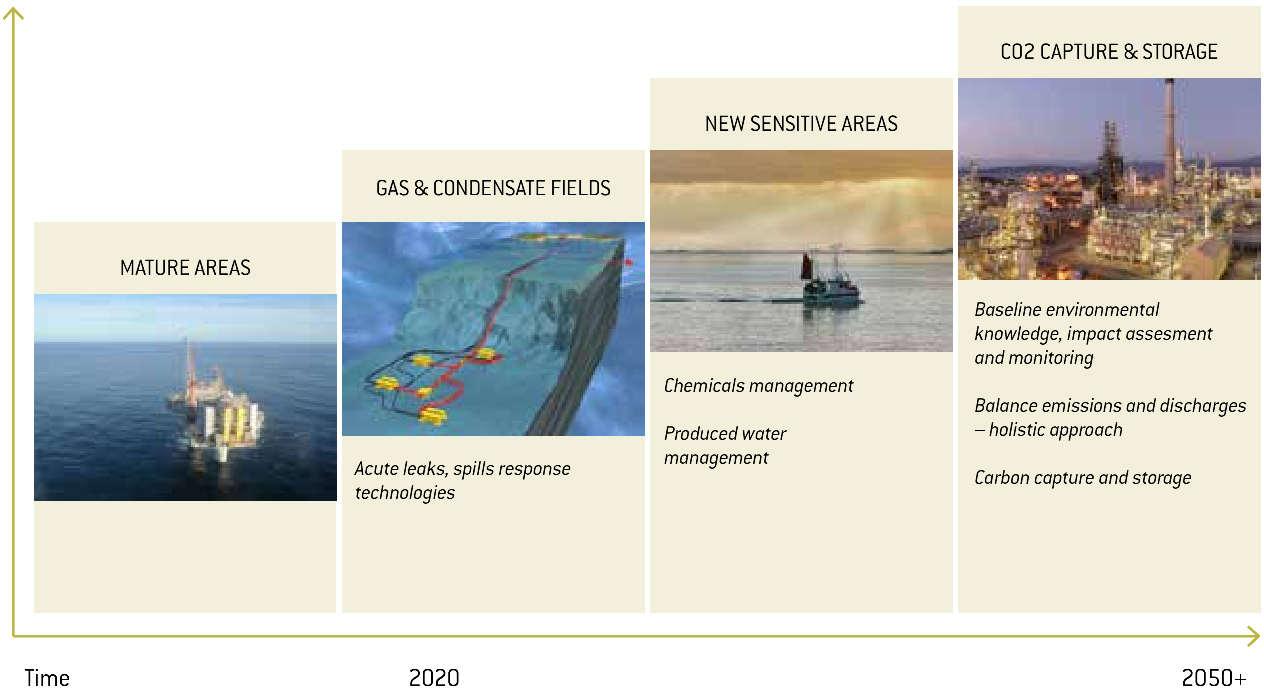
TABLE 10: DRILLING TECHNOLOGIES

Identified R&D need / Technology Gap	*Business Case*	*R&D time*	Costs (MNOK)	*Criticality*	*Market value*	*OG21 strategic goal*	*Barriers*	*Priority for industry funding*	*Priority for public funding*
Drill slender wells	1,2,3	5	1000	High	High	1,3,2,4	C/I/D	1	2
Cuttings handling i.e injection and disposal	1,2,3	5	100	Medium	Medium	3,2,4	C/I/D	2	2
Drilling operations using parallel control rooms	1,2,3	5	500	High	High	4,2,3	C/I/D	1	2
Forecasting simula-tions based on well responses whilst drilling	1,2,3	5	500	High	High	4,2,3	C/I/D/P	1	2
Secondary contain-ment, leakage detection at the well head, and well integrity monitoring	1,2,3	10	1000	Medium	Medium	4,2,3	C/I/D	2	2
Capping and containment technologies and systems	1,2,3	5	5000	High	High	1,4,3,2	C/I/D	1	2

ROADMAP FOR THE FUTURE

A road map for the future, regarding “Energy efficient and environmentally sustainable technologies”, is illustrated in Figure 6 below.

FIG 6: “ENERGY EFFICIENT AND ENVIRONMENTALLY SUSTAINABLE TECHNOLOGIES” – A ROAD MAP FOR THE FUTURE.



LINK TO OTHER TTAS

Environmental technology should be incorporated into all technology development to obtain energy efficient and environmental sustainable development, and it is expected that several of the projects discussed in the other TTAs will cover similar needs that have been identified within this report. The identified interfaces are listed in Table 6.

The main objective of listing interfaces to the other TTAs is to maintain consistency, and to ensure important technology gaps have not been adressed. There is no conflict in overlapping priorities.

TABLE 6: INTERFACES WITH OTHER TTA GROUPS

Item	*Relevance for other TTAs*
CO2 value chain	TTA2 - Exploration and Increased Recovery Energy21 CCS report by Climit
Drilling technologies, including cuttings handling Capping and containment systems	TTA3 - Cost-Efficient Drilling and Intervention
Processing technologies, leak detection, and on-line oil-in-water monitoring	TTA4 - Future Technologies for Production, Processing and Transportation
Leak detection	TTA4 - Future Technologies for Production, Processing and Transportation TTA3 - Cost-efficient Drilling and Intervention
Chemicals	TTA2 - Exploration and Increased Recovery
Energy efficiency	TTA2 - Exploration and Increased Recovery TTA3 - Cost-efficient Drilling and Intervention TTA4 - Future Technologies for Production, Processing and Transportation

RECOMMENDATIONS

Priorities have been listed in order of importance with particular emphasis on technological issues that will need governmental support, either for initialisation, acceleration or development of competences. R&D needs that are industry-funded, or covered by existing initiatives, have not been included in this report.

The main areas are:

1. Develop methods to improve the energy efficiency of offshore operations as well as processing and transport of oil and gas
2. Improve knowledge of real-time integrated monitoring and modelling systems
3. Systems to limit and control emissions to air
4. Increase the fundamental understanding of the fate and effects of EOR/IOR chemicals, including produced water treatment
5. Improve knowledge and understanding of the natural environment and the ecosystems
6. Develop new and continue to improve oil spill response systems
7. Improve systems for leak detection, including real time monitoring and remote control systems for pipelines, risers, subsea and surface equipment

A review of on-going activity shows there is a need for improved energy efficiency for the oil and gas industry throughout all phases such as exploration, development, production and abandonment. Recent acute spills e.g. Macondo in the Gulf of Mexico, events have also shown the need for better spill response systems.

It appears to be a lack of knowledge about the effects from operational and acute discharges, which may be the cause for not opening for oil and gas exploration in new sensitive areas. Increased focus on environmental monitoring is a key, and real-time integrated monitoring and modelling systems should be prioritized

There is still an apparent lack of initiatives to address a holistic approach to environmental issues, i.e. balancing emissions to air, discharges to sea, and waste management. Stakeholder focus and efforts to create awareness must be emphasised. It is imperative to create a positive public perception, and this can be achieved via communicating the standards and track records of the business, and the exciting future opportunities. This is vital to improve public perception and recruitment to the industry.

In order to promote, and strengthen, the position of the Norwegian oil and gas industry, developing environmental legislation and technology is crucial. To achieve this, emphasis on cooperation between authorities, research facilities and industry is needed. Continuous innovation and development is important to attract international companies, to support export of world leading environmental technologies.

TTA 2
TECHNOLOGY STRATEGY
EXPLORATION AND INCREASED RECOVERY

Lead Party
Statoil

TTA group companies and organisations:
SINTEF, ConocoPhilips, Badger, Shell, Iris, Schlumberger, CMR, FMC Technologies, Statoil, Total, CMR, Lundin, EON, GDF Suez, IFE.

CONTENT TTA 2

EXECUTIVE SUMMARY

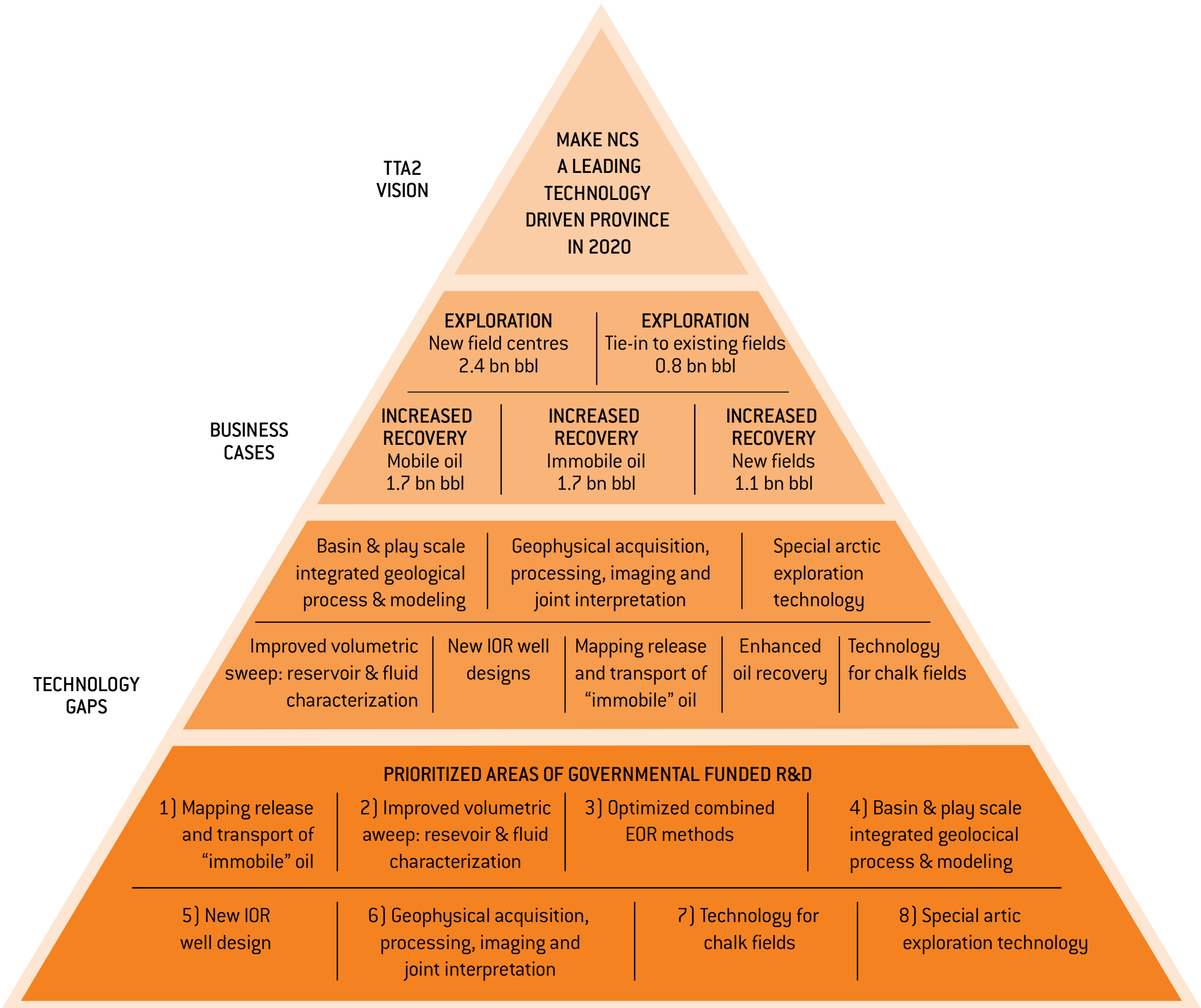


FIG ES.1: SUMMARY OF THE STRATEGY.

OG21 – Oil and Gas in the 21st Century – is now organized in four Technical Target Areas (TTAs), and this document is Norway's technology strategy for TTA2: "Exploration and Increased Recovery". This strategy is developed by distinguished experts from oil companies, service companies, R&D institutes and academia. The business case is shown in the table below.

Exploration challenges:
- *Large yet-to-find fields* are technologically challenging to discover
- *Many small marginal yet-to-find fields* to be discovered as NCS matures

Increased recovery challenges:
- *Immobile oil* constitutes about half of remaining oil in fields in production and cannot be produced by reservoir depletion or standard water or gas injection.
- *Limited window of opportunity* for large and mature sandstone fields with already high recovery factor
- *Average oil recovery factor has flattened out*
- *Small fields* have a recovery factor of only 30% and has not increased last 20 years
- *High reservoir complexity* gives low recovery

TABLE ES: BUSINESS CASE OF NEW EXPLORATION AND INCREASED RECOVERY TECHNOLOGY.

Business case	*Descripion*	*Added Recoveable Rescources*
Exploration for resources to new field centres	New knowledge and technology to discover 15% of yet-to-find volume.	2.4 billion boe
Exploration for resources tied into existing infrastructure	New knowledge and technology to discover 5% of yet-to-find volume.	0.8 billion boe
Sum exploration technology	20% of 16.2 bn bbl o.e. yet-to-find recoverable resources on NCS	3.2 billion boe.
Increased recovery immobile oil of fields currently in production	Add 3% on the average recovery factor, 1% gives 570 mill. bbl o.e.2, p. 55	1.7 billion boe
Increased recovery mobile oil of fields currently in production	Add 3% on the average recovery factor, 1% gives 570 mill. bbl o.e. 2, p. 55	1.7 billion boe
Future new field developments and gas recovery	1/3 of the contribution to increased recovery of oil for fields in production	1.1 billion boe
Sum increased recovery	About 30% increased IOR cost-efficiency and 50% reduction in uncertainty is needed to realize the potential	4.5 billion boe
Sum total TTA2		7.7 billion boe.

Increased recovery needs strong growth impulses from new technology to break through the current level of 46% to pilot & implement new technology on NCS.
Main priorities for increased recovery:

1. Optimized combined EOR methods
2. Improved volumetric sweep: reservoir & fluid characterization
3. Mapping, release and transport of "immobile" oil
4. New IOR-well designs (addition/support to TTA3)
5. Technology for chalk fields

Main priorities for exploration:
1. Large scale (basin & play) integrated geologic process and modelling
2. Geophysical acquisition, processing, imaging and joint interpretation
3. Special arctic exploration technology

The priority list for public funding is:
1. Mapping, release and transport of "immobile" oil
2. Improved volumetric sweep: reservoir & fluid characterization
3. Optimized combined EOR methods
4. Large scale (basin & play) integrated geology and geophysics modelling
5. New IOR-well designs
6. Geophysical acquisition, processing, imaging and joint interpretation
7. Technology for chalk fields
8. Special arctic exploration technology

NUMERICAL ROCKS DRAIN. NUMERICAL ROCKS AS.

INTRODUCTION

The OG21 – Oil and Gas in the 21st Century - is now organized in four Technical Target Areas (TTAs). This document is Norway's technology strategy for TTA2: "Exploration and Increased Recovery".

The OG21 strategy has four strategic goals:
1) Value creation through production and reserve replacement
2) Energy efficiency and cleaner production
3) Value creation through export of technology
4) Value creation through employment and competence development

TTA2 is strategically well aligned. Exploration technology contributes to reserve replacement by discovering new recoverable resources that are matured to added reserves through field development and Increased Oil Recovery (IOR) contributes directly to added reserves for fields in production. Contributions to the second goal include more energy-efficient recovery of resources. Reduced subsurface uncertainty reduces kick and blow-out risk. However, chemical injection methods have environmental challenges regarding cleaner production. Exploration and increased recovery technology are in well-developed global markets.

Sustainability and employment in the Norwegian petroleum industry depends on discovered new fields to be developed and produced. Exploration is the single most important factor for long term employment in the petroleum industry.

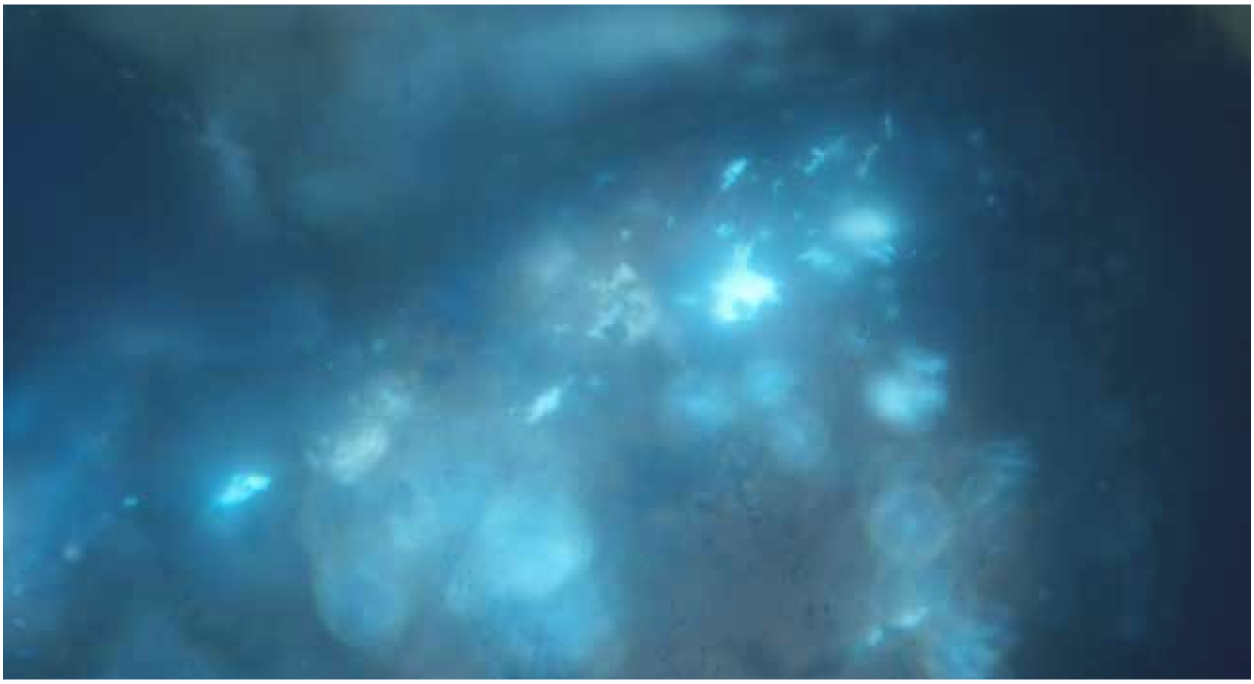
Chapter 2 is a brief statement of the vision and goals. Chapter 3 and 4 are on Exploration and Increased Recovery, respectively. These chapters have sections of "business case" and "future challenges and technology gaps". The sections on "business case" give a strategic analysis and discussion of business opportunities and challenges where technology plays a major role. The business case is a rough overall estimate of added oil and gas volume (recoverable resources and reserves) that can be unlocked with new technology. The sections on "future challenges and technology gaps" briefly describe the technology gaps and gives tables with overview of time to market, cost, criticality, global market value, link to OG21 strategic goals and main barriers. Chapter 5 has environmental considerations. Chapter 6 has R&D priorities, time frame and funding. Chapter 7 has a simplified roadmap for the future and Chapter 8 has recommendations on public funding.

TTA2 VISION AND GOALS

The vision of exploration and recovery is to develop new exploration and increased recovery technology to make NCS a leading technology driven petroleum province in 2020.

The goal is to develop new technology to add 7.7 billion boe. recoverable resources (3.2 bn boe.) and reserves (4.5 bn boe.)

"The vision of exploration and recovery is to develop new exploration and increased recovery technology to make NCS a leading technology driven petroleum province in 2020"



BUSINESS CASE : EXPLORATION

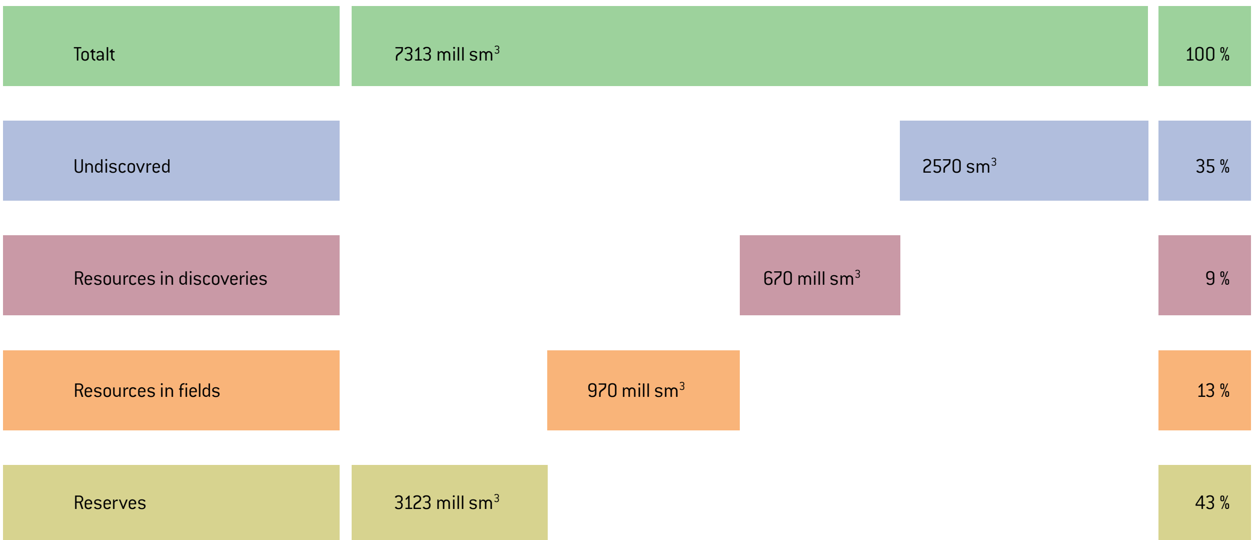
NCS has both great challenges and great opportunities. Remaining reserves and recoverable resources on NCS are given in Figure 3.1

Figure 3.1. NCS resources and reserves2. From bottom to top: remaining reserves, recoverable resources in fields, recoverable resources in discoveries, un-discovered recoverable resources and total recoverable in (mill. Sm3). The percentage split and uncertainty is given to the right.

The remaining reserves and recoverable resources are as follows (Figure 3.1):

- Undiscovered recoverable resources: 16.2 bn boe.
- Recoverable resources in discoveries: 4.1 bn boe.
- Additional recoverable resources in fields are 6.1 bn boe.
- Reserves in fields are 19.6 bn boe.

FIG 3.1: NCS RESOURCES AND RESERVES.



Source: Ministry of Petroleum and Energy. St. meld. nr. 28 (2010-2011). En næring for fremtida - om petroleumsvirksomheten.

Figure 3.2 shows the creaming curve of NCS that is a plot of the cumulative resource growth in time for new fields. The trend can be described as follows:

- NCS is a maturing petroleum province with a creaming curve that is flattening out. This is roughly a consequence of exploring the largest fields first.
- Based on the creaming curve one may predict an increasing number of smaller marginal fields to be discovered. Small discoveries are important to prolong field life.
- Due to varying degree of maturation on NCS and large acreage not yet opened for exploration, one may still expect to discover many large fields on NCS.
- The recent discoveries of Luno, Johan Scverdrup (not in Figure 3.2) proved that apparently mature area can contain large un-discovered fields in new exploration models.

Exploration aims at predicting discoveries starting with basin scale gravity, magnetic, seismic and electromagnetic surveys to identify interesting geological features:

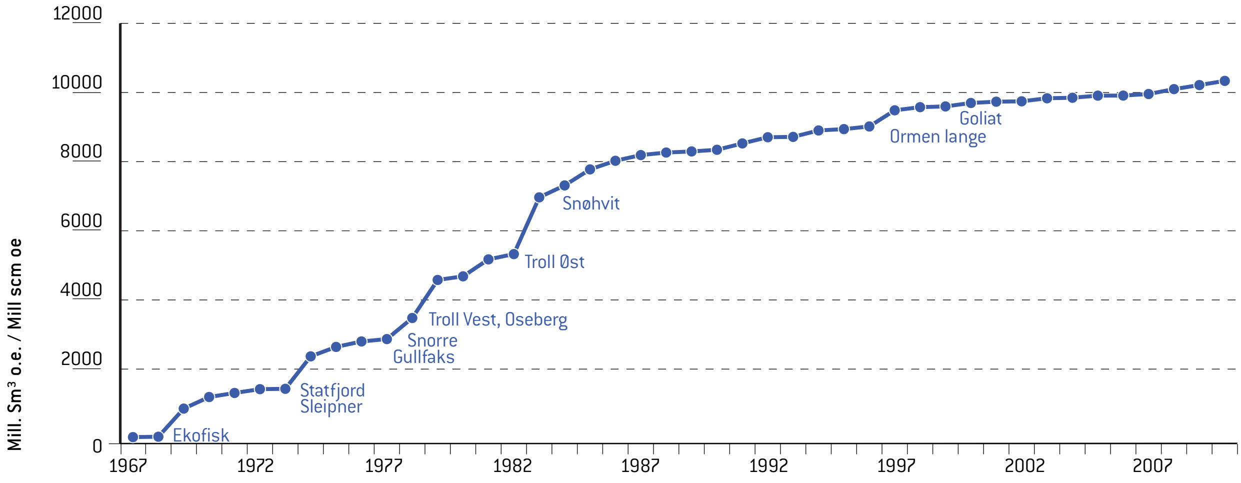
- Play: a localized collection of reservoir opportunities with similar combinations of source, migration routes, reservoir, seal and trap.
- Lead: Interesting reservoir structures within a play are called leads
- Prospect: a lead that is mapped with recoverable volume is a prospect. A drillable prospect is a prospect with expected recoverable resources that justify future costs.
- Probability of discovery: is assigned to each prospect. The probability of discovery Pd is, for example, given by, Pd = PsPrPt where Ps is the probability of source & migration, Pr is the probability of reservoir and Pt is the probability of seal & trap. A risked volume is recoverable volume multiplied by probability of discovery.

We divide the exploration business case in two parts:

- Exploration for resources to new field centres
- Exploration for resources tied into existing infrastructure

Roughly, the division reflects the two types of exploration rounds on NCS: Awards in Predefined Area (APA, or "Tildeling i Forhåndsdefinerte Områder", TFO) and numbered exploration rounds.

FIG 3.2: NCS CREAMING CURVE SHOWING CUMULATIVE RESOURCE GROWTH IN TIME2.



Source: Norwegian Petroleum Directorate

Exploration for resources to new field centres is characterized by:

- Lack of geological knowledge, exploration wells and production data in the area.
- Low probability of discovery (risked hard), so large prospects may not be drilled.
- Large strategic and business risk of "lost opportunities" that is the risk of not maturing/drilling a prospect that would result in a large discovery.
- Good business case for new knowledge and technology: an increase of d P from 10% to 30%, increases the business case (risked volume) by 200%.

Exploration for resources tied into existing infrastructure is characterized by:

- High probability of discovery. Other exploration wells and nearby fields in production have confirmed a mature source rock, migration routes, reservoir, and seal.
- Small recoverable volume of prospects
- Low recovery factor (see Figure 4.4)
- Critical business driver for extending the lifetime of existing infrastructure.
- Limiting factors are drilling capacity and cost, and to a less extent new knowledge and exploration technology.

Based on the above, we weight the business case for technology that supports exploration for resources to new field centres to $^3/_4$ and exploration for resources tied into existing infrastructure to $^1/_4$ of the total new exploration technology business case. We assume that about 20% of the yet- to-find volume of on NCS is critically dependent on new geological knowledge and new technology (see gaps in next section). The business case for exploration in terms of recoverable resources is given in Table 3.1. Note that Johan Sverdrup alone have recoverable resources of 1.7 to 3.3 bn boe (October 2011).

TABLE 3.1: BUSINESS CASE FOR NEW EXPLORATION TECHNOLOGY.

Business case	*Description*	*Added Recoverable Resources*
Exploration for resources to new field centres	New knowledge and technology to discover 15% of yet-to-find volume.	2.4 billion boe.
Exploration for resources tied into existing infrastructure	New knowledge and technology to discover 5% of yet-to-find volume.	0.8 billion boe.
Sum exploration technology	20% of 16.2 bn boe. yet-to-find recoverable resources on NCS	3.2 billion boe.

FUTURE CHALLENGES AND TECHNOLOGY GAPS WITHIN EXPLORATION

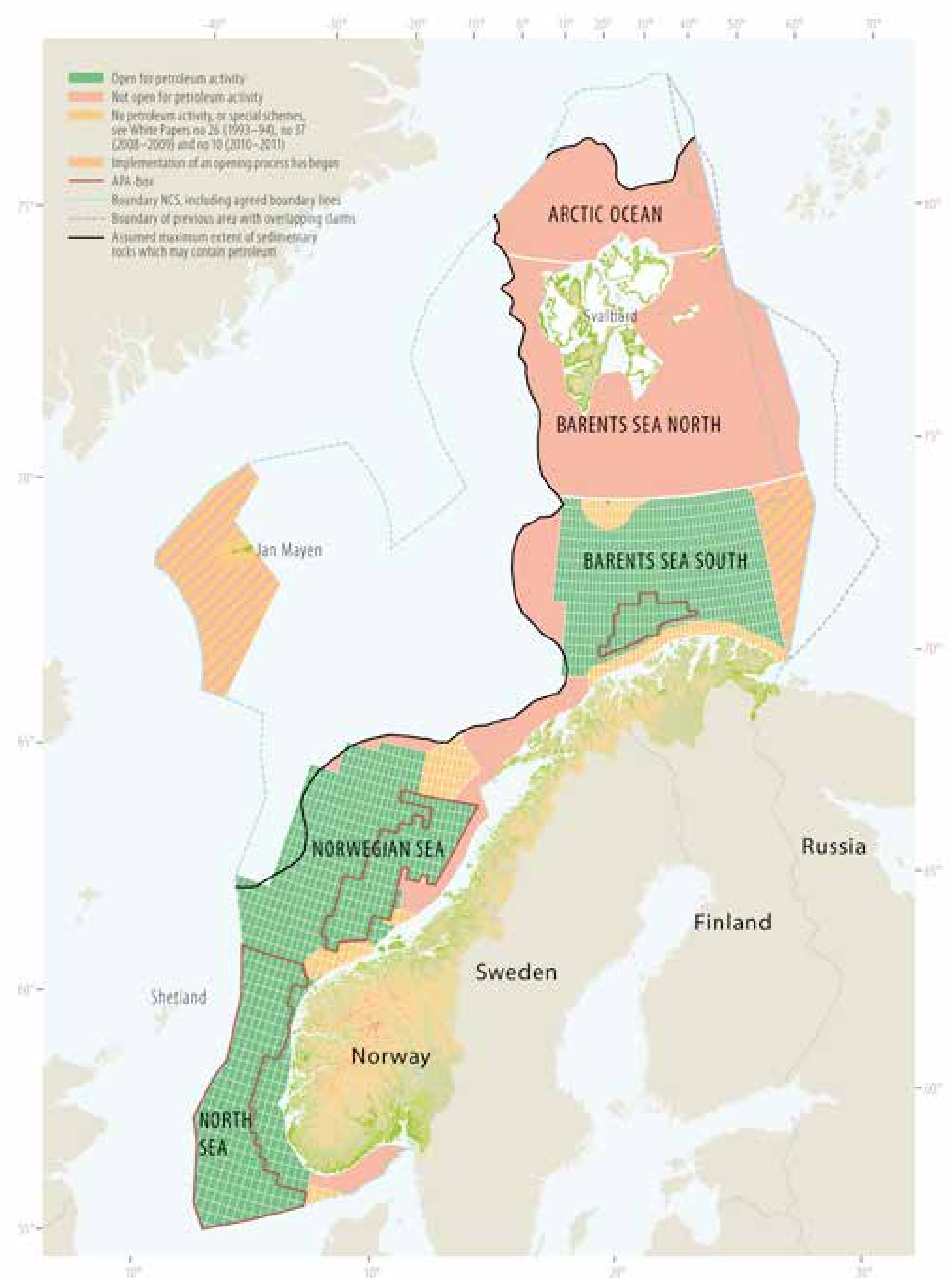


FIG 3.3: (NORWEIGAN PETROLEUM DIRECTORATE) OVERVIEW OF NCS. OPEN FOR PETROLEUM ACTIVITY (GREEN), NOT OPENED FOR PETROLEUM ACTIVITY (RED), NO ACTIVITY OR SPECIAL ARRANGEMENTS (YELLOW), STARTED AN OPENING PROCESS (ORANGE). AWARD IN PREDEFINED AREA (APA = "TFO") BOXES ARE INDICATED IN OPENED AREA.

REGIONAL CHALLENGES

Main regional challenges on NCS within exploration are (see overview of NCS in Figure 3.3):

- *Barents Sea*: Uplift and erosion requires a stronger technology development within basin and petroleum system geology and a special effort to integrate all the information. More reliable direct hydrocarbon indicators are important in immature area. Take out tie-in potential in APA acreage, including explore for more gas in Snøhvit area.
- *North Sea and shallow water Norwegian Sea*: Take out the full potential of exploration for discoveries to be tied in to existing infrastructure. Discover large yet-to-find resources in-between mature areas.
- *Deep water Norwegian Sea*: Imaging reservoirs covered by heterogeneous structures of volcanic rock formed by lava (basalt). Technology for this includes seismic imaging, new gravity/magnetic, electro-magnetic and special acquisition schemes. Note that 70% of earth is covered by volcanic rock. Value of transfer to other regions: India, Southern Atlantic ocean, UK, Northern part of South America.

Large scale (basin & play) integrated geological process and modelling

The first four technology gaps in exploration given in Table 3.2 are related to large scale integrated geology and geophysical modelling. There is a risk of lost opportunities that large yet-to-find reservoirs will never be discovered as they are hidden in blurry data of a petroleum system that is not well understood.

The discovery of Johan Sverdrup was found in an area where most companies did not originally expect to make large discoveries. Most plays are based on structural traps generated by folding and faulting. Recent discoveries show that there can be an unexplored potential for stratigraphic/subtle traps. Stratigraphic traps include pinched-out reservoir and unconformities formed by erosion that can be difficult to identify from seismic. Unconventional traps are typically assigned a high risk and thereby have a large potential for risk reduction through new knowledge and technology. Also oil migration paths from source rock to reservoir need a better understanding.

There is a gap on the integrated interpretation of large and diverse data sets. It is an appreciation in the industry that for example EM data are not stand-alone data but should be analysed together with well log and seismic data, and with the best geological understanding. Experience transfer from advanced ensemble model-based reservoir history matching to exploration modelling may be useful.

Geophysical acquisition, processing, imaging and joint interpretation

Exploration is heavily dependent on geophysics, and in particular seismic acquisition, processing and interpretation (see Figure 3.4). Direct hydrocarbon indicators (DHI), such as a seismic bright spot that indicates a gas filled reservoir and a flat spot that indicate a water-oil contact, are the holy grail of exploration geophysics. Advances in processing and interpretation to find more bright/flat spots can give new discoveries. However, the potential may be even greater in identifying stratigraphic and subtle traps by geophysical methods and new geological knowledge, and thereby support the identification of new exploration models that otherwise will be overlooked.

Interpretation of reservoir quality and better delineation of a field is also important. There is a gap for models that supports seamless work processes and has a geological model memory along the value chain of the phases of exploration, field development and production. Joint inversion may lead to more reliable DHIs and identification of subtle traps. There are gaps on the resolution and accuracy of seismic data, so that one may improve the analysis of stratigraphic traps. Sub basalt and sub salt imaging have gaps that are treated somewhat differently. Full wave field seismic is relatively new and sophisticated acquisition and processing method that makes better images of complex geometries.

Special arctic exploration technology

If new exploration acreage is opened in the arctic there may be a need for new exploration technology needed for these areas due to climatic and environmental reasons or the particular geology in these regions. Also there are other than geophysical methods that can be used. Most petroleum systems leak small amounts of oil and gas. Micro oil spills can be detected by remote satellite sensing and seabed micro seepage tracking. There is a gap in integrating these technologies with basin models to improve the understanding of petroleum systems.

Overview of technology gaps

Table 3.2 shows an overview of technology gaps as discussed above. Notes are given below the table. The total development cost of this program is 1.25 billion NOK.

FIG 4.3: SCHEMATIC ILLUSTRATIONS OF GEOLOGICAL MODELLING AND IMAGING BY SEISMIC.

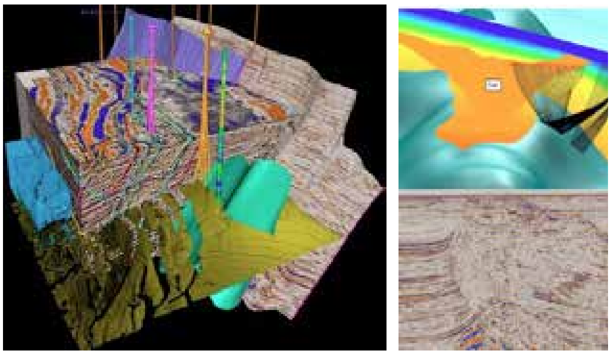


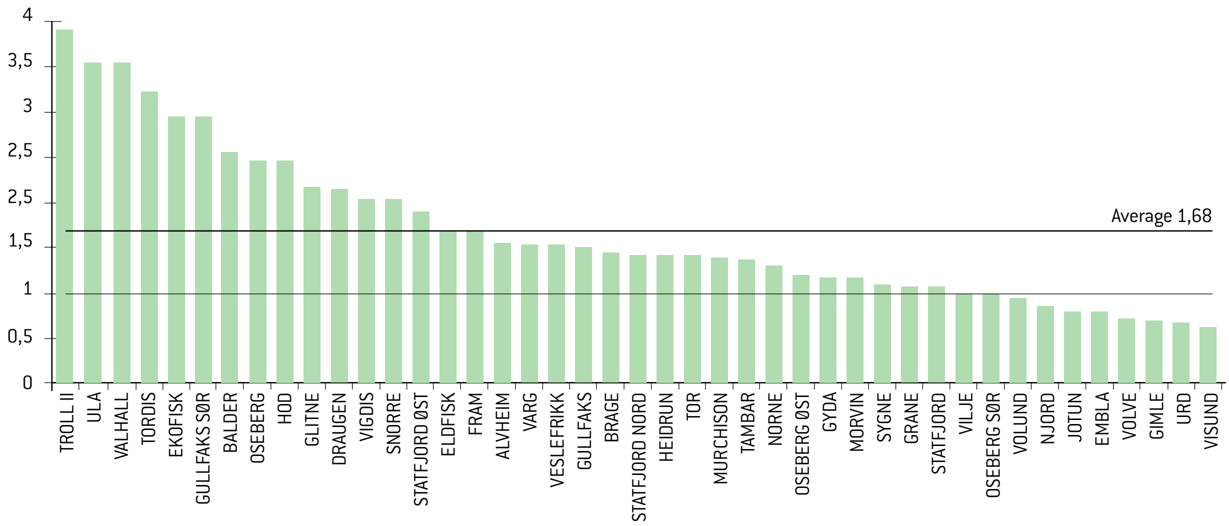
TABLE 3.2: TECHNOLOGY GAPS FOR EXPLORATION.

Technology gap	*Time to market (year)*	*Cost (MNOK)*	*Criticality Business Case (L,M,H)*	*Global market value (L,M,H)*	*OG21 Strategic Goals Prioritized order*	*Main barriers*
Petroleum system models, source rock, geochemical parameters, alternative migration paths, stratigraphic and structural traps (national maps/models systema-tion) (semi-automation of basin model building)	1-10	100	H	M/H	1,4,3	
Geological model and process understanding linked to computational models	0-10	100	H	H	1,4,3	Constraints and validation
Geological process modelling: Basin & play models Analogues Aggregation from large number of data sources Models with memory of knowledge from exploration to production, and back into new exploration	1-10	100	H	H	1,4,3	Important to view in connection with improved imaging
New play models NCS	1-10	100	H	L	1,4	Competence
3D joint inversion methods (seismic, EM, grav/mag, rock physics), including for direct hydrocarbon indicators	3-6	100	M	M	1,3,4	Talent
Double spatial resolution and accuracy from seismic data	0-10	200	H	H	1,3,4	Identify structure and migration paths
Sub basalt seismic, EM, gravity imaging	5-10	200	H	H	1,4,3	Sub basalt calibration well is preferable
Sub salt imaging full wave field	2-5	50	L	H	4,1	Large prospects not identified on NCS
Special arctic exploration technology	5-15	250	M	M	1,4,3	

Notes to the table: (H = High, M = Medium and L = Low) "Cost" relates to development costs from idea to qualified technology (excluding piloting and field implementation costs), "Criticality" is related to the need for addressing the technology gap for realization of the business case, "Global market value" relates to a global possible market for each technology gap. "OG21 strategic goals" are given as follows: 1) value creation through production and reserve replacement, 2) Energy efficient and cleaner production, 3) Increased export and 4) Value creation through employment and competence development.

BUSINESS CASE: INCREASED RECOVERY

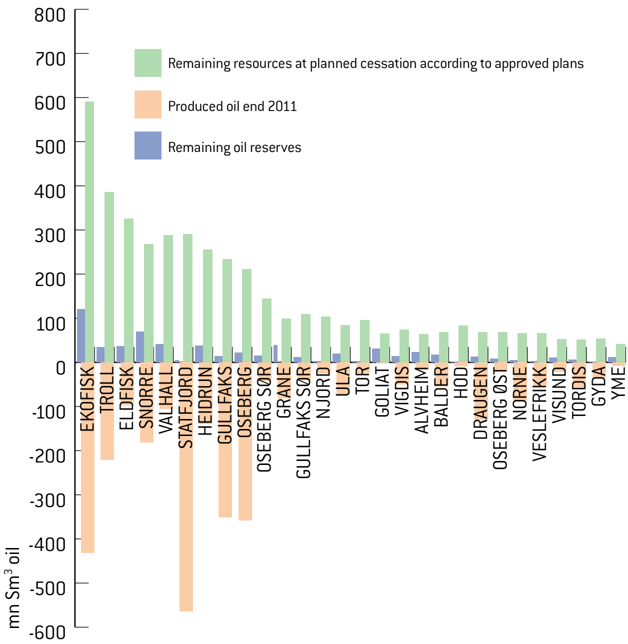
FIG 4.1: RESERVE GROWTH RELATIVE TO INITIAL ESTIMATE IN PLAN FOR DEVELOPMENT AND OPERATION.



Source: Ministry of Petroleum and Energy. St. meld. nr. 28 (2010-2011). Based on Norwegian Petroleum Directorate.

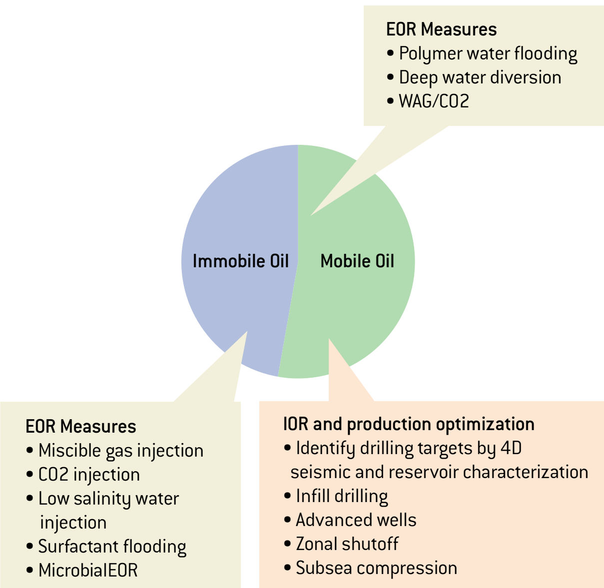
NCS has a proud history of increasing recovery over time by using new technology such as horizontal drilling, reservoir characterization, 4D seismic and new injection techniques. On average fields have added 68% reserves compared to the initial PDO, see Figure 4.1. New growth can be made with new technology in the future. Figure 4.2 shows that there will be large oil volumes left in the fields at end of production and Figure 4.3 shows a 46 % - 54% split between immobile and mobile oil volumes left in fields and technical options to attack remaining oil. Water based EOR methods have not yet been full-field implemented on NCS.

FIG 4.2: TOTAL VOLUME OF OIL (Y-AXIS) IN FIELDS DIVIDED ON SOLD (ORANGE), OIL RESERVES (BLUE), AND OIL RESOURCES LEFT AFTER END OF FIELD LIFE (GREEN) OF CURRENTLY APPROVED PLANS.2.



Source: Ministry of Petroleum and Energy. (2010). Økt utvinning på norsk kontinentalsokkel – En rapport fra utvinningsutvalget. Based on Norwegian Petroleum Directorate.

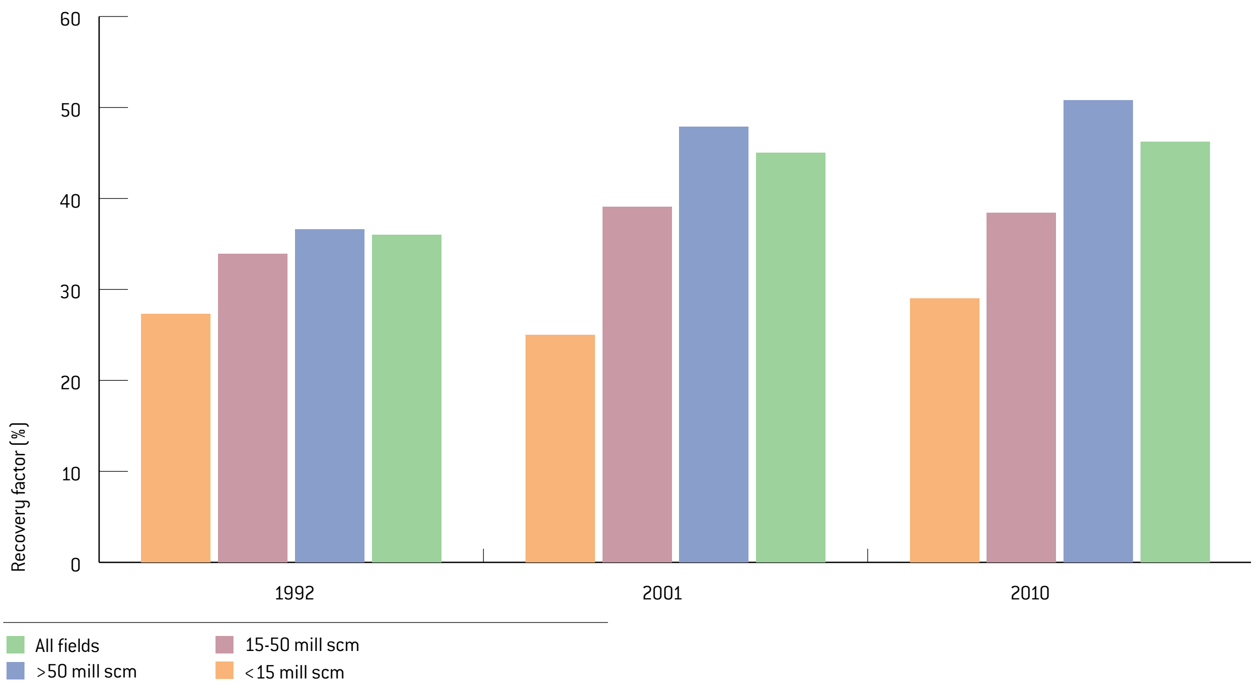
FIG 4.3: FRACTION OF OIL LEFT IN FIELDS IN PRODUCTION CLASSIFIED IN THE TYPES OF IMMOBILE OIL AND MOBILE OIL. THE BOXES SHOW IOR MEASURES THAT CAN BE USED. (BASED ON FIGURE FROM NPD).



Source: Ministry of Petroleum and Energy. (2010). Økt utvinning på norsk kontinentalsokkel – En rapport fra utvinningsutvalget. Based on Norwegian Petroleum Directorate.

Figure 4.4 shows the average recovery factor for different classes of field size. The average recovery factor for oil on NCS has flattened out since 2004. The smaller oil fields have the same average recovery factor of about 30% today as they had 20 years ago in 1992. However, the larger fields have increased from about 35% to 50%.

FIG 4.4: DEVELOPMENT OF THE AVERAGE OIL RECOVERY FACTOR FOR FIELDS OF VARIOUS SIZES.

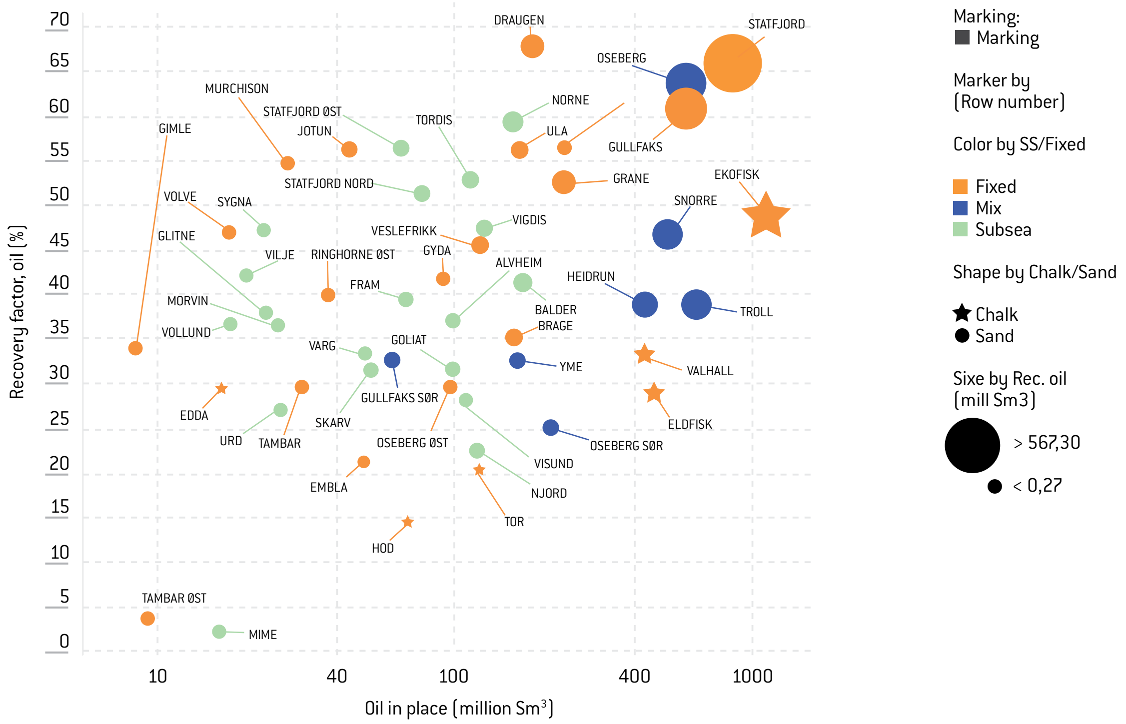


Source: Norwegian Petroleum Directorate.

Figure 4.5 shows the oil recovery factor versus volume of recoverable oil. The largest sandstone fields (Statfjord, Oseberg and Gullfaks) have high recovery factor. Statfjord is in a blow down phase to produce injected gas, while Oseberg is approaching such a phase, but still have options regarding water/gas injection. Gullfaks has water injection and options for water-based EOR. Draugen has the largest recovery factor of 67%. Subsea fields can have very high recovery factor such as Norne with above 60% or very low such Njord with 23%. Ekofisk increased the recovery factor from 17% to almost 50% by starting with water injection. On long term CO2 may be an option for the chalk fields. Heidrun, Snorre and Troll have lower than average recovery. Heidrun have permeability contrasts in the lower geological layers, Snorre has isolated fluivial sand bodies and Troll has a thin oil zone between gas and aquifer water. In-fill drilling is important for most fields. Figure 4.6 shows recovery factor for oil versus PDO year, and there is a negative trend.

To explain why fields have different recovery factors, the complexity of the fields have been looked at and correlated with the recovery factor. The recovery factor of oil, Rf, is given by three independent factors Rf=RVRHRμ, where RV is the vertical sweep efficiency (fraction of field thickness that is swept), RH is horizontal sweep efficiency (fraction of field area that is swept) and Rμ is microscopic sweep efficiency (fraction of oil pore volume that is swept). The product RVRH is volumetric sweep efficiency.

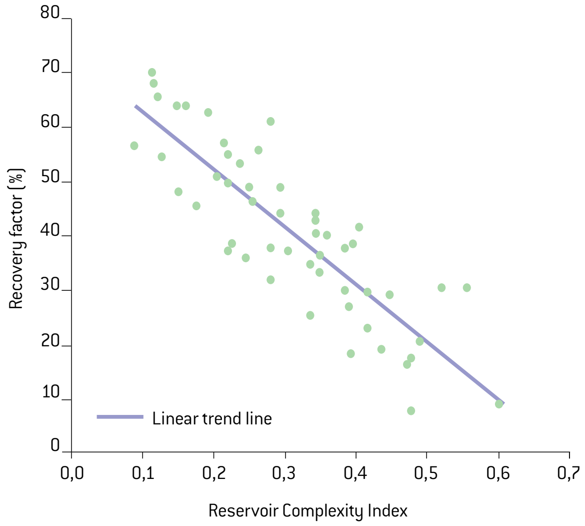
FIG 4.5: OIL RECOVERY FACTOR VERSUS VOLUME OF RECOVERABLE OIL. COLOUR CODE IS WELL TYPES (FIXED, MIXED, SUBSEA), AND SHAPE CODE IS SANDSTONE AND CHALK. (NPD RESOURCE ACCOUNT 31 DEC. 2010).



Source: Norwegian Petroleum Directorate resource account 31 Dec. 2010

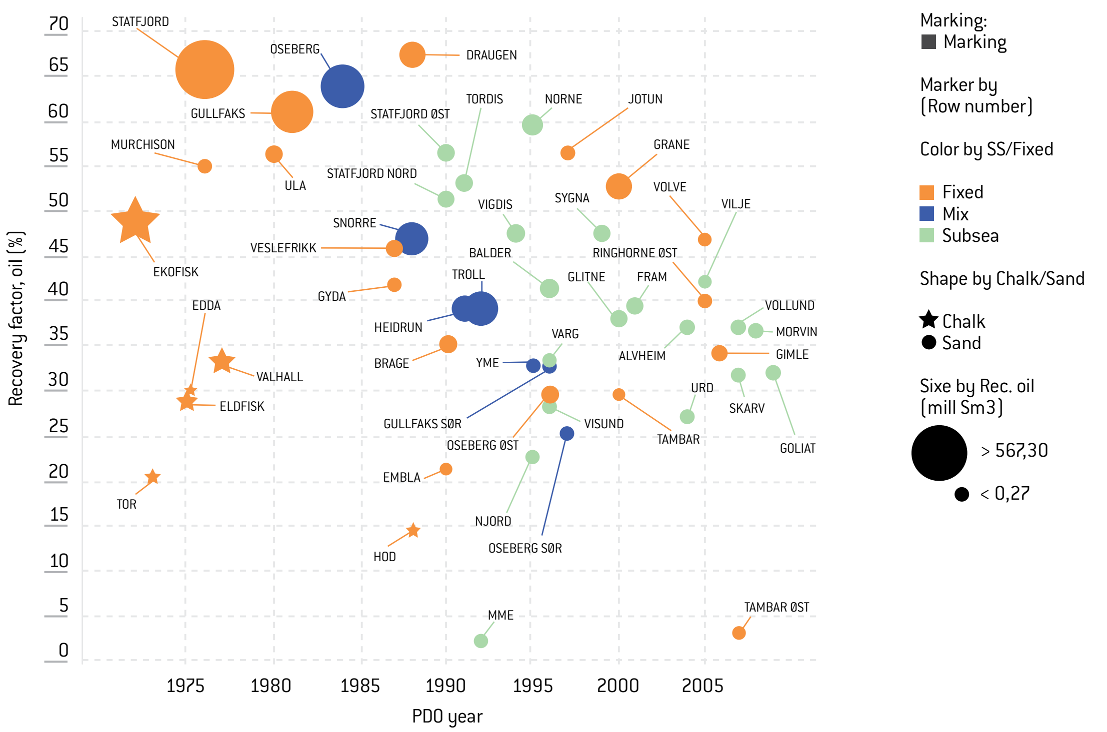
NPD's resource report 2005 showed a good correlation between recovery factor and a Reservoir Complexity Index (RCI) as shown in Figure 4.7. The RCI is a non-linear combination of the six most significant reservoir complexities on NCS: average permeability, permeability contrast, structural complexity (faults), lateral stratigraphic continuity, STOOIP density and coning tendency and the attributes of RCI factors are given in Appendix B. Since few fields have attacked immobile oil, the microscopic sweep efficiency has not been included in the RCI. One can therefore expect that reservoir complexity is a part of the explanation of the recent negative trend of the recovery factor versus PDO.

FIG 4.7: RECOVERY FACTOR (Y-AXIS) FOR OIL VERSUS RESERVOIR COMPLEXITY INDEX (RCI) FROM NPD'S RESOURCE REPORT 2005.



Source: Norwegian Petroleum Directorate resource report 2005

FIG 4.6: RECOVERY FACTOR OF OIL VERSUS PDO YEAR. COLOUR CODE IS WELL TYPES (FIXED, MIXED, SUBSEA), AND SHAPE CODE IS SANDSTONE AND CHALK. (NPD RESOURCE ACCOUNT 31 DEC. 2010).



Source: Norwegian Petroleum Directorate resource account 31 Dec. 2010

Remaining oil and gas volumes in producing fields are a great opportunity for new technology:

- Today average recovery factor for oil is 46% and for gas is 70% on NCS. Thus 54% of the oil and 30% of the gas is left when the fields are shut in with current plans.
- Recovery with today's technology and plans will leave 30 billion bbl. of oil in current fields on NCS
- 1% increased recovery gives 570 mill. bbl extra oil or gross 350 billion NOK2, p. 55
- Reserves are 19.6 billion boe. and additional recoverable resources in fields are 6.1 billion boe.

The above analysis points at the following main business challenges:

- Immobile oil constitutes about half of remaining oil in fields in production and cannot be produced by reservoir depletion or standard water or gas injection.
- Limited window of opportunity for large and mature sandstone fields with already high recovery factor
- Average oil recovery factor has flattened out
- Small fields have a recovery factor of only 30% and has not increased last 20 years
- High reservoir complexity gives low recovery

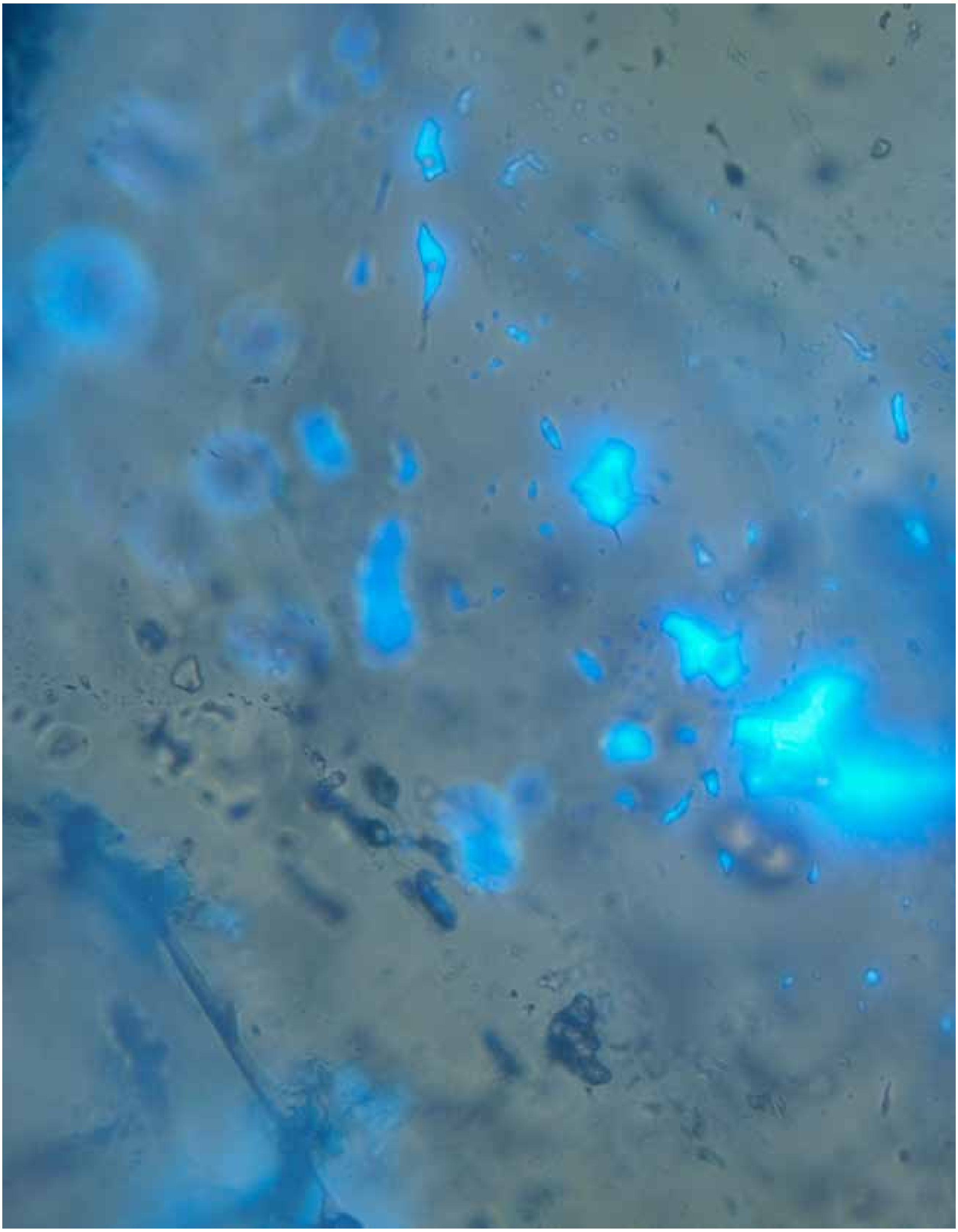
If the above business challenges are resolved it should be possible to increase the recovery according to the business case in Table 4.1.

Note that for a field with 50% recovery, a 1% point increase in recovery factor equals 2% increase in produced reserves.
Company estimates indicate that a 30% increase in cost-efficiency (increased effect or reduced cost) and 50% reduction in uncertainty of production profile will give a breakthrough for the IOR potential on NCS.
Cost can be reduced of the order of 10% - 30% by combining methods (one vessel, two chemicals) and optimizing capacity by economy-of-scale (one vessel, chemicals for two fields).
New well designs with several wells through one wellhead and subsea EOR may have similar cost reducing effect. Onshore fields have a typical well spacing of about 300 m and can add reserves up to 10% - 20 % of STOOIP (Appendix E).
Efficiency increase of 10% - 30% can be achieved through a combination of improved static and dynamic modelling and new more efficient water injection chemicals. Reservoir modelling is a more mature technology, but has a large "market" as all reservoir management is highly dependent in this technology. Chemical development is less mature, and thereby has a larger potential for technology development, but also have a smaller number of suitable fields per chemical (polymer, surfactant, etc.).

However, the technology-economic challenge should not be underestimated. Realizing this business case requires nothing less than step change technology development similar to the major step changes we have seen in the past that gave increased recovery.

TABLE 4.1: BUSINESS CASE FOR INCREASED RECOVERY.

Business case	*Description*	*Added Reserves*
Increased recovery immobile oil of fields currently in production	Add 3% on the average recovery factor, 1% gives 570 mill. Boe Ref. 2, p. 53	1.7 billion boe
Increased recovery mobile oil of fields currently in production	Add 3% on the average recovery factor, 1% gives 570 mill. boe. Ref. 2, p. 53	1.7 billion boe
Future new field developments and gas recovery	1/3 of the contribution to increased recovery of oil for fields in production	1.1 billion boe.
Sum increased recovery		**4.5 billion boe.**



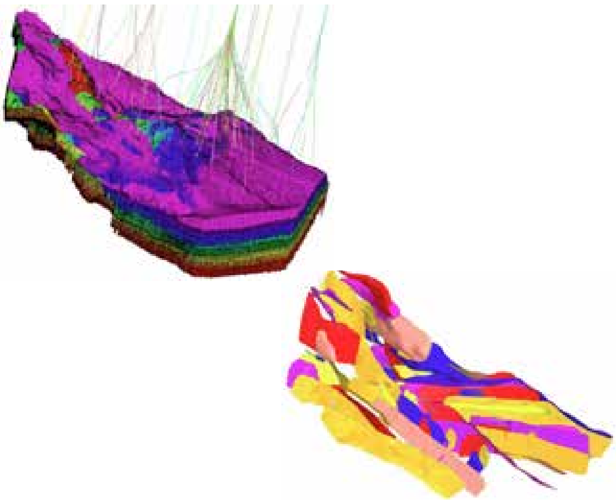
FUTURE CHALLENGES AND TECHNOLOGY GAPS WITHIN RECOVERY

Improved volumetric sweep by more wells: reservoir characterization

Reservoir characterization and good reservoir models is a basis for almost all other IOR technologies as it is a basis for dynamic reservoir simulation to calculate the economic impact of any IOR project, including in-fill drilling of complex or small targets. Reservoir modelling is illustrated in Figure 12. The capability to predict spatial distribution of rock and fluid properties of reservoirs remains a main challenge in the industry. The main sources for information about the specific reservoir complexity of a field are: 3D and 4D seismic, well logs, well monitoring and production data. Sophisticated data analysis and inversion are needed to represent reservoir fluid and rock properties. Production data are used in advanced history matching using ensembles of structural and reservoir models. Efficient and integrated visualization of a growing amount of diversified data that comes in multiple realizations is a challenge that needs to be solved.

This strategy highlights reservoir complexity as a main reason for low recovery, closing the technology gap in predicting reservoir attributes of the RCI (Appendix B) is most important.

FIG 4.8: EXAMPLES OF RESERVOIR MODEL (LEFT) AND STRUCTURAL MODEL (RIGHT) OBTAINED BY INFORMATION FROM SEISMIC, WELLS AND PRODUCTION HISTORY.



Source: Statoil

4D seismic should be further developed to become more quantitative in determining remaining oil saturation and if possible indicate the portion of mobile and immobile oil from combination with other data. Permanent seabed seismic should be cost-efficiently developed to a standard field infrastructure for complex reservoirs where extra high resolution is needed.

For example river (fluvial) deposits at Snorre are discontinuous and have a large complexity of lateral stratigraphic continuity. New seismic inversion and interpretation can better distinguish between good and poor sand. Predictions can give "the most probable" elastic properties and remaining oil saturation. Stochastic realizations give the uncertainty. There is a similar challenge to determine lateral spatial distribution of the reservoir complexity of permeability contrast between geological layers. More reliable production data are needed to improve reservoir characterization. Specifically, new technology in this area should help to increase the recovery factor of smaller fields/segments from 30% toward 60%.

New IOR- well designs

Drilling more wells is the single most important contribution to increased recovery and has its own TTA 3 strategy. We included this section on new IOR-well design to support the TTA 3 strategy with reservoir drainage perspectives on new well designs to specifically address the reservoir complexity on NCS. The following reservoir types may be produced with new well designs:

- Low average permeability
- Low STOOIP density
- High structural complexity: segmented reservoir
- Large coning tendency
- Depleted reservoirs
- Small marginal fields

Complex or small reservoirs could increase the recovery factor from about 30% toward 40%-60% by using new well designs.

Ideas for new well designs include:

- *Increased well density*: The current well density is given by the current well cost, so the unit well cost must be reduced. One may investigate new low cost multi-branched vertical/slanted/horizontal wells that share infrastructure cost of subsea templates, wellheads and upper well sections, so that the well cost scales less than proportional to the number of branches. Multi-branched wells may combine injectors and producers (some branches in Figure 4.9 are replaced by injectors).
- *Production of offshore low permeable reservoirs*: Adopt "shale gas" well designs offshore: multifrac, multibranched, horizontal wells.
- *Standardized subsea EOR water injection systems*: subsea EOR water injection systems based on treated raw sea water. Treatment include desalination and adding EOR chemicals subsea.

Closing this technology gap requires goal directed multidisciplinary R&D.

Mapping, release and transport of "immobile" oil

About half of the remaining oil in producing fields on NCS is immobile with standard water or gas injection methods. Water-based EOR methods (chemical methods) and miscible gas injection methods (CO_2) can be used to remobilize and produce remaining immobile oil. Gaps on EOR methods are treated in next section while the more fundamental gaps related to immobile oil are treated here.

There are knowledge gaps on how oil is immobilized and mechanisms to remobilize and transport residual oil. Immobile oil can be trapped by snap-off (isolated oil in large water-wet pores), and by-passed by microscopically capillary fingering or due to small scale heterogeneities. For example the degree of snap-off increases with pore to pore-throat ratio, so well sorted sand with cemented pore throats should have higher immobile oil saturation than non-cemented pore throats. A more precise knowledge of these mechanisms could be used to estimate the volumetric distribution and type of immobile oil. Mapping of immobile and residual oil after water flooding on different scales may take into account size distribution and spatial correlation of oil clusters and small scale geological heterogeneity.

Recent development in micro flooding CT scanner technology and pore-scale flow/network simulations opens up new ways to gain fundamental insight. Still phenomena of fundamental importance for recovery of immobile oil, such as how crude oil wets the rock through nano-metre scale water films are not well understood. There can be spin-offs from chemistry (ion-exchange), physics, nano-technology and micro fluidics to petroleum technology. Special design molecules and particles should be explored to mobilize trapped oil. The goal of this research is to break through the barrier of implementing the first full field water-based flooding for producing otherwise immobile oil.

FIG 4.9: ILLUSTRATION OF THE DIMENSIONS OF MULTILATERAL HORIZONTAL.

Source: Statoil

Enhanced oil recovery

Table 4.2 shows a rough estimate of added reserves for enhanced oil recovery (EOR) methods in suitable NCS fields. The percentages in the table are added to the recovery factor in (%). The challenge is that up till now these methods have not been economic. Onshore fields have proven up to ten times greater percentage increase than in Table 4 (see Appendix E). Apparently, there is a great potential in combining high well density and EOR methods.

Large IOR technology implementation projects may have pilots that cost 0.1-1 billion NOK and full field implementation that cost 1-10 billion NOK. It is challenging for a license to justify large EOR projects with a relatively small and uncertain added production distributed far in time. The economy is typically marginal or negative. New technology can improve the economy in three ways: increase added reserves, reduce cost of implementation, and reduce uncertainty in added, see Figure 4.10. This economic situation applies to most IOR measures including the multibillion cost of a new subsea well template for infill drilling and the cost of subsea re-compression.

Specific gaps on EOR related to increasing added reserves and reducing uncertainty are:

- Design new super efficient EOR chemicals: for example grafted polymers with functional surfactant groups (or viscoelastic surfactants), field-specific deep water-diversion molecules and low cost super surfactants
- Dynamic simulation models with more physical effects including polymer degradation, adsorption, chemical reaction, ion exchange and wettability alteration
- Upscaling of EOR methods to recover by-passed oil located in heterogeneities

Another way to optimize the EOR economy is by reducing unit cost by cost sharing through combination of methods or combining fields. Examples are:

- Deep water diversion + polymer flooding: double IOR effect and reduce polymer consumption
- Polymer flooding + surfactant flooding: double IOR effect and lower chemical cost (if two functions in one molecule)
- Low salinity flooding + surfactant/alkaline (in situ soapification) flooding: double IOR effect and reduce chemical cost by less surfactant adsorption
- Economy of scale to reduce unit cost: One EOR vessel serving two fields

TABLE 4.2: ROUGH ESTIMATE ENHANCED RECOVERY METHODS FOR SUITABLE NCS RESERVOIRS.

EOR Method	*Added reserves in (%) of original in place oil volume (STOOIP)*	*Type of reservoir complexity or oil*
Polymer flooding	3%	Viscous oil, permeability contrast
Deep water divergence/blocking	2%	Permeability contrast, lateral stratigraphic continuity
Surfactant flooding	5%	Immobile oil
Low salinity flooding	**2%**	**Immobile oil**
Microbial enhanced recovery	2%	Immobile oil
CO_2 flooding	5%	Mobile and immobile oil
WAG/CO_2	5%	Vertical distribution of mobile oil

Challenges and gaps for chalk fields

Chalk fields have some features that distinguish them from the sandstone fields:

- Produce slower and are typically not time critical for EOR, such as CO2
- Is softer than sand: chalk is prone to rock compaction and subsidence
- Has a different wettability and chemistry than sand: chalk as opposite surface charge and react differently to chemicals than sand
- Has two types of porosity: pores and fractures
- Has extremely high porosity up to 50%, and still very low permeability (ffmD)

It is recommended that each of these features has a special focus though

- Coupled geo-mechanical/flow models
- Rock mechanics (weakening) due to CO2 and EOR chemicals
- Reliable dual porosity dynamic simulation tool
- Well stimulation by fracturing
- EOR wettability alteration by adding ions to water

Overview of technology gaps

An overview of technology gaps is given in Table 4.3. Notes are given below the table. The total cost is 2.6 billion NOK.

FIG 4.10: NEW IOR TECHNOLOGY TYPICALLY OPTIMIZES OIL AND GAS VOLUMES OR REDUCES THE UNCERTAINTY OF THE VOLUME ESTIMATE, BOTH ARE CENTRAL IN DECISION MAKING.

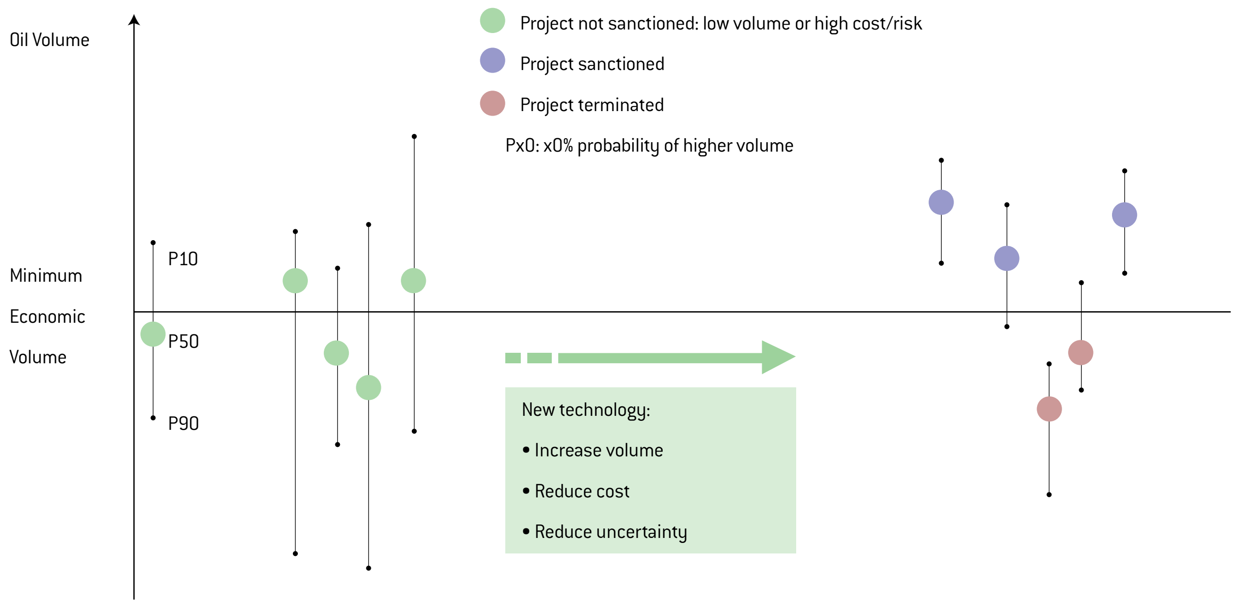


TABLE 4.3: OVERVIEW OF TECHNOLOGY GAPS WITHIN INCREASED RECOVERY. *Table continues on the next page.*

Technology gap	*Time to market (year)*	*Cost (MNOK)*	*Criticality Business Case (L,M,H)*	*Global market value (L,M,H)*	*OG21 Strategic Goals Prioritized order*	*Main barriers*
Improved volumetric sweep: reservoir & fluid characterization Identify complex and marginal in-fill drilling targets: Reservoir characterization, 3D/4D seismic, logs and production data Identify innovative technology to improve volumetric sweep	1-10	500	H	H	1,4,3,2	Competence and innovation capability , permanent seismic
New multi branched EOR/IOR well design for higher well density of reservoir with high reservoir complexity index with combined injection and production. Subsea EOR "plug and play"	8-10	400	H	H	1,3,4,2	Multidiscipline R&D: reservoir + drilling & well
Mapping, release and transport of "immobile" oil: Microscopic oil trapping mecha-nisms (snap-off and by-passing) and immobile oil cluster size distributions for different reservoir types Macroscopic mapping of immobile oil Crude oil wettability	5	300	H	H	1,3,4,2	Highly time critical, Justify test/pilot, all the way from fundamental R&D to full field

• Avoidance of oil trapping ***Immobile oil release and transport mechanisms (i.e. low salinity, MEOR, surfactant, wettability alterating agents, visco-elastic polymer)***	implementation in a few years

Notes to the table: "Cost" relates to development costs from idea to qualified technology (excluding piloting and field implementation costs), "Criticality" is related to the need for addressing the technology gap for realization of the business case, "Global market value" relates to a global possible market for each technology gap. "OG21 strategic goals" are given as follows: 1) value creation through production and reserve replacement, 2) Energy efficient and cleaner production, 3) Increased export and 4) Value creation through employment and competence development.

Technology gap	*Time to market (year)*	*Cost (MNOK)*	*Criticality Business Case (L,M,H)*	*Global market value (L,M,H)*	*OG21 Strategic Goals Prioritized order*	*Main barriers*
Decision support for EOR: reduce uncertainty by 50% Improve dynamic simulation and measurement of EOR processes to reduce uncertainty on value by 50% EOR methods: polymer flooding, deep water diversion (water shut off), deep gas diversion (foam), low salinity water flooding, surfactant flooding, MEOR	5	300	H	H	1,3,4,2	Justify test/pilot, capacity, competence and time critical
Optimize combined EOR methods by 30%: Find the ideal cocktail (i.e. low salinity + polymer + surfactant + water diversion) Identify new methods and/or hybrids (i.e. ASP) Develop new super chemicals Use nano-technology for EOR	2-7	600	H	H	1,3,4	Environmental acceptance, time critical capacity of competence and products
Chalk specific technology: Coupled geomechanical/flow models Rock mechanics (weakening) due to EOR chemicals and CO2 Reliable dual porosity simulation tools	5-15	500	H	M	1,4	Competence

Notes to the table: "Cost" relates to development costs from idea to qualified technology (excluding piloting and field implementation costs), "Criticality" is related to the need for addressing the technology gap for realization of the business case, "Global market value" relates to a global possible market for each technology gap. "OG21 strategic goals" are given as follows: 1) value creation through production and reserve replacement, 2) Energy efficient and cleaner production, 3) Increased export and 4) Value creation through employment and competence development.

ENVIRONMENTAL CONSIDERATIONS

Exploration and increased recovery technology reduce subsurface uncertainty through better static and dynamic reservoir modelling and prediction. Accurate prediction of subsurface fluid pressure and flow capacity are important parameters in kick and blow-out risk estimation, both in terms of probability of kick and blow-out occurrence and the consequence in terms of blow-out flow rate, duration and discharged oil volume. Thus, the TTA2 technology has a potential to reduce blow-out risk. One should seek opportunities to implement subsurface uncertainty-reducing technology into blow-out modelling.

Oil production in general and EOR projects may contribute to increased potential harmful emissions to air and discharges to sea. CO2 injection is environmentally attractive. However, all types of gas injection will result in emission to air related to production of compression energy.
Water based EOR techniques often involve injection of large amounts of chemicals into the reservoirs (polymers, surfactants and other chemicals). Ideally these chemicals should be retained in the reservoirs, but it may be unavoidable that significant amounts will reach the production wells. It is unrealistic to separate all the chemicals from the produced water. This problem must therefore be solved either by using chemicals that can be discharged to the sea, or by re-injection of produced water preferably to the production reservoir.

The first solution will strongly restrict the choice of chemicals for a given application and the most effective chemicals may have to be excluded. Re-injection of produced water will eliminate potential emissions (except for the injection pump compression energy), and the restrictions in choice of chemicals should disappear. This will also solve the problem of discharge of oil residues and possible production chemicals to the sea. Re-injection of produced water has been taken into use in many Norwegian oil fields.

Injection of low salinity water is an EOR technique that recently has received attention. For this process the sea water has to be partly or fully desalinated and salt (NaCl) may be discharged to the sea. From an environmental perspective this process is unique as no foreign components will be discharged to the sea, only salts that already are present in abundance.
Implementation of EOR techniques may result in production of the targeted amounts of oil in a shorter time compared to continued water flooding. This will gain the environment due to total lower emissions of harmful components related to energy production and of the pollutants to the sea that normally follow oil production.

Exploration has environmental considerations regarding blow-out risk in exploration drilling, and as shown above new TTA2 technology should contribute to reduce this risk. There is an effect of seismic on fish and mammals. Many studies have been performed to investigate a lot of these issues, and will not be covered here. The TTA 1 group is dedicated to environmental considerations.

R&D PRIORITIES, TIME FRAME AND FUNDING

Priorities are based on:
- Value & volume potential
- Time criticality
- Competence
- Service industry development
- Innovation

Main priorities for increased recovery:
1. Optimized combined EOR methods
2. Improved volumetric sweep: reservoir & fluid characterization
3. Mapping, release and transport of "immobile" oil
4. New IOR-well designs
5. New technology for chalk fields

Main priorities for exploration:
1. Large scale (basin & play) integrated geologic process and modelling
2. Geophysical acquisition, processing, imaging and joint interpretation
3. Special arctic technology and micro seepage

Increased recovery is prioritized higher than exploration due to the higher time criticality of increased recovery for mature fields and technologies with a great added reserve potential are not piloted and full-field implemented on NCS.

ROADMAP FOR THE FUTURE

FIG 7.1: ROADMAP FOR ONE TYPICAL TECHNOLOGY.

RECOMMENDATIONS FOR PUBLIC FUNDING

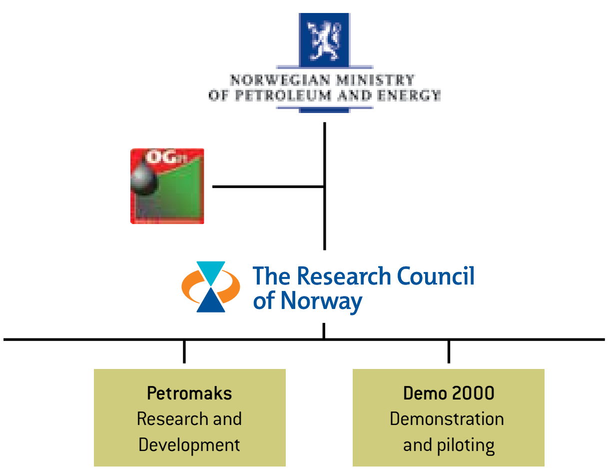
Both exploration and increased recovery technology are valuable for Norway. Overview of previous funding 2004-2010 for exploration and reservoir characterization is given in Appendix D. Increased recovery is prioritized higher than exploration due to:

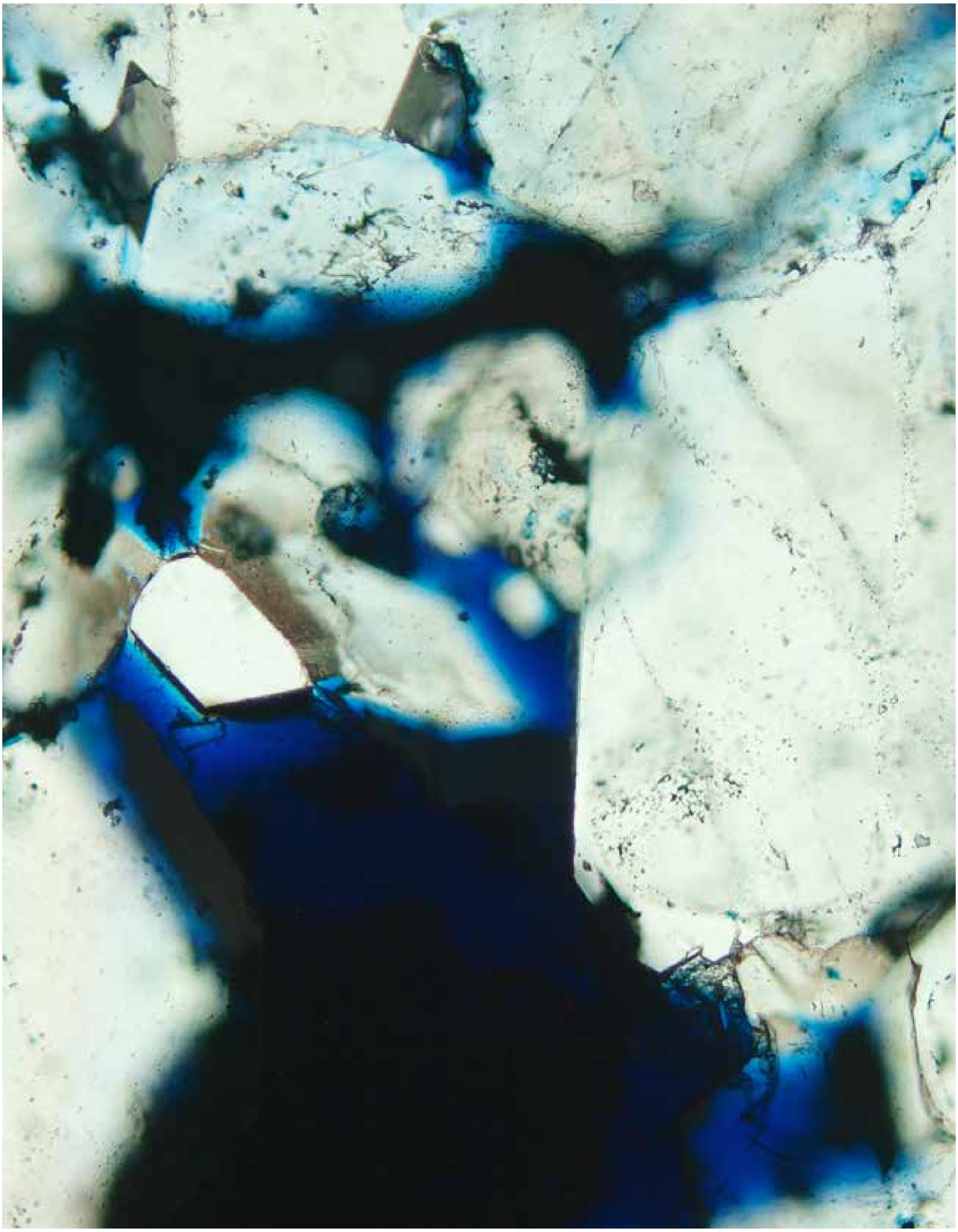
- Increased recovery technology is highly time critical, especially for mature fields
- Increased recovery technology with high piloting and implementation costs are blocked for piloting and full-field implementation due to lack of optimization and too large uncertainty
- Immobile oil has a great "under-explored" potential

The public should support technology and competence development (PhD, postdoc) to un-lock the greatest value potentials for NCS and especially where each licence cannot justify pilots or implementations due to high cost and large uncertainty with today's technology.

1. The priority list for public funding (Figure 8.1) is:
2. Mapping, release and transport of "immobile" oil
3. Improved volumetric sweep: reservoir & fluid characterization
4. Optimized combined EOR methods
5. Large scale (basin & play) integrated geology and geophysics modelling
6. New IOR-well designs
7. Geophysical acquisition, processing, imaging and joint interpretation
8. New technology for chalk fields
9. Special arctic technology

FIG 8.1: OG21 RELATED TO MPE AND RCN.





TTA3
FUTURE TECHNOLOGIES FOR COST-EFFECTIVE DRILLING AND INTERVENTION

Lead Party
ExxonMobil

TTA3 group companies and organizations:
BP, ENI, GDF-Suez, Shell, Statoil, Total, CMR, IRIS, SINTEF, NTNU, Aker Solutions, eDrilling Solutions, FMC, GE Oil and Gas, Schlumberger.

CONTENT TTA 3

EXECUTIVE SUMMARY

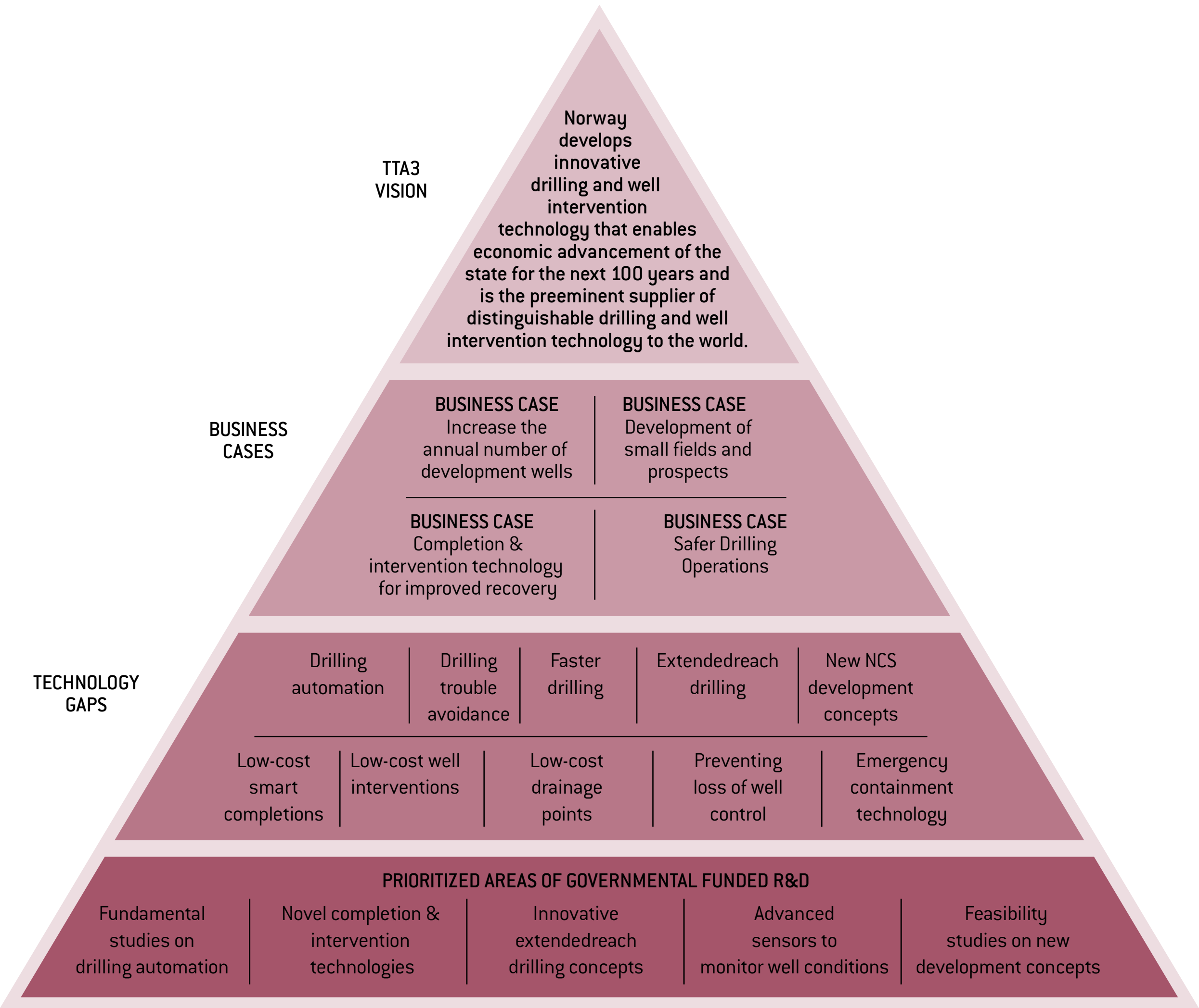


FIG ES 1: VISION, BUSINESS CASES, TECHNOLOGY AND COMPETENCE NEEDS, AND PRIORITIZED AREAS FOR GOVERNMENT FUNDING FOR OG21 TTA3

The OG21 Cost-effective Drilling and Intervention (CEDI) Technology Target Area (TTA3) has been sanctioned by the OG21 Board to help implement the strategy in the areas of drilling and well intervention. This document proposes the substrategy for TTA3.
The key focus of the substrategy is the identification of key strategic technology needs in the areas of drilling and well intervention.

These key strategic drilling and well intervention technology needs are primarily based on development of four broad business cases directed at enhancing NCS recovery and operational integrity. The business cases are:

- Increase in the Annual Number of NCS Development Wells Drilled,
- Completion and Intervention Technology to Increase Field Recovery,
- Development of Small Drilling Prospects and Fields,
- Safer Drilling Operations.

A gap analysis has been performed to assess the key strategic R&D needs to be addressed for the business cases to be successful. These key strategic R&D needs are:

- Drilling automation to improve drilling efficiency and safety,
- Drilling trouble avoidance,
- Faster drilling,
- Extended-reach drilling,
- New small field development concepts,
- Reliable low-cost smart completions,
- Low-cost well interventions,
- Technology for low-cost drainage points,
- Improved technology to prevent a loss of well control,
- Technology for capping and containment of NCS wells

In addition to the key strategic R&D needs for the business cases, several other drilling and well intervention gaps related to the OG21 goals have been identified. These are

- Technology for reducing well abandonment costs,
- Technology for production from fields with low permeability and/or abnormal pressure,
- More environmentally-friendly drilling and intervention technology,
- Deepwater drilling and completions,
- Cost-effective arctic drilling,
- Basic geomechanical research and competence development.

In terms of government funding, the priority should be placed on the following areas.

1. Fundamental studies related to drilling automation to enhance drilling efficiency
2. Innovative completion and intervention technology to improve recovery
3. Innovative concepts for step-out extended-reach drilling to enable development of small prospects
4. Development of advanced sensors to monitor well conditions during drilling and production
5. Feasibility studies on new development concepts/platforms for small fields

Additional recommendations include:

- The overall OG21 goals should include an increased emphasis on safety in all aspects of hydrocarbon production.
- The perceived gaps in addressing the key strategic drilling and well intervention R&D needs should be communicated to the principal developers and suppliers of new drilling and well intervention technology, including the service companies, research institutes, universities, operators, and other organizations involved in drilling and well intervention technology development.
- The needs and gaps in the area of drilling and well intervention should be reviewed on an annual basis and communicated to the appropriate government agencies.
- The government should increase seed funding via the Research Council of Norway for proposals that address the strategic drilling and well intervention needs.
- Where consistent with business interests, operators should consider increased funding for development of drilling and well intervention technology that meet the strategic needs for Norway.
- The industry should develop new creative partnering and risk sharing models for development of capital-intensive new drilling and well intervention technology.

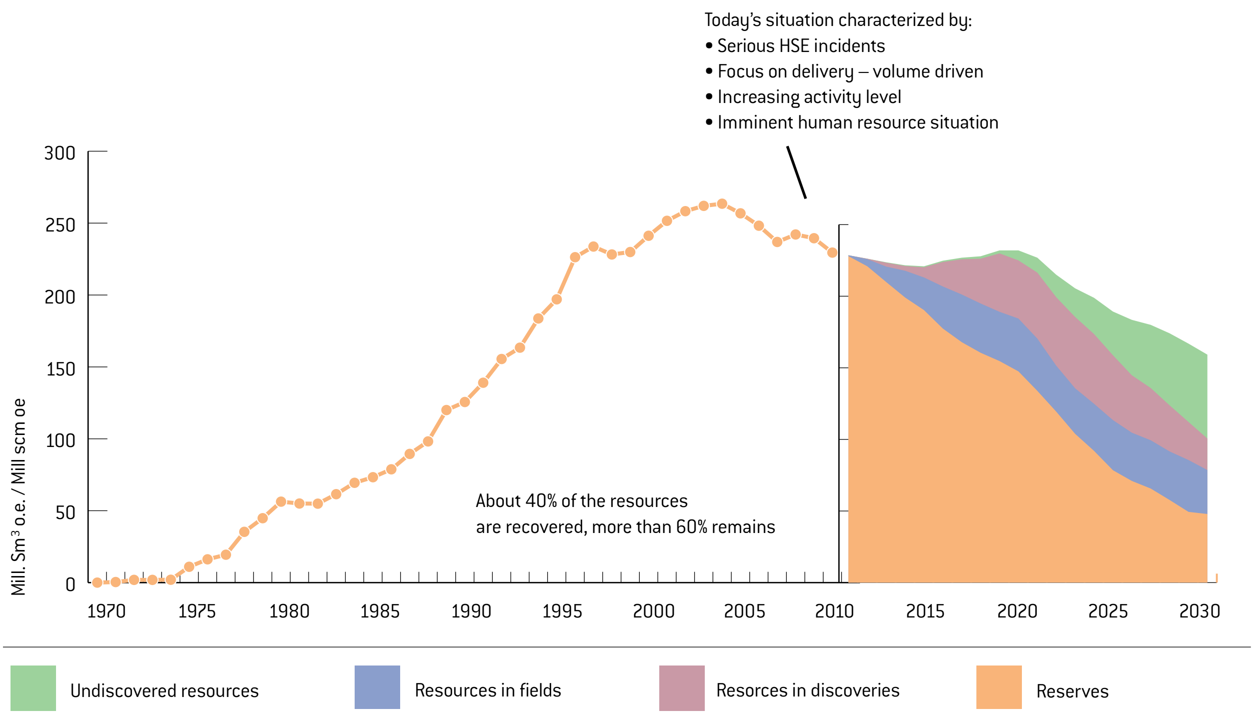
Figure ES 1 provides a summary chart showing the vision, business cases, technology and competence needs, and prioritized areas for government funding for TTA3.

TTA3 VISION

The vision for TTA3 is that Norway develops innovative drilling and well intervention technology that enables economic advancement of the state for the next 100 years and is the preeminent supplier of distinguishable drilling and well intervention technology to the world.

"The vision for TTA3 is that Norway develops innovative drilling and well intervention technology that enables economic advancement of the state for the next 100 years"

FIG 2: HISTORICAL PETROLEUM PRODUCTION AND FORECAST PRODUCTION UP TO 2030



Source: Norwegian Petroleum Directorate.

BUSINESS CASE 1: INCREASE IN THE ANNUAL NUMBER OF NCS DEVELOPMENT WELLS DRILLED

BUSINESS CASES FOR TECHNOLOGY DEVELOPMENT

To help understand some of the challenges and technology needs in the area of drilling and well intervention, several hypothetical NCS "business cases" are presented. The idea is to identify a business concept that has potential value, but that also has a number of key technology gaps that would need to be addressed for the business concept to be successful. Four business cases that have gaps in the drilling and well intervention area are presented:

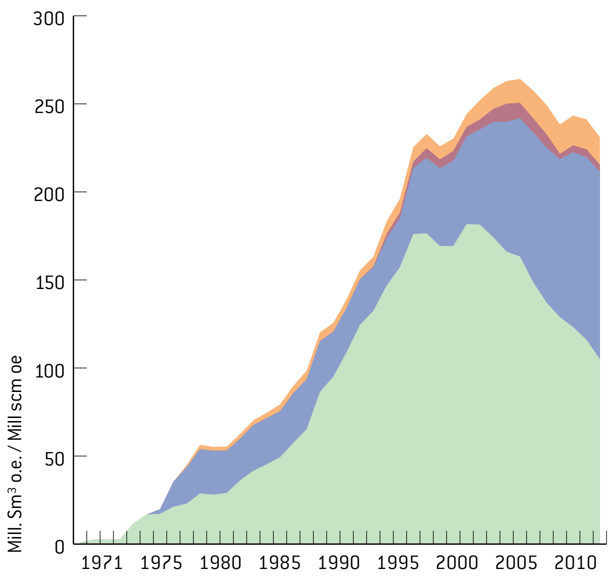
- Increase in the Annual Number of NCS Development Wells Drilled,
- Development of Small Drilling Prospects and Fields,
- Completion and Intervention Technology to Increase Field Recovery, and
- Safer Drilling Operations.

For each business case, the motivation and potential value are discussed and key technology gaps are presented. For each business case, a table is provided discussing the time frame for addressing each gap, the cost level, time criticality, market value, and OG21 strategic goals that would be addressed by the technology development effort.

Business Case 1: Increase in the Annual Number of NCS Development Wells Drilled

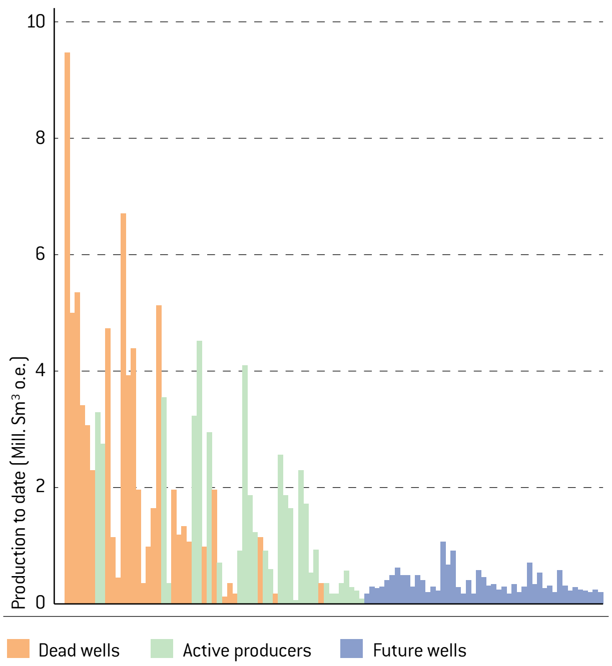
More than 60% of the NCS endowment of hydrocarbons remains to be recov ered (see Figure 2). Yet, the annual production of hydrocarbons has been declining since the peak in 2004 and is forecast to continue this decline, especially for oil (see Figure 3). In addition, the reserves recovered per well are decreasing due to smaller reservoir targets as the bigger targets get drilled (see Figure 4). The result is that significantly more wells will need to be drilled

FIG 3: TOTAL PETROLEUM PRODUCTION



Source: Norwegian Petroleum Directorate/Ministry of Petroleum and Energy

FIG 4: THE RESERVES CAPTURED PER WELL IS FORECAST TO SIGNIFICANTLY DECREASE



Source: Statoil

each year to achieve production targets. In addition, one of the main conclusions of the 2010 Åm IOR report (Reference 2) is that the best way to increase recovery of Norwegian oil and gas is to drill more wells.

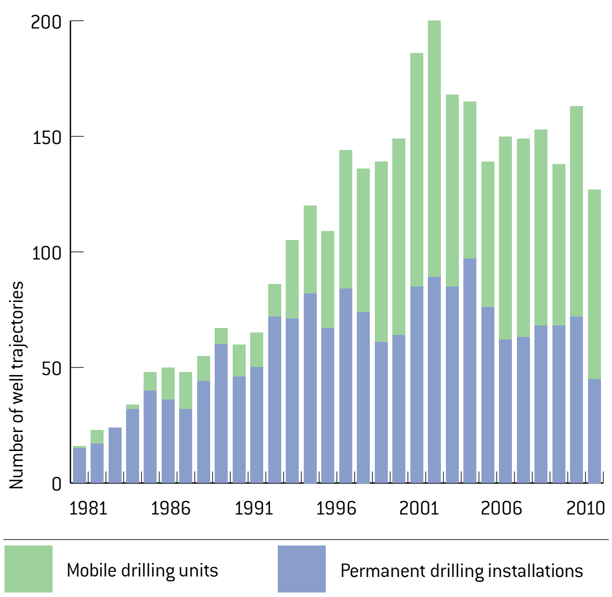
While more production wells are needed, the annual number of NCS production wells drilled has actually been decreasing from a peak of about 200 in 2001 to about 130 in 2010, a decline of 35 percent (see Figure 5). In the six largest fields, the annual number of production wells drilled has been halved (from about 60 to 30) over the last eight years (see Figure 6). This is in contrast to the number of exploration wells which has significantly increased over the last five years. Perhaps the main reason for this decrease in production wells is that the average cost of each well has increased. For example, the average cost of each production well drilled in the six largest fields has more than doubled in the last four years (Figure 6). This is due to a variety of factors, including increasing well complexity, market forces that increase rig rates, and regulations that limit rig supply and increase labour costs. The net effect of the smaller reservoir targets and increased well costs is that it is harder to bring forward profitable well projects on NCS, and thus the number of wells drilled declines. For the larger fields, this is exacerbated by the fact that most of the sweet-spot targets have been drilled.

There are a number of additional reasons why the annual number of production wells has declined. These additional reasons include:

- Rigs are increasingly being used for well interventions,
- Increased completion complexity requires more rig time,
- Increased time required for maintenance of drilling facilities,
- Lack of rigs approved to operate on the NCS, and
- Increased use of NCS rigs for exploration and appraisal.

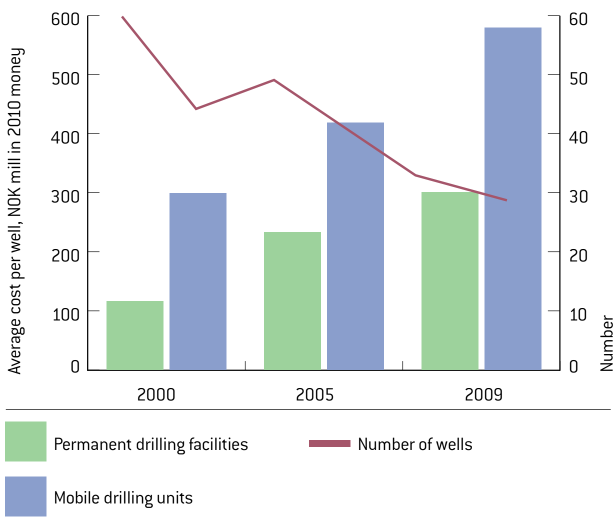
OG21 is a technology strategy for Norway. While many of the causes of high well costs are nontechnical, such as labour and safety regulations, there are a number of technical solutions that should be considered. What is primarily needed is drilling technology to reduce drilling and completion times and well costs. The key technology gaps are discussed below.

FIG 5: NUMBER OF DEVELOPMENT WELL STARTS EACH YEAR (NPD)



Source: Norwegian Petroleum Directorate

FIG 6: NCS DRILLING COSTS AND NUMBER OF WELLS IN 6 LARGEST FIELDS (FROM PETORO)



Source: Norwegian Petroleum Directorate.

Key Technology Gap: Drilling automation

If properly developed and implemented, increased automation of the drilling process should allow faster drilling with less trouble and cost. While the industry has made some advancements in automating the drilling process (e.g., the Iron Roughneck), there is still a long way to go before the process of constructing a well is fully automated. Automated well construction would be somewhat analogous to using an autopilot to fly an airplane. The operator would select the target, and then the rig would drill the well to the target. While this full capability is a long way off, elements of rig automation could be very valuable today. If well construction could be made more automated, a number of benefits would likely accrue:

- Improved safety (fewer people in harms way)
- Improved efficiency (e.g., optimized ROP)
- Reduced well cost (fewer people required on the rig)
- Improved recovery factors (via more and better wells)

As an example, Figure 7 shows an automated pipe handling system that would allow connections to be broken or made up while tripping the pipe (see Reference 4).

FIG 7: PROPOSED RIG SYSTEM THAT ALLOWS CONNECTIONS TO BE MADE/ BROKEN WHILE TRIPPING (COURTESY WEST DRILLING PRODUCTS)

Studies (Reference 4) have shown that just automating the tripping process could result in a well cost savings on the order of 15-25%, both due to time savings and reduced problems associate with conventional tripping.

And automation and optimization of the process of breaking rock with the drill bit could easily achieve similar savings (e.g., Reference 5).

Key Technology Gap: Drilling trouble avoidance

Technology is needed to help avoid drilling trouble, especially in real time (RT). Reducing drilling trouble, which can be as high as 35% of well costs, will help improve project economics and thereby allow more wells to be drilled. Such technology might include:

- Realistic RT integrated drilling simulation models,
- RT diagnosis & decision support methods and technology,
- Advisory technology for more optimal drilling, and
- Virtual wellbore/visualization.

In some cases, drilling is limited by small margins between the fracture pressure and the downhole circulating pressure. These small margins often lead to drilling trouble (e.g., lost returns or hole instability). In these cases, managed pressure drilling (MPD) can help drill through a small drilling margin window. MPD involves using rotating well control devices and chokes on the mud returns. Qualification of MPD for drilling from floating rigs offshore Norway is needed.

Key Technology Gap: Faster drilling

Technology to increase the overall rate of penetration is also needed to facilitate drilling more wells. This technology might include new technology to mitigate downhole vibrations of the drill string. Vibrations can hinder penetration rates by sapping energy and creating bit wear. Vibrations can also cause non-productive time due to damage of downhole equipment. Technology might involve improved modelling and design of the drill string and/or improved equipment to dampen drill string vibrations. Fundamental studies are also needed to understand the effect of drilling fluid properties and pressures on drill string vibrations and drilling rate. Such studies could also impact drilling automation by requiring improved automation of the drilling fluid circulation system.

In addition, development of robust, systematic limiter redesign processes is needed. In many cases, the limits to faster drilling are not related to the bit or rock, but rather to other drilling issues such as hole cleaning or connection time or flat time associated with casing operations or formation evaluation. A comprehensive system to understand what is the true limit to increased drilling rate is needed.

Technology for new methods of drilling, such as particle impact drilling or electric drilling, should also be considered as a means of improving drilling efficiency.

Also, technology to facilitate specialized and/or batch drilling can often reduce costs. For example, a specialized rig dedicated to just setting the top hole casing for subsea wells might be beneficial on the NCS.

The following table lists some of the key technical gaps that need to be addressed to increase the annual number of development wells on the NCS.

TABLE 1: TECHNICAL GAPS FOR INCREASING THE NUMBER OF NCS DEVELOPMENT WELLS

Key Technology Gap	*Gap*	*Time to complete (yrs)*	*Costs (MNOK)*	*Criticality*	*Market value*	*OG21 strategic goal*	*Barriers*
Drilling Automation	Improved drilling data quality	2-4	10-40	High	High	1,2,3,4	Innovation Cost
	Closed loop system that optimizes drilling parameters	3-6	3-10	High	Medium	1,2,3,4	Reliable downhole data Integration of all drilling systems
	Automated pipe handling that makes/breaks connections while tripping	3-7	50-150	Medium	Medium	1,2,3,4	Innovation Cost Reliability Demonstration
	Automated BHA selection and makeup	3-7	50-150	Medium	Medium	1,2,3,4	Innovation Cost Demonstration
	Automated drilling rig	10-20	3000-6000	High	High	1,2,3,4	Innovation Cost Demonstration
Drilling Trouble Avoidance	Trouble Avoidance Technology (RT advisor)	5-10	10-40	High	High	1,2,3,4	Reliable RT data Cost Demonstration
Faster Drilling	Understanding effect of fluid properties on drilling vibrations and drill rate	2-4	4-15	High	Medium	1,2,3,4	Physics understanding Modelling Verification
	Faster Overall Drilling Technology (limiter redesign process)	3-6	3-10	High	High	1,2,3,4	Innovation Cost Demonstration

BUSINESS CASE 2: DEVELOPMENT OF SMALL DRILLING PROSPECTS AND FIELDS

DEVELOPMENT OF SMALL DRILLING PROSPECTS AND FIELDS

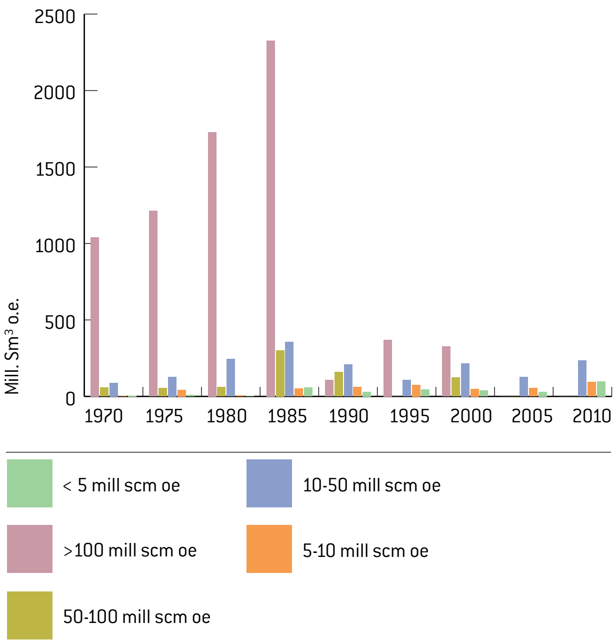
As indicated in Figure 8 (and Reference 6), the size of new discoveries on the NCS is declining. The average discovery size is in the future is forecast to be 50-100 million boe. This contrasts with the large fields in the past such as Ekofisk, Statfjord, Gulfaks, Snøvhit, or Ormen Lange were the field size exceeds 1000 million boe.

In addition, there are numerous small prospects around existing fields that are not currently economic to develop. To make these smaller fields and prospects profitable, it is increasingly necessary to come up with new drilling and development approaches.

Konkraft has estimated that the potential development of small (< 50 bn boe) discoveries could add 2 bn boe by 2040 (Reference 7). Another indication of value is the fact that the average annual number of plans for development and operation (PDO) is significantly less than the average number of discoveries each year. For example, there were 28 new discoveries in 2009 and 16 new discoveries in 2010, but only four PDOs for new fields were submitted in 2010 and only about seven PDOs are expected in 2011 (Reference 8). This suggests that many of the discoveries are too small to be economic with current technology.

This business case proposes development of drilling technology and field development concepts to facilitate profitable development of small fields.

FIG 8: RESOURCES IN DISCOVERIES PROVEN IN FIVE-YEARLY PERIODS BY DISCOVERY SIZE, 1966-2010



Source: Norwegian Petroleum Directorate.

KEY TECHNOLOGY GAP: EXTENDE D-REACH DRILLING

For small prospects near existing infrastructure, one approach is to use existing drilling facilities to drill the prospects using extended-reach drilling (ERD). ERD wells drilled from existing platforms are often an efficient way of draining remote accumulations of hydrocarbons. A good analog example is the Sacate field offshore California, where 10+-km ERD wells are being used to capture reserves from an existing platform where the water depth is about 350 m. These reserves are not economic to produce using alternative development concepts, including subsea wells (Reference 9). ERD wells could also be a cost-effective way of drilling exploration prospects from existing drilling centres. Currently, the industry record for the horizontal departure for ERD wells is approximately 12 km. However, to reach some fields and prospects from existing NCS infrastructure, it is necessary to increase the horizontal reach of such wells to 15 or 20 km.

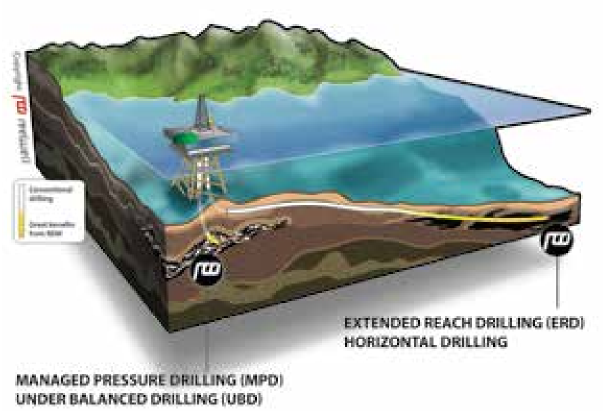
Extended-reach wells drilled from existing platforms are an efficient way of draining remote accumulations of hydro-carbons. Also, this would maximize the use of existing infrastructure before the infrastructure becomes economically unusable.

Several Norwegian concepts for drilling with reaches of 20-30 km have been proposed. Two examples are illustrated in Figures 9 and 10. Other concepts, such as tunneling from shore to reach distal reserves have also been proposed.

In addition to extending the reach of wells beyond 12 km via new rig equipment such as shown in Figures 11 and 12, other new technology is needed so that existing rigs can reach farther. This could greatly improve project economics. Such technology might include new methods to reduce torque and drag and downhole circulating pressures. Also, the managed pressure drilling method discussed earlier could facilitate ERD using existing rigs.

FIG 9: DUAL-WALL DRILLSTRING ULTRA-ERD CONCEPT

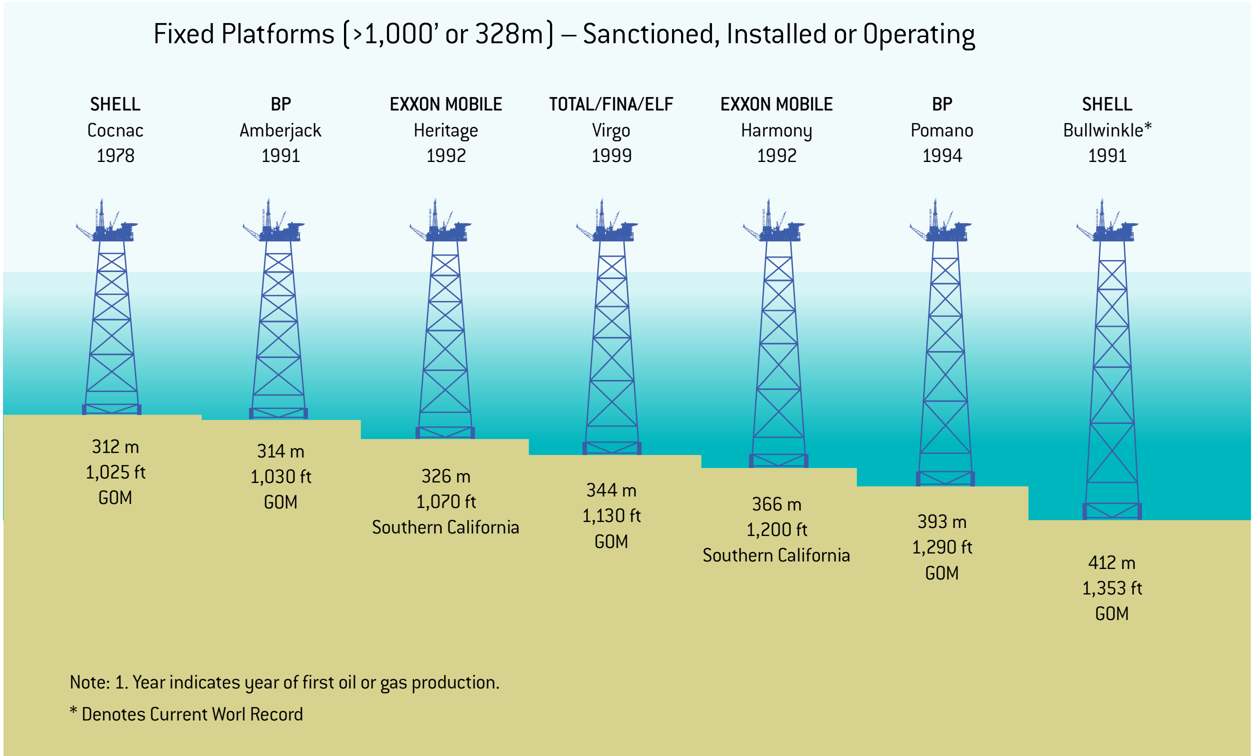
FIG 10: ERD CONCEPT INVOLVING MULTIPLE INFLATABLE OPENHOLE



KEY TECHNOLOGY GAP: NEW NCS DEVELOPMENT CONCEPTS

Another approach to facilitate the development of smaller fields in certain cases is the use of steel jackets with drilling facilities and dry trees. This has been proposed for water depths up to 350 m (Reference 10). The current maximum water depth for a steel jacket in the NCS is about 200 m. Yet there is industry experience outside the NCS with steel jacket platforms in water depths up to ff400 m (see Figure 11). The use of dry trees would help avoid the recovery penalty (as much as 20%) associated with subsea wells. And steel jacket platforms are often less costly than floating platforms or a subsea development, especially as the well count increases. General studies are needed to determine the maximum water depth where a steel jacket could be used under NCS conditions. Studies are also needed to determine if guided towers, such as the Lena platform in the GOM and those being considered for India and elsewhere, might be cost-effective dry-tree solutions for the NCS. Government-funded studies might provide the basis for operators to try new small-field development concepts. Studies are also needed to qualify steel jacket platforms for specific NCS fields in greater than 200 m of water. Studies are also needed to optimize such platforms. For example, the platforms could be designed to facilitate removal of the drilling rig once all of the wells have been drilled, perhaps replacing it with a lower-cost intervention system.

FIG 11: INDUSTRY EXPERIENCE WITH DEEP STEEL JACKET PLATFORMS

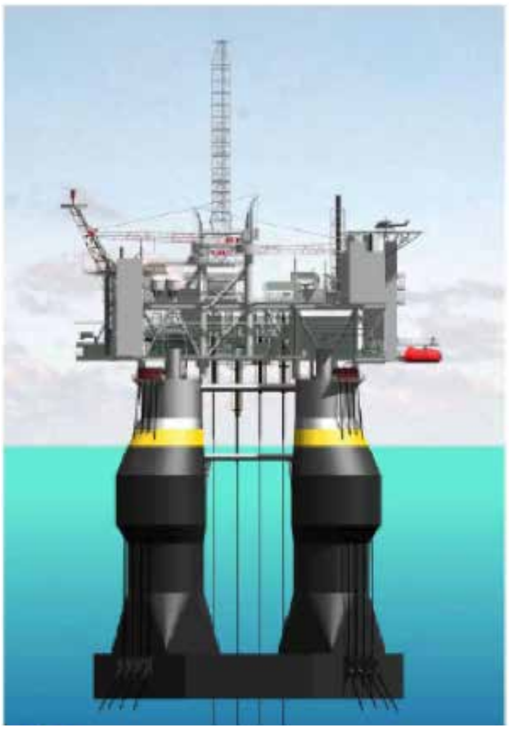


Source: Courtesy Mustang engeneering

Another development concept for small fields is to use a small floating drilling, production, and offloading vessel (FDPO). The idea is that the wells would be predrilled by a mobile offshore drilling rig and then tied back to the FDPO using a dry tree system (Reference 10). The FDPO would include a small "singles" drilling rig for well tie back and intervention operations during the life of the field (see Figure 12). Such a platform has been approved for use on the UK side of the North Sea. Government funded studies to qualify such systems for the NCS might be justified. Again, rigorous studies are needed to evaluate the use of such a system for a specific NCS field.

While these small-field development concepts are not directly related to drilling technology, they would greatly facilitate cost-effective drilling of and intervention in wells in small fields. And because they both employ dry trees, expected recovery factors would be higher than subsea approaches.

FIG 12: SMALL, FLOATING, INTERVENTION, PRODUCTION, OFFLOADING SYSTEM WITH DRY-TREE PREDRILLED WELLS



Source: Eni and Saipem

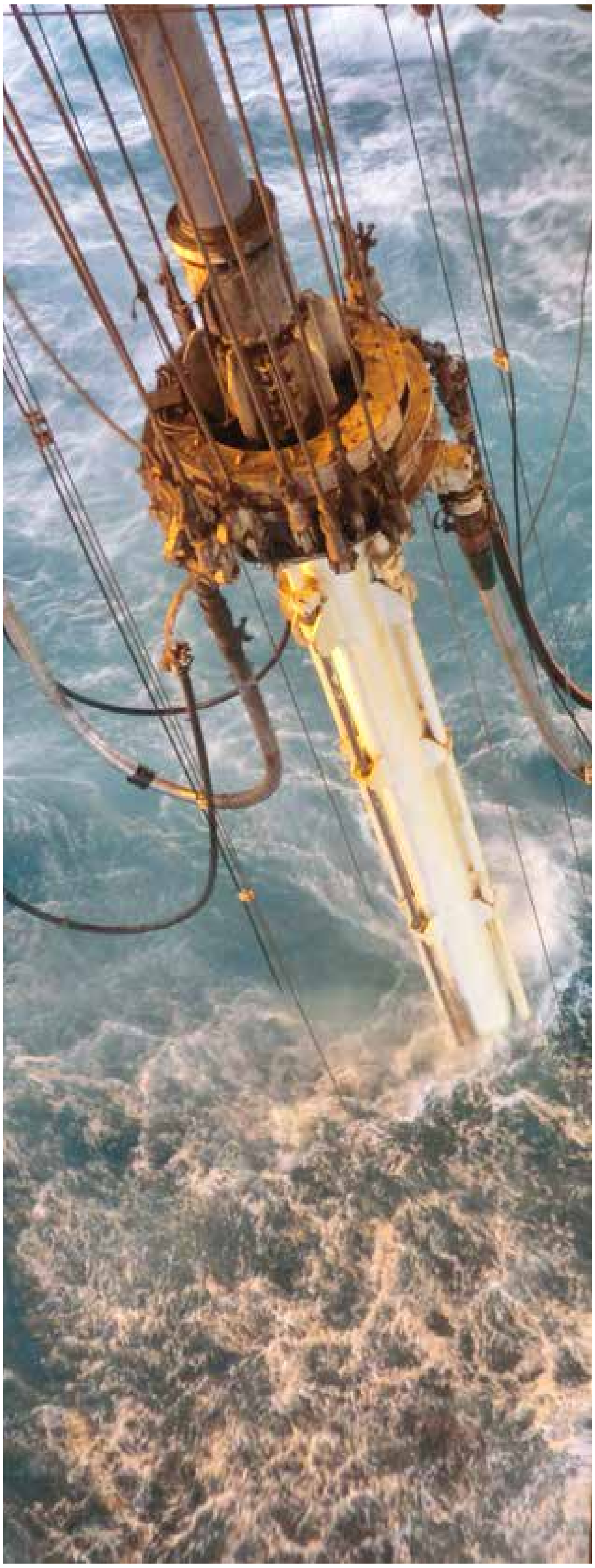


TABLE 2: TECHNICAL AND OTHER GAPS FOR DEVELOPMENT OF SMALL FIELDS

Key Technology Gap	*Gap*	*Time to complete (yrs)*	*Costs* (MNOK)*	*Critical-ity***	*Market value****	*OG21 strategic goal*****	*Barriers*
Extended Reach Drilling	Completion technology for ultra ERD wells	5-15	100-500	High	High	1,2,3,4	Innovation Demonstration
	Techniques for intervening in ultra ERD wells	5-15	30-150	High	High	1,2,3,4	Innovation Demonstration
	Techniques to reduce torque/drag	3-10	20-60	High	High	1,2,3,4	Innovation Demonstration
	Techniques to reduce surface and downhole circulat-ing pressures	5-10	20-60	High	High	1,2,3,4	Innovation Demonstration
	Techniques to reduce the time to run pipe into and out of a well	3-7	50-150	Medium	High	1,2,3,4	Innovation Cost Demonstration
New NCS Development Concepts	Specific field studies in support of steel jackets in 350 m of water on the NCS	2-4	10-30	Medium	Medium	1,2,3,4	Candidate identification Operator support
	Studies in support of a FDPO dry-tree system	2-4	10-30	Medium	Medium	1,2,3,4	Candidate identification Operator support

**) Costs relates to development costs from concept to qualified technology*
***) Criticality is related to the need for addressing the technology gap for realization of the business case.*
****) Market value relates to a global possible market for each technology gap.*
*****) Ref OG21 strategic goals given in OG21 strategy document on page 3 and on page 3 in this report*

BUSINESS CASE 3: COMPLETION AND INTERVENTION TECHNOLOGY FOR IMPROVED RECOVERY

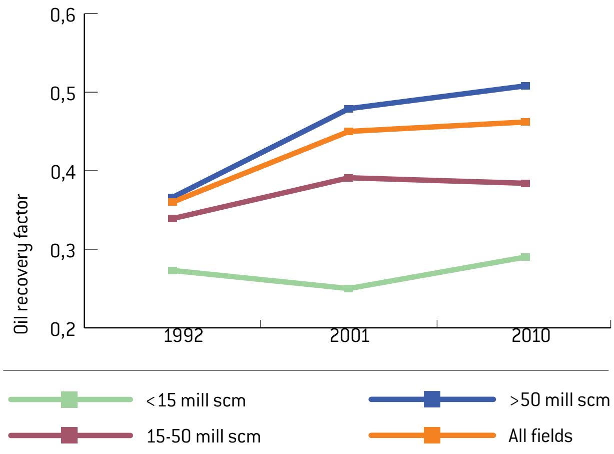
COMPLETION AND INTERVENTION TECHNOLOGY FOR IMPROVED RECOVERY

As indicated in Figure 13, the recovery factor for the NCS has flat-lined at about 46%. Also, current projections indicate significant reserves will remain in most fields at the currently-planned cessation of production (see Figure 14), especially for the larger fields.

As indicated in the Åm report (Reference 2), just a 1% increase in recovery of original oil in place will yield about 340 bn NOK in 2012.

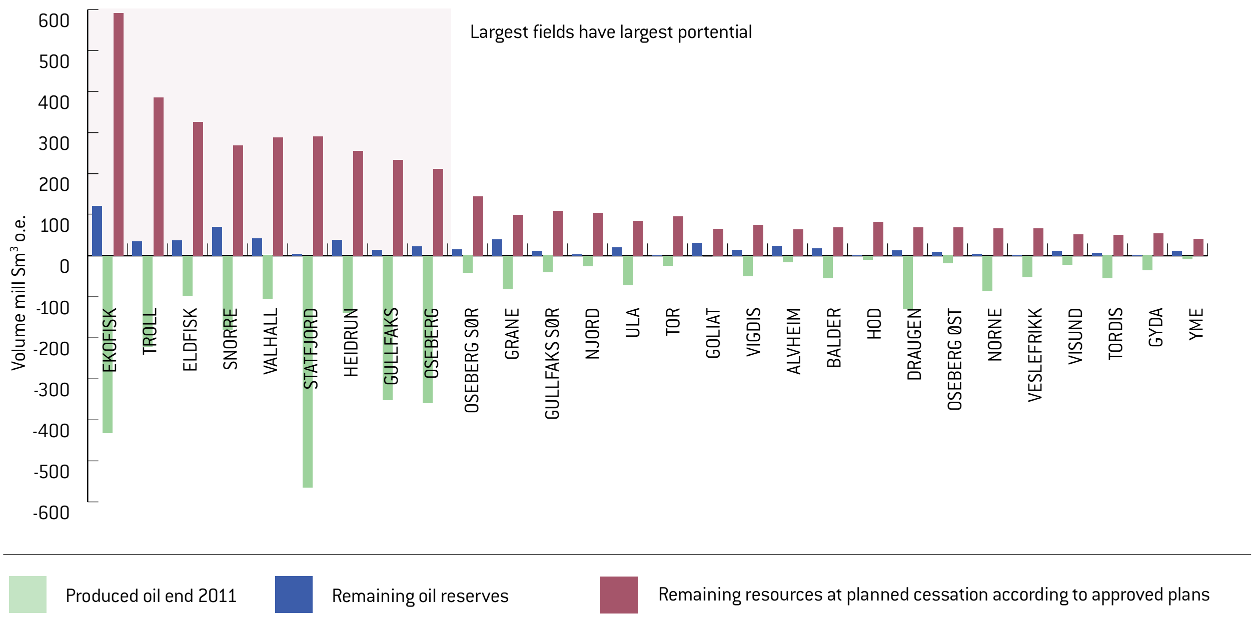
Three key gaps are suggested to improve the recovery factor. First, reliable, lower-cost smart completions are needed to facilitate reservoir management. Second, improved technology for intervening in wells is needed to maintain or increase production. Finally, wells architectures that facilitate

FIG 13: HISTORICAL ESTIMATES OF RECOVERY FACTOR FOR NCS FIELDS (NPD)



Source: Norwegian Petroleum Directorate.

FIG 14: ESTIMATED RESOURCES REMAINING IN NCS FIELDS AT PLANNED SHUTDOWN (NPD).



Source: Norwegian Petroleum Directorate.

multiple drainage points are needed. Potential approaches are discussed in the following technology gaps.

KEY TECHNOLOGY GAP: RELIABLE LOW-COST SMART COMPLETIONS

To improve well recovery, reliable completion technology that can be easily reconfigured is needed. Such technology would allow improved reservoir management at a reasonable cost. Smart or intelligent completions with control lines that extend to the wellhead are available, but innovation is needed to reduce the cost and improve the reliability of these systems. Increased use of electronics and batteries in completions to facilitate opening, closing, or adjusting downhole valves and sleeves may be one approach to pursue.

Increasingly, wells are being completed with openhole packers and passive inflow control devices (ICDs) to try to control the inflow profile to improve recovery (Reference 11). This is challenging because the reservoir characteristics (e.g., permeability and pore pressure profiles) over the life of the well must be accurately known prior to running the completion. A key need is a low-cost way of adjusting the ICDs. This potentially could be done via sliding sleeve technology and wireline tractors. Such technology is needed right away to cost-effectively enhance the performance of new wells.

Also, new technology is needed to reliably monitor the inflow/outflow profile along a completion. Profile technology based on continuous fiber optic or other types of cable may be beneficial.

KEY TECHNOLOGY GAP: LOW-COST WELL INTERVENTIONS

In addition, development of improved technology that allows cost efficient well intervention operations in existing wells is needed to avoid early abandonment due to well problems and to prolong tail production. This challenge is expected to increase as the production from the NCS further matures. Technology is needed for both platform and subsea wells. Potential rigless technology might include new through-tubing tractor technology for both wireline and coiled tubing, new downhole water-gas shutoff and zonal isolation tools, and low-cost intervention systems and vessels.

Technology for riserless light well intervention into subsea wells could have a big impact in improving recovery on the NCS. Such technology could be used for cost-effective wireline work in subsea wells, for example, to perform logging, to repair safety valves, or to adjust the completion.

Improved technology to log and to stimulate wells and to remove and prevent scale, asphaltenes, and other deposits that can hinder well performance is also needed. One concept is to have battery-operated, tractor-driven, autonomous tools (e.g., logging sondes) that are a permanent part of the lower completion with wireless communication to a communication cable on the tubing string.

KEY TECHNOLOGY GAP: LOW-COST DRAINAGE POINTS

Another approach to improving hydrocarbon recovery from a reservoir is to increase the number of drainage points, say via branching completions. Branched completions can be an effective solution for increased reservoir access, especially where there are platform or template slot limitations. Improved screening tools are needed to help assess the appropriateness of a branched completion. Technology to increase the reliability and lower the cost of multilateral completions is needed to make the economics work in many cases. Also, improved technology for intervening in branched completions is needed. Multilateral technology could also be applicable in carbonate basins, offering an opportunity for technology export.

Also, improved technology for through-tubing sidetracks would be useful for creating low-cost drainage points and for re-using existing infrastructure. For example, improved technology for milling a casing window exit to facilitate running expensive drilling bottomhole assemblies and completion liners with less risk would be desirable. Studies on designing wells to facilitate through-tubing sidetracks should be also considered.

In addition, new approaches to increase the contact with the reservoir using needle-like penetrations, hydraulic jetting, or other methods might be considered.

Table 3 highlights the key gaps that need to be addressed.

TABLE 3: TECHNICAL GAPS FOR COMPLETION AND WELL INTERVENTION TECHNOLOGY TO IMPROVE RECOVERY.

Key Technology Gap	*Gap*	*Time to complete (yrs)*	*Costs (MNOK)*	*Criticality*	*Market value*	*OG21 strategic goal*	*Barriers*
Reliable, low-cost smart completions	Improved systems for remote control of inflow and outflow profiles	2-4	10-50	Medium	High	1,2,3,4	Innovation Reliable downhole data Demonstration
	Low-cost systems to adjust inflow and outflow profiles (adjustable ICDs)	2-5	10-30	High	High	1,2,3,4	Innovation IP Demonstration
Low-cost well intervention technology	Novel well intervention systems (wireline or CT)	3-6	10-50	Medium	High	1,2,3,4	Innovation Demonstration
	Technology for riserless light well intervention	3-6	10-60	Medium	High	1,2,3,4	Innovation Cost Demonstration
Low-cost drainage points	Enhanced low-cost drainage points (e.g., multilaterals)	3-7	50-150	Medium	High	1,2,3,4	Innovation Cost Demonstration
	Improved technology for slot recovery (e.g., TT sidetracks, improved window milling)	2-5	10-60	Medium	High	1,2,3,4	Innovation Cost Demonstration

BUSINESS CASE 4: SAFER DRILLING OPERATIONS

SAFER DRILLING OPERATIONS

The 2010 Macondo incident in the Gulf of Mexico has had a dramatic effect on the oil and gas industry worldwide. This tragic incident not only resulted in the loss of 11 lives and significant economic damage, but also resulted in a significant escape of hydrocarbons to the sea as the result of the loss of well control for a period of months. The operator was able to eventually cap the well using capping-stack technology that was developed during the incident. This incident showed that containment technology is the true last line of defense for a loss of well control. Should a similar incident occur offshore Norway, the impacts would be devastating. The colder, harsher conditions may exacerbate the damage to the environment. And because oil and gas is such a large percentage (ff50%) of the Norwegian economy, the economic impact would likely be crushing. Consequently, particular focus should be placed on technology for emergency containment of an uncontrolled well offshore Norway. While some containment technology has been developed for the Gulf of Mexico, and a number of NCS operators are participating in this effort, it is not clear that such technology would be fully applicable for Norwegian conditions. Studies and technology are needed that address well containment on the NCS.

Based on the outcomes from the Macondo incident, a loss of well containment offshore Norway could have catastrophic effects on the nation. While the Macondo incident involved an exploration well, it is conceivable that a similar incident could occur for an existing subsea well during intervention operations or via a leak to the environment from a completed subsea well. And the North Sea is one of the leading provinces for subsea wells. R&D is needed to resolve two key technology gaps: (1) prevention and (2) containment.

KEY TECHNOLOGY GAP: METHODS FOR REDUCING DRILLING HAZARDS AND ENHANCING LIFETIME WELL INTEGRITY

Drilling safety is paramount, and much work has been done to improve drilling safety on the NCS and elsewhere. As shown by the Macondo incident, better technology to prevent a well control event is still needed. There is a continuing need for R&D to develop technology to reduce and mitigate drilling hazards; examples include improved sensors to monitor the drilling and production process, more reliable shear rams, improved well control simulation, better pore pressure prediction, electric drill pipe to transmit more data quickly to the surface, improved technology for operational training. In addition, as pointed out by the Petroleum Safety Authority, (Reference 12), improved technology is needed for drilling risk assessment. Also, drilling automation is viewed as a key safety technology, since it will likely help avoid kicks and removes people from harms way.

In addition, methods and technology to enhance lifetime well integrity are needed to avoid costly well problems after a well has been drilled and put on production (or injection). Technology to help design a well for its entire anticipated lifetime, including the potential effects of local subsidence, is needed. In addition, better tools for life-of-well corrosion prediction and materials selection are needed.

KEY TECHNOLOGY GAP: TECHNOLOGY FOR EMERGENCY CONTAINMENT OF AN UNCONTROLLED WELL OFFSHORE NORWAY

Several NCS operators are participating in development and deployment of well containment technology designed for Gulf of Mexico conditions (Figure 15). This system is being designed to handle a flow rate of 100,000 BD. The system will be prepositioned along the Gulf coast to facilitate rapid deployment. The key elements include a subsea containment assembly, a dispersant fluid system, risers, capture vessels, and shuttle tankers. A key concern of the designers is to avoid shutting the well in to avoid the risk that hydrocarbons could broach around the well and escape to the sea at the seabed. Such a broaching event would be very difficult to manage.

While many elements of this system would be applicable to the NCS, some features may not be applicable. First, having the system located in the Gulf coast would mean that it would likely take a week or more to mobilize the equipment to the NCS. One obvious solution would be to preposition a system nearer the NCS. One could also consider having certain key elements air transportable. Second, because of the harsh North Sea weather conditions, it is likely that the planned shuttle tankers would be not able operate at all times. This suggests that it may be necessary/prudent to construct a subsea storage system so that the flow can continue during periods of bad weather. Also, the shallower water on the NCS may make it necessary to redesign the riser system and other components. Another gap in the GOM system is that it does not currently include any equipment to contain hydrocarbons that might be broaching around a well.

The Norwegian Petroleum Safety Authority (PSA) is investigating post Macondo follow-up activities for the NCS, and several NCS operators have joined the Europe-based Well Response Project. Consequently, it may be prudent to defer consideration of any government funding until these groups have had a chance to assess the technical needs.

FIG 15: KEY ELEMENTS OF PLANNED MARINE WELL CONTAINMENT SYSTEM FOR THE GULF OF MEXICO

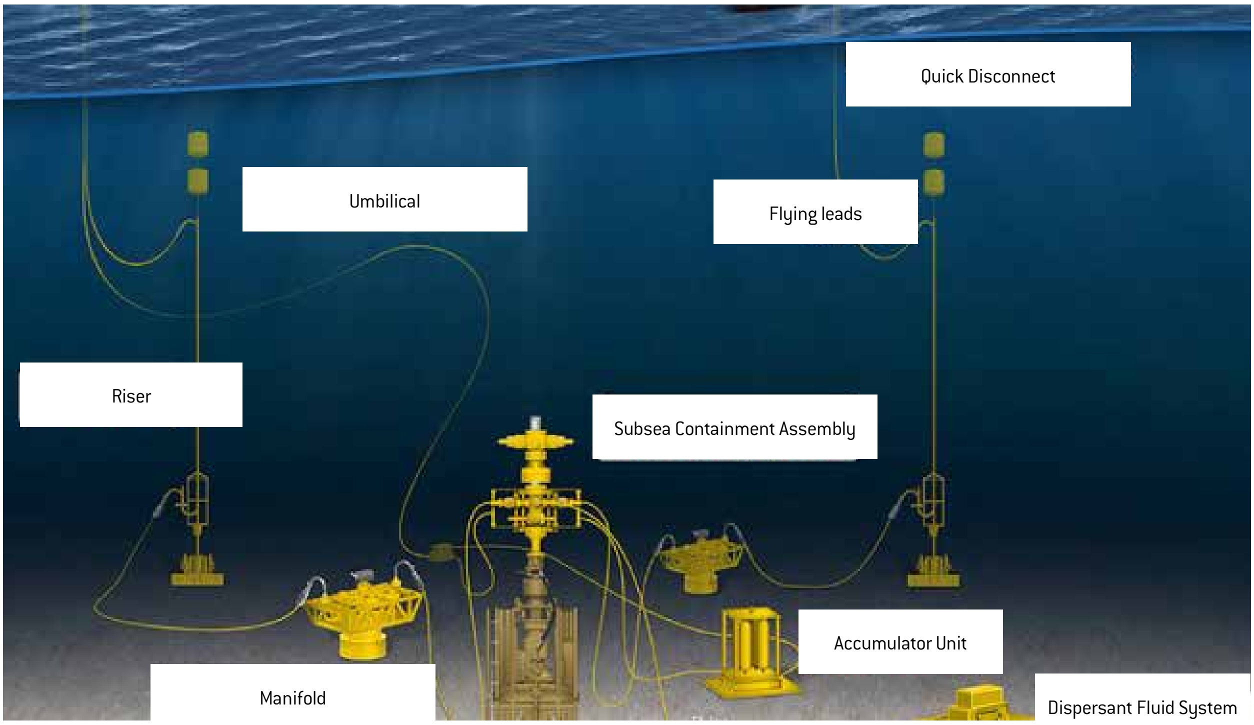


TABLE 4: TECHNICAL AND OTHER GAPS FOR NCS MARINE WELL CONTAINMENT SYSTEM.

The following table illustrates the time perspective, cost level, time criticality, market value, and response to OG21 strategic goals for some of the most important gaps that need to be addressed for this business case.

Key Technology Gap	*Gap*	*Time to complete (yrs)*	*Costs (MNOK)*	*Criticality*	*Market value*	*OG21 strategic goal*	*Barriers*
Methods to prevent loss of well integrity	Improved barrier monitoring	3-6	30-150	High	Medium	1,2,3,4	Innovation Demonstration
	Improved BOPs (e.g., shear rams)	2-5	50-200	High	Medium	1,2,3,4	Innovation Demonstration
	Improved risk assessment technology	2-4	5-25	Medium	Medium	1,2,3,4	Innovation Demonstration
Technology for capping and containment	Development of a business plan	1-2	2-5	High	Medium	1,2,3,4	Lack of Government Imperative
	Study for selection of NCS location	1-2	1-3	High	Low	1,2,3,4	International Considerations
	Study on adapting GOM MWC system	1-2	2-5	High	Medium	1,2,3,4	International Cooperation
	Containment if fluids are broaching around well	3-5	30-150	High	High	1,2,3,4	Innovation Demonstration
	Subsea hydrocarbon storage	2-3	15-100	High	Medium	1,2,3,4	Innovation Demonstration Pilot installation
	Riser redesign for NCS	1-2	15-100	High	Low	1,2,3,4	Innovation Demonstration Pilot installation
	Components redesign for NCS	1-2	10-50	High	Low	1,2,3,4	Innovation Demonstration Pilot installation

OTHER CHALLENGES AND TECHNOLOGY GAPS

There are several other drilling and well intervention technology challenges and gaps beyond those associated with the business cases discussed above. These additional specific technology gaps are further discussed below.

TECHNOLOGY FOR REDUCING WELL ABANDONMENT COSTS

According to the NPD, there are 12 concrete, 19 floating steel, and 88 steel facilities resting on the seabed of the NCS. In addition, there are about 350 subsea systems. A number of these facilities are approaching end of life and will need to be abandoned. For example, 14 facilities will be shut down in the period 2010-2015 and 18 facilities are scheduled for shut down in 2015-2020. Many of these facilities contain well-heads.

As NCS fields mature, there will be increasing costs associated with well abandonment. Often, it is necessary to mobilize a rig to effect well and platform abandonment, and this results in significant costs. Technology to facilitate well abandonment, especially without requiring a rig, will be of increasing importance.

TECHNOLOGY FOR PRODUCTION FROM FIELDS WITH LOW PERMEABILITY AND/OR ABNORMAL PRESSURE

Production of gas and oil from shale and other tight rock has had an enormous impact in North America. It is strongly suspected that such plays will rapidly move to Europe and other areas. Technology to capture hydrocarbons from shale and tight rock represents a huge opportunity for technology export from Norway.

In addition, as Norwegian fields mature and reservoir pressures decline, it becomes more difficult to drill wells and other problems, such as compaction-induced well failures, arise. There is an increasing need for well technology to help drill and produce reservoirs with low reservoir pressure.

Also, improved technology is needed for drilling and completing high-temperature/high-pressure (HPHT) fields. Such fields often have narrow drilling margins and materials challenges.

MORE ENVIRONMENT-FRIENDLY DRILLING AND WELL INTERVENTION

Compliance with environmental regulations and public concerns while drilling and intervening in wells is seen to be a growing challenge. This is especially important as the industry seeks cost-effective development of resources in the Barents Sea ecosystem and other arctic areas. Environmental issues are expected to become more severe and could impact the ability to discharge materials. Zero discharge of cuttings from large top hole sections provides a significant challenge because the volume of cuttings generated is typically larger than other intervals. In addition, wells to facilitate continuous injection of CO_2 to reduce greenhouse gases may be required. The industry should be encouraged to develop new technology that is environment friendly and reduces costs. Examples might include slim wells and/or more reliable multi-lateral wells to reduce wastes, new extended-reach technology to reduce footprints and avoid rigs in fishing areas, new cuttings disposal technology, and new well materials for mitigating CO_2 attack.

DEEPWATER DRILLING AND COMPLETIONS

While Norway currently is just beginning to develop deepwater fields, there is considerable potential for additional deepwater reserves off the NCS. And Norwegian operators are venturing into other deepwater provinces. Worldwide, deepwater is one of the fastest growing drilling technology areas. Potential technology might include further development of the buoyant seabed drilling systems, geohazards avoidance methods, and dual gradient drilling systems. Technical challenges associated with long risers also need to be addressed. Examples include heave, gas kicks and hydrate formation issues.

Technology for deepwater completions is also needed. Improved multi-zone completion technology may key to cost-effective reserve recovery. And smart well technology that facilitates reservoir management and helps avoid costly deepwater intervention should continue to be encouraged.

COST-EFFECTIVE ARCTIC DEVELOPMENT

All the challenges described above are important to support exploitation in arctic areas as well as being issues applied to general geographical areas. However, there are other challenges specifically addressing drilling operations in harsh environment and arctic conditions. These include:

- Rigs adapted to drilling in ultra-harsh weather conditions, including snow/ice mitigation, operation in rough seas, and strong station keeping. Such rigs could increase the available time window for drilling in arctic waters.
- Logistics is very challenging in the arctic and equipment reliability is a concern. Also, drilling rigs must have large storage capacities so they can operate independently for extended periods.
- Gas hydrates in the shallow soils are expected to be more common in arctic areas. Drilling through hydrates creates risk of unexpected gas influx into the well.
- Protection of wellheads from gouging by sea ice or ice bergs is a concern.
- The accuracy of magnetic and gyroscopic directional surveying tools will decrease at higher latitudes (arctic areas) because of short distances to the magnetic and geographic poles. In addition, both harsh environment and increased solar activity causing magnetic storms will contribute to a degradation in both accuracy and reliability making wellbore directional and positional control more challenging.

BASIC GEOMECHANICS RESEARCH AND COMPETENCE DEVELOPMENT

As indicated above, drilling, completion, and intervention challenges are becoming more complex and addressing these challenges requires increasing levels of knowledge and competence. There is a need for highly educated personnel who can perform basic and applied research to gain a better physical understanding of the well construction and operation processes. In particular, better fundamental understandings of geomechanics, and subsurface properties such as pore pressure, anisotropic rock strength, and chemical fluid-rock interactions are needed. New and upgraded large-scale experimental research facilities in the area of drilling and completions may also be warranted. Such facilities greatly help Norway achieve distinguishable status in the development of new solutions to drilling and completion challenges. It is much less costly and often more controlled to demonstrate new solutions onshore than offshore on the NCS. In addition, strong programs and new techniques to train young talent in the areas of drilling and completions are needed. Efforts to attract young people to the industry by communicating its state-of-the-art technical nature and long-term importance should be encouraged. Active international collaboration between Norwegian and international universities to exchange ideas and promote new solutions should be developed or expanded.

ENVIRONMENTAL CONSIDERATIONS

In addition to the technology needs discussed above, consideration should also be given to broader environmental concerns. For example, use of slimmer well designs will create less waste (e.g., cuttings). In addition, the use of solar and/or hydrogen to power rigs and associated equipment would also reduce CO2 emissions. These technologies might also afford the valuable benefit of reducing space requirements. Also, technologies to facilitate exploration well testing without bringing hydrocarbons to surface would improve both environmental and health safety.

R&D PRIORITIES, TIME FRAME AND FUNDING

Areas where government funding is most important are:

1. Fundamental studies related to drilling automation to enhance drilling efficiency
2. Innovative completion and intervention technology to improve recovery
3. Innovative concepts for step-out extended-reach drilling to enable development of small prospects
4. Development of advanced sensors to monitor well conditions during drilling and production
5. Feasibility studies on new development concepts/platforms for small fields

The highest priority is to support technology to increase the number of development wells drilled per year on the NCS. Studies on fundamental drilling mechanics and drill string vibrations could allow wells to be drilled faster and with less trouble. For example, better understanding on the effective of drilling fluid properties and flow rate and pressure on drill string vibrations is needed. Such studies could also play an important role in the systems needed for drilling automation. For some of the large mature fields, reserves may be lost due to aging of the infrastructure and field abandonment. Consequently, government encouragement of technology to drill more wells is advised.

The second highest priority is to support innovative completions and intervention technology that will allow better reservoir management and hence higher recovery. There is a need for low cost and more reliable technology that allows remote adjustment of downhole inflow and injection profiles.

Also, improved and lower-cost technology for well intervention is needed, especially for subsea wells. Such technology would help reduce the recovery penalty suffered by subsea wells because of the current high cost of using a conventional rig to re-enter a well.

The third highest priority is to support technology that allows small prospects and fields to be profitably developed. As indicated above, the size of new discoveries or existing prospects has significantly declined over the last several decades to the extent that it is difficult to economically justify development using conventional approaches. Step-out ERD technology to reach prospects from existing infrastructure should be supported by both government and industry. Such ERD technology not only will enable development of distal prospects, but will also likely increase recovery compared to subsea approaches. Government support for pilot tests of new ERD systems or major components should be considered.

Improved systems for monitoring well integrity barriers should also be given a high priority for government funding. This may require development of improved sensors and data transmission schemes. Also, studies and technology to enable lower-cost development concepts (e.g., wellhead towers in 350 m water) for small fields should be encouraged.

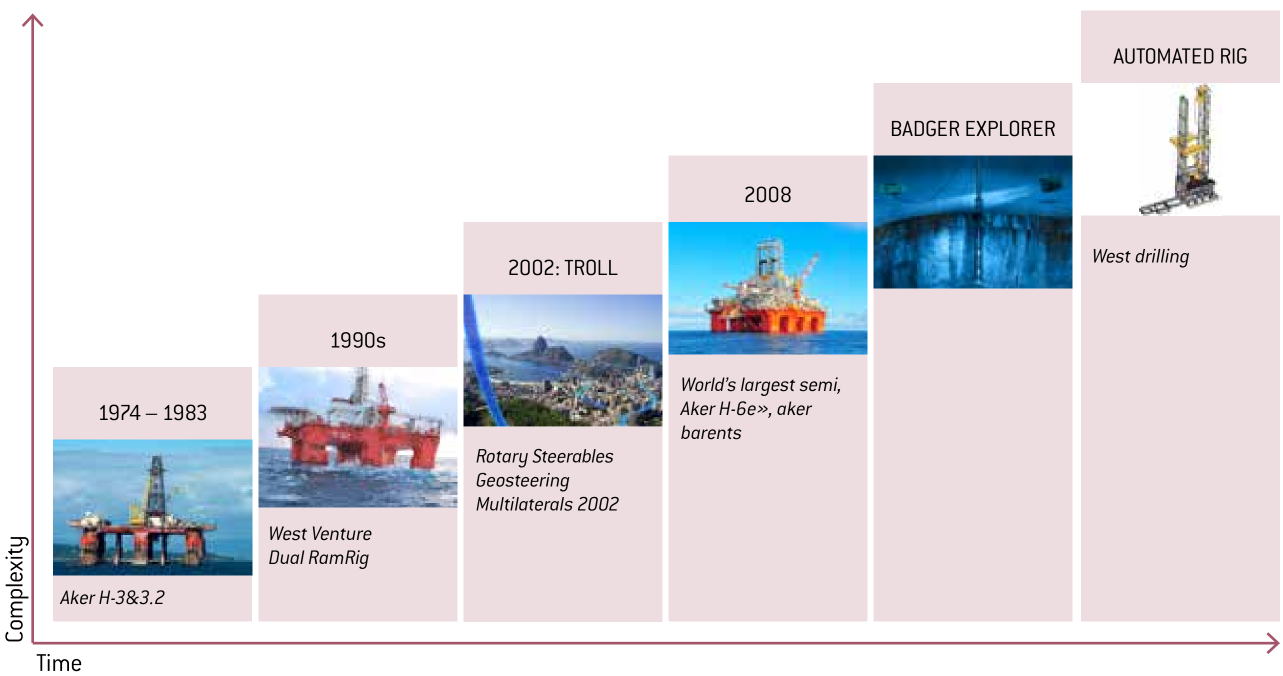
Some R&D related to increasing drilling efficiency and ERD capability on the NCS and other issues has been funded by the government and the industry. Tables 5-6 (at end of report) list the projects funded by Petromaks and DEMO 2000 in the wells area. Each of these projects typically has financial support from one or more operators active in Norway.

ROADMAP FOR THE FUTURE

The following figure provides a road map from the past to the future with respect to drilling and well intervention. Norway has been a very innovative leader in this area, and the roadmap just shows examples of Norwegian drilling and intervention technology.

In the 1970s and 1980s, Norwegian companies, led by Aker, developed the 8-column Aker H-3 line of semi-submersible drilling rigs. This design has been the basis for more semi-submersible rigs than any other design, with more than 35 rigs having been built, with many still in service. In the 1990s, Norwegian companies developed the Ramrig concept in which hydraulic cylinders replaced the conventional draw-works in the rig hoisting system. This understanding of the use of hydraulic cylinders for rig pipe handling, carries on today with a high interest in drilling automation. In the early 2000s, Norway pioneered the use of advanced drilling technologies to develop the Troll oil rim. These included the use of rotary steerable tools, geosteering, and multilaterals. The use of

FIG 16: ROADMAP TO THE FUTURE FOR COST-EFFECTIVE DRILLING AND INTERVENTION



these technologies dramatically increased the hydrocarbon recovery from Troll and provided an example for many other fields. In 2008, Norwegian rig maker Aker developed the world's largest harsh-environment semi-submersible rig design (H6-e), with a 10,000-ft water-depth capability and an enormous storage capacity that is critical for arctic drilling. The Aker Barents, based on the H-6e design, is currently operating in the Barents Sea. A Norwegian company is also pursuing an innovative rigless robotic drilling system, the Badger Explorer, for low-cost exploration. If successful, the Badger will be game-changing technology. And several Norwegian companies are pursuing various aspects of developing and automated drilling rig.

RECOMMENDATIONS

The following, in priority order, are the key strategic drilling and well intervention research and development needs to help meet the OG21 objectives.

- Drilling automation to improve drilling efficiency and safety,
- Drilling trouble avoidance,
- Faster drilling,
- Extended-reach drilling,
- New small field development concepts,
- Reliable low-cost smart completions,
- Low-cost well interventions, and
- Technology for low-cost drainage points.
- Improved technology to prevent a loss of well control, and
- Technology for capping and containment of NCS wells

Additional NCS technology needs to help meet the OG21 goals in the drilling and well intervention area include:
- Technology for reducing well abandonment costs,
- Technology for production from fields with low permeability and/or abnormal pressure,
- Environmentally-friendly drilling and intervention technology,
- Deepwater drilling and completions,
- Cost-effective arctic drilling, and
- Basic geomechanics research and competence development.

Areas where government funding is most important are:
1. Fundamental studies related to drilling automation to enhance drilling efficiency
2. Innovative completion and intervention technology to improve recovery
3. Innovative concepts for step-out extended-reach drilling to enable development of small prospects
4. Development of advanced sensors to monitor well conditions during drilling and production
5. Feasibility studies on new development concepts/platforms for small fields

The following are some additional recommendations:
- The overall OG21 goals should include an increased emphasis on safety in all aspects of hydrocarbon production.
- The perceived gaps in addressing the key strategic drilling and well intervention R&D needs should be communicated to the principal developers and suppliers of new drilling and well intervention technology, including the service companies, research institutes, universities, operators, and other organizations involved in drilling and well intervention technology development.
- The needs and gaps in the area of drilling and well intervention should be reviewed on an annual basis and communicated to the appropriate government agencies.
- The government should increase seed funding via the Research Council of Norway for proposals that address the strategic drilling and well intervention needs.
- Where consistent with business interests, operators should consider increased funding for development of drilling and well intervention technology that meet the strategic needs for Norway.
- The industry should develop new creative partnering and risk sharing models for development of capital-intensive new drilling and well intervention technology.

TTA 4
FUTURE TECHNOLOGIES FOR PRODUCTION, PROCESSING AND TRANSPORTATION

Lead Party
Statoil

TTA group companies and organizations:
Shell, Total, Statoil, ENI, DetNorske, Gassco, Aker Solutions, GE, DNV FMC Technologies, Siemens, SPT Group, , IFE, SINTEF Energy Research, SINTEF Petroleum Research, CMR, FACE SFI, NTNU, UiS.

CONTENT TTA 4

EXECUTIVE SUMMARY

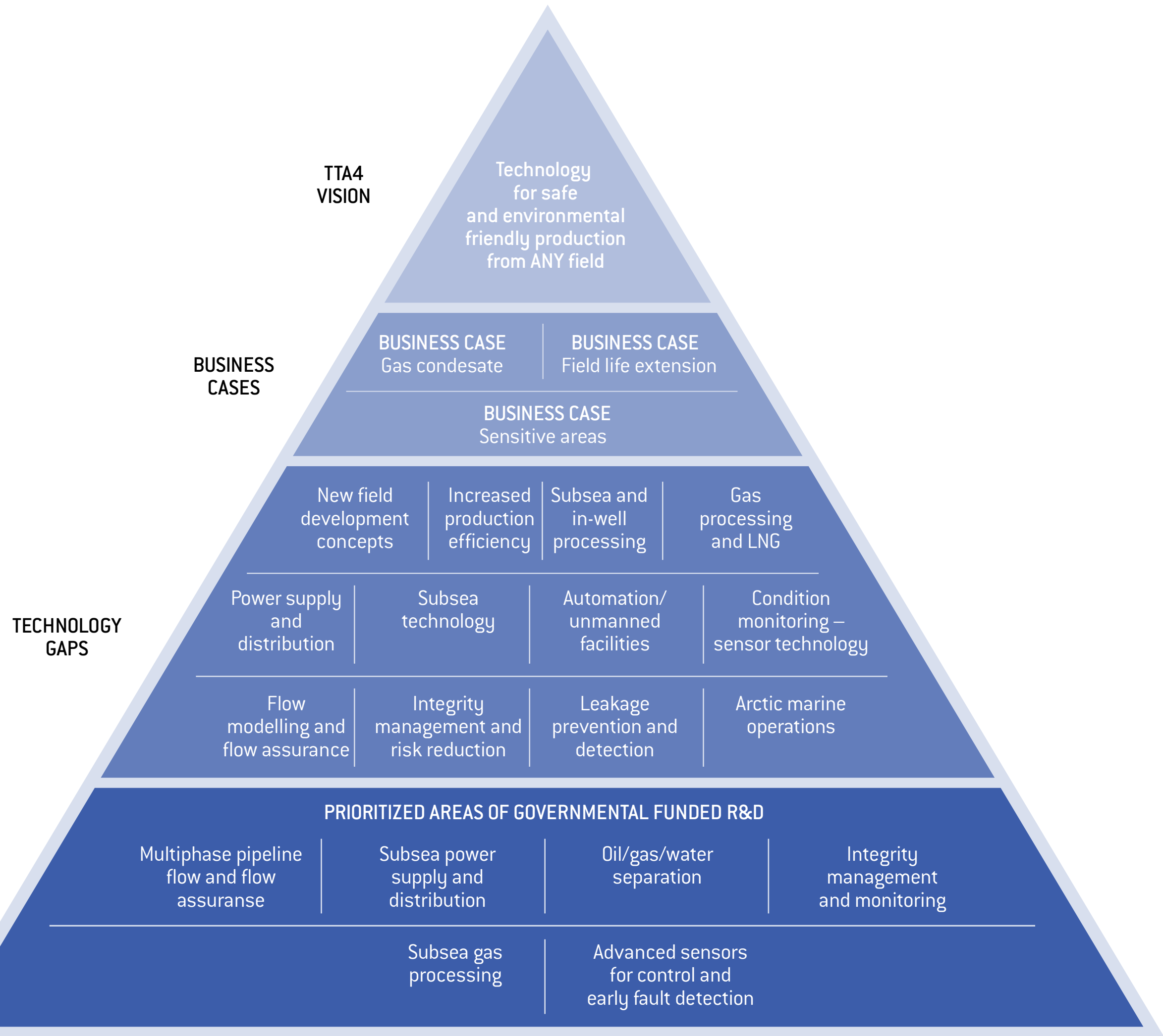


FIG ES 1: VISION, BUSINESS CASES, TECHNOLOGY AND COMPETENCE AREAS, AND PRIORITIZED AREAS FOR GOVERNMENTAL FUNDING FOR OG21 TTA4

Future Technologies for production, Processing and Transportation covers the technology and competence necessary to effectively and safely transport wellstream from the wellhead to a platform or to an onshore facilities, platform and subsea facilities, processing technology logistics and marine operations, and export pipelines. Decommissioning and downstream gas and oil processing and refining is excluded, apart from LNG technology seen as an integrated part of the upstream plant. This delimitation has been approved by the OG21 board.

The goal of this document is to outline the business potential that can be realized on NCS with new technology, outline the relevant technology gaps, prioritize the technology areas that are most important for NCS, recommend prioritized areas for governmental funding, and finally give advice on funding levels both totally for TTA4 technologies, and for individual areas.

The vision of the "Future Technologies for production, Processing and Transportation" TTA is:
Technology for safe and environmental friendly production from any offshore field

The current and future business challenges on the NCS have been evaluated from a TTA4 perspective. The three most important business cases are considered to be:
1. Barents Sea Gas Condensate Field Development
2. Oil and Gas Developments in Environmentally Sensitive Areas
3. Field Life Extension

For each of these areas the value potential, technology gaps and detailed technology needs are identified. For each of the technology needs the time perspective, cost level, time criticality, market value, fulfilment of OG21 strategic goals, and main barriers for success are outlined.

A detailed description of each of the technology and competence areas covering NCS gaps are provided, and include:
1. Flow modelling and flow assurance
2. Subsea and in-well processing
3. Power supply and distribution
4. Subsea technology
5. Automation/unmanned facilities
6. New field development concepts
7. Integrity management and risk reduction
8 Arctic marine operations
9. Increased production efficiency
10. Condition monitoring - sensor technology
11. Leakage prevention and detection
12. Gas processing and LNG

A general assessment of NCS technology needs, forms the basis for the prioritized Technology Areas for TTA4. The list is compiled from the overall assessments of technology gaps on the NCS, the three identified business cases with their respective technology gaps. These areas are identified based on importance for the industry independently of the funding source for the technology development.

This list of prioritized Technology areas has been assembled by leading experts from O&G companies, manufactures and R&D institutes/universities. Their experience and expertise secures the relevance and prioritized order of the list. The five focus areas are:

1. Subsea power transmission and distribution
2. Integrity management technology
3. Extended multiphase transport
4. High performance subsea separation for long distance transport
5. Real-time condition monitoring technology

An important aspect for all areas is to develop technologies and solutions contributing to increased safety and minimum environmental impact for operations on NCS. It is also expected that R&D within these areas will contribute to increased energy efficiency in oil and gas production, directly leading to decreased environmental impact through reduced CO2 emissions. This is in line with the overall strategic goals of OG21.

It should be emphasized; however, that this list is not a direct guidance for government funded R&D. This is because the priorities for public funding must also consider the aspects such as 1) market failure, 2) competitiveness of Norwegian technologies, 3) job creation, 4) attractiveness towards international suppliers, 5) Pre-competitive technology development needs strong governmental incentives, 6) development of technologies otherwise not developed from a pure business perspective, but that will provide significant upside for the society, and 7) export of Norwegian technology.

These arguments for government funded R&D lead to the following prioritized list of specific areas for government funding:

1. Fundamental knowledge on multiphase pipeline flow and flow assurance
2. Long range subsea power supply and distribution
3. Fundamental understanding and models for oil/gas/water separation, including fluid characterisation, fluid mechanics and produced water handling
4. Models for ice loads and ice interaction, and materials for Arctic applications
5. Integrity management and monitoring
6. Advanced sensors for control and early fault (including leakage) detection
7. Subsea gas processing

Figure ES 1 show the vision, business cases, technology and competence areas, and prioritized areas for governmental funding for OG21 TTA4

The funding from the Research Council of Norway should reflect these prioritized areas for government funding. There is a lack of support to some areas; particularly subsea power supply and advanced sensors and these should be given higher priority in future calls.

Ice loads and ice interaction have already been given a boost by the new Centre for Research based Innovation SAMCOT – Sustainable Arctic Marine and Coastal Technology.

For RCN projects the distribution of funding is 50 % to competence building (FP and KMB), 15 % to applied research (BIP) and 35 % to demonstration activities (DEMO2000). This illustrates a lack of funding for applied research projects.

In general, the total volume of funding of TTA4 Technologies should be increased by 50 % from today's level of approximately 100 MNOK/yr, i.e. to 150 MNOK/yr. This to enable a step up in financing the new priorities without reducing today's activity level of the other important areas. Emphasis should be put on competence building projects and applied research projects.

INTRODUCTION

The goal of this document is to outline the business potential that can be realized on NCS with new technology, outline the relevant technology gaps, prioritize the technology focus areas that are most important for NCS, recommend prioritized areas for governmental funding, and finally give advice on funding levels both totally for TTA4 technologies, and for individual areas.

The OG21 key strategic goals are given in the OG21 strategy and comprise the following:

1. Value creation through production and reserve replacement
2. Energy efficient and cleaner production
3. Value creation through increased export of technology
4. Value creation through employment and competence development

When evaluating the different technology gaps/requirements for each of the Business cases in Chapter 3, reference is made to these goals by their number.

TTA VISION AND GOALS

TTA4 covers a broad range of technology areas within production, processing and transportation of oil and gas including:

- Subsea technology including processing and boosting/compression
- Subsea electric power supply
- Long range multiphase pipeline transport
- Fixed and floating production units
- Marine operations
- Offshore pipelines

The Norwegian oil and gas cluster has been in the forefront with respect to develop and apply technology within all these areas. Currently, it is in the areas of subsea technology and multiphase transport where Norway is the global leader.

Future challenges connected to offshore production are: remote areas, deeper waters, harsh and vulnerable environment, more viscous oils, marginal fields, and requirements for increased recovery. To meet these challenges there is a strong need for new technology.

Based on this, the vision for TTA4 is to develop:

Technology for safe and environmental friendly production from any offshore field.

Towards fulfilment of this vision the following goals are set:

- Maintain and secure Norway's position as the world leading knowledge and technology cluster within subsea production, processing and long range transport technologies.
- Enable field developments in harsh and/or vulnerable environments, including surface facilities as well as subsea and sub ice.
- Ensure safe and environmentally acceptable operation of ageing installations.
- Establish Norway as the leading cluster within Arctic technology.

"The vision for TTA4 is to develop technology for safe and environmental friendly production from any offshore field"

BUSINESS CASE 1: BARENTS SEA GAS CONDENSATE FIELD DEVELOPMENT

The current and future business challenges on the NCS have been evaluated from a TTA4 perspective. The three most important business cases are considered to be:

1. Barents Sea Gas Condensate Field Development
2. Oil and Gas Developments in Environmentally Sensitive Areas
3. Field Life Extension

For each of these the value potential, technology gaps and detailed technology needs are identified. For each of the technology needs the time perspective, cost level, time criticality, market value, fulfilment of OG21 strategic goals, and main barriers for success are outlined.

BARENTS SEA GAS CONDENSATE FIELD DEVELOPMENT

Presently, the Barents Sea Gas field development scenario does not include tie-back to existing export gas pipeline infrastructure, hence near future developments will aim at LNG production and ship transport, or CNG production as an option. The typical scenario will include onshore gas treatment, LNG production, storage and shipment, similar to the Snøhvit / Melkøya development. However, there will be an extended step out for the offshore field development. The selected business case aims at 150-300 km wet gas transport between subsea templates and onshore facilities. The main technology gaps relate to the extended step-out. Offshore floating and/or compact LNG or CNG processing technology may be alternatives to wet gas transport to shore for remote gas fields (see Section A2.1.12 for the technology gaps in this area.)

The NPD has estimated the total gas condensate reserves in the Barents Sea (proven + undiscovered) to be approximately 800 bn Sm3. The economic value of these reserves, based on an assumed gas price of 2 NOK/Sm3, is in the order of 1600 bn NOK.

Technology gaps

The following list covers technology gaps for long tie-back gas/condensate fields, mainly focusing on four main technology areas: Power, Processing, Operation and Controls, and finally Modelling and Sensor Technology.

Subsea HV power supply is crucial for this business case. AC transmission technology is presently coming close to a limit with regards to step out, but there are several concepts for extending the AC transmission step out limits significantly. Furthermore, DC transmission systems will be needed and may be more efficient for new field developments far from shore. The development of sufficient DC will depend on synergies with the offshore renewable industry and is considered too expensive for the subsea industry to develop this alone.

Main technology gaps for power transmission are:

- Power transmission and distribution for very large power requirements
- Low frequency AC (16 2/3 Hz) for long step out
- HVDC for very long step out
- Module-based concepts for reduced weight and size (both for low frequency AC and HVDC)
- Pressure tolerant power electronics
- Insulation materials for cables and power electronics – compatibility between the various materials

Two of the main challenges in long distance transport of gas, condensate and water in a multiphase pipeline are 1)hydrate management and 2)slug handling. One possible solution to these problems could be to remove free liquid in combination with dehydrating the gas to prevent liquids condensing in the pipeline. Technologies for the removal of free liquids subsea already exist. To develop technology concepts for subsea gas dehydration is considered to be important for new field developments in remote areas. Alternative technologies to pipeline transportation of the removed condensate would also be interesting to develop for a subsea dehydration case.

Concepts for subsea compression are seen as an important area for further development and validation, including concepts for down-hole compression. Reliable concepts for subsea compression will facilitate the development of new fields far from shore. Down-hole compression could enable tie-back of smaller gas/condensate accumulations to a hub facility (topside or subsea). Other challenges are hydrate formation, corrosion and scale inhibition. Presently, chemicals are used to avoid such problems. The technology gaps are relatively small for subsea injection of chemicals (mainly related to the pump), but the currently available technology will require qualification in realistic conditions. An alternative technology for hydrate prevention is heating the pipeline. Direct electric heating (DEH) is currently applied for pipeline distances up to ﬀ50 km. More efficient concepts for long distance heating of pipelines with lower power consumption will be important for new developments. This concept has a clear advantage when considering the environmental perspective.

Main technology gaps for process technology and flow assurance are:

- Management of the condensate if not transported with the gas in the same pipeline; (e.g. shuttle tankers offshore)
- Subsea processing (gas dehydration, coolers, LNG)
- Subsea water treatment
- Subsea injection of chemicals
- Electrical heating to avoid hydrate formation – particularly challenging for long distance gas transport
- Wellstream compression

All electric controls and/or hydraulic power generated locally at the subsea template (HPU) will be important building blocks for the 150+ km step out. There are still some technology gaps to achieve all-electric control systems. This will require validation of umbilical's including two-way power and signal transmission.

Main technology gaps for operation and controls:

- Long step-out control systems

Developments in the Barents Sea will need sensor/measurement technology for environmental monitoring due to the sensitive Arctic marine eco-system.

Process condition monitoring is closely related to the simulation of the multiphase flow, as it provides real life data of the simulated flow. Further improvements in flow predictions from models are required in order to obtain the right amount of confidence in engineering choices for deep water developments and very long gas condensate pipelines. This will reduce the uncertainty in design such as slug catcher size and inhibitor system capacity.

Development and implementation of process condition monitoring systems distributed along the pipe will support the closing of flow modelling technology gaps. Sensor technology gaps relating to distributed monitoring are mainly related to deposit and pipe integrity monitoring: hydrate, wax, scale, liquid accumulation and wall thickness (corrosion).

Due to harsh weather conditions, intervention of future Barents Sea subsea installations by surface vessels will be challenging. At present, the availability of detailed meteorological and local marine data do not meet the demands to enable the required operability level; hence the meteorological and marine data coverage will have to be improved.

Main technology gaps for modelling, prediction and sensor technology are:

- Modelling and simulation of gas condensate pipelines (with low liquid content)
- Multiphase flow modelling covering extended step out and low ambient temperature
- Improved confidence in process modelling through extended process monitoring
- Process condition monitoring sensor technology for subsea application
- Distributed subsea power supply systems for process and pipeline integrity monitoring
- Distributed signal transmission for process and pipeline integrity monitoring
- Subsea leakage detection
- Environmental monitoring and monitoring of maritime data

Technologies for local power generation would be a game changing technology enabling completely different development concepts. Long distance power transfer would not be necessary if power could be generated locally.

Technology gaps for other possible enabling technologies:

- Materials technology
- Local power generation

The following table illustrates the time perspective, cost level, time criticality, market value, and response to OG21 strategic goals for the most important technology gaps that need to be addressed for this business case:

Technology Gap / Requirement	*Time to project selectable (yrs)*	*Costs* (MNOK)*	*Criticality for business case*	*Global market value*	*OG21 strategic goal***	*Main barriers to success*
Extended range AC	3-7	100-500	High	High	1,3,2,4	Innovation Demonstration Pilot installation
All electric control systems, reduced umbilical	3-7	20-100	High	High	2,3,4	Competence Innovation Demonstration
Sensor technology and condition monitoring for subsea production systems (incl. pipeline)	3-15	30-300	High	High	2,4,3	Competence Innovation Demonstration
Multiphase flow modelling and simulation	3-15	20-100	High	High	1,4,3	Competence Innovation
Subsea dehydration	3-7	100-500	High	Medium	1,2,4,3	Innovation Demonstration
Subsea chemical injection	3-7	20-50	Medium	Medium	4,3,2	Innovation Demonstration
Subsea cooler	3-5	15-100	Medium	Medium	3,4	Innovation Demonstration Pilot installation
Wet gas compression	1-5	100-500	Medium	Medium	1,3,4	Demonstration Pilot installation
Subsea HVDC	10-30	> 1000	Medium	Medium	1,2,4,3	Competence Innovation
Pipeline heating systems for long distance gas transport	5-15	50-300	Medium	Medium	3,4,1	Innovation
Local Power Generation	10-30+	300-1000	Low	High	1,4,2,3	Competence Innovation
In-well compression	5-10	100-500	Low	Medium	1,4,3,2,	Innovation Demonstration

\) Costs relate to development costs from idea to qualified technology (project selectable level, typically Technology Readiness Level 4 or 5 (API 17N))
***) Ref OG21 strategic goals given in Chapter 1.*

In total, technology gap closure investments (0.5-2 bn NOK, excluding HVDC and local power generation) in comparison to the value of available reserves (1600 bn NOK), indicates an excellent business case. Most of the technologies listed are within reach, given the time perspectives listed above.

BUSINESS CASE 2: OIL AND GAS DEVELOPMENTS IN ENVIRONMENTALLY SENSITIVE AREAS

OIL AND GAS DEVELOPMENTS IN ENVIRONMENTALLY SENSITIVE AREAS

The Norwegian Continental Shelf has some particularly environmentally sensitive areas. This section highlights the issues related to new and improved technologies that are relevant for entry into such areas. The decision to open sensitive areas for field development is with the Norwegian Government. This is likely to be a long-term process, which may require development of solutions that can eliminate or drastically reduce the environmental impact of oil and gas field development. Such new technology will also benefit the industry in general.

Environmentally sensitive areas on the NCS are generally characterized as being:

- Close to shore
- Important areas for fishing and fish reproduction
- Vulnerable marine ecosystems such as coral reefs
- High tourist value (scenery)

The most important issues when entering into particularly sensitive areas are related to oil spill and other environmentally harmful discharges. While general environmental issues are addressed in OG21 TTA1, technical solutions to avoid discharges as well as monitoring systems are relevant for this TTA. Examples of new, beneficial technologies are secondary containment systems (i.e. pipe-in-pipe solutions), leakage detection systems and integrity monitoring and assessment systems.

As an example of the resource base that may be available, NPD has estimated the value of oil and gas outside Lofoten, Vesterålen and Senja to have an expected NPV of 105 bn NOK. Obviously the amount has a large degree of uncertainty and the NPV estimates mentioned range from -7 bn NOK to about 500 bn NOK. Also note that the NPD report gives the earliest time frame for development as 2024, with 2030 being a more realistic date.

The following technologies are enablers for entry into environmentally sensitive areas, and may be viewed as requirements for "Licence to Operate". They may also be enhancing for developments in mature areas:

- Improved leakage detection systems (applies to both oil and chemicals in production system + sea-floor monitoring for hydrocarbons and optionally for CO_2
- Leakage response systems and fast remote monitoring technologies
- "Absolute Zero Discharge Developments" (all-electric control systems, secondary containment systems, minimize use of chemicals)
- Integrity monitoring and assessment systems (corrosion modelling and monitoring, subsea and pipeline inspection technologies, stress and fatigue monitoring)

The following technologies may be enhancing or enabling for specific field developments:

- Subsea Processing
- Multiphase transport and flow assurance
- Ultra long distance well construction

Subsea processing may be attractive in areas where surface or land installations may not be acceptable. Ultra long distance wells may enable drilling from shore in some near-shore areas.

Ultra long distance well construction may belong to a different TTA, but is mentioned here for completeness. Multiphase transport is relevant for joint development of smaller fields found in the area.

Based on the development scenarios from the NPD report and the characteristics of environmentally sensitive areas described, the following are key technologies:

- Online seabed survey and environmental monitoring
- Subsea processing hub with inherent leakage detection and prevention systems; separation, water treatment and reinjection, and oil and gas boosting for transport to shore.
- Power from shore to operate the subsea processing hub.
- Enhanced trawl protection and design for co-existence with fisheries
- Subsea wells and production system with integrated secondary containment system and online leakage and integrity monitoring.

Present technology gaps to realize the above are:

Leakage detection and prevention

- New, more accurate sensors and systems to detect leakages on the sea bed, under ice and on the surface
- New containment solutions that can collect leakages and avoid spill
- Online corrosion monitoring
- Online stress and fatigue monitoring
- Online produced water monitoring
- On-site inspection technologies (i.e. AUVs) to obtain more frequent or online inspection.

Subsea processing

- Oil and gas treatment and processing to avoid surface or onshore facilities
- Produced water handling
- Increased maintainability/design for minimum intervention. Includes preparation for preventive maintenance.

Entry into environmentally sensitive areas may have a long time frame, however some of the technologies identified will need a long time to develop and qualify:

- Remote/online monitoring for leakages and process conditions
- Modelling of material behaviour, degradation and impact on structural integrity
- Mechanical integrity monitoring and inspection technologies
- Advanced subsea processing (i.e. gas dehydration, export quality processing, fiscal metering, automation)

The following table illustrates the time perspective, cost level, time criticality, market value, and response to OG21 strategic goals for some of the most important technology gaps that need to be addressed for this business case.

Technology Gap / Requirement	*Time to project selectable (yrs)*	*Costs* (MNOK)*	*Criticality for business case*	*Global market value*	*OG21 strategic goal***	*Main barriers to success*
Leakage detection	5-15	30-300	High	High	2,4	Competence, Innovation
Subsea containment solutions	5-10	50-300	High	High	2,4	Innovation, demonstra-tion
Online stress and fatigue monitoring	3-10	20-200	Medium	Medium	1,2,4	Competence, Innovation Demonstration
On-site inspection technologies (i.e. AUVs) to obtain more frequent or online inspection.	3-10	20-200	Medium	Medium	2, 3,4	Innovation Demonstration
Subsea and in-well processing	3-15	50-500	Medium	Medium	1,,3,4,2	Innovation Demonstration
Subsea tunnelling (from shore to wellhead)	5-20	50-500	Medium	Medium	1,3,4,2	Competence, Innovation
Produced water monitoring and handling	5-15	20-200	Medium	Medium	2,,4	Competence Innovation Demonstration
Design for maintain-ability and minimum intervention	3-10	20-200	Medium	Medium	3,1	Innovation Demonstration
Subsea to shore technology for +50 km oil tie-backs (including flow modelling, cold flow, co-mingling fluids and flow assurance)	5-15	50-500	Medium	High	1,2,,4,3	Competence Innovation Demonstration

**) Costs relate to development costs from idea to qualified technology (project selectable level, typically Technology Readiness level 4 or 5 (API 17N))*
***) Ref OG21 strategic goals given in Chapter 1*

The development cost for the required technologies is in the order of 0.3 – 3 bn NOK. This more than indicates a strong business case when compared to the NPD estimate of an NPV of 105 bn NOK for the petroleum resources in the Lofoten, Senja and Vesterålen.

BUSINESS CASE 3: FIELD LIFE EXTENSION

FIELD LIFE EXTENSION

According to the Åm report, the average planned recovery from Norwegian oil fields is 46% as of 2010. By increasing the recovery by 1% the value creation will be of the order of 270 billion NOK (@70 USD/barrel). This will however, require a combination of EOR measures on existing fields as well as tying in adjacent, smaller fields. Some of the installations are of considerable age, implying a need to develop the adjacent fields quickly in ways that are compatible with the existing process equipment, before the integrity of platforms, process equipment and transport facilities go too far beyond their intended lifetime.

By adding new production to the diminishing volumes from the older fields, these fields will be able to increase their own ultimate recovery in a profitable manner. As the remaining water capacity available for new fields is typically limited on most installations, the benefit from early removal of produced water from the new production will greatly increase the chance for an early tie in. Hence, adding new production from adjacent fields to existing production facilities is characterized by:

- Afterlife of facilities possibly involving extension beyond the original design criteria. Typically water and gas processing limitations.
- Compatibility issues between new and existing well streams.
- Mutual benefits from older and new tie in fields with respect to cost sharing and increased recovery factors.
- Availability of riser slots and viable connection points for the new production.
- Need for coordination of different licenses and development plans.

”Ageing is not about how old your equipment is;it’s about what you know about its condition andhow it is changing over time”, (Petroleum SafetyAuthority, 2008).

A large number of the installations on the NCS were installed in the seventies and eighties. During the last 5 years , a significant number of life extension projects have been given the green light from the PSA.

Among these are: Åsgard C (until 2018) , Ula (until2028), Ekofisk 2/4- B (until2015), Statfjord A (until2028), Valhall (until2010/2015), Hod (until2015), Norpipeoil (until2028), Gyda (until2030), Veslefrikk A&B (until2020) and NorpipeGas (until2028).

Management of ageing is often divided in 3 categories:
1. Management of material degradation
2. Management of obsolescence
3. Management of organizational issues All 3 categories, inspection/assessment, technology, and (organization) are equally important, but the OG21 focus is limited other first two.

An example of tying in new fields to older facilities is illustrated by the Jotun - Jetta case. Jetta is a new field under development in the vicinity of Jotun. Central issues are the processing capacity for gas and water and whether to drill production wells from Jotun or separate semisubmersible rig.

In addition to the Greater Ekofisk Area, where life extension and substantial re-development is already ongoing, the Snorre Area holds a significant part of the remaining reserves on the NCS. Snorre is a large field where redevelopment activities including IOR- and EOR measures are pushing for a life extension targeting 2040. Assessment of current state and integrity level of the Snorre A platform is a key element when selecting alternatives for extension.

Enabling technologies:

- Monitoring and integrity management
- Real-time prediction and model-based control
- Improved understanding of fluid characterization and compatibility – new knowledge
- Subsea removal of the water as early as possible

Typical challenges:

- To obtain knowledge of the current state, how the integrity level is affected by ageing
- To establish reliable estimation of material degradation (data, models, uncertainty)
- To establish a life extension management plan that is adapting to new operation and organization, including relevant risk-reducing measures
- Mixing fluids from new fields with other fluids in existing process equipment, and subsequent challenges due to compatibility of the fluids and the effects of pressure-temperature changes
- Reservoir souring – facility aspects

Important knowledge gaps:

- Understanding and assessing degradation mechanisms (including modelling) for materials and equipment
- Assessment and monitoring of facility loads
- Advanced interpretation of results from testing, inspection and monitoring of equipment
- Developing reliable methods for subsea inspection and monitoring
- Assessing effects of subsidence on structure and topside
- Wellstream compatibility and solids depositions, such as asphaltenes, wax and gas hydrates, with subsequent challenges to remediation processes

Important research areas:

- Analyses of degradation mechanisms - modelling, combined effects of several degradation mechanisms, common cause failures, impact of operational conditions, systems for data collection, use of existing field experience with degradation failures.
- Maintenance management systems
- Guidelines for life extension processes
- Fluid chemistry and subsequent hydrocarbon incompatibility
- Prediction models for fluid behaviour

The following table illustrates the time perspective, cost level, time criticality, market value, and response to the OG21 strategic goals for some of the most important technology gaps that need to be addressed for this business case.

Technology Gap / Requirement	*Time to project selectable (yrs)*	*Costs* (MNOK)*	*Criticality for business case*	*Global market value*	*OG21 strategic goal***	*Main barriers to success*
Condition monitoring – structures (well-head to topside)	1-5	20-200	High	High	1,4	Innovation
Integrity management	1-5	30-300	High	High	1,4	Competence Innovation
Flexible risers, lifetime prediction	1-5	20-200	High	Medium	4,2	Innovation
Reliable online stress and fatigue monitor-ing	1-5	20-200	High	Medium	4,2	Demonstration
Compatibility of different fluids	3-15	30-300	High	High	1,,4,	Competence, Innovation Demonstration
Gas and water handling capacity	3-15	50-500	High	High	1,4	Innovation Demonstration
Reduced manning, automation	3-10	50-500	Medium	Medium	1,4,3	Innovation Demonstration
Increased production efficiency (reduced downtime)	5-10	20-200	Medium	Medium	1,4,3	Innovation
Risk reduction	3-10	30-300	High	High	1,2,4,3	Innovation
Reservoir souring. facility aspects	1-5	20-100	Medium	Medium	1,4	Innovation

**) Costs relate to development costs from idea to qualified technology (project selectable level, typically Technology Readiness level 4 or 5 (API 17N))*
***) Ref OG21 strategic goals given in Chapter 1*

In total, technology gap closure investments of 0.2-2.5 bn NOK. Compared to the Åm report estimate of a value creation of 270 bn NOK for only 1 % increase in the recovery factor, this implies a strong business case.

ENVIRONMENTAL CONSIDERATIONS

Due attention must be paid to safety and the protection of the environment. Improved technology for condition monitoring, leak detection and reduced use of chemicals will be important for environmentally safe development of the NCS.

The industry aims to reduce the amount of chemicals in use, and develop more environmentally acceptable substitutes. This is not only a question of practising good environmental stewardship – it is compulsory if we are to meet the increasingly stringent demands from society and the authorities.

In some areas, for example along the Arctic coastlines, the use of surface structures might not be acceptable. Together with the stringent environmental restrictions, this imposes significant limitations on field development schemes. In fact, subsea production and processing combined with long distance multiphase transfer to shore may be the only viable solution.

Subsea processing and transport will reduce the use of chemicals for enhanced separation due to the avoidance of tight emulsions created in topside valves and piping. Subsea separation will reduce the energy consumption for water injection significantly because the pump suction pressure is higher than it is topside, and since the pressure loss in lifting the water to the platform is avoided.

Recent incidents on the NCS have demonstrated the need for improved competence and technology regarding the long-term integrity of components in use offshore.

Technologies that avoid discharges during normal operation are sought when new subsea technologies are developed. One example of this is electrically operated subsea valves, avoiding the discharge of hydraulic fluids. Also there is a need for better technology for leakage detection from subsea components.

R&D PRIORITIES

The recommended R&D areas for TTA4 are guided by the vision “Technology for safe and environmental friendly production from any offshore field” and by the most evident and common priorities listed within the three business cases.

A general assessment of NCS technology needs, form a basis for the prioritized Technology Focus Areas for TTA4 given below. The list is compiled from the overall assessments of technology gaps on the NCS, the three identified business cases and the technology gaps described in Appendix 2. These focus areas are identified based on importance for the industry independently of the funding source for the technology development.

This list of prioritized Technology Focus Areas has been assembled by leading experts from O&G companies, manufactures and R&D institutes/universities. Their experience and expertise secures the relevance and prioritized order of the list. The five focus areas are:

1. Subsea power transmission and distribution
2. Integrity management technology
3. Extended multiphase transport
4. High performance subsea separation for long distance transport
5. Real-time condition monitoring technology

Within all these focus areas an important aspect is to develop technologies and solutions contributing to increased safety and minimum environmental impact for operation on NCS. It is also expected that R&D within these focus areas will contribute to increased energy efficiency in oil and gas production from the NCS, directly leading to decreased environmental impact through reduced CO_2 emissions. This is in line with the overall strategic goals of OG21.

It should be emphasized; however, that this list is not a direct guidance for government funded R&D. This is because the priorities for public funding must also consider the following aspects.

Government funding should be used to alleviate market failure. In the Norwegian R&D market there are issues that can be regarded as “market failures”:

1. *Education*; public funding supports basic and high level education to support the need of society in both the public and private sector.
2. *Open, basic research*; when research results are open there will be fewer incentives in the market for financing R&D.
3. *Long term research*; even though the benefit for society will be very high from long term research in specific areas, the market may refuse to finance such research.
4. *High risk projects*; piloting of new technology is one example of high risk projects. Operators are often reluctant to take such risk. Development of new technology with high potential and high risk is another.
5. *Publicly available research infrastructure*; the Norwegian research community (Universities and institutes) need relevant up-to-date research laboratories in order to deliver relevant R&D results. When this infrastructure shall be available for all interested parties there is less incentive for private investments.

In addition:

- NCS is in its nature a frontier petroleum region, with a continuous need for new technology. By securing public funding the government will contribute to closing of the NCS technology gaps by the use of knowledge and technology developed in Norway.
- Using NCS as a test site for development of Norwegian technology has been a success and should remain.
- Norway has a leading market position internationally within technologies addressed in TTA4. The value for society of these technologies is illustrated with the size of the supply industry (number of jobs and turnover) and their export volume, it is important to ensure that the unique knowledge and competence within the Norwegian industry and the research community is maintained and further strengthened.
- To maintain competitiveness of Norwegian industries and Norwegian jobs in a market with increasing competition, a continuous development of improved, more knowledge intensive products should be supported. Again, the government should support education, long term basic research and provide risk reduction for SMEs.
- The international market for equipment to be used for production, processing and transport of oil and gas is growing and the competition is stronger – particularly when including costs as a factor knowing that the international competition to a large extent will come from low cost countries.
- The international supplier industry has established departments in Norway based on the competence and experience in Norwegian industry clusters. These clusters are fed by a knowledge economy and a continuous R&D activity. The governmental support in education and research is essential to maintain a competitive Norwegian industry and attract international companies.
- Most of the petroleum related R&D is funded by the petroleum industry. However, pre-competitive and fundamental R&D is in its nature more open and will to a large extent need public co-financing.
- There will also exist technologies that are not possible to realise from a pure business perspective, but will provide significant upside for the society. For such technology developments, governmental financing is crucial.
- To ensure export of new technology developed in Norway demonstration programs such as Demo2000 is essential to obtain verified, field tested products. Public and private cooperation is extremely valuable in these test programs.

These arguments for government funded R&D lead to the following prioritized list of specific areas for government funding:

1. Fundamental knowledge on multiphase pipeline flow and flow assurance
2. Long range subsea power supply and distribution
3. Fundamental understanding and models for oil/gas/water separation, including fluid characterisation, fluid mechanics and produced water handling
4. Models for ice loads and ice interaction, and materials for Arctic applications
5. Integrity management and monitoring
6. Advanced sensors for control and early fault (including leakage) detection
7. Subsea gas processing

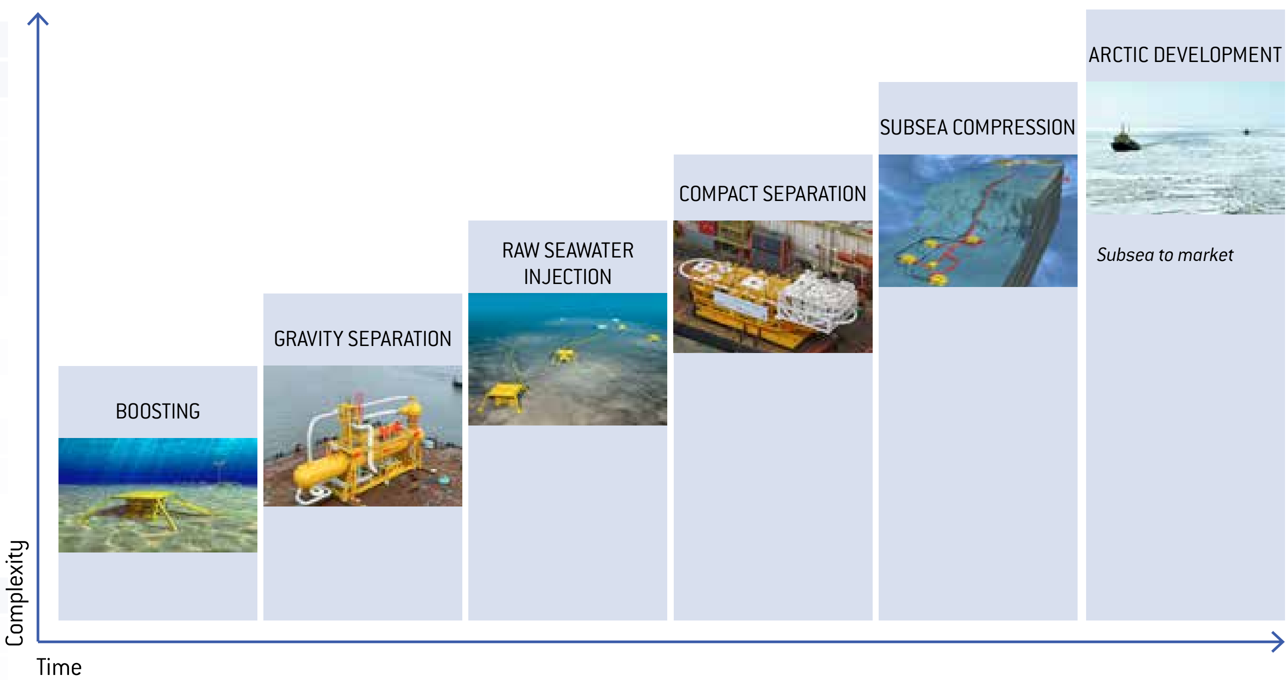
ROADMAP FOR THE FUTURE

A general road map for the development of new applications regarding offshore oil and gas production is illustrated in Figure 6.1.

Successful new technology applications are predominantly based on a combination of using existing solutions, know-how and field experience combined with extensive testing and qualification of the new technology. To be successful in getting the new solutions installed on offshore fields, significant effort is required to increase reliability and performance of the systems. Novel technology will often over time also be available to make conventional oil and gas production more efficient. Further, by using the existing infrastructure to pilot and mature new technology the risk with the new technology will be reduced.

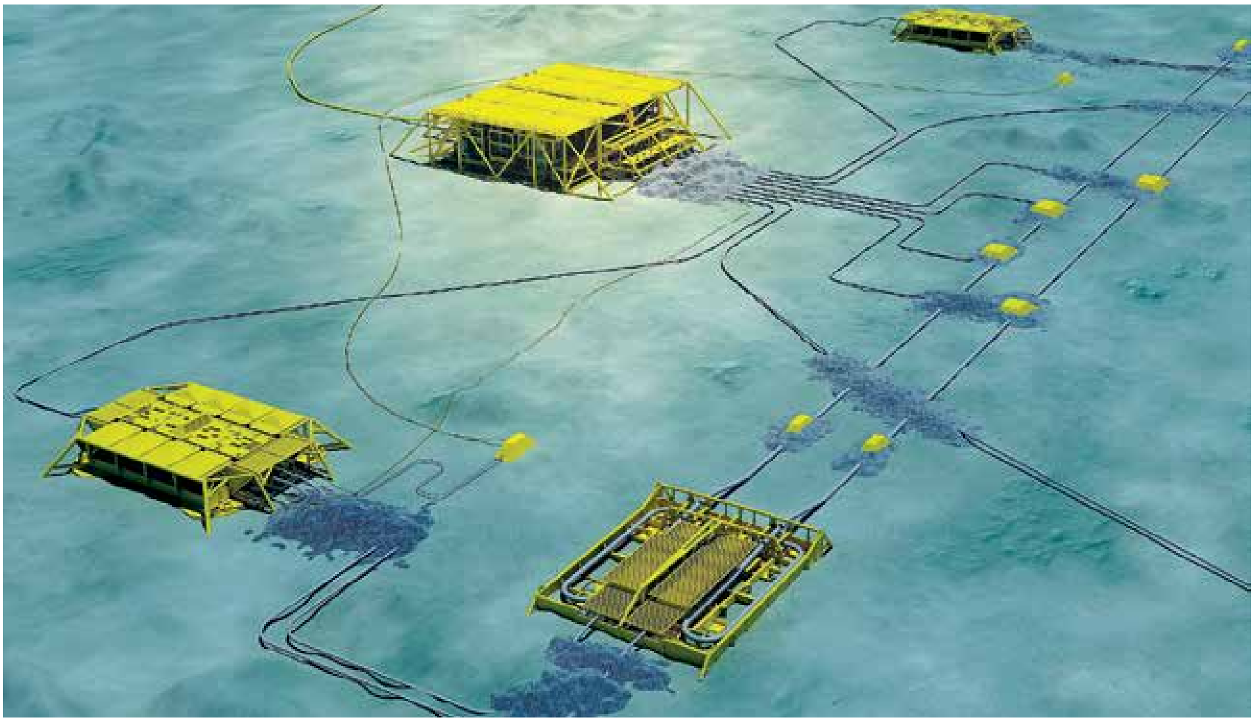
The area of subsea processing and long distance multiphase transport are seen as particularly important to fulfil the Business cases 1 and 2 presented in Chapter 3 and also for the further development Barents Sea and the Arctic. Therefore a more detailed roadmap is presented in Figure 6.2 for this area.

FIG 6.1: ROADMAP FOR SUBSEA PROCESSING AND LONG DISTANCE MULTIPHASE TRANSPORT



Subsea boosting has seen numerous applications in the last decade. Subsea separation started out in the North Sea (Troll Pilot in 2001 and Tordis in 2007), and were followed by several applications worldwide in both West Africa (Pazflor), GoM (Perdido) and Brazil (BC-10), and most recently with a compact separation solution in Brazil (Marlim SSAO). Raw seawater has been implemented on Tyrihans and other fields globally, and Subsea Gas Compression will be applied firstly in the North Sea on Åsgard.

Future technologies should aim at producing oil and gas directly to the market. The Arctic area will require further development of technologies in order to facilitate cost efficient and environmentally sustainable development of the reserves present.



RECOMMENDATIONS FOR GOVERNMENTAL FINANCIAL INSTRUMENTS

Currently, nearly 90 % of the total profit from the petroleum production on the NCS is ultimately state income, and as such the state has significant responsibility with respect to supporting technology development to ensure continued sustainable production from the NCS. In this context, the Norwegian state should direct more funding towards petroleum related R&D.

Funding from the Norwegian state should be allocated to the following:

- Continuity and predictability of fundamental R&D programmes –strengthen Petromaks II
- Continuity and predictability of demonstration programmes – maintain and strengthen Demo2000
- Large scale infrastructure for testing, verification and demonstration of new technology, and computer models
- Develop financial instruments for rapid market penetration of new technologies

Decreased government funding will have the following consequences:

- Not realization of the full value potential given in the business cases
- The Norwegian knowledge base and technology development will be eroded and the NCS will be more dependent on imported technology
- International supplier industry moving out of Norway if we cannot maintain and further strengthen the knowledge base we have.
- A decrease in petroleum technology based jobs in Norway

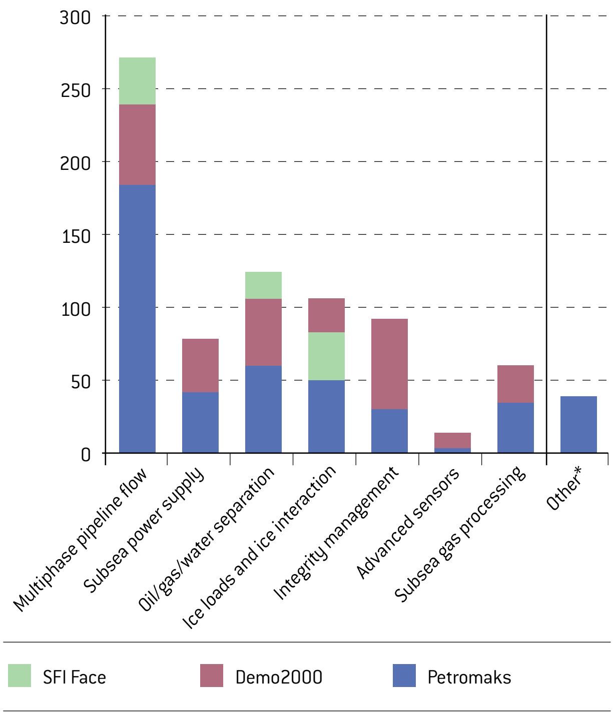
The consequences from a socio-economic perspective are even more critical than from a purely business perspective because of synergies to local economies, employment rates and tax income.

Specifically for the prioritized areas for government funding given in Chapter 5, Figure 7.2 shows the funding from the Research Council of Norway (RCN), including funding from the Petromaks programme (KMB, BIP and FP), the Demo2000 programme and through SFI FACE. The figure provides total funding during last 7 years for Petromaks, 11 years for Demo2000, and 5 years for SFI

The figure is based on substantial information from the RCN and has been simplified with respect to year of funding and duration of projects. It should also be emphasized that all areas have not been open for applications in each call. However, the figure clearly illustrates the trends of important areas for government funding up to now.

The funding from RCN should reflect the prioritized areas for government funding, as listed in Chapter 5. Comparing Figure 7.2 with the list of priorities in Chapter 5 one find a lack of support to some areas, particularly Subsea power supply and Advanced sensors, and these should be given higher priority in future RCN calls.

FIG 7.2: FUNDING FROM THE RESEARCH COUNCIL OF NORWAY FOR TTA4S PRIORITIZED AREAS. FIGURE SHOW TOTAL FUNDING DURING LAST 7 YEARS FOR PETROMAKS, 11 YEARS FOR DEMO2000, AND 5 YEARS FOR SFI



Ice loads and ice interaction have already been given a boost by the new Centre for Research based Innovation SAMCOT – Sustainable Arctic Marine and Coastal Technology.

For RCN projects the distribution of funding is 50 % to competence building (FP and KMB), 15 % to applied research (BIP) and 35 % to demonstration activities (Demo2000). This illustrates a lack of funding for applied research projects.

In general, the total volume of funding of TTA4 Technologies should be increased 50 % from today's level of approximately 100 MNOK/yr, i.e. to 150 MNOK/yr. This to enable a step up in financing the new priorities without reducing todays level of the other important areas Emphasis should be put on competence building projects and applied research projects.

[2] *Norwegian acronyms for RCNs project types: FP=Forskerprosjekt, KMB= Kompetanseprosjekt med Brukermedvirkning, BIP= Brukerstyrt innovasjonsprosjekt*

APPENDIX 1 FUTURE CHALLENGES AND TECHNOLOGY GAPS

Key future challenges on the Norwegian Continental Shelf and internationally are:

- Long distance wellstream transport
- Tie in smaller fields
- Deep water production
- Arctic frontier production
- Environmentally sensitive areas
- Increased hydrocarbon recovery
- Safe and effective use of ageing infrastructure
- Falling production efficiency
- Cost efficient tail end production

The present status regarding technology and competence in the TTA4 area on the NCS is to a large extent represented by the three business cases described in Chapter 3. However, there are some issues that are not covered by the business cases that still are of importance for this TTA – such as Arctic marine operations (Section A2.8) and gas processing and LNG (Section A2.12). Arguments for their respective importance are given there.

The following sections give a detailed description of each of the technology and competence areas covering these gaps. These areas include:
1. Flow modelling and flow assurance
2. Subsea and in-well processing
3. Power supply and distribution
4. Subsea technology
5. Automation/unmanned facilities
6. New field development concepts
7. Integrity management and risk reduction
8. Arctic marine operations
9. Increased production efficiency
10. Condition monitoring - sensor technology
11. Leakage prevention and detection
12. Gas processing and LNG

A2.1.1
FLOW MODELLING AND FLOW ASSURANCE

Flow modelling and Flow Assurance covers the technology and competence necessary to effectively model and predict multiphase wellstream transport to a platform or to onshore facilities. This includes the ability to predict and prevent problems with hydrates, asphalthenes and indigenous surfactants, waxes, emulsions and sand handling. Furthermore, transport of heavier and more viscous oils presents a significant future challenge. The ability to model and predict the behaviour of such systems is currently a major gap in the area of flow modelling and flow assurance.

Development of improved models for slugging, liquid accumulation and instabilities in multi-phase flow represents a cornerstone of future flow assurance models. In order to increase the predication capabilities for long distance multiphase transport, increased modelling accuracy through improved mechanistic models will be required.

The current high uncertainty in the prediction of liquid accumulation in gas condensate pipelines with a low liquid flow rate highlights the need for improved understanding of multiphase flow. Improvements in simulations models of such multiphase flow systems will be imperative to develop remote gas condensate fields.

Accurate mechanistic models require experimental data for final closures. In recent years, modeling concepts have started to move away from hydraulic assumptions and currently commercial simulators (OLGA and LEDAFlow) offer models based on multi-dimensional modeling concepts. Unfortunately, there is very little high-quality experimental data available that provides cross-sectional information of the flow field in a multiphase system. This type of data is urgently needed in order to allow the multi-dimensional modeling concepts to be developed further. In order to facilitate high-quality experimental data collection, further developments in multiphase flow measurement technology is required, both at laboratory and field scale. The latter will be further covered in Section A2.1.10.

Both on the NCS and internationally, there is a growing interest in the production of heavier, more viscous fluids. In general, available multiphase flow models for viscous fluids are limited in both number and range of validity, and they are not able to account for the presence of surfactants. Uncertainties in current flow models grow larger with increasing viscosity and the need for model improvement is significant. Increased oil viscosity and density also implies that the influence of the production system, most notably the choke, valves and pumps/compressors will play an increasingly important role in the separation process.

Modelling of fluids and surfactants (both indigenous and artificial), including the effect on emulsification, rheology, multiphase transport and separation, presents a significant challenge for future multiphase flow models since surfactants affect emulsion stability. Furthermore, as the NCS is maturing, the need for cost-efficient production of smaller fields will require co-mingling of wellstreams with different fluid characteristics from different wells and reservoirs. There is a lack of basic understanding and accurate prediction tools for mixed production streams and their physiochemical properties.

The continued development of appropriate models for hydrate slurry transport, sand transport/sedimentation/re-suspension and gelled oil behaviour will improve confidence in long distance oil wellstream transport. Further developments on erosion modelling should also be pursued, along with improvements of thermal simulation models and improved surveillance and monitoring equipment for production systems.

A2.1.2
SUBSEA AND IN-WELL PROCESSING

Some of the future fields to be developed will be at greater water depths and some with low pressure and temperature at the wellhead. In addition the oil could possibly be very viscous and have a complex chemistry. A promising solution to overcome these challenges is processing the oil and gas on (or below) the seabed prior to transportation to shore or surface facilities. The benefits of subsea processing includes increased flowrate/production, reduced topside constraints, improved hydrate management, better utilization of existing infrastructure, reduced development cost and reduced environmental footprint.

To compensate for the low pressure, efficient subsea pumps need to be developed for deep water operation. One of the challenges will be the efficiency of the pump. The power requirement is directly proportional to the water column. Another challenge is the use of pumps in combination with artificial lift. Today, a rig is needed to install Electrical Submersible Pumps (ESPs). This operation is both expensive and time consuming. Development of technology to perform such installations from supply vessels, along with increasing the lifetime of the ESP, will be economically beneficial.

Efficient, reliable and qualified subsea-, or even more challenging in-well separation equipment, will be a major boost to the further development of remote and /or deep water fields (sometimes with complex chemistry). The objective should be to separate water as early as possible, in an efficient and environmentally safe way. A long-term goal is to develop subsea separation technology that facilitates sale quality of the oil and export specification for the gas. Technologies for water and HC dewpoint depression are therefore important technologies, as well as CO2 and H2S removal in an even longer time frame.

Successful pumping and separation will depend on in-depth knowledge of how the increased viscosity and the complex chemistry affects fluid phase behaviour. The interaction between fluid mechanics and fluid chemistry must be understood in order to optimize the process parameters (e.g.

from predictions of how an emulsion is formed and how it evolves). The mixing of different wellstreams may introduce compatibility issues that will affect both pumping and separation.

While significant steps have been made in subsea gas compression with the Ormen Lange Åsgard and Gullfaks subsea compression pilots, there is still a need for further development. Key areas are: Simplification of the total compression system, pressure tolerant power electronics, more liquid tolerant compressors, material compatibility of motor and internal compressor parts, applications at higher temperatures and simplified and robust control systems.

A2.1.3
POWER SUPPLY AND DISTRIBUTION

The subsea electrical equipment seen so far is mainly control systems operating at relatively low voltages, and pumps with power in the range 500 kW to 3 MW and voltages up to 12 kV. Upcoming field developments will demand steadily higher power at longer distance from existing infrastructure or shore.

The typical layout for a subsea pump system today is a topside Variable Speed Drive (VSD) with an umbilical supplying the subsea load. In some cases a topside step up transformer and a subsea step down transformer are included. As the typical future subsea field application will consist of a number of power consumers, it will be of great importance to develop robust and flexible infield power distribution systems to avoid dedicated cables for each consumer with the appurtenant CAPEX and an impractical number of cables/risers. High voltage subsea cables already exist, but no medium voltage switchgear is yet in operation subsea. The development of subsea VSDs is also important to complete the subsea power supply system.

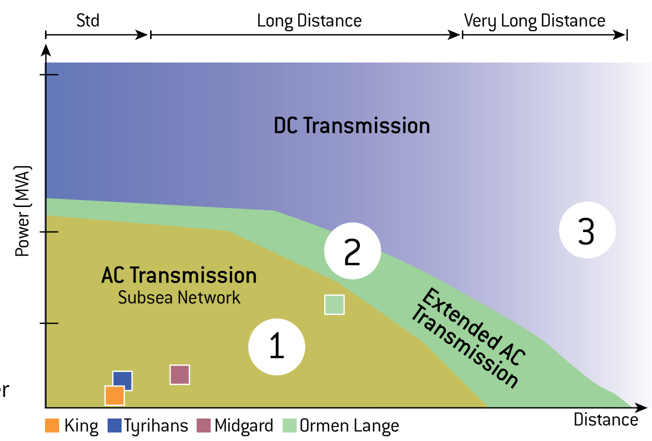
Today's and tomorrow's power supply systems are based on AC supply, but when the power needs and step out distance becomes long enough, DC transmission systems for use subsea will be needed. Figure 4.1 illustrates the different power transmission systems foreseen in a distance vs. power map. Area 1 shows the application of traditional AC, Area 2 shows the AC with application of phase compensating technologies, and finally Area 3 indicates the distance extends the maximum range for AC (often foreseen to be 300 to 500 km) and where DC is the only option.

The development of power supply equipment is expected to go in steps following the needs of upcoming field developments. Components that will be needed are: penetrators and wet mateable connectors with sufficient voltage and current rating, variable speed drives with sufficient power, MV switchgear including breakers, bus bars, and protection systems, subsea reactive power compensation equipment.

Major and fundamental challenges in the power supply area are related to pressurized frequency converters, the influence of humidity, temperature and pressure on insulation material lifetime, high voltage design of components, test/qualification methods for electrical equipment to be used subsea, methods for extended range AC transmission and systems for DC transmission.

Local power generation is an option that should receive increased attention. In particular, floating windmills supplying power to equipment that can run intermittently like seawater injection for pressure support seems an attractive option. Local power supply of a larger fraction of the power demand on the facilities is not considered realistic at the moment, but may be an option in the future.

FIG 4.1: DIFFERENT POWER TRANSMISSION SYSTEMS APPLICATION IN POWER VS. DISTANCE MAP (ILLUSTRATION FROM GE).



Source: GE

A2.1.4
SUBSEA TECHNOLOGY AND PIPELINES

In order to support the present strategy and business cases, further development of the basic subsea equipment such as Xmas trees, manifolds and control systems will be required. This is partly to meet new requirements in terms of integrity and maintainability and partly to support new developments in subsea processing systems and power supply and distribution systems.

To further improve system integrity, new connectors and sealing technologies for Xmas trees and manifolds should be developed. Control systems need to be upgraded to accommodate the increased amount of monitoring data for environmental purposes.

Hydraulic control fluid supply will become increasingly more difficult with deeper water and longer step outs and may be replaced with all-electric systems or systems using a combined hydraulic and hydrate prevention fluid.

In order to support more advanced subsea systems, the control systems need to be designed for much larger and more secure network traffic. There will also be a need to simplify the overall controls and power distribution systems to reduce the number of electrical connections, as this may become unmanageable for a large subsea processing station. It is likely that the subsea facilities may develop to be more autonomous to tolerate short interruptions in onshore or host communications. This will require a step change in subsea control system design.

There is a need for standards and specifications for the more advanced subsea systems. At present company requirements vary considerably and result in bespoke designs. This makes it difficult to transfer experience between projects and result in designs that are not cost effective. In the process safety area requirements should be set by standards.

Steel pipelines represent today the most important infrastructure for transport of oil and gas to onshore facilities in Norway and Europe. The recent trend towards oil and gas explorations in deeper waters, where diver support is impossible, imposes challenges to repair welding and hot tapping. Fully automatic remotely controlled welding process and equipment must be developed. This point requires a build-up of knowledge on the effects of pressure on actual welding processes and innovations in associated equipment for fully remote control.

A2.1.5
AUTOMATION/UNMANNED FACILITIES

The current trend in the oil and gas industry is to operate systems and sub-systems remotely by electronic, mechanical or hydraulic means. This applies to both subsea and dry systems. Although such systems form the basis on which to build automation on, truly automated and unmanned facilities of some complexity have not been put into operation.

The main obstacle for the massive introduction of unmanned- and automated facilities is the need for equipment maintenance as well as changing conditions to be met by the facilities over their life time. Full automation will therefore require more redundancy or shorter operating time for the facilities in question. The ability to avoid any safety- or environmental issues related to automated- or unmanned facilities will also require very strict safety standards to be followed.

Progress in this area will therefore be gradual and include simpler sub-systems before entire facilities are considered. Drilling operations is one of the areas where expert systems and automation are slowly being introduced.

Power from shore or nearby platforms will facilitate the introduction of unmanned installations as the gas turbines in use for power production are relatively manning intensive.

A2.1.6
NEW FIELD DEVELOPMENT CONCEPTS

In order to increase recovery from the NCS, smaller and more remote fields will require new field development concepts in order to be economically feasible. Due to the limited size of these fields, they will only be producing for a few years. Investments in conventional permanent production facilities, pipeline and permanent transportation infrastructure will often be too high to allow development. Cost-effective alternatives are therefore needed.

For oil dominated fields, the commonly used field development solution for such fields worldwide is "standardized" FPSOs that can move from field to field with limited modifications. However, on the NCS, the use of FPSOs has been limited to purpose built permanent units for relatively large oil fields. FPSOs can offload oil directly to tankers.

For gas dominated fields ("stranded gas"), ship-shaped solutions with gas conversion to liquids or cryogenic processes for liquefaction (LNG or HLG) are seen as the solutions. Several other concepts for transportation of smaller amounts of gas exist on the market. Compressed Natural Gas (CNG), where the gas is compressed to high pressure, and transported more or less unprocessed on special vessels, is a typical concept. Another option is conversion to gas hydrates that can be transported on bulk carriers.

Low cost access to wells is seen as important in order to increase recovery. In deep water on the NCS, steel jacket structures and concrete GBS structures will not be economically feasible. This calls for development solutions with dry trees on floaters for harsh conditions. SPAR buoys and tension leg platforms (TLPs) with dry trees are commonly used in GoM. Scaling down such facility solutions to marginal fields, as well as developing new concepts such as semisubmersible floaters (SEMIs) with dry trees, may enable the development of smaller deepwater fields on the NCS.

A promising option to address these challenges and reduce the dependency on topside facilities is increased processing of the oil and gas on the seabed, combined with subsea boosting to increase transportation distances and utilize existing infrastructure where available.

New and more radical concepts should be encouraged. One example of innovative solutions can be a "slurper", a ship-shaped unit moving from well centre to well centre, restarting production, filling up the cargo tank, shutting down the well(s) and transporting the cargo to a terminal. Other concepts to enable continuous production can be subsea processing with subsea liquid storage on the seabed. The oil could then be treated to storage specification, and be harvested from ships on the surface.

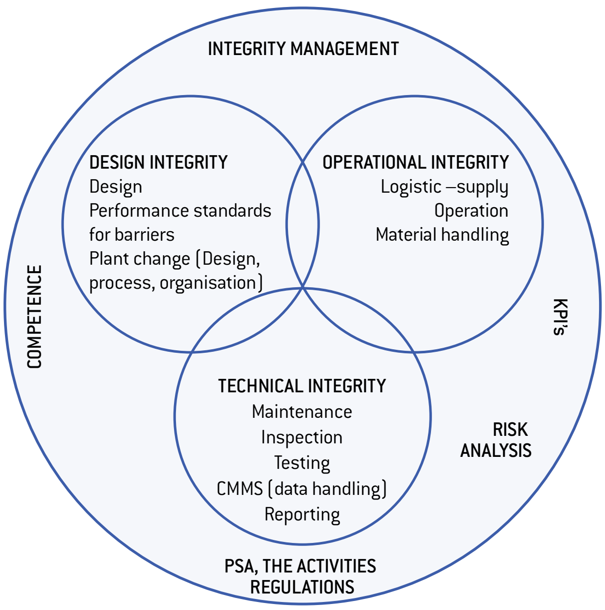
A2.1.7
INTEGRITY MANAGEMENT AND RISK REDUCTION

Integrity Management (IM) may be defined as the systematic process to assess and maintain the integrity of equipment used for production, processing and transportation throughout the lifetime of the equipment. It is defined as a continuous improvement process. IM ensures that facilities are managed safely with sufficient safety margins throughout design, construction, maintenance, operations and decommissioning An integrated part of IM is Design Integrity, which can be defined as the process to assure that the facilities are designed in accordance with current governing standards and meet specified operating requirements, it is important to emphasize that these conditions may change and be modified over the lifetime of the asset and must be managed accordingly. The second fundamental element of IM is Technical Integrity, which is linked to proper maintenance and inspection systems to manage the integrity of the equipment and systems during the operational phase. Finally, there is Operational Integrity which addresses the work processes, manning, competence and access to quality data which is essential to operate the facility and a safe and reliable way.

IM is of importance for sustained production on the NCS by efficient use of ageing infrastructure. Sustained production is dependent on how the installed assets are robust to changes in production profiles and lifetime extensions.

Key areas for further development of IM technology are:
- Development of seamless integration of data from various systems
- Establishment of integrity management of systems that are used to monitor integrity
- Enhanced use of prediction models, for example to predict development in degradation
- Development of decision support systems/procedures for
- Development of more insight into factors that contribute to high integrity ("resilient integrity")
- Development of IM visualization tools.
- Enforcement of management of change procedures
- Access to updated design documentation throughout the field life
- Establishment of a risk based (informed) approach to maintenance management

FIG 4.2: WHOLE INTEGRITY MANAGEMENT SYSTEM THAT IS INFLUENCING UPSTREAM PRODUCTION.



A2.1.8
ARCTIC OPERATIONS AND INTEGRITY

It is required to develop reliable decision support tools that enable safe and cost-effective operations and design of structures and vessels in the Arctic. Key focus areas here are the reliable prediction of ice loads on both fixed and moored offshore structures. For moored structures in particular, the response estimation and coupling to the external ice loading is challenging. Modelling techniques have to be developed to simulate the effects from the ice environment with the same reliability and validity as for open water structures.

For vessels and floating structures operating under various ice scenarios, with and without ice management assistance, station keeping techniques such as dynamic positioning (DP) systems will be required. A lot of experience has been gained the in the last few decades for DP operations in open waters. However, these operations are quite different compared to DP in ice. Therefore, existing technologies and procedures have to be improved when operating under Arctic conditions. It is also necessary to develop procedures and tools for Arctic marine operations, such as simulator-based training courses for navigation in ice and ice management. In addition, physical ice management should be assisted with an integrated ice management system in which the key components incorporate detection, forecasting, threat analysis, physical management and, if necessary, suspension of operations and disconnections.

Moving into arctic regions presents design solutions and associated materials with harsh and challenging conditions. Low temperatures, large temperature variations and ice are key parameters in this respect. The challenge is further augmented by a general lack of standards and experience for the use the materials under such conditions. In order for the industry to be prepared to take on the general challenge of hydrocarbon exploration and production in the Arctic, it is believed that a focused effort towards use of materials is necessary. Important areas are: Low temperature properties of steels and weldments, performance of polymer materials, and protective and ice phobic coatings. As weight savings will probably be of special interest in the Arctic, light weight solutions using high-strength steel, composites, aluminum, and hybrid solutions should also be given priority. A systematic effort where a combined knowledge-base on behavior of materials and requirements to be put on their use under Arctic conditions is established is strongly encouraged. Finally, there is a strong call for field analyses and full scale data, theoretical studies and evaluation of technical solutions and concepts to launch new and innovative technology developments for handling risks and challenges, and expanding the operational window in the Arctic. For example, the development of a robust and mobile drilling unit is required for drilling on a year round basis in shallow waters with extensive multi-year ice.

A2.1.9
INCREASED PRODUCTION EFFICIENCY

Production efficiency is a volume-based parameter expressing regularity; i.e. the amount produced (oil, condensate and gas) related to the theoretical possibility. The main area affecting production efficiency is planned and unforeseen activities such as well intervention and maintenance activities on subsea- and topside process equipment. In addition there are different causes of reduced production and lower production efficiency due to failures and dependencies between installations and to onshore terminals/refineries/gas-treatment plants.

Existing installations and infrastructure are faced with new operational challenges as the majority of installations have moved from autonomous oil producers to interconnected production units dependent on importing/exporting oil and gas as well as receiving/delivering an increasing amount of utility functions. Existing installations often serve as hubs for new field developments. Field development and tie-ins are important measures to utilize free capacity, extend life and decrease field development costs but challenging in terms of production efficiency. Each new project with a tie in to existing facilities will often require need for shutdown activities thus leading to even more shutdown on the hub itself as well as on other interconnected installations upstream or downstream. Over the last two decades the degree of interconnections has grown rapidly and the amount of indirect losses due to dependencies is today significant. Knowing that ageing facilities will most likely require extended maintenance and modification activities to avoid critical failures and remove obsolete equipment provides a list of challenges to ensure high production efficiency.

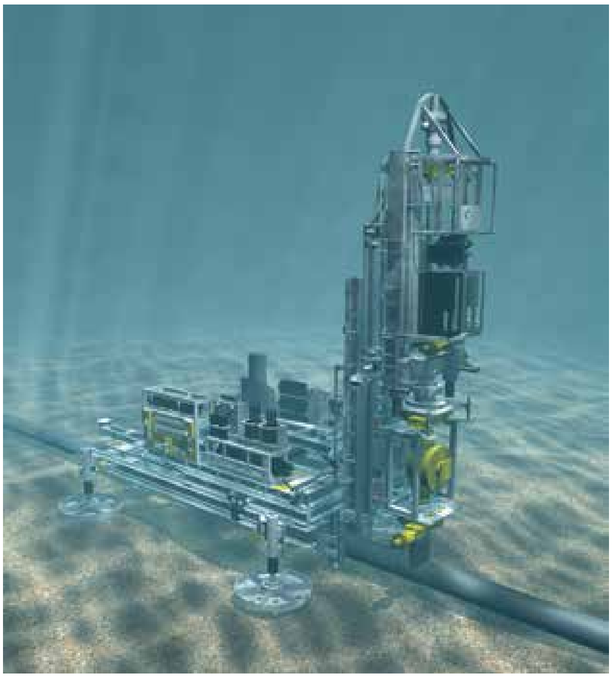
In green field areas such as the Barents Sea the production efficiency will be driven by the inherent reliability/design of new installations as well as logistic demands to support operations.

The challenge to increase production efficiency requires efforts to improve all activities causing shutdowns, both planned and unforeseen.

Decreasing the frequency by moving from yearly turnaround to turnaround each 2nd or 3rd year reduces the number of shutdown and start-up sequences that are a significant part of the total duration. The challenge is to avoid an increase in unforeseen shutdowns.

Integrated planning and scheduling is an area of great opportunity to improve production efficiency. This includes both strategic planning as scheduling turnarounds down to operational planning avoiding and/or handling unforeseen activities requiring shutdown on a day-to-day basis. Decreasing frequency of turnarounds, removing activities requiring shutdown, increasing awareness of equipment condition and integrated planning across all installations are key areas to increase production efficiency.

Major technology gaps are:
- New tools and competence in shutdown planning
- Standardization, tools and methods to support integrated planning across installations
- Improved work processes, tools and competence to remove activities requiring shutdown



A2.1.10
CONDITION MONITORING – SENSOR TECHNOLOGY

Improved process modelling confidence is closely linked to the availability of reliable process data. Online process fluid characterization will allow real-time process prediction and model-based control. Development of subsea sensor technology for process fluid characterization per well will predict process compatibility of the co-mingled production, leading to improved production reliability mainly through reduced flow assurance issues.
Longer step out imposes more complex flow assurance and condition monitoring along the pipe; pressure, temperature, solid build-up (i.e. wax, hydrate) and liquid as well as wall-thickness monitoring. Water salinity measured per wellstream will also be required.

Topside and subsea integrity management systems to include analysis of testing, inspection and monitoring of equipment to allow for a safe prolonged lifetime for new and existing topside and subsea installations, as well as pipelines are required. Reliable online corrosion, stress and fatigue monitoring systems should be implemented.

On-site inspection technologies (i.e. AUVs), for frequent or online inspection is required. Finally, assessment and monitoring of facility loads will have to be implemented in future integrity management systems.

For future Barents Sea field developments, improvements in meteorological and marine data coverage are required for obtaining an acceptable subsea intervention operability level. Project development in the Barents Sea and other sensitive marine areas will require seabed ecosystem and leakage monitoring.

Produced water discharge monitoring still requires development focus. For the sensor installation along multiphase transport pipes, new infrastructure is required for signal transmission and power distribution.

Sensor design should focus on sensor robustness and reliability. Process monitoring sensors should be non-invasive (clamp-on) if possible or non-intrusive as an alternative if no non-invasive design is available.

A2.1.11
LEAKAGE PREVENTION AND DETECTION

A licence to operate will have to include reliable and efficient leakage prevention and detection solutions both topside and subsea. While general environmental issues are addressed in TTA1, technical solutions to avoid discharges as well as monitoring systems are relevant for this TTA.

For subsea installations, all-electric control systems will remove the risk of hydraulic fluid discharge, and in general minimum use of chemicals should always be sought. The industry should seek development of new containment solutions collecting possible leakages and secondary containment systems (e.g. pipe-in-pipe solutions).

In future subsea wellhead, production and processing systems should include:

- inherent leakage prevention and detection
- on line leakage and integrity monitoring
- optionally, integrated secondary containment systems

Enhanced trawl protection design is to be included for co-existence with fisheries, where applicable.

Proactive leakage prevention is also obtained through integrity monitoring and management systems technologies as described in Section 4.7.

Further development is needed for the subsea leakage detection systems in order to extend the range, sensitivity and detection limit:

- Leakage sensors to cover detection of chemicals and CO2 in addition to hydro-carbons.
- Leakage detection applications to cover detector systems for sub-ice and surface applications.
- Leakage detection infrastructure to form fast online signal transmission available through web-based geographical information systems for oil company safety management and the authorities etc.

Finally, reliable online oil-in-water monitoring is needed for the produced water treatment plant, for early warning of increased oil concentrations.

A2.1.12
GAS PROCESSING AND LNG

The challenges in gas processing and LNG are related to the reduction of energy consumption, reduction of flaring and reduction of emissions with continuous focus on security of supply and safety.

The concentration of trace components in gas streams (CO2, H2S) is continuously increasing, both on the NCS and abroad. In addition, environmental regulations are becoming stricter, strongly limiting the use of chemicals such as MDEA. New processing technologies are needed, in particular technologies that are unaffected by vessel movement in floating production.

New process and operational concepts are needed to minimize flaring (e.g. at start-up or LNG loading). Better understanding of non-equilibrium effects in flow and heat transfer of hydrocarbon mixtures (vaporization, condensation) will help to increase the safety in transient operations and reduce the costs. Fundamental understanding of liquefaction processes will help preventing unwanted phenomena such as “Rapid Phase Transition (RPT)”.

Floating LNG can be a solution to produce from remote medium sized fields. Better use of metocean data is important as well as continuous focus on safety of operations. For smaller fields, small scale LNG is an emerging topic that can bring cost-effective solutions.

In particular for the NCS, further efforts are needed in sustainable power and heat supply for driving liquefaction plants based on electrical supply.

ABBREVIATIONS

AUV	Autonomous Underwater Vehicle
BIP	Brukerstyrte Innovasjons Prosjekter
BOE	Barrel of Oil Equivalent
CCS	Carbon Capture and Storage
CNG	Compressed Natural Gas
E&P	Exploration and Production
EOR	Enhanced Oil Recovery
FME	Centre for Environment-friendly Energy Research
FP	Framework Programme (EU innovation, research and development grants)
IOR	Increased Oil Recovery
JIP	Joint Industry Project
KMB	Kompetanseprosjekt Med Brukermedvirkning
LCA	Life Cycle Assessment
LNG	Liquefied Natural Gas
NCS	Norwegian Continental Shelf
NDP	Norwegian Deepwater Program
NPD	Norwegian Petroleum Directory
o.e.	oil equivalents
OED	Oil and Energy Directory
OG21	Norway's official technology strategy for the petroleum sector
OGP	International Association of Oil & Gas Producers
OLF	Oljeindustriens Landsforening (Norwegian version of OGP)
PWT	Produced Water Technology
R&D	Research and Development
RCN	Research Council of Norway
Scm	Standard cubic metres
TTA	Technology Target Area
TTA1	"Energy efficient and environmentally sustainable technologies" – one of four TTAs as outlined by the OG21 Board

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PHOTO:

PAGE 4:	SHUTTERSTOCK
PAGE 6:	STATOIL
PAGE 23:	SHUTTERSTOCK
PAGE 27:	BIOTA GUARD AS, VIDAR SKÅKEVIK
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