The Research Council of Norway

OG21
A new chapter

Oil and gas for
the 21st century

OG21

The energy transition brings about a new chapter for petroleum and the NCS

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EXECUTIVE SUMMARY

1.1 BACKGROUND AND PURPOSE

OG21 has its mandate from the Norwegian Ministry of Petroleum and Energy (MPE). The purpose of OG21 is described in the mandate: *"OG21 will contribute to efficient, safe, and environmentally friendly value creation from the Norwegian oil and gas resources. This will be achieved through a coordinated engagement of the Norwegian petroleum cluster within education, research, development, demonstration, and commercialization. OG21 will inspire to development and adoption of new and better knowledge and technology, aligned with an energy system under transition and the goal of reduced greenhouse gas emissions".*

OG21 brings together oil companies, universities, research institutes, suppliers, regulators, and public bodies to develop and maintain a national petroleum technology strategy for Norway.

The strategy is written in English with the Executive Summary translated into Norwegian.

1.2 SUMMARY WITH RECOMMENDATIONS

- The energy transition brings about a new chapter for petroleum and the NCS

A growing global population, expected to reach 9.7 billion people by 2050, needs access to affordable and sufficient energy, food, clean water, and sanitation. Petroleum has historically been important to address such challenges. However, the production and use of petroleum also causes greenhouse gas (GHG) emissions. Moving forward, GHG emissions will have to be reduced, which will require collaboration and concerted efforts.

Demand for oil and gas declined in 2020 as a result of the Covid-19 pandemic. The demand has since recovered, and oil and gas prices are by October 2021 much higher than before the pandemic. A continued high demand is expected over the next years, but the long-term outlook is uncertain. The Norwegian petroleum industry needs to be prepared for tighter markets, lower prices, and higher volatility. In such an energy future, the competition for market shares, as well as for talent and investments, will increase.

In OG21's opinion, oil and gas producers that can deliver petroleum at low costs, with low GHG emissions, and with accept and support from stakeholders, are likely to outcompete their peers. Stakeholder accept and support hinges on the ability to reduce GHG emissions, achieve excellent safety results, and deliver competitive returns.

- Norway is a global leader in petroleum technology, but innovation is required to maintain our competitive edge

The Norwegian Continental Shelf (NCS) is well positioned to stay competitive in an energy landscape under transition where the battle for market shares, talent and investments could become more intense. The NCS is characterized by:

- attractive and stable frame conditions,
- a safe and very cost-efficient infrastructure which will continue to produce existing reserves as well as new oil and gas resources,
- a promising discovery portfolio with resources that could be tied back to and produced through the existing infrastructure,
- attractive acreage close to existing infrastructure,
- world leading environmental performance, including among the lowest GHG emissions per barrel produced,
- a well-respected safety collaboration between regulators, employers and employees which has resulted in world leading safety standards and emission results.

Research, development, and innovation (R&D&I) is critical for maintaining the competitive edge:
New technology and knowledge, and the ability to adopt technology and knowledge fast, will be instrumental in keeping costs down, reduce CO_2-emissions and continually improve safety. OG21 is of the opinion that research, technology development, and innovation within 8 technology areas are especially important (details on technology and knowledge priorities in section 4 of this report):

1. **Improved subsurface understanding** and tools are fundamental for the attractivity and competitiveness of the NCS. The technology area has important ties to all disciplines: it will improve identification of opportunities and exploration for resources; improve well positioning and aid in the completion of wells; improve drainage of reservoirs; reduce water production which is the main contributor to energy use and GHG emissions on the NCS installations; and reduce safety risks associated with drilling. It is also fundamental for efficient carbon capture and storage (CCS).
2. **Cost-efficient drilling and P&A** address two major cost elements of offshore operations. More cost-efficient drilling requires improved methodologies and tools for well construction, more efficient drilling technologies for subsea wells, improved completion solutions, and better subsea well intervention technologies. In addition to reducing costs, such methodologies and tools could also reduce emissions and improve recovery from challenging reservoirs. Plugging and abandonment of wells (P&A) represents a potential high

future cost for oil companies and the Norwegian state, and it is a pressing need for development and application of significantly more cost-efficient technologies.

3. **Utilizing existing infrastructure efficiently** will be key to produce remaining reserves in the fields and to realize contingent resources. Contingent resources could be in fields, in the NCS discovery portfolio, and in new near-field discoveries. Existing infrastructure should also be evaluated for re-purposing when approaching end of production, for instance for late-life deposits of CO_2 in relation to CCS. The technology area includes technologies and knowledge for process optimization and integrity management, for instance: improved process simulators, condition monitoring, risk-based maintenance and improved understanding of materials and material degradation mechanisms.

4. **Unmanned facilities and subsea tie-back solutions** include technologies such as flow assurance models to extend the possible tie-back distances, subsea processing technologies, and unmanned production facilities.

5. **Energy efficiency and cost-efficient electrification** are of paramount importance to meet the industry's ambitious GHG emission target of 50% reduction by 2030. Electrification from shore and use of offshore renewables are the most important technologies to reduce operational GHG emissions. There are many costly technical challenges to be solved such as power transfer through FPSO turrets, subsea HVDC converters and long-range AC transmission. Electrification hubs and large grid systems could also reduce costs. Energy efficiency can be improved for instance with technologies to reduce water production, water processing downhole or subsea, combined cycle gas turbines, and the use of low carbon fuels in gas turbines.

6. **Carbon capture and storage (CCS)** is a key technology area to reduce CO_2-emissions. Firstly, CCS provides an opportunity to de-carbonize natural gas either onshore or offshore (gas-to-X where X could be either blue hydrogen or electrical power). Secondly, an opportunity to apply CCS directly to offshore gas turbines to reduce operational emissions, should be explored. In addition, CCS represents an industrial opportunity for broad multi-industry application.

7. **World leading HSE and environmental performance** is a fundamental value for the industry and a pre-requisite for society acceptance. It includes improved knowledge to understand and mitigate risks related to adoption of new technologies and new business models, better tools for understanding major accident risks and uncertainties, improved management of cyber security risks, and the continual effort to understand and reduce working environment risks.

8. **Digitalization** spans across all disciplines. The technology area is fundamental for improved and faster decision processes, which will reduce costs, increase the resource base, reduce GHG emissions and improve safety. The development and application of new tools and solutions such as artificial intelligence, robotics and drones, and digital twins, are key to achieve a digital transformation of the industry. To get there, there is a need for acquiring and processing data more efficiently, a need for more collaboration on data access, data formats and data quality, and a need to change work processes and business models to fully utilize the potential of new technology.

Several factors may inhibit R&D&I that could benefit industry enterprises as well as the society. For example, it might be more attractive to be an early adopter rather than the developer of technology, individual enterprises might alone have a limited application scope of new technology whereas the application scope aggregated across a group of enterprises could be large, and some technologies could have important societal benefits whereas business impact is uncertain or low. Industry collaboration as well as public R&D&I incentives, are required to address such R&D&I challenges.

- Our industrial heritage and world-leading technology and competence could be the steppingstone to new industrial ventures

The Norwegian petroleum industry's contributions to the energy transition and a zero-emission society include three elements:

- De-carbonatization of the petroleum production phase as described in Konkraft's roadmap (Konkraft, 2020), (Konkraft, 2021), see Section 3.3.

- De-carbonization of petroleum value chains, which in addition to abating CO_2-emissions, also could contribute to securing the future market for natural gas.

- Participation in and transfer of competence and solutions to emerging low-carbon industries.

Just as the Norwegian petroleum industry once was built on competence and skills from the maritime industries, Norway is now well positioned to take a leading role in emerging industries where our world leading petroleum competencies and solutions will provide a competitive edge.

Whatever the future holds, our industrial base will stand on the shoulders of our past pioneers and our world leading competence

Currently, half of the Norwegian petroleum production is natural gas, and it is expected to stay at this level for the next decade. Nearly all the natural gas is exported to EU countries and the UK where it could continue to replace coal and thus reduce CO_2-emissions. Nevertheless, the industry needs to be prepared for a possibly reduced future demand for natural gas. To secure the market for natural gas in the longer term, the gas can be de-carbonized either into blue hydrogen and hydrogen-derived fuels like ammonia, or into low-emission electrical energy.

CCS is a key technology in this transition. Competence and solutions from the petroleum industry are essential for safe and lasting storage of CO_2, e.g. to understand the geology where the CO_2 is sequestered, possible migration paths, as well as monitoring for leaks. In addition to enabling continued sales of natural gas, CCS also represents a wider industry opportunity for de-carbonizing other industries with high CO_2-emissions such as cement production and steel production. The Longship project to demonstrate the CCS value chain is therefore very important. We need continued research and innovation to broaden the industry scope for CCS and to make CCS value chains more cost-efficient.

Hydrogen and hydrogen-derived fuels produced from natural gas in combination with CCS is also an industrial opportunity for Norway. Traditionally, hydrogen and ammonia have been used in some industrial processes, but the potential application scope is a lot bigger. Hydrogen could be used as the reducing agent in steel production; as an energy carrier for heating of buildings; as a fuel in electricity generation; and as a transportation fuel. Common for all such new application areas is that new value chains need to be established and demonstrated.

Floating offshore wind energy is still in the demonstration phase, but it represents a great opportunity for Norwegian suppliers and energy companies. In addition to provide electricity to the onshore energy system, offshore floating wind could also produce clean energy for the NCS petroleum activities. Examples of transferable world-class petroleum competence and solutions that could provide a competitive advantage, include: Offshore floating structures; offshore dynamics analysis; mooring and positioning; offshore power connectors and transmission; condition monitoring and maintenance; and robotics and automation.

Marine minerals mining is still in a very early conceptual stage. There are potentially large volumes of minerals at the mid oceanic ridge, which could contribute to meeting a rising demand for minerals. Many challenges need to be solved before seabed mining is realized, e.g.: deep sea mining equipment must be developed; logistics need to be solved; and environmental risks need to be understood, mitigated, and managed. All such challenges resemble challenges the Norwegian petroleum industry is used to handling.

Development of new industries that could contribute to the energy transition, should take place in parallel with the further development of the petroleum industry so that synergies could be leveraged.

- Sufficient technology development and uptake will require leadership, new talent as well as broad collaboration in a well-functioning innovation system

To stimulate the required innovation, OG21 believes three elements are critical:

A. We need to attract and develop talent. The petroleum industry is approaching "the great crew change". A high portion of the employees will retire over the next decade, and experience and domain knowledge could be lost. New technology, especially advanced digital technologies, will require new competencies and skills.

Two competence areas could become especially important for maintaining the innovation capability:

I. Attracting new graduates by offering exciting and meaningful jobs and by convincing them through tangible results that the industry takes climate change seriously.

II. Training and developing the existing workforce to understand, develop and adopt new technologies.

B. The efficient innovation system in Norway needs to be maintained and further developed.

I. The close collaboration between industry, research institutes and universities, stimulated by governmental funding and tax incentives, has been a successful recipe for the petroleum sector. It needs to continue.

II. Governmental R&D funding for the petroleum sector should reflect the technology priorities of this OG21 strategy. R&D strengthens the competitiveness of the NCS, and includes R&D aimed at reducing GHG emissions as well as R&D for more cost-efficient petroleum resource utilization. The high portion of high-quality R&D projects that fails in the competition for governmental funding, in combination with the many challenges the industry is facing, clearly shows that petroleum R&D is underfunded. Governmental funding of petroleum R&D should therefore be increased.

III. Petroleum research programs should encourage cross-discipline R&D, including system perspectives, so that the value of new technologies and how technologies depend on system integration becomes more apparent. More collaboration across disciplines such as science, engineering, technology, mathematics, and social sciences should be encouraged. The RCN should evaluate new and more agile approaches to R&D funding to complement the current system and identify for what types of projects and calls such approaches could be applied.

IV. The established sectoral approach to R&D is important as it draws attention to specific R&D challenges within an industry and facilitates alignment between industry, academia and the government on objectives and priorities. It does, however, come with some drawbacks. It lacks a high-level agenda setting mechanism and mechanisms for holistic coordination and management. OG21 therefore supports the idea of supplementing the well-established and efficient sectoral approach to R&D&I, with cross-sectoral "missions" to guide R&D&I efforts on societal challenges reaching across sectors.

C. We need visible and consistent **technology leadership at executive level**:

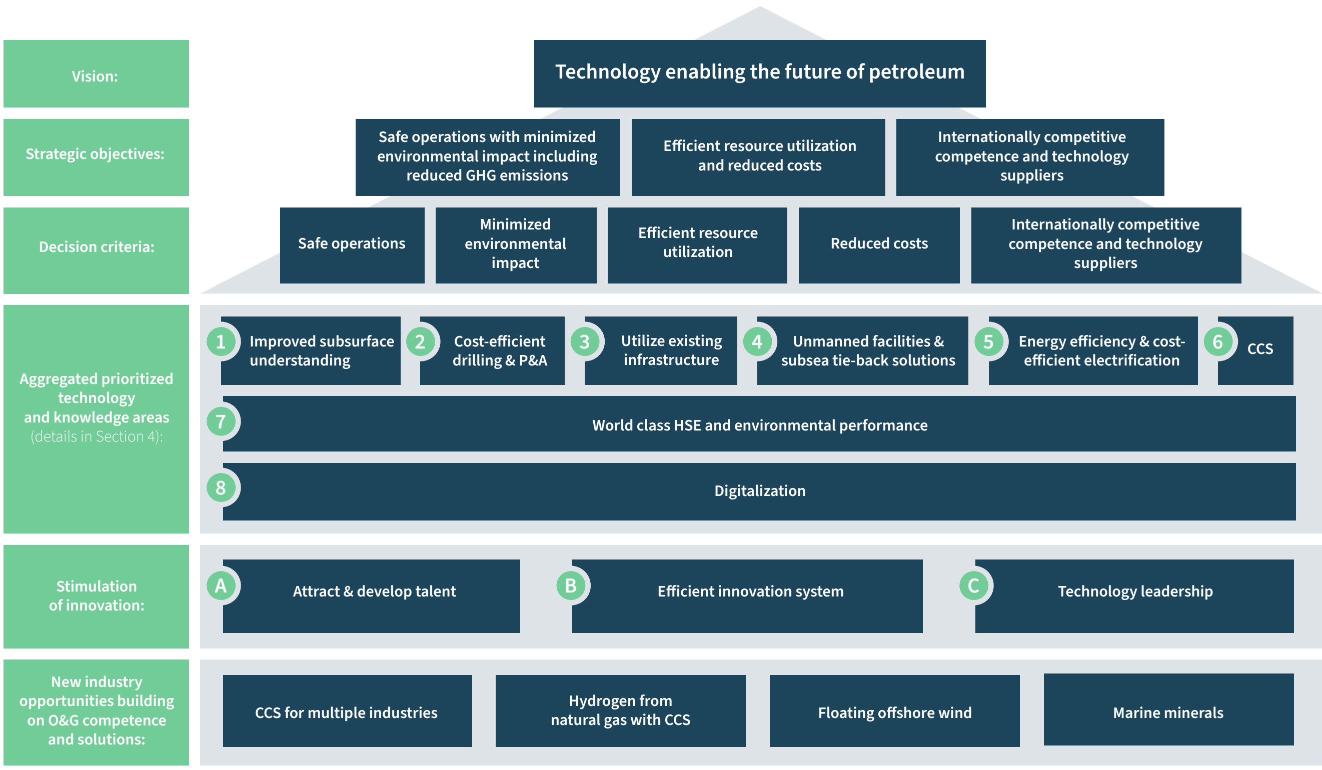
I. Industry enterprises need to have visible "technology champions" at the executive level that provide consistent signals on the need for technology to maintain competitiveness, and which have the willingness and stamina to develop, test and improve technology. The responsibility for technology should start at the executive level and be distributed throughout the organization. The responsibility should be reinforced through key performance indicators and incentives.

II. The larger oil companies need to have a portfolio rather than a project approach to new technology. Petoro should advocate for technology collaboration across the wide range of production licenses they are involved in. The NPD and the PSA should leverage their influence on technology development and adoption in the production licenses.

III. Executive level technology managers should make sure that technology opportunities are identified and communicated to potential technology suppliers early so that suppliers have a possibility to suggest and develop new value-creating technology in time.

The new OG21 strategy is summarized in Figure 1.

Figure 1. Summary of the OG21 strategy



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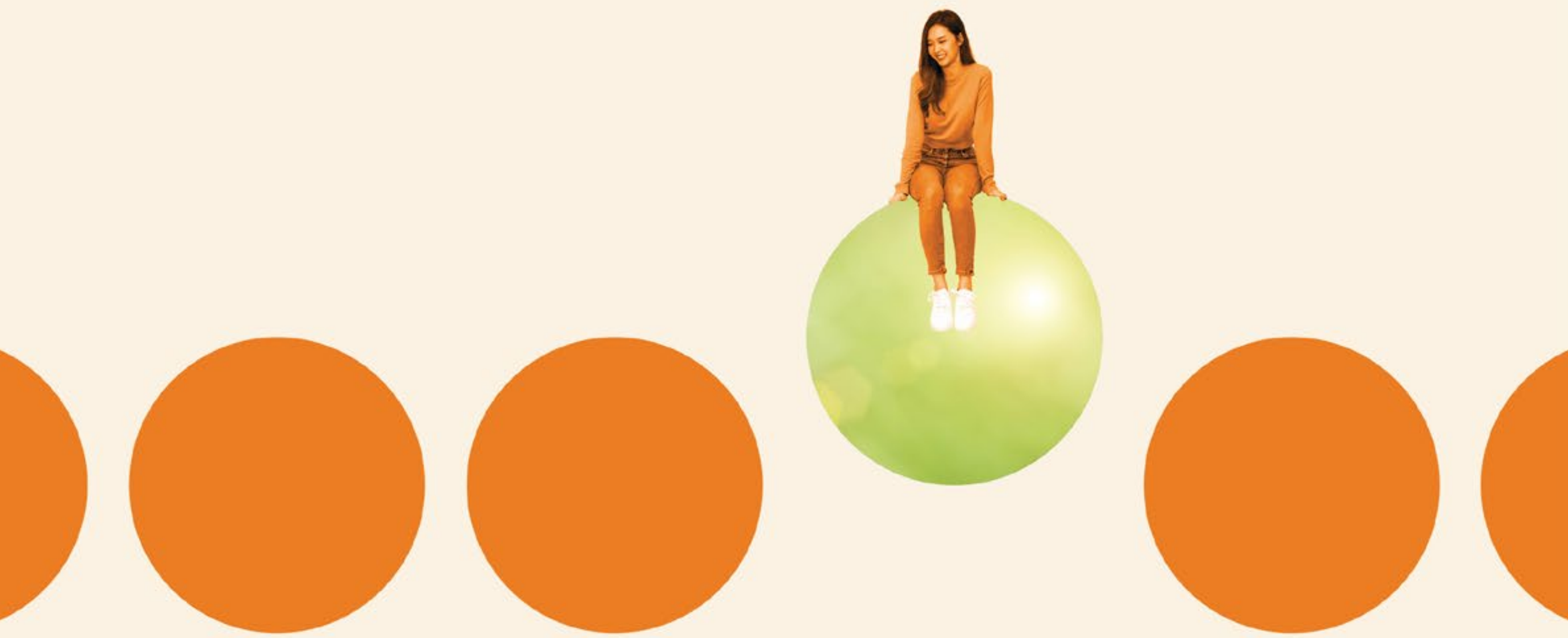
THE FUTURE OF PETROLEUM IN THE ENERGY TRANSITION



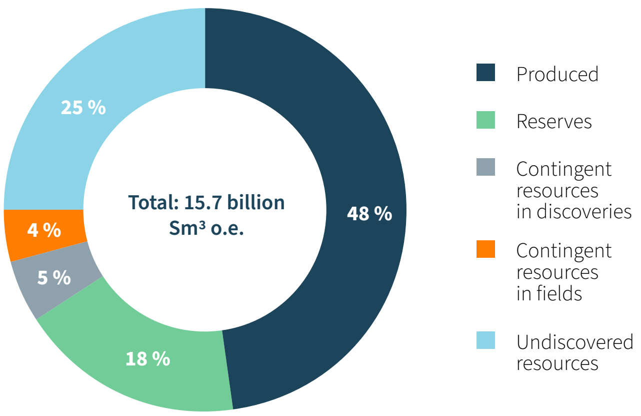
2.1 THE ROLE OF THE NORWEGIAN PETROLEUM INDUSTRY IN THE ENERGY TRANSITION

Climate change is occurring, and the world needs to curb GHG emissions. Since fossil fuels are a main contributor to GHG emissions, the petroleum industry needs to contribute to addressing the challenge. Emissions from production should be reduced and new industries should be developed to support the energy transition.

The inertia in the energy systems is however significant. For instance: A typical fossil fueled power plant operates for at least 25 years; an internal combustion engine (ICE) car has a life expectancy of more than 10 years; the electrification of societies requires massive investments in power grids and buildings and will take time. In addition, oil and gas is hard to replace for many end-uses such as for fertilizers and industry products. This means that even with global decisions to curb emissions, there will be demand for oil and gas for many decades to come. How fast the transition will go and how the oil and gas demand will be impacted, depends on: (i) how successful global leaders are in developing and implementing policies and binding agreements, and (ii) cost and technology advancements of low-emission alternatives both on the energy supply and demand sides.

Less than half of the estimated resources on the NCS has so far been produced, and the NCS is currently highly competitive in the market with low lifting costs and low CO_2-emissions per barrel o.e.

Figure 2. Resources on the NCS (NPD, 2020)



OG21 believes that the NCS and the Norwegian petroleum industry can continue to deliver value to the Norwegian society in terms of revenue and jobs along three dimensions:

1. Successfully compete for market shares in the oil and gas markets. Future markets and prices are uncertain, and to stay competitive the production needs to be highly cost-efficient, and the industry needs to deliver on the ambitious GHG emissions targets set forward by Konkraft (2021).

2. Secure deliverables to the European market for natural gas by de-carbonizing the gas. CCS is a key technology to de-carbonize natural gas, either into low-emission hydrogen or electrical power.

3. Contribute with competencies and solutions to the development of new industries, e.g. blue hydrogen and ammonia, CCS, offshore wind power and marine minerals mining. Developing such industries would assist in the energy transition and should take place in parallel with the further development of the petroleum industry to leverage synergies.

Development of resources on the NCS should continue. The NCS offers stable and secure supply in addition to among the lowest CO_2-emissions in the world.

2.2 ENERGY POLICIES SETTING THE DIRECTION

2.2.1 National policies

Several governmental and industry policy documents for the Norwegian petroleum sector have been published or updated in recent years. Combined they describe a Norwegian petroleum industry that will:

1. Continue to be important for the Norwegian society in the coming decades, although with a gradually declining relative importance for the society.

2. Need to reduce its CO_2-emissions, both in the production phase and along the value chains.

3. Contribute with technology, competence, and solutions to enhance its competitive edge and also develop new industries.

The Governmental white paper launched in June 2021 on *long-term value creation from Norwegian energy resources (Meld.St.36 (2020-2021))*, describes four main objectives:

- Value creation that provides new jobs in Norway. The Government wants the Norwegian renewable energy resources, to the largest extent possible, to be utilized and refined in Norway.

- Electrification to make Norway "greener". A new electrification strategy is launched as part of the white paper. It aims at finding a balance between the need for more power and improvements to the grid and the associated environmental consequences and concerns.

- Establishment of new profitable industries, such as hydrogen, offshore wind, CCS and battery production.

- Further development of a petroleum industry fit for the future and aligned with Norwegian climate goals. In addition to continued stable frame conditions, the Government wants to actively contribute to R&D on good resource utilization and lower operational GHG emissions. The Government also wants to continue the established exploration policy of making new areas available in regular licensing rounds.

In *"Perspektivmeldingen 2021"*, the Government describes which challenges the Norwegian society faces towards 2060 and the Government's strategies to address those challenges. Climate change and its impact globally and locally receives high attention in the white paper. It describes a need for ambitious national measures as well as a need for global cooperation. To meet the goals in the Paris Agreement, large and expensive emission cuts must be implemented globally and nationally. The white paper nevertheless predicts that there will be a continued need for new investments in oil and gas, and that the consequences for the Norwegian oil and gas activities therefore could be modest, (Meld.St. 14 (2020-2021)).

In the white paper *"Klimaplan 2030"*, the Government presents its plan for how Norway will achieve climate goals and green growth towards 2030. The climate plan has a main emphasis on emissions that are not part of the EU quota system, i.e. transport, waste, agriculture, construction and parts of the emissions from industry and oil and gas activities. It does however also address some emissions that fall under the EU quota system, including emissions from the industry and the oil and gas activities. The Government describes in the white paper that it will increase the CO_2 tax so that the combined levy, including quotas, reach 2000 NOK/ton CO_2 by 2030, *(Meld.St. 13 (2020-2021)).*

The industry employers' organization NHO and the labor organization LO have together published a white paper, *"The energy and industry platform"*, on the transformation of the industry to a low-emission society (NHO/LO, 2021). In the report NHO and LO emphasizes that the Norwegian industries' competitiveness depends on:

- An energy policy that stimulates ambitious industry development, and includes strengthening and upgrading of the power grid, increased renewable power production, and new measures to improve energy efficiency.
- Access to renewable energy at competitive prices.
- A further development of a safe and efficient Norwegian power system that is based on principles of business and socio-economic profitability, but which provide the opportunity for industry production to be scaled up in response to demand and for a corresponding faster development of the power grid.
- A holistic electrification strategy that combine industrial opportunities, climate goals and improvements in the power system.

Konkraft published early 2020 *"A climate strategy towards 2030 and 2050"* for the NCS, with support from all its members: the Norwegian Oil and Gas Association, the Federation of Norwegian Industries, the Norwegian Shipowners Association, the Confederation of Norwegian Enterprises, and the Norwegian Confederation of Trade Unions. A status report was published in 2021. The strategy sets forth ambitious climate reduction targets of 40% reduction in operational GHG emissions by 2030, further reduced to near-zero by 2050. It also suggests how the petroleum industry can contribute to reducing GHG emissions along the value chain of hydrocarbons and simultaneously create new industries, (Konkraft, 2020) and (Konkraft, 2021). The 40% target for 2030, was further strengthened to 50% reductions by 2030 through a Parliament request forming part of the Corona stimulus package for the petroleum industry, agreed in the Parliament in June 2020.

2.2.2 Global policies influencing the energy sector

Norway is one of 196 countries that have adopted the legally binding international treaty on climate change developed at the UN COP21 meeting in Paris in 2015. The goal of the agreement is to limit global warming to well below 2 degrees Celsius, and preferably to 1.5 degrees Celsius, as compared to the pre-industrial levels. The Paris Agreement forms the basis for EU as well as Norwegian energy policies.

The 6th assessment report from IPCC is being developed. The contributing report from IPCC's Working Group 1 on the physical science of climate change, released early August 2021, further strengthens the call for action to curb GHG emissions (IPCC, 2021).

The 2030 Agenda for Sustainable Development, adopted by all the member states of UN, is another UN policy document with high impact. Its 17 Sustainable Development Goals are widely referred to in regional and national policies and strategies.

2.2.3 EU Green Deal transforming the European energy landscape

The European Green Deal (EGD), the climate and growth strategy for EU, was launched in December 2019. The EGD and its related targets, measures and strategies are aimed at securing a green and digital transformation of the EU society, economy, and industries. (European Commission, 2019b).

The EGD has transformational impact on all sectors in EU, including the energy sector. The energy sector today contributes with around 75% of EU's GHG-emissions. The transformation from a fossil-fuel based energy system to a system based on renewable energy is therefore an essential part of the EGD.

At the core of the EGD is a new EU climate law which put forward a target of making EU carbon-neutral by 2050. On the path there, GHG emissions shall be decreased by 55% within 2030. The law passed the EU Parliament in May 2021 and entered into force in July.

Numerous and comprehensive plans, programs and underlying strategies have been developed to support the EGD and set strategic direction. The next step is to transform the EGD supporting strategic documents into directives and regulations. The "Fit for 55" package presented in July 2021 is part of that.

The EGD impacts Norway both through the adoption of regulations and directives, and through changes to physical and financial value chains. For enterprises and organizations historically involved in the Norwegian petroleum industry, impact on at least three areas could be envisaged:

1. Production costs:
- Revision of the ETS quota system will increase costs of CO_2-emissions. Impact on petroleum production in Norway will depend on how the CO_2-tax in Norway is adjusted.

2. Access to capital and financing:
- The EU Taxonomy, the strategy for sustainable financing and the directive for non-financial reporting, could make investments in petroleum projects less attractive.

- Research and innovation funding may create opportunities for enterprises and organizations that have growth strategies that align with EU's strategies, see Section 5.2.6 for details.

3. Access to market & new industry opportunities:
- The EU demand for natural gas could be reduced if the natural gas is not de-carbonized and delivered as low-carbon energy carriers, see section 2.4.

- The EU Hydrogen strategy opens for blue hydrogen (produced from natural gas with CCS) in a transition period, but the strategy's main objective is to make green hydrogen competitive.

- The EU Offshore renewable energy strategy aims at making offshore renewable energy a core component of Europe's energy system. It addresses various types of offshore renewables, but offshore wind is expected to be the major contributor.

2.3 THE ENERGY TRANSITION – GLOBAL FORECASTS

2.3.1 Wide span in global energy forecasts

The global total primary energy demand (TPED) in 14 scenarios provided by 5 well recognized organizations [1], is shown in Figure 3. There is a considerable spread in the forecasts towards year 2050, depending on the assumptions they are based on. The assumptions on whether the world meets the targets and ambitions of the Paris-agreement and to which extent CCS is implemented, are the most important.

With exception of the Shell Sky scenario, which assumes an even more extensive use of CCS than the other "less than 2 degrees" scenarios, the "less than 2 degrees" scenarios describe an energy future where the world's energy demand peaks before 2035. They describe a future where renewables such as hydro, bioenergy, solar power, and wind power, dominate the energy mix and where coal has largely been phased out. The relative contribution of oil and gas is smaller than today, but still significant, typically 30-40% of the energy demand. In all the scenarios where the world meets the 2-degree target, CCS plays an important role.

1 IEA WEO 2020, IEA NZE, Shell Scenarios 2020, OPEC WOO 2020, Equinor Energy Perspectives 2020, DNV GL ETO 2020.

Figure 3. Total Primary Energy Demand (TPED) of different scenarios (Rystad Energy, 2021)
Gigatonne of oil equivalent

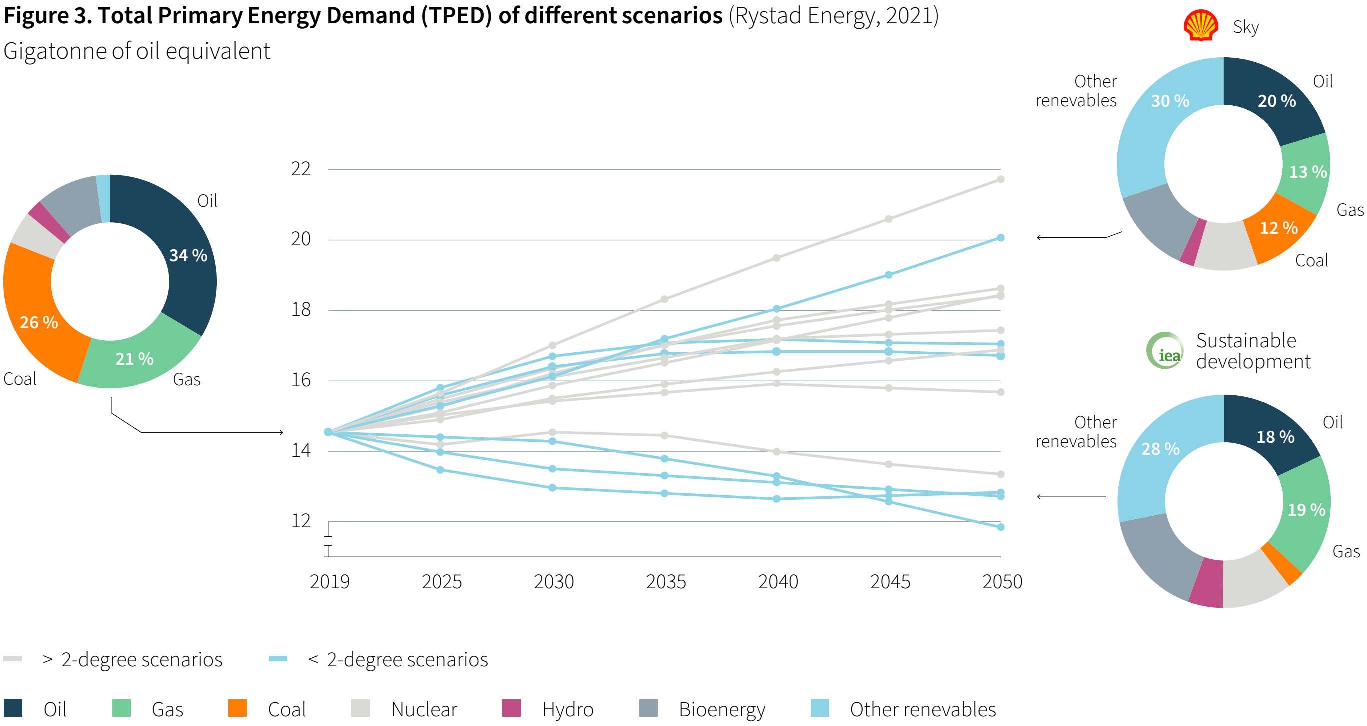
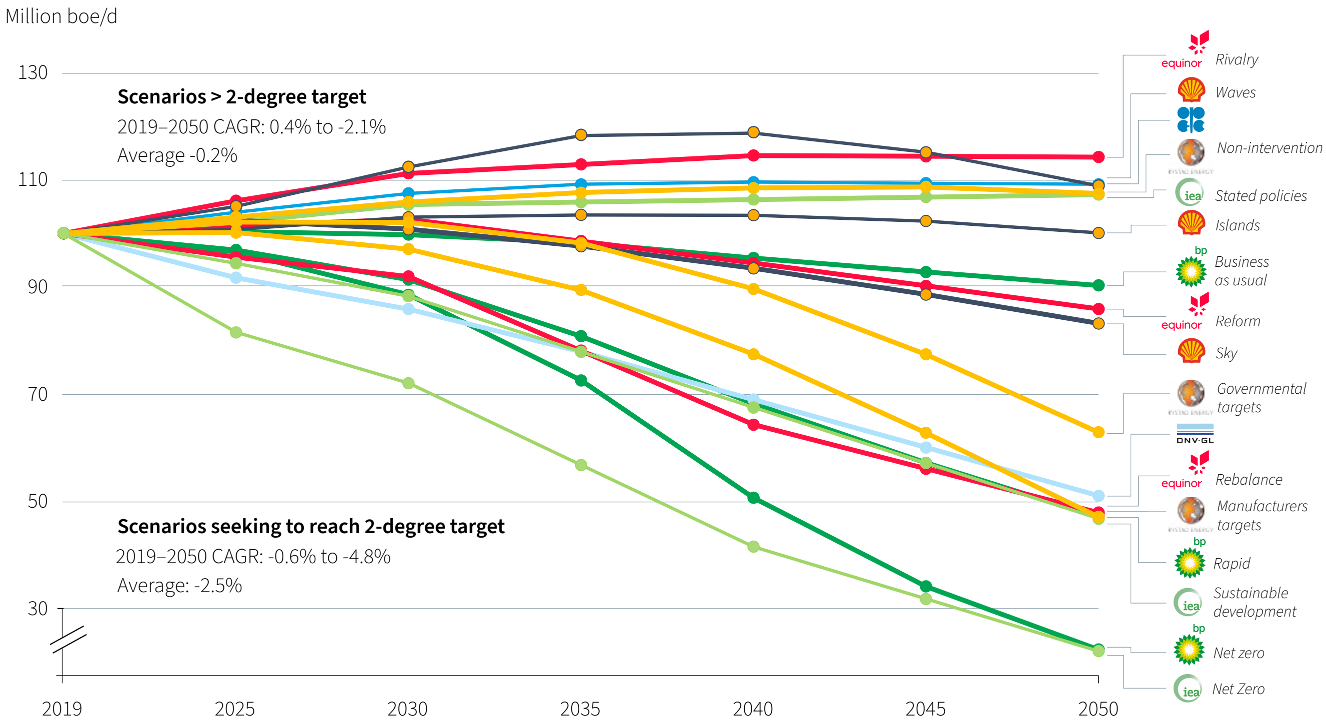


Figure 4. Global liquid demands in different scenarios* (Rystad Energy, 2021)



* Indexed to IEA 2019 levels as different providers define units and markets differently EIA not included as they don't have any updated post-COVID scenario, making it less relevant and comparable.

2.3.2 Oil and gas demand during the energy transition

Oil and gas are likely to continue to play an important role in the global energy mix in the decades to come, but the long-term demand is increasingly uncertain. Figure 4 shows the large span of liquid demand scenarios from recognized sources such as IEA, DNV GL, Equinor, BP and OPEC (Rystad Energy, 2021).

The scenarios compared can largely be grouped into two: those describing a transition to an energy mix that meets the 2 degrees target of the Paris-agreement, and those that do not meet the target.

The "low carbon" scenarios reflect major technological and investment shifts both on the energy supply and the energy demand side. For instance, and as Figure 5 indicates, large scale electrification of road transportation could alone address nearly half of today's oil demand (30% of the 2019 oil production was used for fueling light vehicles and buses and 18% was used for light and heavy trucks). Provided that the electricity is generated from renewables or de-carbonized fossil fuels, electrification of the transport sector is becoming increasingly more attractive, both from an emission and an economic perspective.

Other parts of today's oil use could be more challenging to replace. Maritime transport and aviation require a much denser energy storage than what today's electric batteries can offer, and further advancements of batteries, biofuels, hydrogen, and hydrogen-derived fuels will be important. Furthermore, oil is used in petrochemical and other industries where it could prove hard to replace. For such industries, the search for cost-efficient alternatives to oil as well as re-cycling of oil-derived products, will be important to reduce demand.

Figure 5. What oil was used for in 2019 (Rystad Energy, 2021)

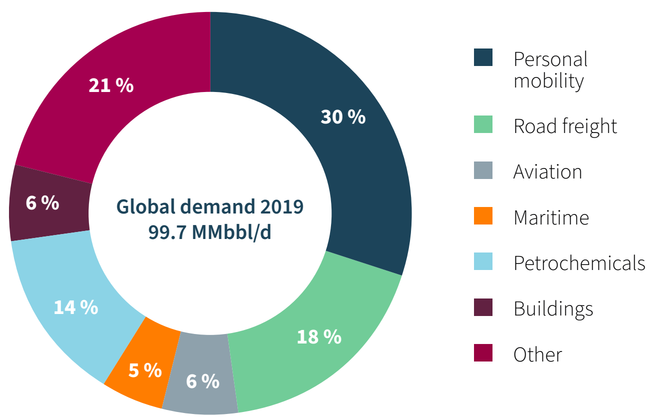
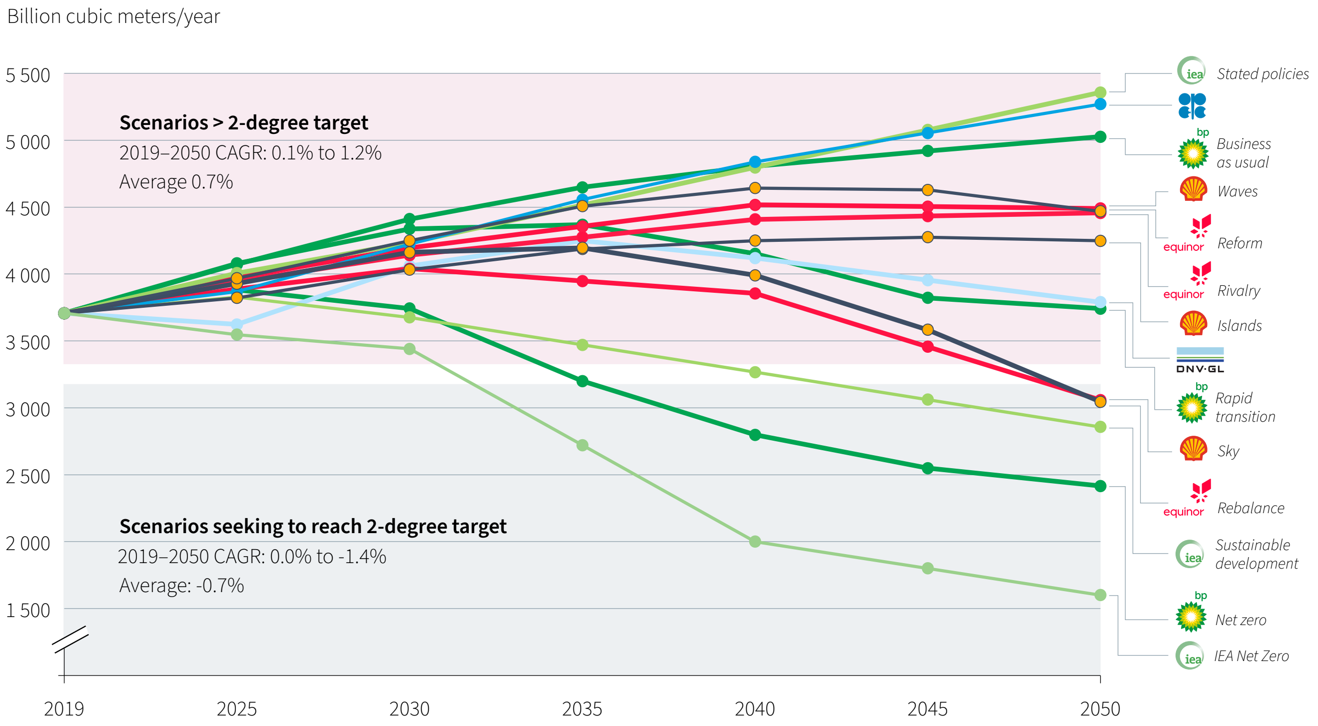


Figure 6. Global gas demand scenarios* (Rystad Energy, 2021)



* Indexed to RE 2019 levels as different providers define units and markets differently.

The transition to net-zero societies globally is therefore going to take time, and oil is likely to be needed for many decades to come.

The future demand for natural gas is also uncertain as Figure 6 shows. However, all scenarios that aim at meeting the Paris-agreement 2-degree target, predict that also global gas demand will peak by 2035 and decline towards 2050.

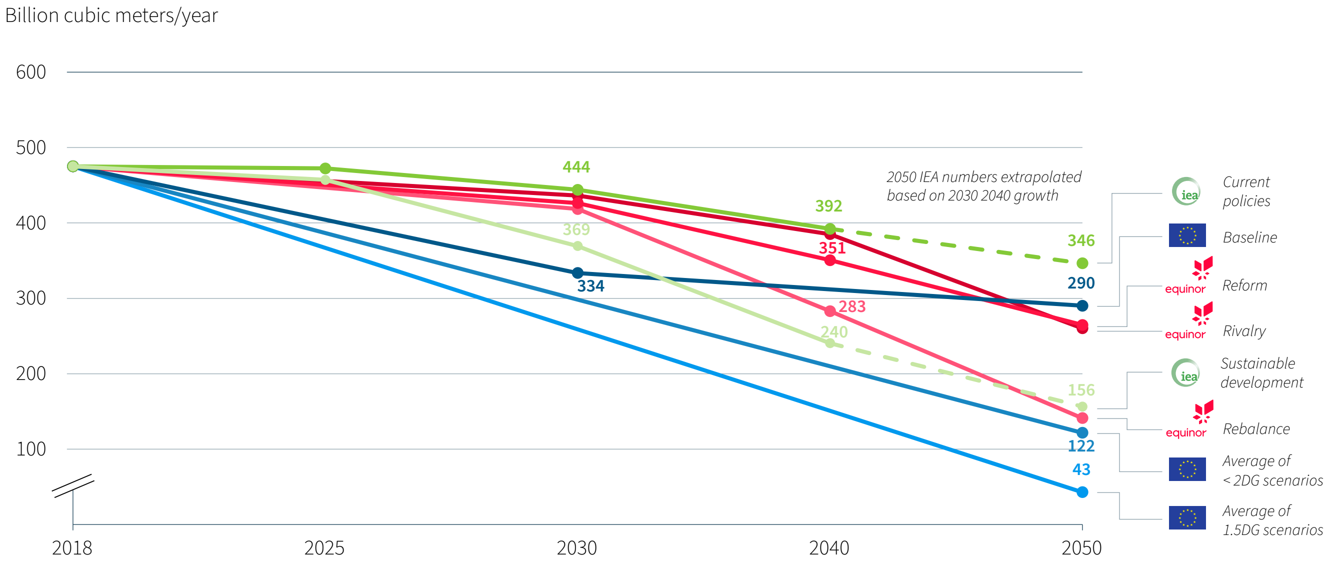
Gas markets are regional to Asia, the Americas and Europe. Long distances between the regional markets, lack of import/export infrastructure and high shipping costs limit the trade between the markets.

More than 95% of Norway's gas production is piped to the European market, with the remainder shipped as LNG to other markets. The European market is therefore of key importance for the sales of natural gas from the NCS.

Most scenarios show robust demand for natural gas in Europe near-term and until year 2030. The use of natural gas in modern gas power plants results in only half the CO_2-emissions from coal-fired power plants, and as such natural gas is an important energy carrier to reduce European emissions in the short to medium term.

However, EU is implementing its Green Deal with a zero-emission vision for 2050, and in the scenarios supporting the vision, natural gas without CCS plays a limited role. De-carbonizing natural gas would therefore be crucial in a long-term strategy for the Norwegian gas. Gas-to-X technologies (blue hydrogen, electricity or other energy carriers) with CCS are key elements of such a strategy.

Figure 7. European (EU+UK) gas demand in different scenarios* (Rystad Energy, 2021)



*Indexed to IEA EU28 gas demand as definitions vary across scenarios. Source: Rystad Energy research and analysis; IEA WEO 2020; EU Commission; Equinor Energy Perspectives 2020

2.3.3 The IEA Net Zero by 2050 scenario

The IEA Net Zero by 2050 scenario (NZE) has drawn significant attention since its release in May 2021. It provides a roadmap to achieve net zero CO_2 emissions by 2050, and the path described meets the 1.5 degrees ambition of the Paris Agreement with a 50% probability.

The NZE predicts a peak in global energy demand by 2023 before a reduction of 10% towards 2050. With a growing population, the energy demand per capita would over the same period be reduced by 25%. Oil and gas would in 2050 contribute with 8% and 11% respectively of the total energy supply (8% natural gas with CCUS, and 3% without).

The NZE hinges on many uncertain assumptions. IEA highlights large behavioral changes on the individual level, modern bio-energy and its associated large land-use, and a fast pace of CCUS adoption, as the three most important. Several other assumptions stand out in addition, most notably the need for alignment and concerted efforts on a global scale, massive investments e.g. in electricity systems, a rapid maturing and broad adoption of new technology such as hydrogen, and access to sufficient quantities of rare earth minerals and critical metals.

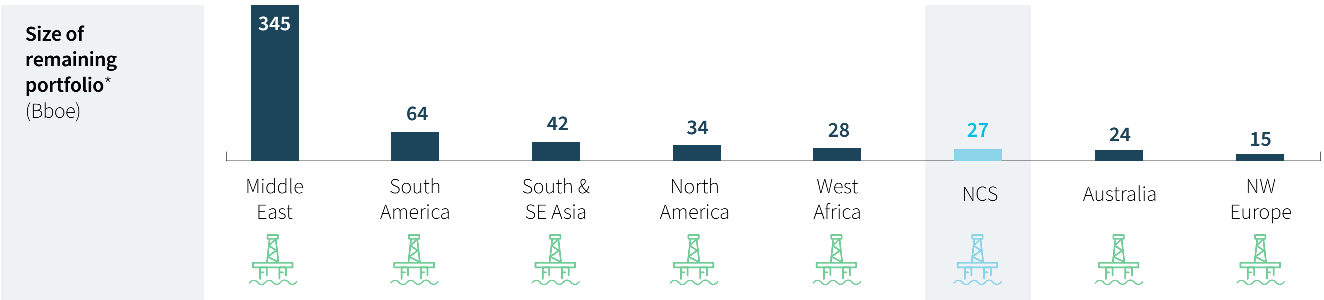
To facilitate an orderly transition to zero-emission societies it is going to be important that policies to curb supply are aligned with policies to curb demand. In a comment to the NZE, Jason Bordoff of Columbia University writes: *"Unless both supply and demand change in tandem, merely curbing the oil majors' output will either shift production to less accountable producers or have potentially severe consequences on economic and national security interests while doing little to combat the climate crisis"* (Bordoff, 2021).

Bordoff bases his analysis on the fact that only 15% of the oil delivered to the market is produced by international oil companies (IOCs). The bulk of the oil (57% in 2018) is produced by national oil companies in OPEC countries plus Russia, and the remainder is produced by independents (OG21, 2020b).

The NZE assumes an oil price decline from 37 $/bbl in 2020 to 24 USD/bbl in 2050 to balance supply and demand, and states: *"The rapid drop in oil and natural gas demand in the NZE means that no fossil fuel exploration is required and no new oil and natural gas fields are required beyond those that have already been approved for development".* Following the arguments of Bordoff in his evaluation of the NZE, the assumed oil price decline would have to be driven by reduced oil demand resulting from substitution with low-emission energy sources outcompeting fossil fuels on costs, and not by curbing oil supply. As such, the eliminated need for new investments in exploration and field development in the NZE should be a consequence of CO_2-pricing and large-scale development of low-emission energy, and not a result of unilateral political decisions on banning exploration and field development.

If the NZE projected price trajectory should materialize, it is not a given that remaining resources in existing fields are more cost and emission effective than resources in new fields. For the NCS, new resources close to existing infrastructure could very well be economically viable within the 30-35$/bbl oil price range projected by the NZE in the period 2030-2040. This is the likely period much of the remaining resources on the NCS would be realized. The associated GHG emissions from such new resources could be substantially lower than from some of the contingent resources in existing fields globally.

Figure 8. Remaining resources on the NCS as compared to other basins (Rystad Energy, 2021)



* *Total volumes in fields in production, under development or discovered, but not yet produced as of 1.1.2021.*

The NZE is one of many scenarios describing the on-going and necessary global energy transition. When evaluating petroleum technology needs for the future, it should be treated as such, although with a considerable weight given the potentially high impact it may have on policy development.

2.4 NORWEGIAN PETROLEUM RESOURCES – LESS THAN HALF PRODUCED AND SOLD

Even though the NCS is maturing, less than 50% of the potential economically viable resources have been produced (NPD, 2020).

As Figure 2 shows, 18% of remaining resources are booked reserves, 4% are contingent upon investment decisions in producing fields, and 5% are contingent upon investment decisions in the existing discovery portfolio. The contingent resources add up to more than 9000 million boe, equivalent to more than 4 times the volumes of the Johan Sverdrup field.

25% of estimated resources are yet to be found. The Barents Sea dominates this category, although related with a high uncertainty span. Half of the Barents Sea estimate is from unopened areas far North. The North Sea and Norwegian Sea are believed to still hold significant, undiscovered resources. The continued discovery trend of small, but still commercial fields, supports this belief.

Improved subsurface understanding, new technology in all disciplines described by OG21's technology groups as well as changes to work processes are all important elements in the maturing of contingent resources and finding and maturing new resources to cost-efficient production with relatively low GHG-emissions.

There are considerable remaining resources on the NCS. Still, in a global context, the NCS resources are rather modest. The bulk of remaining resources globally is in the Middle East and the Americas.

2.5 ON OG21, ITS VISION AND THE STRATEGIC OBJECTIVES

2.5.1 Mandate and organization

OG21 has its mandate from the Norwegian Ministry of Petroleum and Energy (MPE). The purpose of OG21 is to *"work for efficient, safe and environmentally friendly value creation from the Norwegian oil and gas resources. This will be achieved through a coordinated engagement of the Norwegian petroleum cluster within education, research, development, demonstration, and commercialization. OG21 will inspire the development and use of new and improved competence and technology aligned with an energy system in transition and the goal of reduced greenhouse gas emissions".*

OG21 brings together oil companies, universities, research institutes, suppliers, regulators and public bodies to prepare a comprehensive national technology strategy for the petroleum sector which will guide the industry's and the authorities' technology and research efforts.

Technology opportunities and challenges are being identified, described, and prioritized by technology groups (TGs) within the themes shown in Figure 9. The TGs have members from oil companies, universities, research institutes, suppliers, regulators, and public bodies.

Figure 9. Organization of OG21

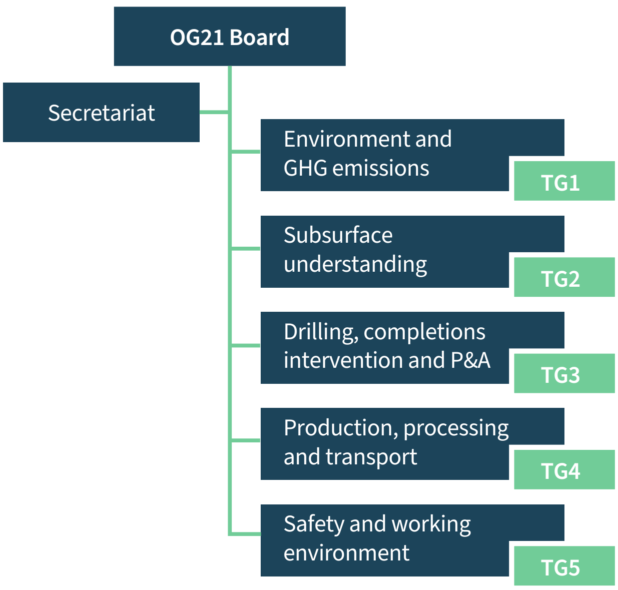
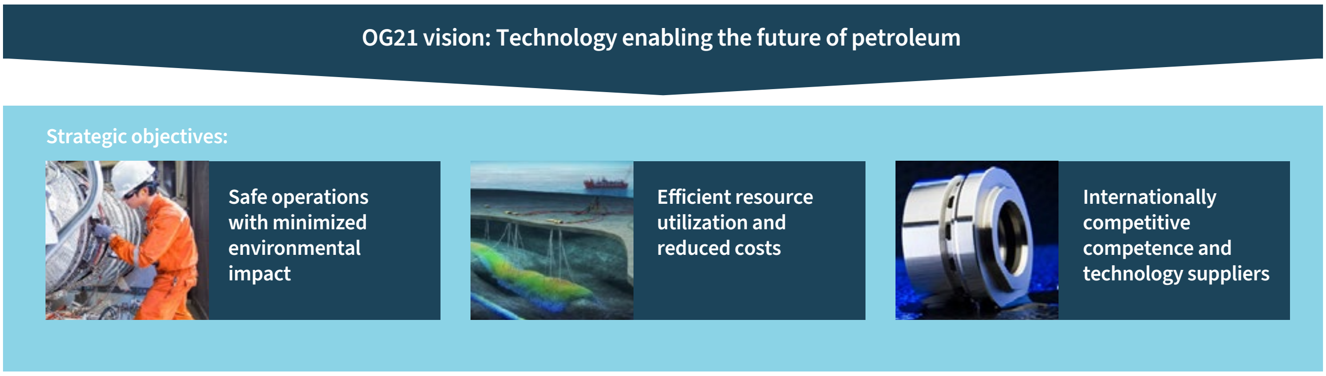


Figure 10. OG21's vision and strategic objectives



2.5.2 Vision and strategic objectives

OG21's vision and strategic objectives are shown in Figure 10.

OG21's vision *"Technology enabling the future of petroleum",* expresses a desire to continue providing petroleum, solutions and services to the global energy markets, but with the understanding that the markets are changing: Technology will be essential to align with a future where GHG emissions related to production are dramatically reduced, petroleum products are de-carbonized, reduced demand for oil and gas have pressed oil and gas prices down, and stakeholders have expectations of excellent safety and environmental performance.

The vision is supported by three strategic objectives that combined bring us to this future.

The strategic objectives have formed the basis for the identification and prioritization of technology and competence needs described in Section 4.

2.5.3 Funding

OG21 is co-located with the Research Council of Norway. In addition to hosting OG21, RCN provides administrative assistance to OG21.

The Ministry of Petroleum and Energy is OG21's main sponsor. In addition, OG21 receives funding from energy companies. Funding energy companies in 2021 are Equinor, Vår Energi, Lundin Norway, OMV, ConocoPhillips and Neptune Energy.

The OG21 budget, income and spending is disclosed in the annual reports published on the OG21 website.

2.5.4 Interfaces with other 21-processes

OG21 has important interfaces to other strategy processes:

Figure 11. Interfaces between OG21 and other 21-processes

Energi21 is the national technology strategy for renewable energy and transportation. OG21 has interfaces with Energi21 on energy efficiency, carbon capture and storage (CCS), power transmission and grids, and use of renewables for power supply.

Maritim21 is the national technology strategy for the maritime industry. Interfaces with OG21 include marine operations, mobile drilling units, gas transport, emergency preparedness technologies and automation and autonomy.

Prosess21 is the national strategy for the process industries. Interfaces include energy efficiency, CCS, and power transmission and grids.

Digital21 is the national strategy for digitalization of Norwegian industries. Interfaces include all OG21 prioritized technologies with a high degree of digitalization. Digital21 emphasize 5 key strategic technologies that all are highly relevant for OG21: AI, big data, internet-of-things, autonomous systems, and cyber security.

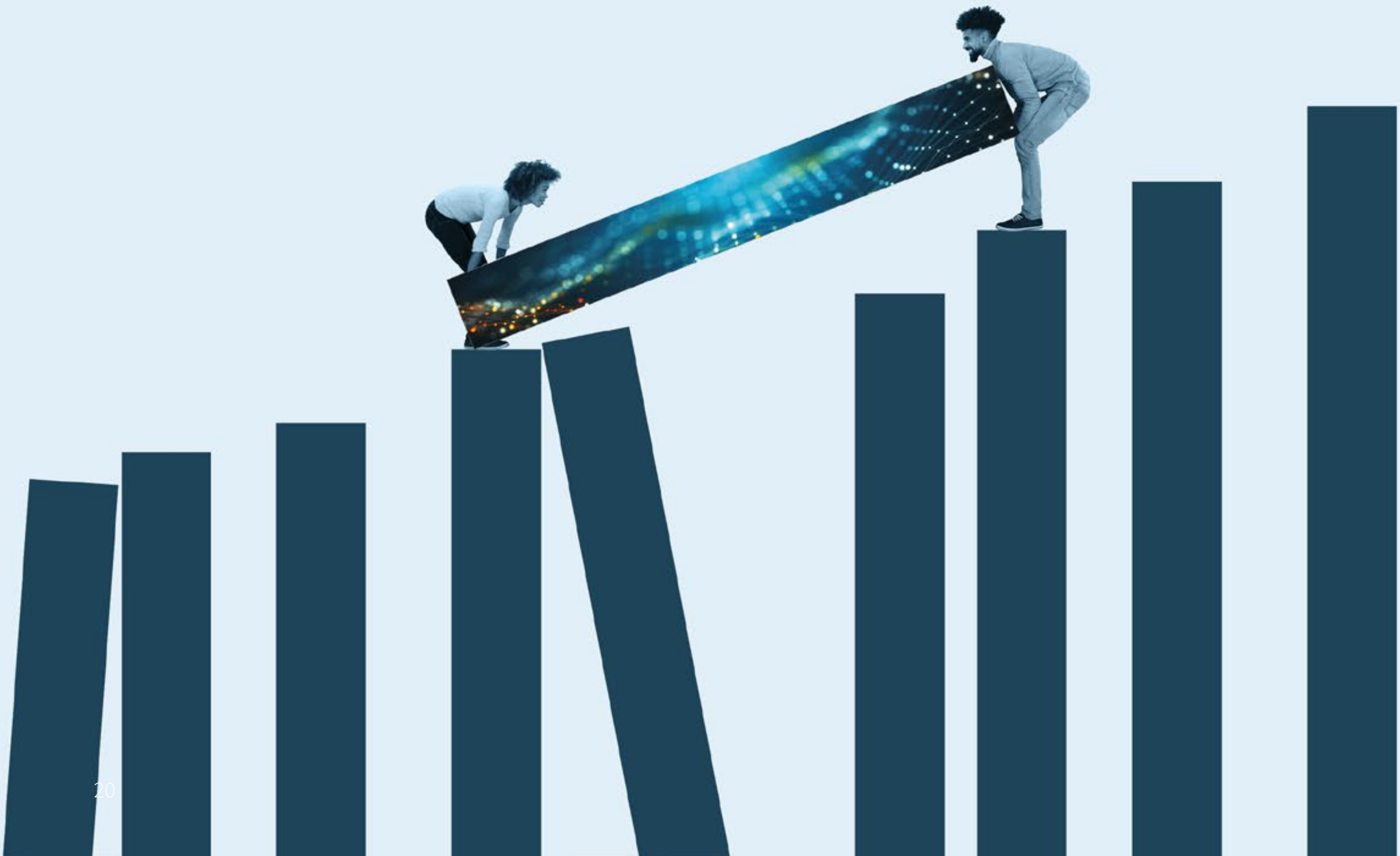
Representatives from the other 21-processes have been engaged throughout the development of this OG21-strategy.

The 21-processes are organized in accordance with the sectoral approach to R&D in Norway, discussed in section 5.2.1. It comes with some obvious benefits such as ensuring alignment between industry, academia and the ministry on objectives and priorities. As such the approach has proven efficient to produce results with significant impact.

The sectoral approach also has some drawbacks, especially related to cross-industry coordination and holistic goals. It could therefore benefit from being supplemented with elements from a mission-oriented approach on societal challenges.

3

THE NEED FOR NEW TECHNOLOGY TO IMPROVE COMPETITIVENESS



3.1 WHAT MAKES AN OIL AND GAS PROVINCE COMPETITIVE?

The prospect of attractive returns is fundamental for attracting investments. Traditionally Net Present Value (NPV) and similar economical metrics have been used to assess the return of petroleum projects. If high commodity prices are expected/-assumed, this may cause a drive for adding volumes as we saw from 2005 and until the oil price slump in 2013. Enterprises in the petroleum industry reacted to the oil price fall by requiring robustness against low oil prices, putting more emphasis on reducing costs. New projects had to demonstrate low break-even prices, in terms of $/bbl, in addition to high NPV to become sanctioned.

The advent of shale oil in North America has highlighted the importance of yet another metric – the lead-time from investment decision to production. Motivated by the uncertainty about future oil prices and CO_2-costs, investors now are looking for faster returns in addition to high value (high NPV) and robustness (low break-even).

More recently investors and enterprises have become increasingly concerned about the carbon footprint of their investments and operations. This is partly driven by an expectation of rising CO_2-emission costs, and partly by stakeholders concerns for climate change and expectations for action.

A fundamental premise for operations is the acceptance in the society. This "license-to-operate" is fragile and is dependent upon the sector's ability to operate safely without major accidents and spills, and the ability to deliver on a credible roadmap for the industry's role in the energy transition.

Going forward we therefore believe that the competitiveness of the NCS depends on the ability to find, develop and deliver cost-efficient resources faster and with lower CO_2-emissions.

The NCS competitiveness and the need for improvements is discussed over the next sub-sections for the following competitiveness contributors:

- Improved safety.
- Reduction of GHG emissions.
- Finding and maturing new resources (volumes).
- Attractive costs.
- Lead times.

3.2 CONTINUAL SAFETY IMPROVEMENT IN A TIME OF CHANGE

The Norwegian oil and gas industry's ambition is to be world leading in health, safety and environmental performance. Returning safely from work and not experiencing work related health problems, is a value which is embedded in the zero-accident philosophy widely adopted in the industry.

Furthermore, accidents and work-related health problems have implications on business opportunities, revenue, and profit. Safety incidents harm companies' and industry's reputation and challenge the "license to operate", cause production down-time, and may erode shareholder value. Examples are numerous, ranging from small incidents like the accidental discharge of 1 m^3 of hydraulic oil from the Eirik Raude drilling rig in the Barents Sea in 2005 causing a three-week delay and a dent in stakeholders' support to Barents Sea operations, to catastrophic accidents like the Macondo explosion, resulting in 11 fatalities, an oil spill of 780 000 m^3, and company costs of more than 65 billion USD.

Figure 12. Lost time injury rate – five-year rolling average by region (IOGP, 2021).

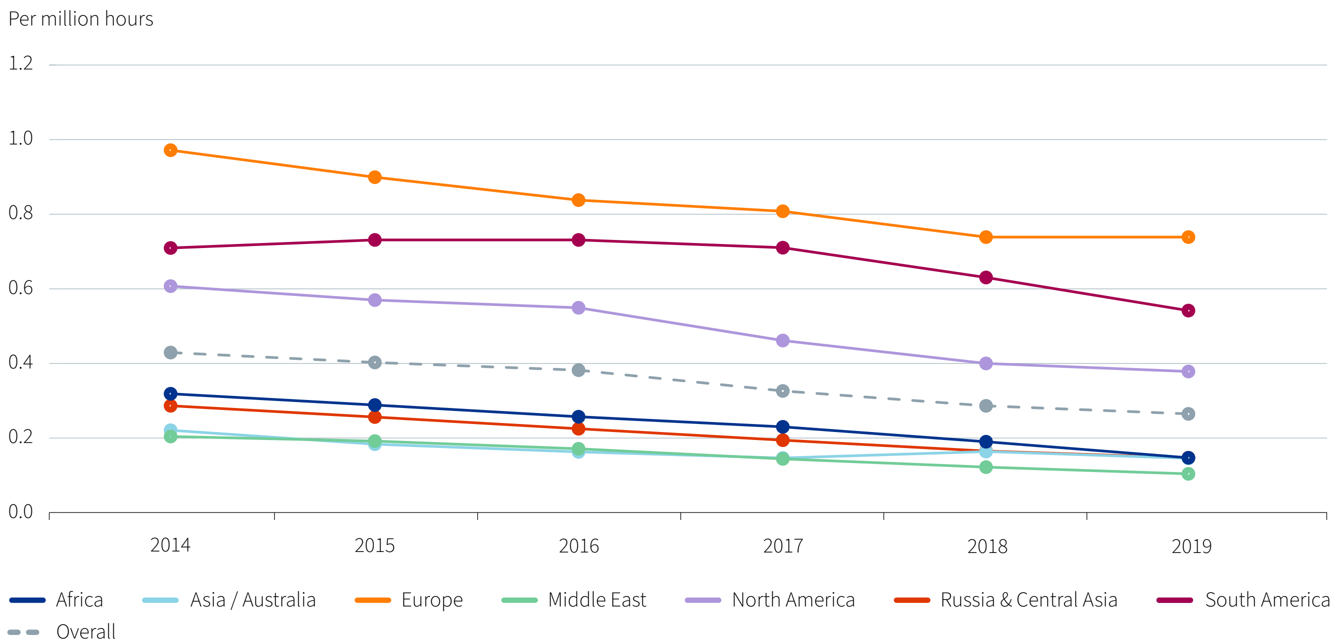
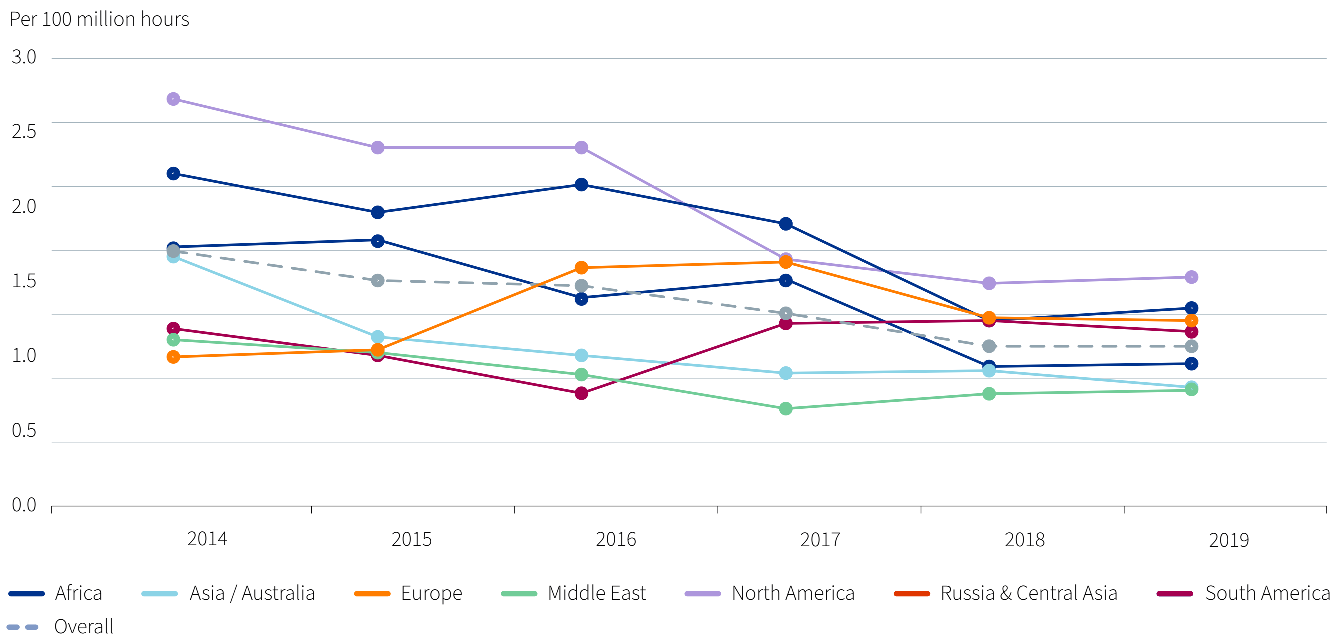


Figure 13. Fatal accident rate – five year rolling average by region (IOGP, 2021).



The zero accidents vision and the no harm principle set the ambition for HSE efforts. However, incidents, accidents, and exposure to working environment hazards still occur. To guide the industry in its endeavor to realize the vision, the principle of continuous improvement is widely applied.

The HSE standards of the Norwegian petroleum industry are recognized to be among the highest in the world. One important reason for this is the continuous efforts made through the Norwegian tripartite cooperation between regulators, employer organizations and trade unions. As Figure 12 shows, this is surprisingly not reflected in international injury statistics collected by the International association of Oil and Gas Producers (IOGP, 2021), where European oil producing countries appear to have poorer lost time injury rate (LTIR) than other regions such as Asia, Russia and Africa where working environment regulations are believed to be less stringent.

Figure 14. Number of incidents with a major accident potential on the NCS (PSA, 2021)

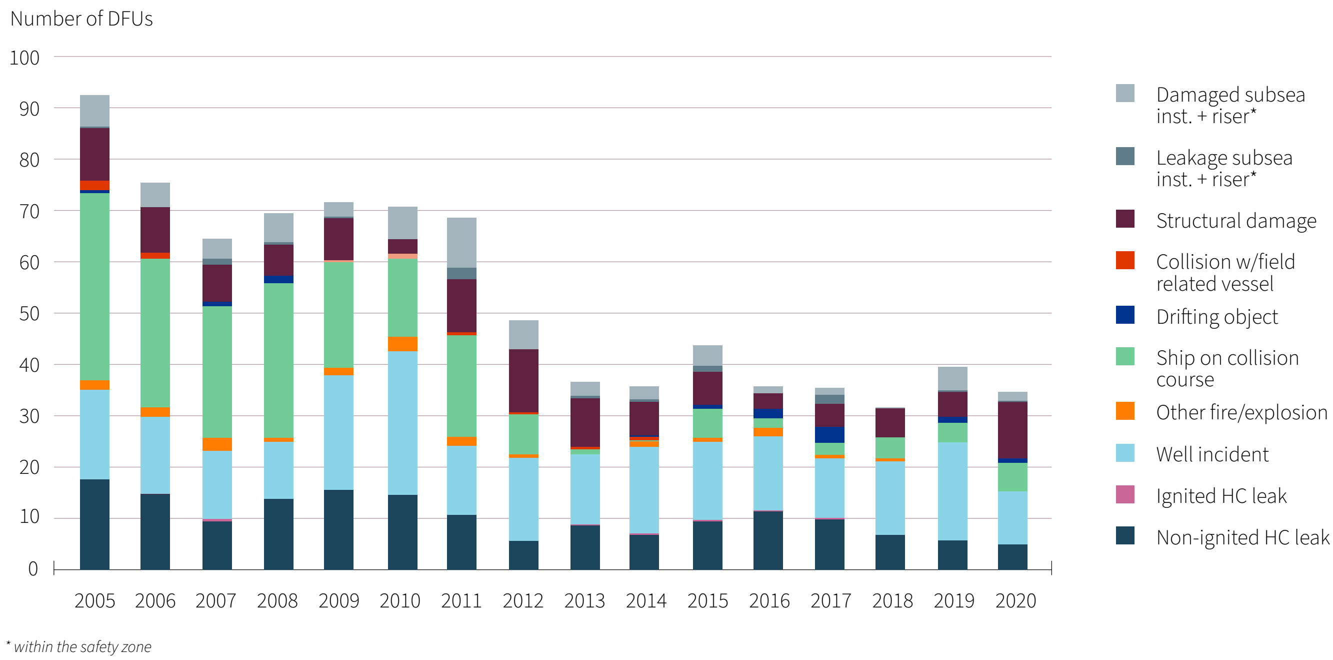
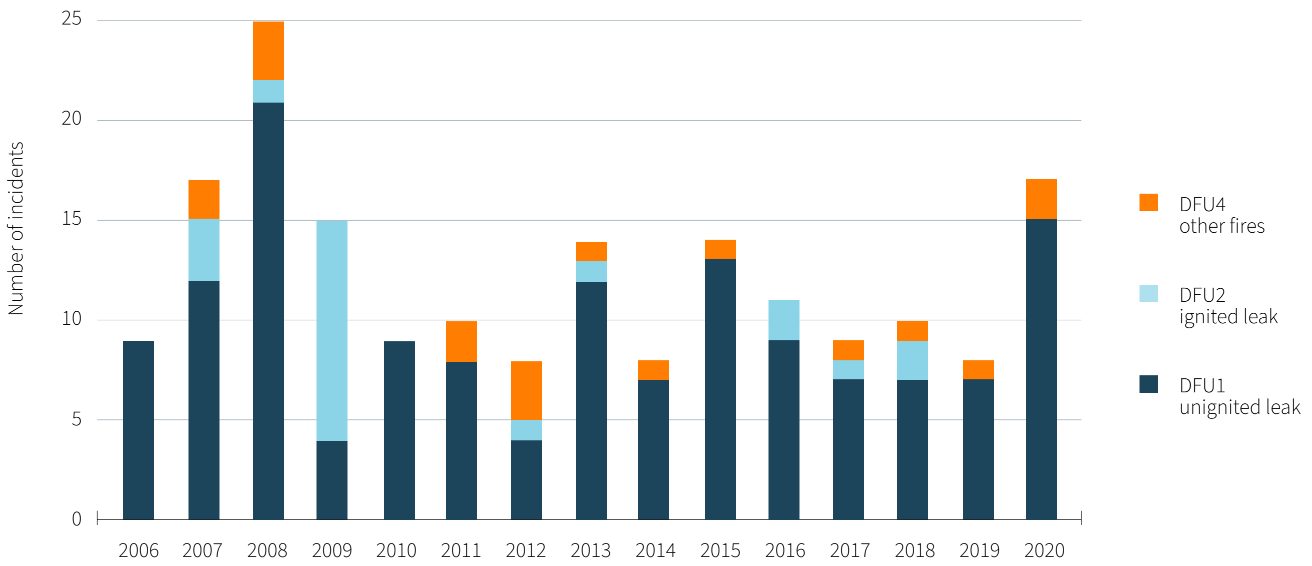


Figure 15. Number of incidents with a major accident potential on onshore plants (PSA, 2021)



The apparently poor safety performance of the European region is less pronounced in the statistics on fatalities, see Figure 13, where the European region is in the middle of the investigated regions. We believe that the reporting accuracy increases with accident severity, and that the lack of correlation between LTIR and Fatal Accident Rate (FAR) numbers reflects diverging reporting practices rather than actual safety performance. OG21 has therefore not used the IOGP statistics as the basis for identifying safety gaps and measures, but instead used data and analyses from the Norwegian Petroleum Safety Authority (PSA) to discuss trends and improvement needs.

In the latest version of its report Risk level on the NCS (RNNP), the PSA concludes that the safety in the Norwegian petroleum industry remains high. The number of offshore incidents with a major accident potential is down, where especially the numbers of hydrocarbon leaks and well control incidents in 2020 were historically low, (PSA, 2021).

However, the trend on some indicators causes concern:

- A sharp increase in incidents with major accident potential at the onshore plants in 2020.
- A noticeable increase in structural incidents such as incidents involving dynamic positioning and mooring systems for mobile and floating installations, structural cracks, and waves on deck.
- Postponement of planned maintenance, especially the increase in maintenance backlog for HSE-critical equipment onshore.
- Negative trend in test results for safety-critical valves on offshore facilities.

However, it is important to state that the RNNP is a tool used to analyze trends over several years that require action or attention. Each report does provide a “snapshot” for a single year, but the formulation of R&D challenges and priorities is based on the trends observed over years.

The further development of the NCS to stay competitive on costs, volumes, emissions and lead times, will require efficiency improvements, where the introduction of digital technologies, new business models and work processes, are central elements. New technology and the accelerating pace of changes introduces new hazards and risks that will have to be managed in the spirit of the zero accidents philosophy.

A continual improvement of HSE performance requires management attention and prioritization, as well as improved understanding of HSE risks, hazards, and under-lying causes. OG21 has in Section 4.1 identified several areas where new knowledge and technology could contribute to a continued positive trend in HSE performance on the NCS.

Figure 16. GHG emission intensity from O&G provinces (Rystad Energy, 2021)

Figure 17. Norwegian GHG emissions per sector in 2018
(Rystad Energy, 2021)

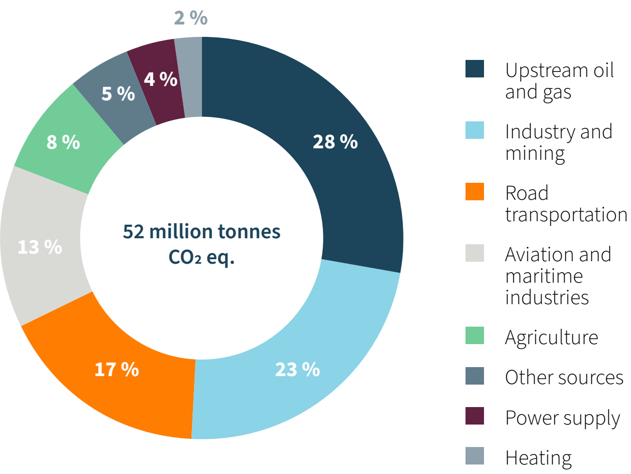
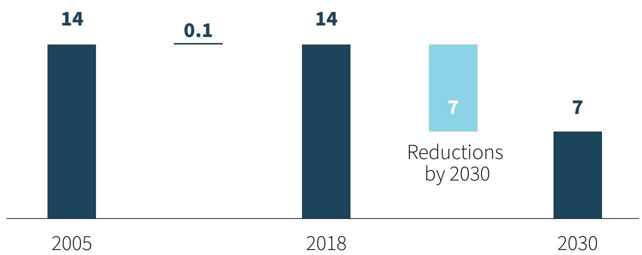
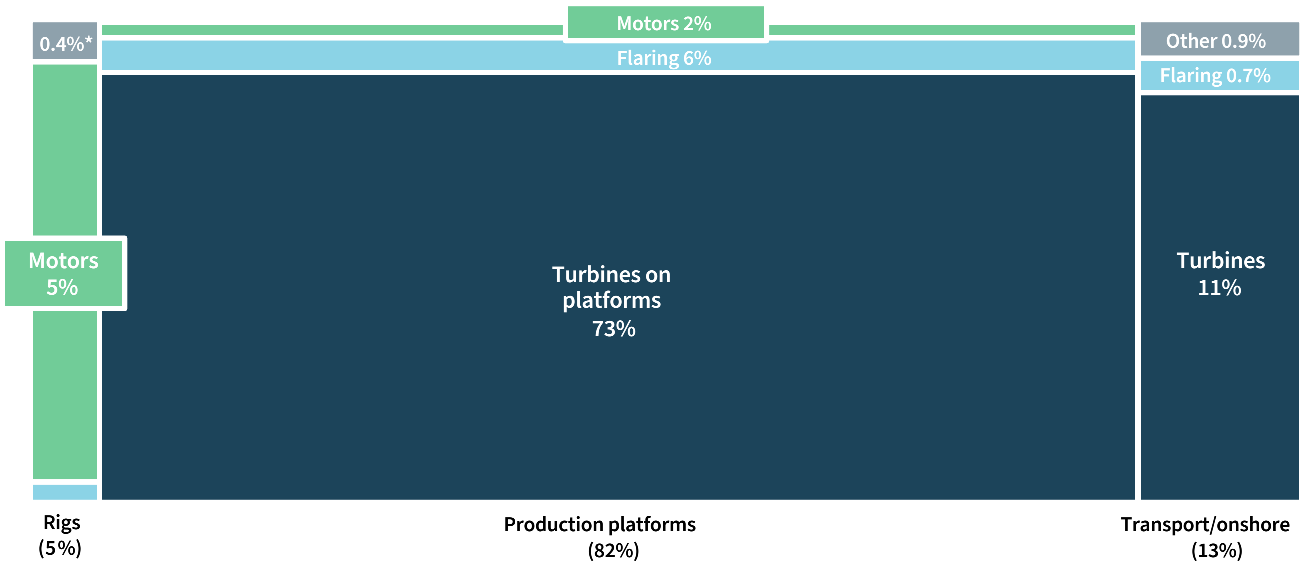


Figure 18. GHG emissions from the Norwegian petroleum industry and near-term reduction ambition
(Rystad Energy (2021) based on Konkraft (2021))



All numbers in million tons CO_2 equivalents

Figure 19. Upstream CO_2 emissions in 2018 distributed on source (Rystad Energy, 2021)



*Includes other greenhouse emission gases in addition to CO_2

3.3 OPERATIONAL GHG EMISSIONS TO BE REDUCED

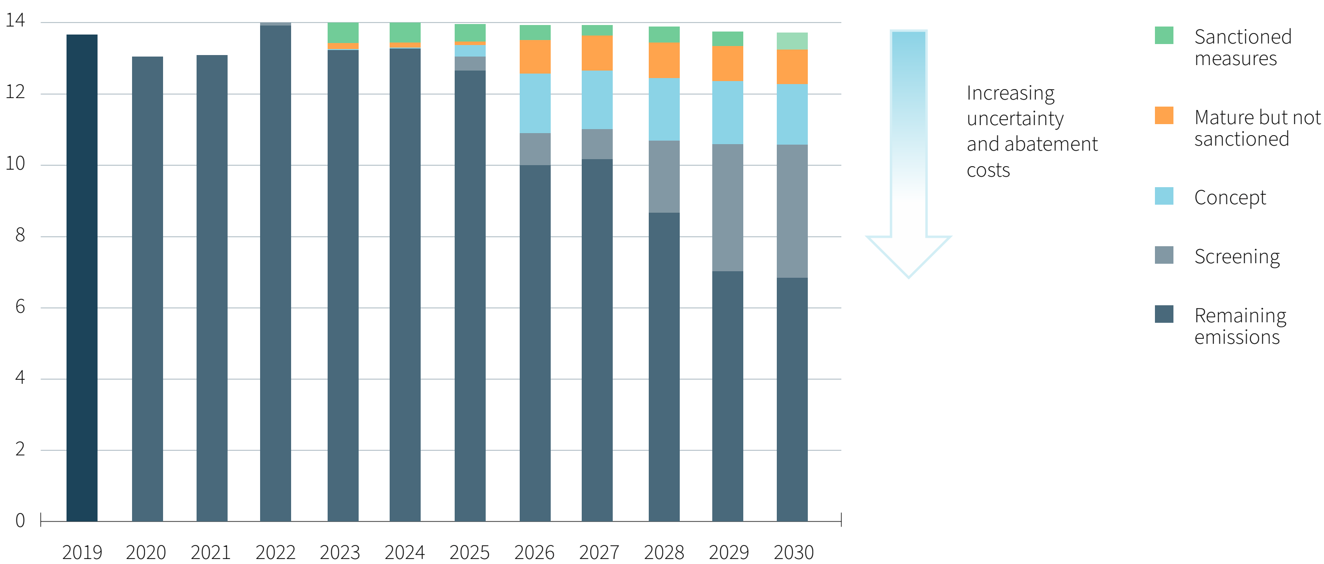
Greenhouse gas emissions (GHG) from the NCS production measured as kg CO_2 per barrel produced (CO_2-intensity), are the lowest among petroleum provinces globally, (Rystad Energy, 2021). This is largely a result of the ban on regular gas flaring introduced in 1974, and the introduction of a petroleum CO_2-tax in 1991.

The Norwegian petroleum industry represented by the Konkraft collaboration, launched ambitious GHG emission targets in 2020 aiming for a 40% reduction in operational GHG emissions by 2030 as compared to the 2005 level, and further reducing the GHG emissions to near-zero by 2050. As part of the temporary tax changes for the petroleum industry agreed in the parliament in June 2020, the parliament asked the industry to further strengthen its 2030 target to a 50% reduction by 2030, see Figure 18. (Konkraft, 2021).

The main contributor to CO_2-emissions on the NCS is turbines, generating energy for the operations, see Figure 19.

The turbines are combustion engines running on natural gas, with thermal efficiencies dictated by fundamental thermo-dynamic laws and the load characteristics. Without bottom-cycle

Figure 20. Opportunity space for 50% GHG emissions by 2030 (Konkraft, 2021)

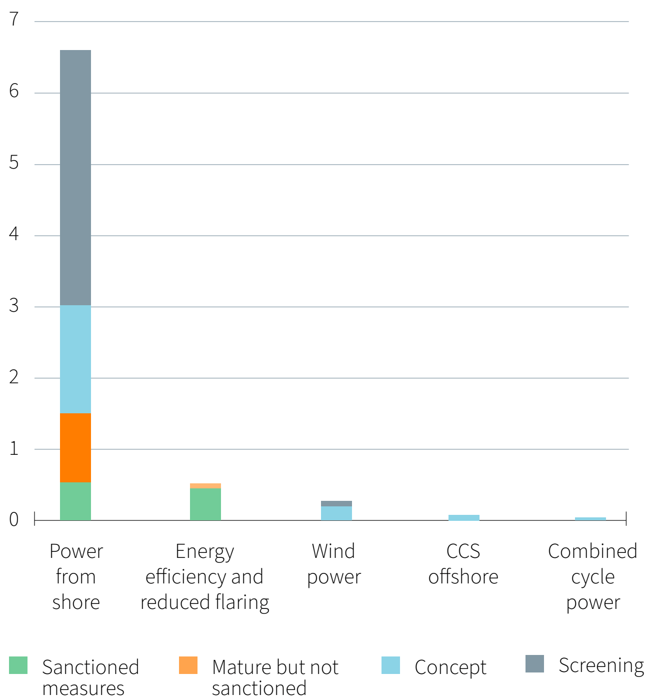


or heat recovery, offshore gas turbines typically have thermal efficiencies in the 30-35% range. The alternative use of the gas in modern combined cycle power plants onshore have a thermal efficiency above 60%, with a corresponding reduction in CO_2-emissions. In addition, capturing CO_2 for sequestration would be easier on large onshore plants. The case for electrification of the NCS with power from shore based on the Norwegian power mix or from other renewables, is hence strong from a technical CO_2 emissions perspective.

Konkraft has started the evaluations of how the 50% reduction ambition by 2030 could be met, see Figure 20. About 30% could be cut by projects already sanctioned and projects that are well matured, but not sanctioned, and a further 20% could be cut by projects currently in the concept phase. Approximately half of the necessary reductions would have to be cut by projects and measures that still need to be identified, matured and sanctioned.

Figure 21 illustrates that electrification from shore is the most important measure to meet the 2030 ambition. However, energy efficiency, reduction of flaring, and wind power have also been identified as important contributors by Konkraft.

Figure 21. CO_2 abatement effect of opportunities according to Konkraft (2021)



As producing fields mature, their CO_2-intensity can be expected to increase unless measures are taken. Such measures include tie-back of new resources to increase the denominator in the metric, reduced water production through better reservoir drainage solutions or water separation downhole or on the seabed, and improved energy efficiency topside. Such measures, and other technology opportunities that could contribute to bring down GHG emissions, are described in Section 4.

The GHG emissions from the consumption of hydrocarbons is considerably higher than the emissions from the production. This does not mean that production emissions are not important. Firstly, the NCS production emissions are a major contributor to national emissions. Secondly, as oil demand over time is reduced in the transportation sector due to electrification or substitution with low-carbon fuels, an increasing portion of the carbon will be locked in petrochemical products, which increases the relative importance of production emissions.

3.4 A MATURING NCS WITH MANY SMALL DISCOVERIES, SUBSTANTIAL RESOURCES IN EXISTING FIELDS AND STILL THE OPPORTUNITY FOR LARGE DISCOVERIES

3.4.1 Many discoveries on the NCS, but the average size is decreasing

The NCS is maturing, which the average field development size per decade from the 70'ies and until today as shown in Figure 22, clearly indicates. At the same time the average number of field developments per decade has increased (NPD, 2019).

Figure 22. Average size at first PDO and number of approved development plans (NPD, 2019)

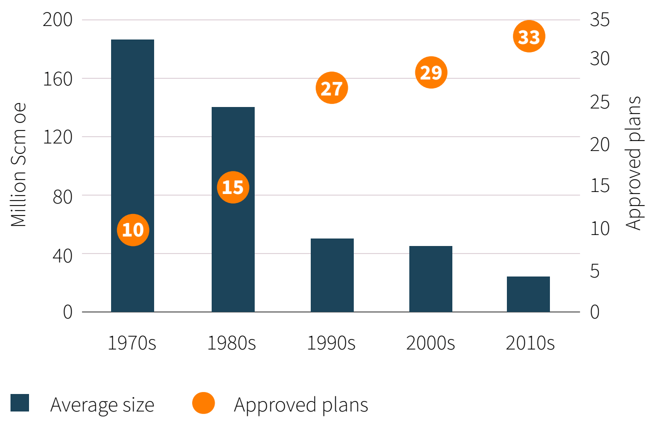
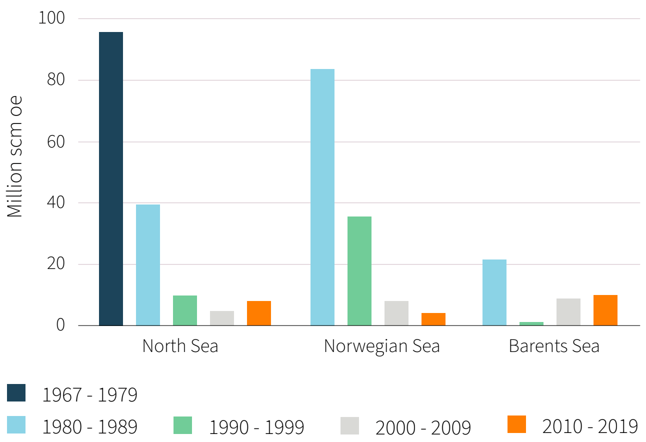


Figure 23. Development of average discovery size by region (NPD, 2020)



The large fields in the North Sea and the Norwegian Sea were mainly developed during the 70's and 80's, see Figure 23. With a few exceptions, notably the Johan Sverdrup field discovered in 2011, the discoveries and field developments have since then been relatively smaller. The Norwegian part of the Barents Sea is less explored, and a similar creaming curve for that basin is still not observed.

The NCS discovery portfolio in 2018 consisted of 85 discoveries with an average size of 49 million boe (NPD, 2019). The average discovery in 2019 and 2020 was approximately of the same size, see Figure 25. The average discovery on the NCS is small compared to many other provinces in the world, but the exploration success rate is high.

Figure 24. Discoveries by sea area and expected recoverable resources at 31 Desember 2018 (NPD, 2019)

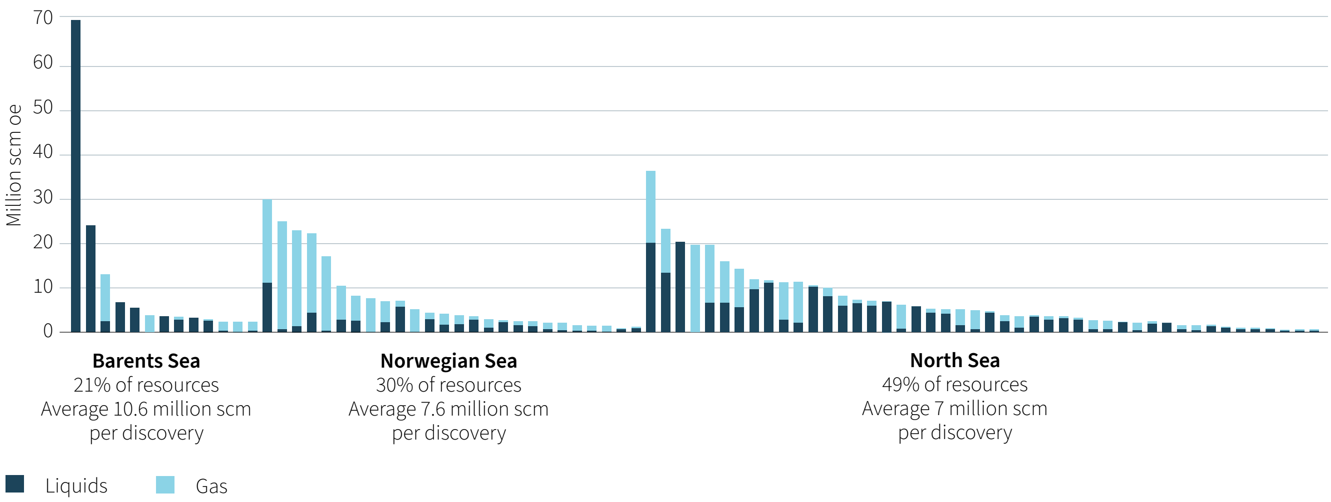
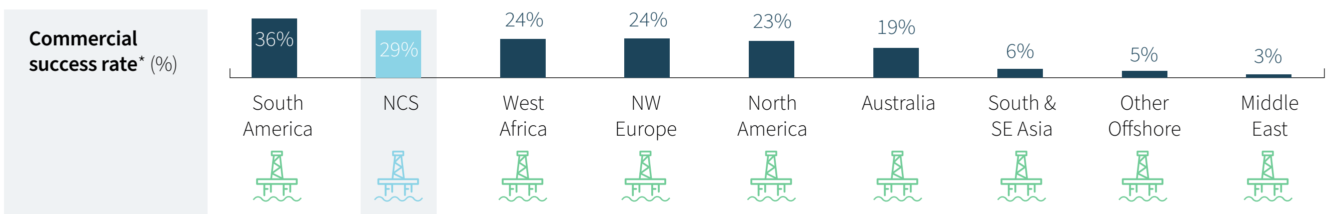
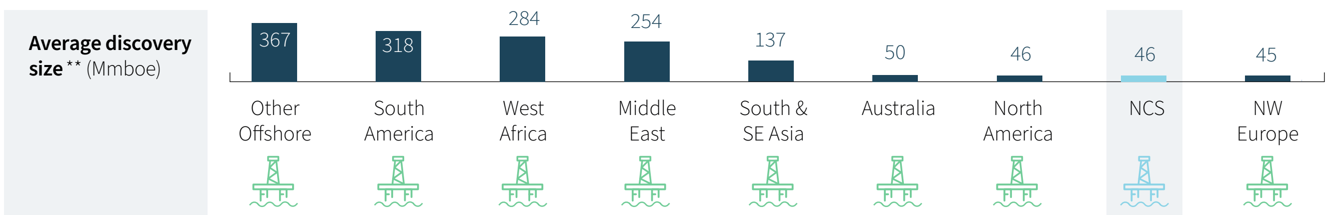


Figure 25. High exploration success rate in 2019/2020, but average discovery rate is relatively small
(Rystad Energy, 2021)

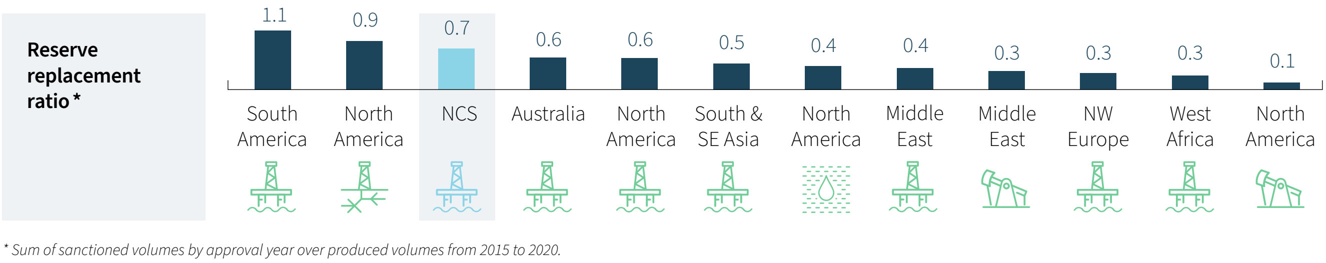


Number of wildcats which lead to commercial discoveries divided by number of wildcats drilled. Only offshore. Includes only commercial discoveries where public information is available. Average of 2019 and 2020.



*** Only offshore. Includes only commercial discoveries where public information is available. Average of 2019 and 2020.*

Figure 26. NCS reserve replacement ratio higher than most other regions
(Rystad Energy, 2021)



With a reserves replacement ratio (RRR) of 0.7, new discoveries on the NCS have not been able to replace the production over the last 5 years, as Figure 26 shows. In a global context, the RRR is competitive though.

The RRR does not reflect reserves growth in existing fields.

3.4.2 Existing infrastructure key to further NCS development

Existing infrastructure is key to the further NCS development:

- Realizing the large contingent resources in existing fields, indicated in Figure 2 in Section 2.4.
- Realizing the large portfolio of smaller discoveries that would require tie-back to a host.
- It encourages further exploration in the proximity of potential hubs.

Contingent resources in existing fields are of the same magnitude as the contingent resources in the discovery portfolio.

Historically, operators in collaboration with suppliers on the NCS have been able to realize such resources with great success.

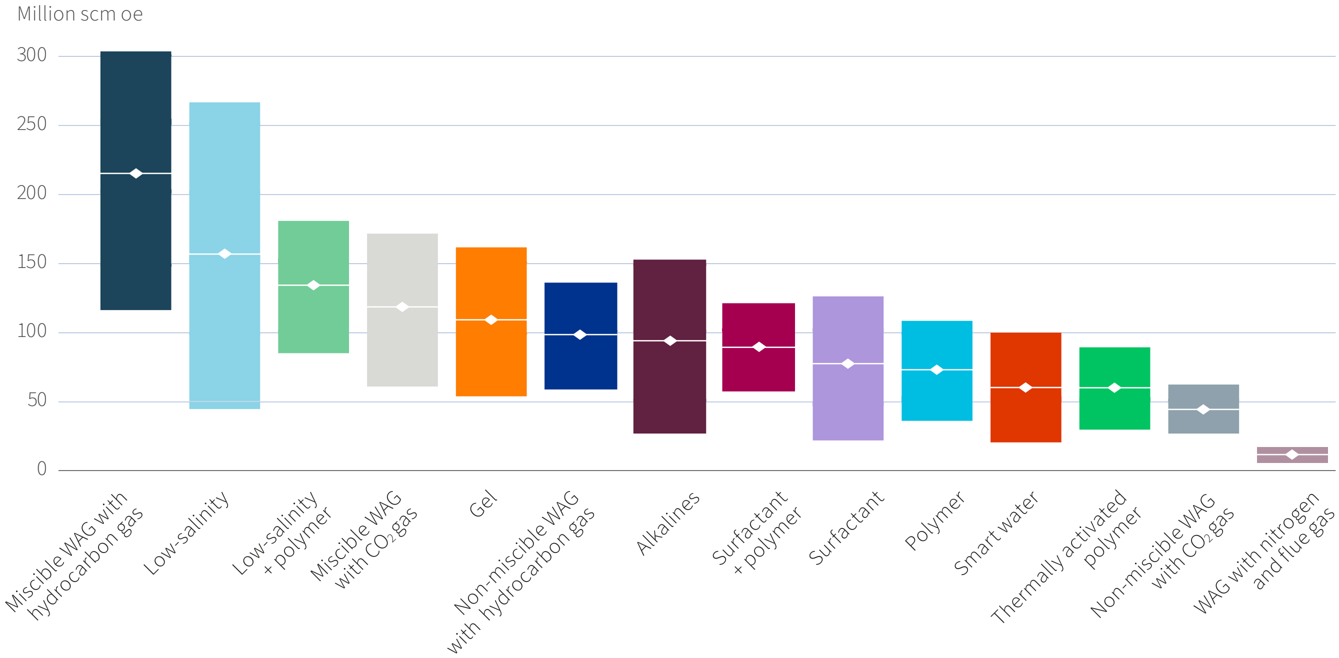
Looking forward, there are numerous projects in the pipeline that would improve oil recovery (IOR) from existing fields – Figure 27 shows specific but undecided projects reported to the NPD. Wells are the most important measure to realize new resources from existing oil fields, whereas low-pressure production is the measure favored for gas fields.

In addition, there is a substantial potential for improved recovery related to more advanced methods, the so-called Enhanced Oil Recovery (EOR) methods, see Figure 28. The figure presents the scaled potential for specific EOR methods summed up for 27 discoveries and fields included in an NPD study on the EOR potential (NPD, 2019). The scaled potential reflects operational criteria as well as economics.

Despite the potential large volumes such measures could provide, there are only few projects currently being considered, as Figure 27 shows.

Figure 27. Projects and estimated recoverable volumes for oil by project category (NPD, 2019)

Figure 28. Potential volumes from Enhanced Recovery Methods on the NCS (NPD, 2019)

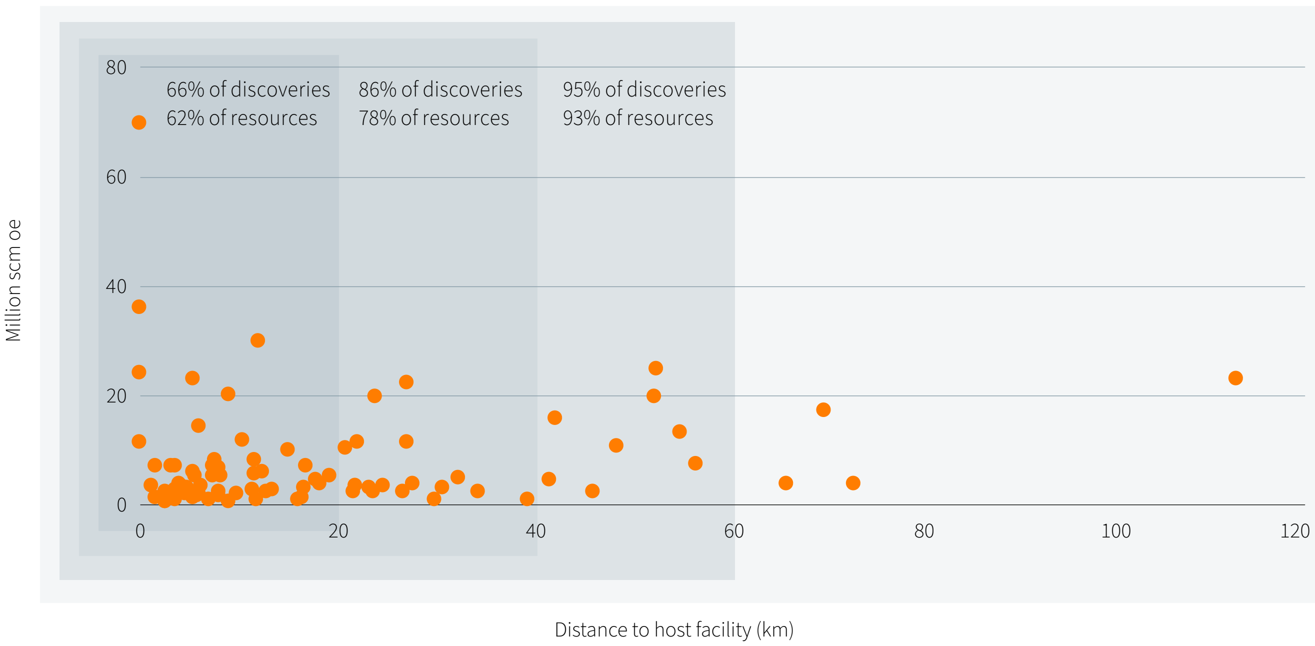


IOR and EOR methods can provide large added volumes. When it comes to investment decisions, many of the methods fall short because of either high costs and/or high GHG emissions.

Most of the 85 discoveries in the NCS portfolio are too small to justify stand-alone developments, and would therefore require tie-back to existing infrastructure to become realized, as Figure 29 suggests. 86% of the discoveries are within a 40 km distance to a possible host discovery. Only 4 of the 85 discoveries are further than 60 km away from a potential host facility.

The size distribution of the discoveries and the proximity to potential host facilities, illustrate the importance of efficiently utilizing existing infrastructure for the further development of the NCS. (NPD, 2019)

Figure 29. Resources and distances to possible host facilities for discoveries in the NCS portfolio (NPD, 2019)



Realizing more resources on the NCS is a cross-functional task involving subsurface, drilling and well, and facilities disciplines, in close collaboration with safety and external environmental groups. This is reflected in the OG21 technology priorities described in Section 4.

Figure 30. Most probable development solution for discoveries (NPD, 2019)

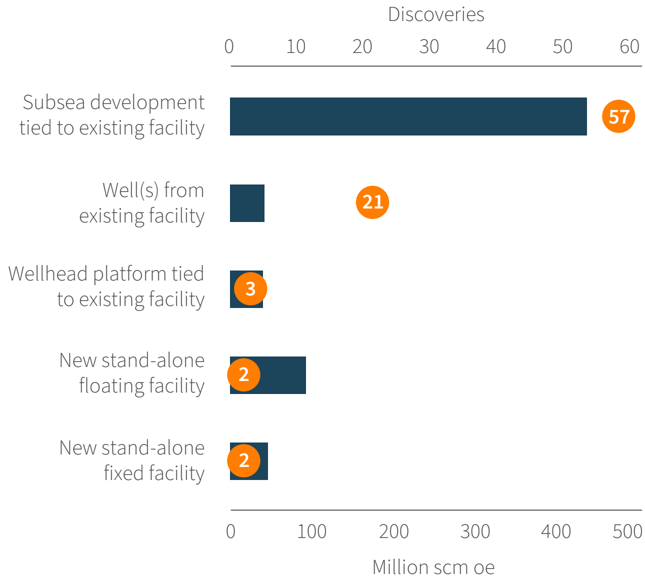
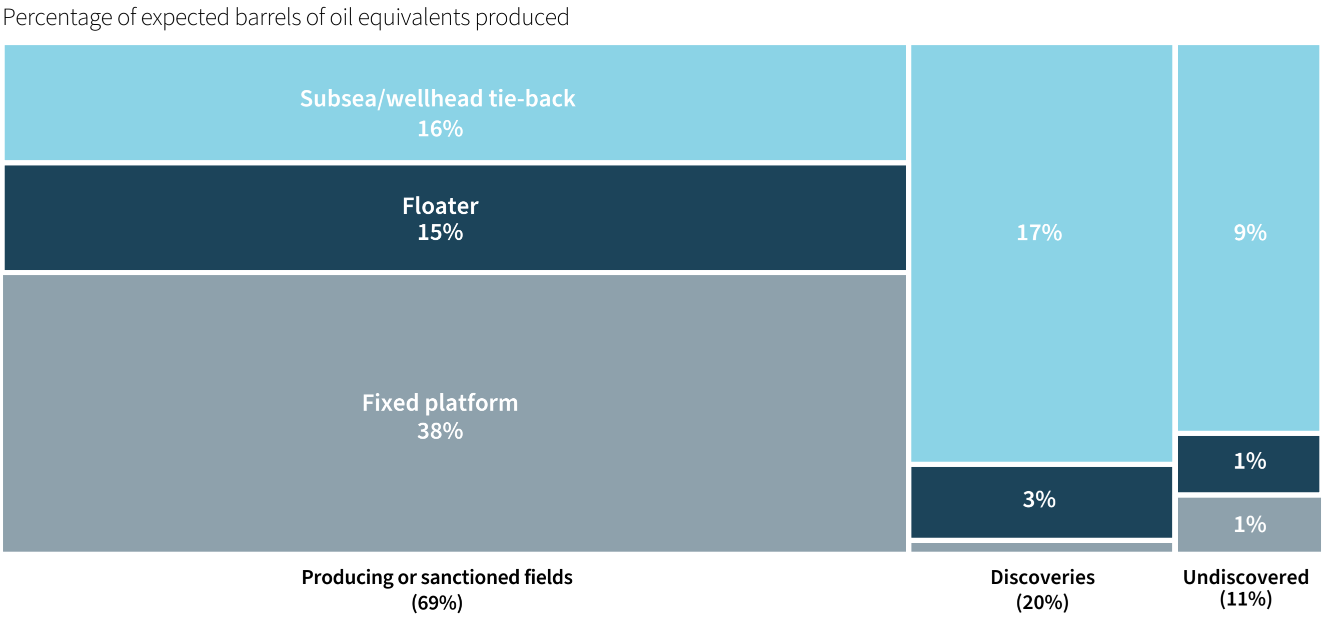


Figure 31. Expected production from the NCS 2021-2050 (Rystad Energy, 2021)



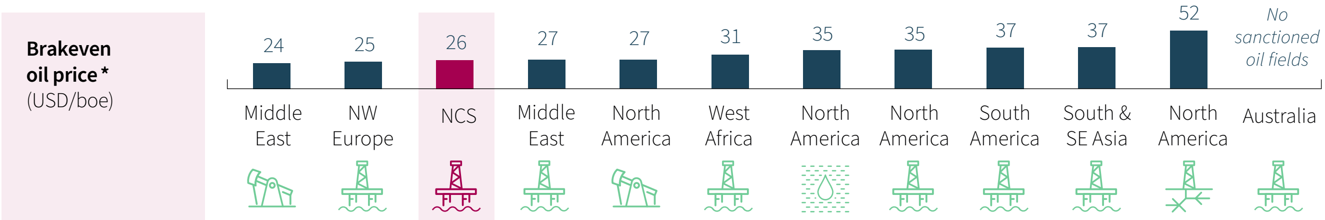
Source: Rystad Energy UCube

3.5 A CONTINUED HIGH ATTENTION TO COST IS REQUIRED TO STAY COMPETITIVE

Break-even prices on the NCS are currently competitive compared to other oil provinces (Figure 32). As Figure 33 indicates, this is mainly due to low operational costs, which again is caused by a cost-efficient infrastructure well suited for development of new resources in the fields or near-field tied back to hubs.

Although exploration costs (Expex) and capital costs (Capex) for new projects have come down considerably since 2014, Figure 33 clearly shows that Expex and Capex on the NCS are relatively high compared to the competition.

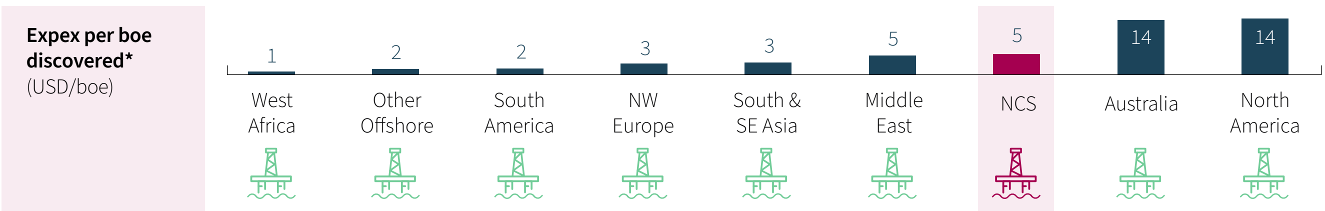
Figure 32. Break-even prices for oil fields sanctioned since 2018 (Rystad Energy, 2021)



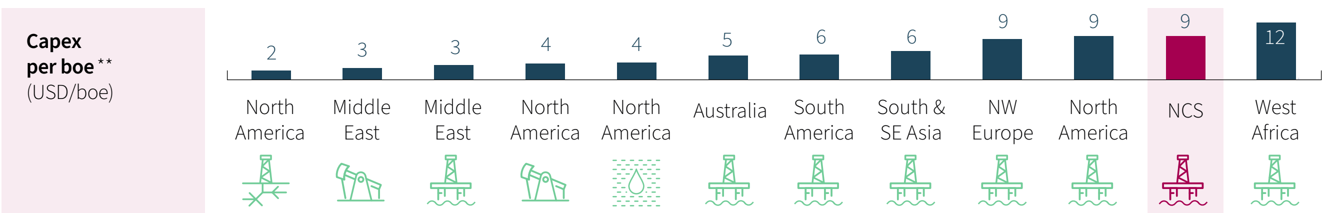
* *Breakeven price for oil fields approved in 2018 seen from the approval year – oil price that returns NPV equal to zero at 10% discount rate. Weighted average of 2019 and 2020.*

Offshore   Shale unconventional   Onshore conventional   Oil sands unconventional

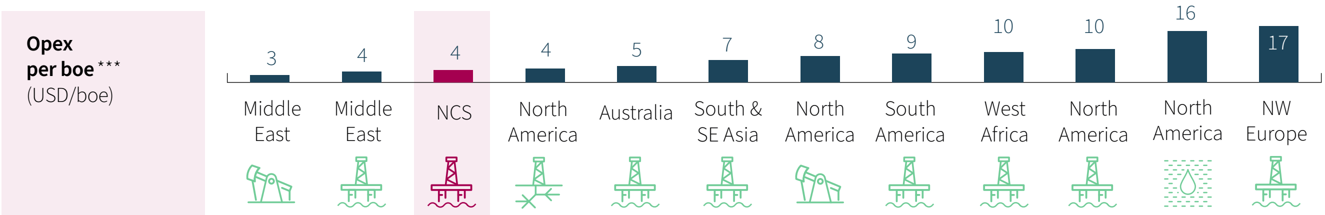
Figure 33. Expex, capex and opex on the NCS (Rystad Energy, 2021)



* *Exploration expenses per found resources. Only offshore. Includes only commercial discoveries where public information is available. Average og 2019 and 2020.*



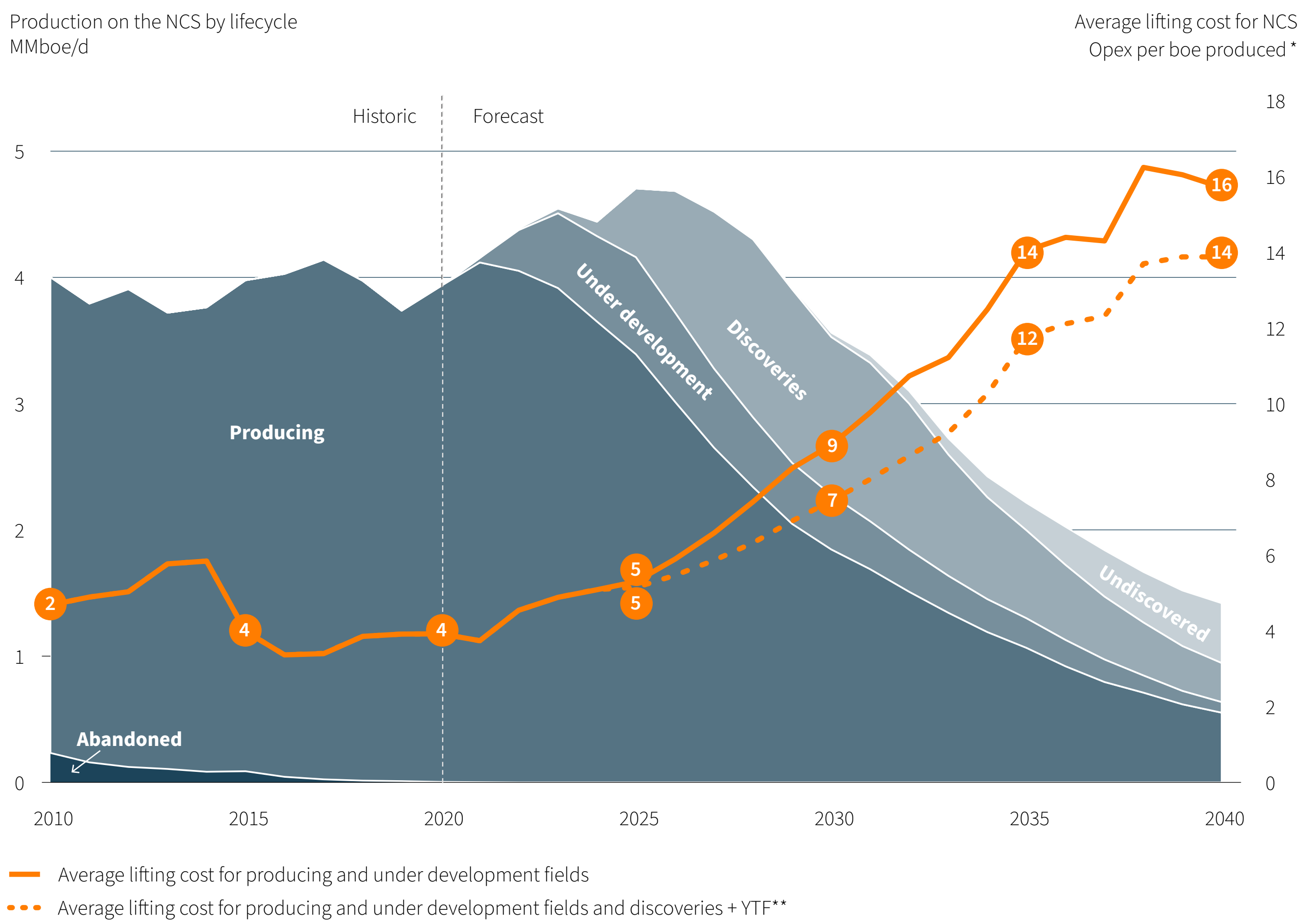
** *Greenfield capital expenditures related to sanctioned oil and gas fields in current year for these fields. Volume weighted average of 2019 and 2020.*



*** *Excludes transportation and tax opex. Includes only opex associated with the production of hydrocarbons in addition to SG&A.*

Offshore   Shale unconventional   Onshore conventional   Oil sands unconventional

Figure 34. Average lifting costs as the NCS matures (Rystad Energy, 2021)

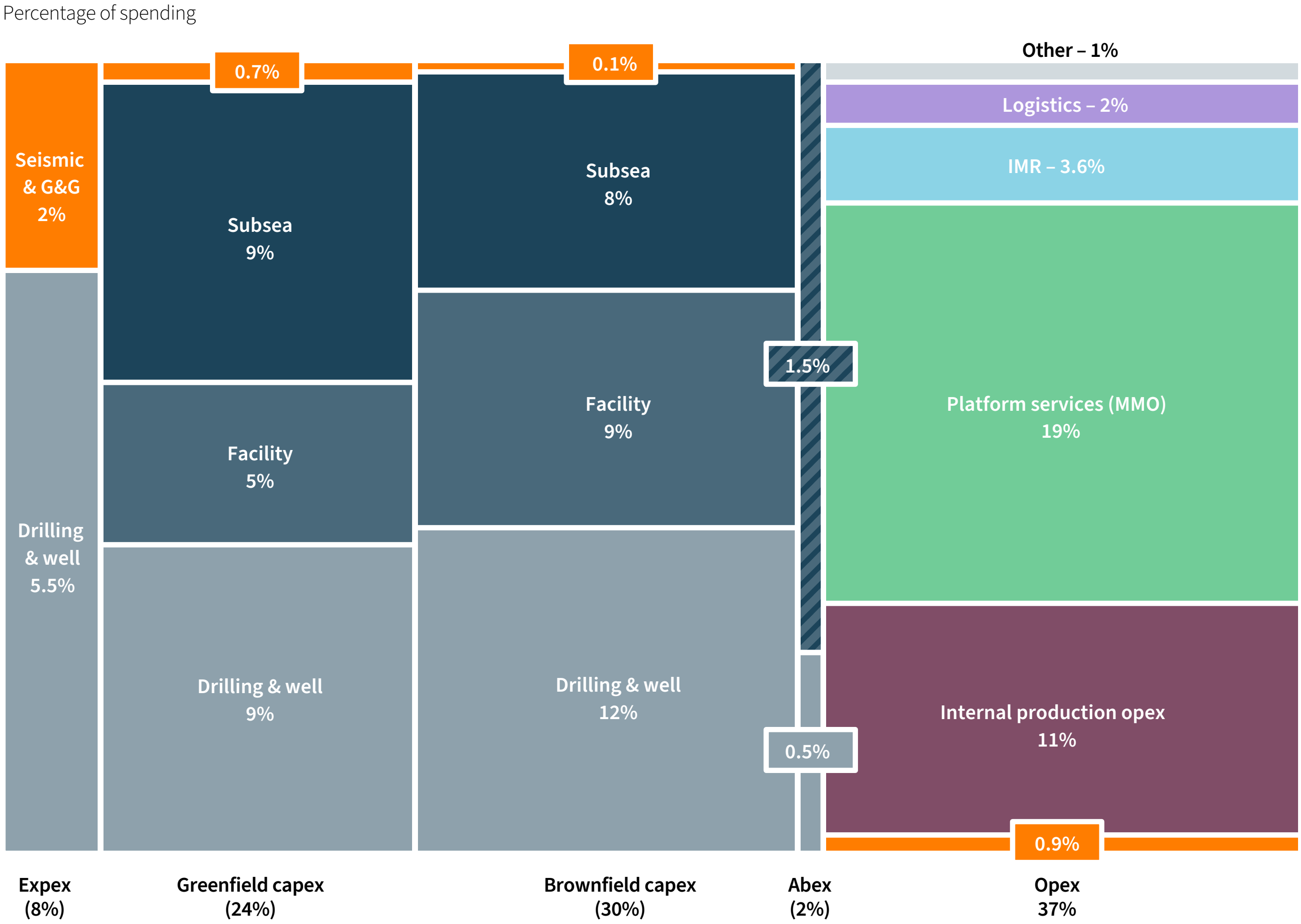


*Production opex only. SG&A and transportation tariffs not included; **only from opened areas

Source: Rystad Energy UCube

To further underline the generic cost challenge, the currently favorable Opex level on the NCS contributing to the low break-even price, cannot be taken for granted. Operational costs remain largely at the same absolute level for an installation throughout its lifetime, and as the production from a field declines, the average lifting costs per barrel increase. Figure 34 illustrates this on an aggregated level for the NCS.

Figure 35. Expected main cost areas for the NCS year 2021–2040 (Rystad Energy, 2021)



Source: UCube, ServiceDemandCube

As Figure 35 illustrates, we expect four main cost areas over the next two decades:

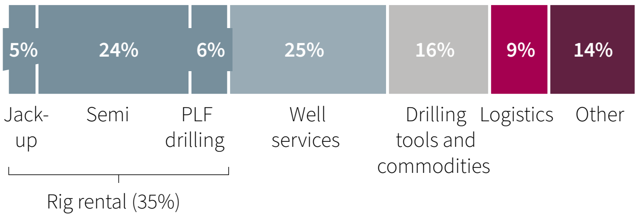
- Drilling and well (28%)
- Facility capex (14%)
- Platform service and maintenance (19%)
- Subsea capex (17%)

A deeper dive into the expected four main cost areas is shown in Figure 36.

Figure 36. Four main cost areas for the NCS 2021-2040 broken down into cost elements (Rystad Energy, 2021)

Drilling & well

Drilling & well spend by component 2021 – 2040
Percentage

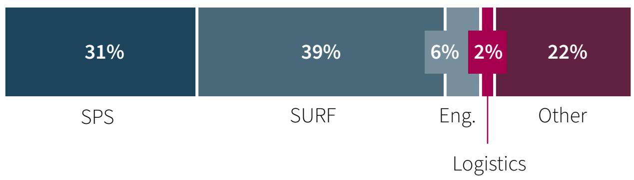


Rigs are 35% of the total well cost, addressing time spent drilling is of high value.

Three large associated buckets with well service, drilling tools and commodities and logistics. These are also highly time dependent.

Subsea capex

Subsea capex by component 2021 – 2040
Percentage

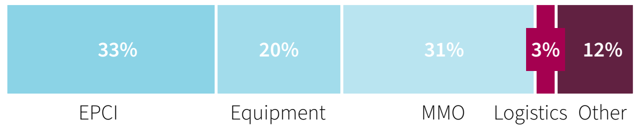


Traditional contract scopes covers 70% of subsea capex. SURF most important as it includes installation.

SPS system typically just below 1/3 of the project cost.

Facility capex

Facility capex by component 2021 – 2040
Percentage

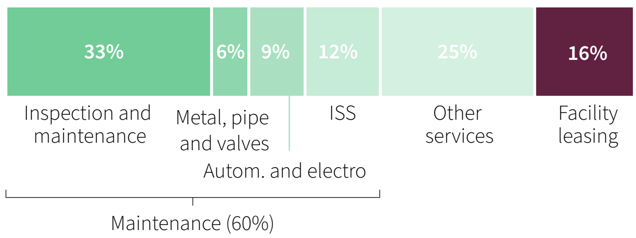


EPCI largest segment covering 33% and equipment it covers more than 20%.

MMO capex including large brownfield topside modules is almost 1/3 of the market.

Platform services

Platform services by component 2021 – 2040
Percentage



The majority of platform services are labor intensive except for facility leasing (leased FPSOs), which makes up 12% of platform services on the NCS.

Maintenance accounts for 50% of the spend, together with MMO capex, this bucket is substantial.

De-commissioning costs is a growing concern on the NCS. Many fields approach the end-of-life, and wells will have to be plugged and facilities removed. UK numbers suggest that plugging and abandonment of wells (P&A) contribute with 49% of de-commissioning costs, whereas removal of facilities, site remediation and monitoring combined contribute with around 34% of the costs.

Figure 37. Break-down of expected de-commissioning costs in the UK over the next decade
(Rystad Energy, 2021, based on numbers from UK Oil and Gas)

UKCS Decommissioning Work Breakdown Structure – Ten-Year Expenditure Forecast

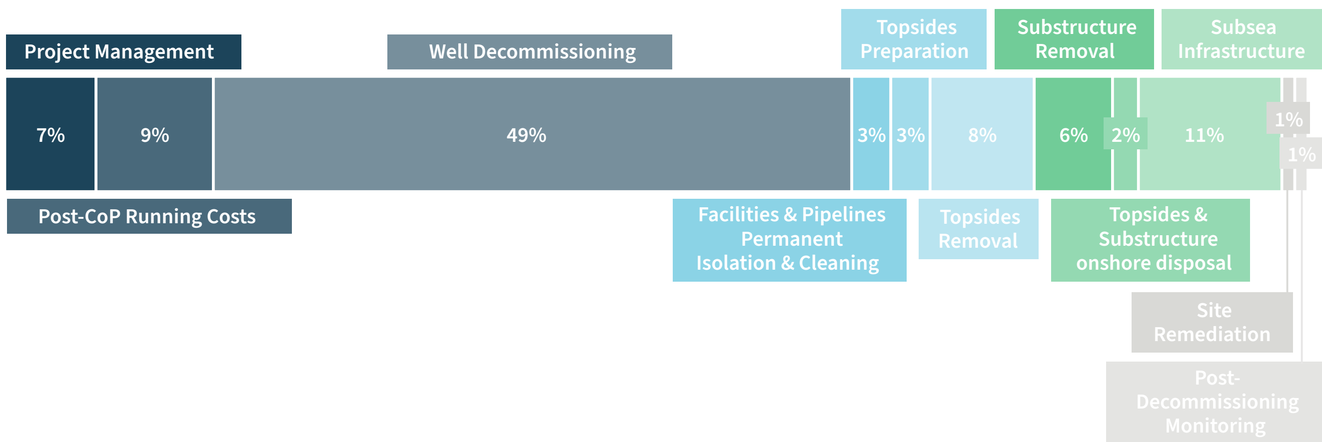
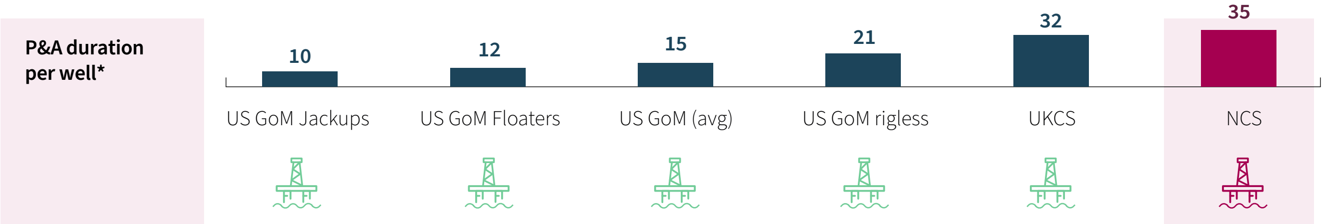
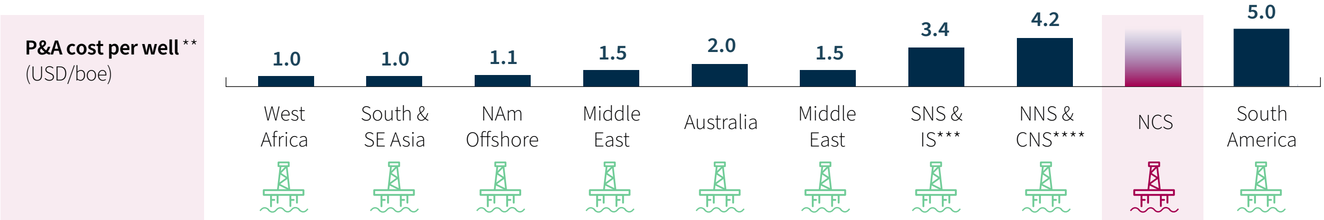


Figure 38 P&A durations and costs on the NCS compared with other basins (Rystad Energy, 2021)



Historical average P&A duration per well depending on region and rig type/intervention unit.



*** Estimated P&A cost per well for offshore regions based on expected activity from 2019 – 2023. *** Southern North Sea and Irish Sea (UKCS). **** Northern & Central North Sea (UKCS)*

More than 3000 wells are going to be plugged and abandoned safely on the NCS over the next decades. A typical P&A operation on the NCS takes 35 days with the use of a mobile drilling unit. This is longer than P&A operations in other offshore petroleum provinces and it drives costs. More efficient P&A methods in addition to methods that would allow lighter vessels to be used for P&A, would have the potential to reduce costs considerably.

Utilizing and extending the life of existing infrastructure contributes to cost-efficient development of new fields in the vicinity. This has a positive effect on NPV as some de-commissioning costs are moved into the future. An alternative use of facilities when the field approaches late-life or even after production has shut down, could have the same effects.

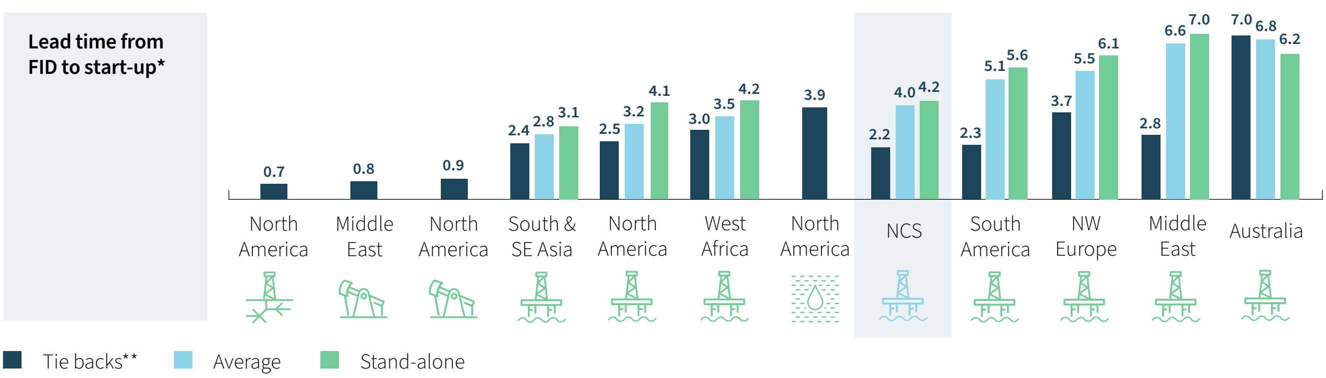
The cost challenge on the NCS remains high in all phases: exploration, field development, production and operations, and de-commissioning including P&A. Bringing costs down is an important driver behind the development and implementation of new technology for all these phases, as the discussion of OG21's technology priorities in Section 4 shows.

3.6 REDUCTION OF LEAD TIME INCREASINGLY IMPORTANT

The lead time, measured as time from investment decision to production starts providing economical returns, is an increasingly important parameter when sanctioning new investments. Shorter lead times reduce uncertainties related to product prices, costs for emitting GHG gases, and policy development.

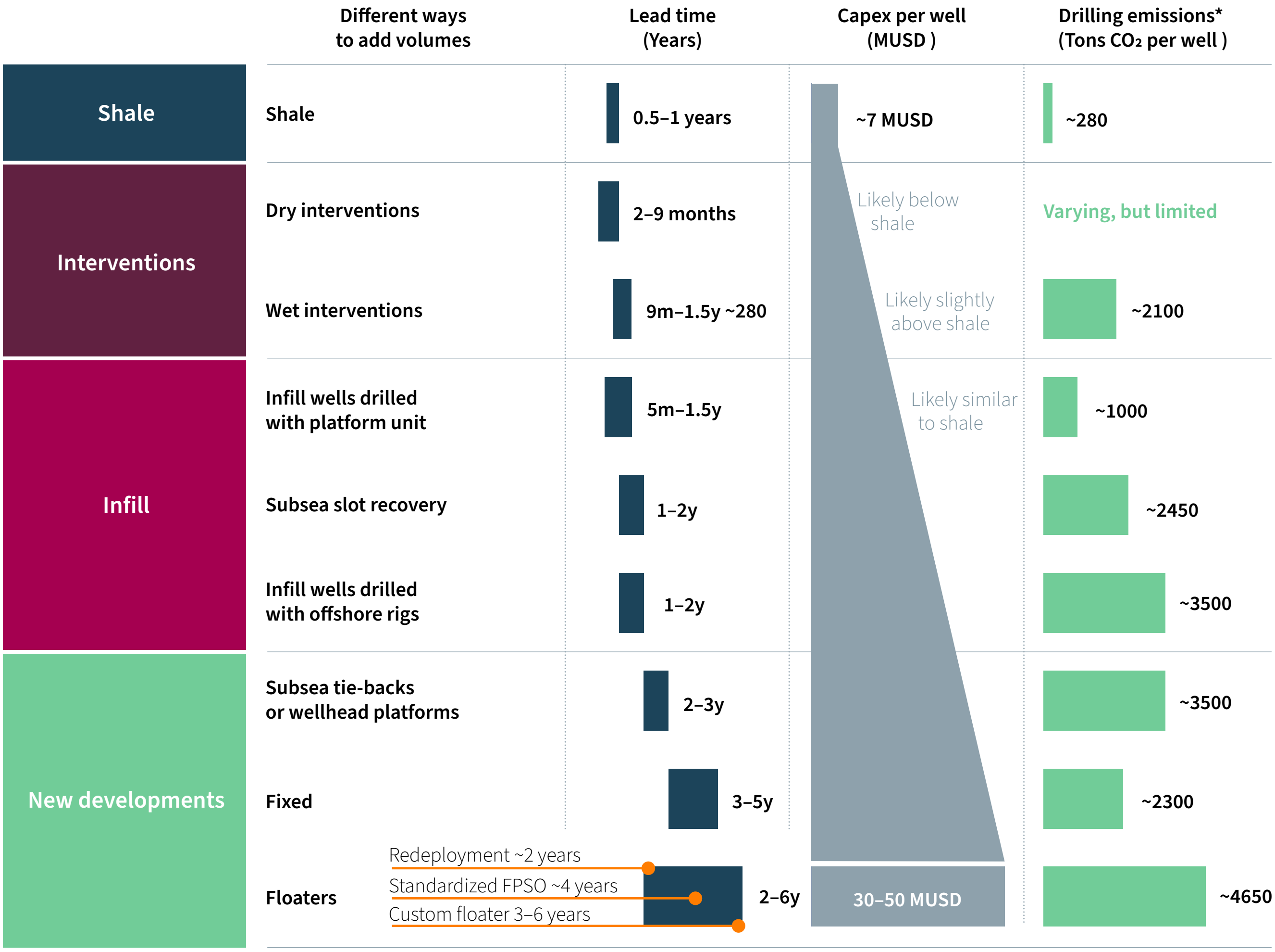
Onshore developments within conventional and shale stand out as the projects with the lowest lead times. The NCS is on the average compared to other offshore provinces on this metric. However, tie-backs to hubs, which is a very important field development solution on the NCS, compare very favorable to other offshore regions.

Figure 39. Lead times from investment decision to production start-up for O&G regions (Rystad Energy, 2021)



** Lead time from FID to production start-up. Fields with start-up from 2015 – 2020 are included. Error margin of +/- 0.5 years. Weighted average*
*** Tie-backs includes subsea tiebacks, wellhead platforms and extended reach.*

Figure 40. Some field development methods provide competitive volumes at low cost and with short lead times
(Rystad Energy, 2021)



Some field development methods on the NCS offer lead times that are at par with the best industry performance. Well interventions and infill wells are examples that provide volumes with lead times ranging from months to less than 2 years.

When considering new technology, the ability of the new technology to reduce lead time and accelerate production should be included.

4

TECHNOLOGY AND KNOWLEDGE NEEDS

4.1 OVERVIEW OF TECHNOLOGY PRIORITIES FOR ALL DISCIPLINES

The overarching goal of technology development and implementation is to realize value from the NCS safely and with minimal environmental impact.

The OG21's technology groups (TGs) have identified new technology and competence that could improve the NCS competitiveness in light of the future demand for oil and gas described in Section 2 and the challenges and opportunities described in Section 3.

A total of 30 technology and knowledge areas have been prioritized. In addition, the TGs have discussed and identified opportunities for new industry development based on the competence and solutions in the petroleum industry as well as opportunities for improved life-cycle management and circular economy.

An overview of the technology priorities per discipline (TG) and interconnections between disciplines, is shown in Figure 41.

Estimates on potential value for technology opportunities is presented in Figure 42. A detailed description of the prioritized technology areas for each TG is provided in the following sub-sections.

Figure 41. Overview of technology opportunities per discipline (TG) and cross-discipline dependencies

TG	Opportunity name	TG1	TG2	TG3	TG4	TG5
TG1 Climate change and environment	Energy efficiency in offshore operations	●	○	○	○	○
	Reduced cost of electrification	●			○	
	Offshore carbon capture and storage	●	○		○	○
	Lifecycle assessments	●	○	○	○	○
	Leak detection and mitigation	●			○	○
	Environmental risk assessment and management	●				○
	Oil spill contingency	●			○	○
	Environmental performance data	●			○	
TG2 Subsurface understanding	Offshore CO2 storage and late-life deposits	○	●	○	○	
	Data acquisition for subsurface understanding and models		●	○		
	Data management for subsurface understanding and models		●		○	
	Subsurface understanding and models	○	●	○	○	○
	Water management	○	●	○	○	
TG3 Drilling, completions, intervention and P&A	Data gathering and optimization of drilling operations		○	●	○	○
	Improved drilling equipment	○		●		
	Advancements in well construction and methodologies			●		○
	Subsea well intervention technologies	○		●	○	○
	Recompletion and multilateral technologies		○	●		○
	Challenging reservoirs	○		●	○	
	More efficient P&A		○	●		○
TG4 Production, processing and P&A	Facility integrity and lifetime extension of fields				●	○
	Data collection for facilities				●	
	Data management for facilities		○	○	●	○
	Digital tools for improved monitoring, better understanding and more efficient operations		○	○	●	○
	Unmanned facilities and subsea tie-backs		○	○	●	○
TG5 Safety and working environment	Consequences and opportunities from adoption of new technologies	○	○	○	○	●
	Consequences and opportunities of new business models	○	○	○	○	●
	Major accidents – improved understanding of risks and uncertainty	○	○	○	○	●
	Improved working environment	○	○	○	○	●
	Cyber security as an enabler for digitalization	○	○	○	○	●

Figure 42 Overview of prioritized technology opportunities and estimated, potential effects on competition metrics for prioritized technologies* (Rystad Energy, 2021)

TG	Opportunity name	Volume additions potential (mmboe 2020–2050)	Cost reduction potential (BUSD 2020–2050)	Upstream emissions reduction potential (mt CO_2 2020–2050)
TG1 Climate change and environment	Energy efficiency in offshore operations	Neutral	5.2	29.0
	Offshore carbon capture and storage	Neutral	-9.0	35.0
	Leak detection and mitigation	Prerequisite for continued operations and future technology adoption		
	Environmental risk assessment and management			
	Oil spill contingency			
TG2 Subsurface understanding	Offshore CO2 Storage and late-life deposits	495	-13.0	Very large, but scope 2 & 3
	Data gathering for subsurface understanding and models	Enabler for technology opportunity #9		
	Data management for subsurface understanding and models			
	Subsurface understanding and models	2560	10.0	1.5
	Water management	1090	0.0	7.0
TG3 Drilling, completions, intervention and P&A	Data gathering and optimization of drilling operations	1550	5.8	1.3
	Improved drilling equipment	0	6.0	2.5
	Advanced well construction and methodologies	840	4.4	0.9
	Subsea well intervention technologies	1520	4.2	0.9
	Recompletion & multilateral technologies	1350	7.0	0.6
	Tight and inhomogenous reservoirs	970	-7.8	-1.9
	More efficient P&A and road to rigless	Neutral	5.9	0.6
TG4 Production, processing and P&A	Material condition detection and degradation mechanisms	Enabler for technology opportunity #21		
	Data gathering for facilities			
	Data management for facilities			
	Digital tools for improved maintenance and more efficient operations	970	20.0	16.5
	Unmanned facilities and subsea tie-backs	800	11.0	1.5
	Standardized subsea templates	710	14.6	Neutral
TG5 Safety and working environment	Consequences and opportunities from adoption of new technologies	Prerequisite for continued operations and future technology adoption		
	Consequences and opportunities from new business models			
	Major accidents: Improved understanding of risk and uncertainty			
	Improved work environment			
	Cyber security as enabler of other digitalization technologies	Prerequisite for digitalization technologies		

* There is a small discrepancy in the naming of technology opportunities in Figure 41 and Figure 42. The reason is that the opportunities have been further matured by OG21 after the final report from Rystad Energy was delivered.

As Figure 41 indicates, a broad range of technologies is needed to improve the NCS competitiveness. Each prioritized technology area offers significant improvements on at least one of the competition metrics. Combined, the prioritized technology areas hold a promise of improving the NCS competitiveness along all metrics, including volumes, costs, and CO_2-emissions.

The prioritized safety and environment technology areas are fundamental for the "license-to-operate". Addressing the technology and knowledge needs within these areas is therefore of vital importance for the further development of the NCS.

Stakeholders in the petroleum sector have a shared responsibility for addressing the technology priorities through R&D&I, and OG21 therefore encourage industry enterprises, universities, research institutes as well as public funding bodies, to reflect OG21 priorities in their R&D&I plans and programs.

We have not indicated current TRL-level for the prioritized areas. The reason is that even for prioritized areas where mature technologies exist in the market, there is still scope for radical new innovations, new components or new knowledge that could replace or improve existing solutions.

4.2 SAFETY AND WORKING ENVIRONMENT

The NCS and the Norwegian petroleum industry compete in global markets. To stay competitive the industry needs to become more cost-efficient, successfully explore and develop new resources, reduce lead times, and significantly reduce GHG emissions as discussed in Section 3. But at the same time, a high safety level must be achieved to maintain support in the society.

The strive for improved competitiveness for a maturing oil province as the NCS introduces safety risks that must be managed, e.g.:

- An aging infrastructure which requires more inspection and maintenance.
- New inspection and maintenance philosophies and technologies.
- New digital technologies like remote operations and autonomy.
- New low-carbon technologies and energy carriers like hydrogen and ammonia.
- A changing operator landscape with fewer large international companies and more medium sized and small independent oil companies.
- New business models and contract models where contractors and suppliers are integrated with operators.
- Increased integration of digital systems and technologies that could render the systems more vulnerable to cyber security threats.

These risks have been the considered when TG5 has prioritized technology and knowledge areas. The prioritized technology and knowledge areas for TG5 are:

- Consequences and opportunities from adoption of new technologies.
- Consequences and opportunities of new business models.
- Major accidents: Improved understanding of risks and uncertainty.
- Improved working environment.
- Cyber security as an enabler for digitalization.

An important principle on the NCS is that changes shall provide at least the same level of safety as prior to the changes. Understanding the safety and working environment consequences of introducing new technology is hence important. We need an improved understanding as well as improved safety risk management of the potential safety and working environment hazards of all types of new technologies being considered for implementation. This includes the technology needs identified by the other OG21 Technology Groups.

The same principle also applies to organizational and structural changes. It is therefore important to improve the understanding of how the changing NCS operator landscape as well as new collaboration models such as strategic alliances between operators, suppliers, and service providers, influence safety and the working environment.

Petroleum operations involve safety risks. The industry works continuously to identify hazards, and understand, reduce, and mitigate risks. To improve, the industry needs to further develop the understanding of risks including how to manage the inherent uncertainty that risks are associated with. This particularly applies to major accident risks. Improvement areas include for instance better integration of human factors in risk management tools, and improved systems for learning from the past.

The precautionary principle should be applied when the consequences of activities are uncertain or unknown. There is a continued need to better understand the physical, chemical, social, or the psychological work environment of ongoing activities. Likewise, such working environment factors should be investigated also when new technology and new work processes are implemented.

The cyber-security area addresses an imminent and rapidly increasing threat to the industry. The industry is progressively making use of digital solutions in numerous new areas. As new digital technologies are implemented and industrial operational systems are becoming more integrated with other information technology systems in enterprises, the design and management of barriers becomes more complex. There is a need to better understand safety implications of new infrastructure complexities and threats, as well as the vulnerability of data and applications. Furthermore, it's important to strengthen the national cyber security competence and the situational awareness on such issues in the Norwegian petroleum industry. The industry is dependent upon a digital transformation to stay competitive, and managing cyber-security threats efficiently, is fundamental to this transformation. In this context it should also be noted that improved management of information and communication technology (ICT) security has a potential large transfer value to other disciplines.

DNV SAFETY 4.0 PROJECT

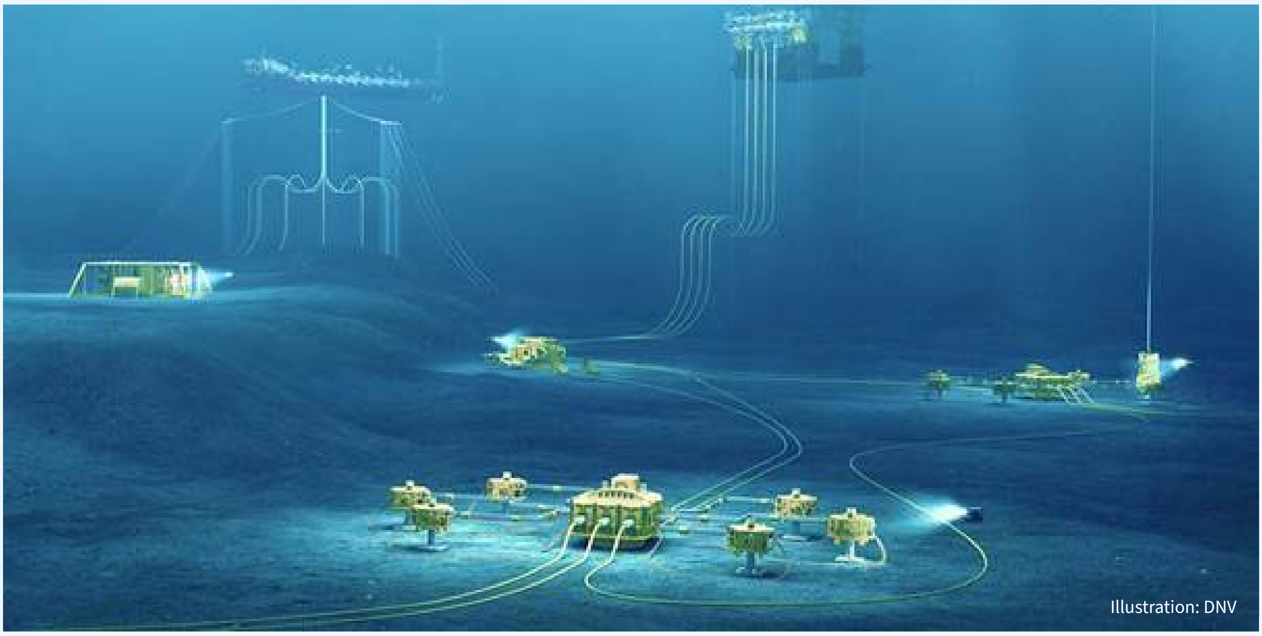


Illustration: DNV

Norwegian HSE regulations accommodate and promote innovation that can enhance safety. However, safety of novel subsea technologies may be cumbersome to demonstrate because current standards may be difficult to apply.

The main objective of the project Safety 4.0 is to enable and accelerate up-take of novel subsea solutions by developing a framework for standardized demonstration of safety.

The project will develop new safety philosophies, integrated solutions, and use of sensor data and data analytics, to demonstrate a sufficient level of safety for three use-cases:

- All-electric safety system, where existing fail-safe philosophies does not apply.
- Subsea process solutions, where process- and safety systems share elements.
- Demonstrate safety of novel subsea technologies.

"The project may contribute to future updates of regulations and standards, and can be applicable to other industries"

Dr. Frank Børre Pedersen, Programme director Oil & Gas at DNV Technology and Research unit.

ID.	TG5 PRIORITIZED AREA	PROBLEM STATEMENT / CHALLENGE	SUPPORTING TECHNOLOGIES & KNOWLEDGE WITH INNOVATION POTENTIAL[2]
#26	**Consequences and opportunities from adoption of new technologies** New technology and the accelerating pace of changes introduces new hazards and risks that will have to be managed in the spirit of the zero accidents philosophy and the continual improvement principle. A continual improvement of HSE performance requires management attention and prioritization, as well as improved understanding of HSE risks, hazards, and under-lying causes.	It is urgent to reduce GHG emissions. Introduction of new technology is a key element to reduce emissions. However, many of these technologies have not been in used in NCS operations. Hence, safety issues must be explored before implementation.	• Improved understanding and management of potential safety and working environment impacts resulting from adoption of low-carbon technologies in the NCS operations, e.g. hydrogen, ammonia, electric boilers, batteries. • Knowledge transfer from other industries that have substantial experience with low/zero carbon technologies.
		A faster pace for adoption of digital solutions to improve the competitiveness of the NCS is needed. Associated safety and risks will have to be recognized and managed. Increased automation and complexity of systems and business processes leads to increased demands for knowledge and understanding of how to secure data models that is transparent, understandable / human conceivable through all phases of technology life cycle. Reduced manning and autonomy offshore mean that more safety system must be operated and maintained remotely. To make this efficient and maintain safe operation and maintenance, designers, operators and leaders competence and expertise should be strengthened on how to design and implement technology that supports human cognition.	• Use of digital technologies for efficient risk reduction in design, fabrication and operations, e.g. digital twins, augmented reality. • Improved understanding and management of potential HSE implications related to the digital transformation of the Norwegian petroleum industry. • Development of holistic approach to include human and operational elements when introducing automation and other digital technologies. • Better detection and management of human – automation risks in digital solutions such as remote control and automation. • New safety philosophies for technologies such as fully electric solutions, completely unmanned installations, and solution such as no standby vessels, no fixed helicopter transport, normally unmanned platforms etc. • Improved understanding and knowledge on how to apply human centered approaches in digital technology. • A more systematic use of human factors in system engineering.
#27	**Consequences and opportunities of new business models** Since 2000, there has been a considerable increase in the diversity of companies operating on the Norwegian shelf. More recently, several strategic alliances and new incentive-based contract models have emerged. It is important that the changes in interfaces between different organizational units and systems, come to benefit safety.	A continued drive for improved efficiency and reduced GHG emissions is required to keep the NCS competitive. Introduction of new business models to leverage the potential of new technology is part of this. It introduces new hazards and risks that will have to be recognized, understood, and managed.	• Improved understanding and management of potential safety implications of changes to business models, the operator landscape, and rules&regulations. • Improved understanding and management of potential working environment implications of changes to business models, the operator landscape, and rules & regulations. • Effects of downsizing / low staffing.

ID.	TG5 PRIORITIZED AREA	PROBLEM STATEMENT / CHALLENGE	SUPPORTING TECHNOLOGIES & KNOWLEDGE WITH INNOVATION POTENTIAL[2]
#28	**Major accidents: Improved understanding of risks and uncertainty** The safety risk level on the NCS is low and the overall risk indicator is trending downwards. Nevertheless, some observations cause concern as discussed in Section 3.2 All major accidents are preventable provided we identify and understand the root causes. It is therefore imperative for the Norwegian petroleum industry that risk management tools are continuously improved.	The industry must work constantly to prevent incidents, reduce risk and improve safety and learn from experiences and incidents, and particularly in relation to major accident risk. Situational awareness, risk understanding, understanding of barrier principles and uncertainty, are crucial for the industry's work in preventing major accidents, while improving involvement, knowledge, and engagement of humans.	• Improved management of safety barriers, including an improved understanding of safety barrier integrity and of how an increased use of sensor technology and data analysis can support operational barrier management. • Better integration of human factors in risk management tools used during planning and execution of operations. • Improved tools for safety risk analysis that also include a better understanding and description of uncertainties and of the knowledge (i.e., assumptions and evidence) that support the risk analyses. • Holistic approach to learning from experiences and incidents and implementation of this learning into risk management tools and practices. • Safe life extension of facilities far beyond design life enabled by extensive monitoring or compensatory measures to ensure safety. • Improved tools for simultaneous operations to aid in risk understanding and awareness of each operation and their inter dependencies. Monitor and display continuous change in risk level for each ongoing and planned operation and the impact this have on the total risk picture. Provide support for safe and informed decision making and activity planning.
#29	**Improved working environment** The management of the working environment in the petroleum industry aims at minimizing exposure to hazards and risks that could cause short-term or longer-term health issues.	Following the no harm principle, all working environment hazards and risks (including psycho-social factors) will have to be recognized and fully understood, and exposure prevented or limited to safe levels. A continual drive to understand and manage working environment hazards will bring the industry towards the vision.	• Better understanding of working environment risks and uncertainties to eliminate potential short-term and long-term health problems. • Increased knowledge on health outcomes in relation to exposure assessments. • Improved monitoring of the working environment, including the physical, chemical, social and psychological work environment.

2 These are examples. Other solutions addressing the prioritized technology areas should also be sought and developed.

ID.	TG5 PRIORITIZED AREA	PROBLEM STATEMENT / CHALLENGE	SUPPORTING TECHNOLOGIES & KNOWLEDGE WITH INNOVATION POTENTIAL[2]
#30	**Cyber security as an enabler for digitalization** A faster pace for adoption of digital solutions to improve the competitiveness of the NCS, is needed. Associated cyber security and risks will have to be recognized and managed.	The increased pace of digitalization requires sharing of data between multiple users. This increases the vulnerability for cyber security attacks in IT and OT systems. Many OT systems today are not ready for this, as they provide a hierarchical data access structure, preventing customers to access data in a secure manner. To build high quality data lakes that can be used in data analytics applications, such as AI and ML, require data models of the system that describe data transformations performed. Furthermore, the data models need to be made available to the end user in a machine-readable format. In addition to the cyber security threats related to technology and system integration, the industry needs to address the increasing demand of cyber security competence. This includes competence at the subject matter expert level, as well as a general understanding at all organization levels. This is needed to improve the awareness of cyber security threats and the vulnerabilities in data and applications.	• Use of AI and ML for threat hunting. • Develop cyber security management tools. • Better understanding of complexity and interdependency of systems and data flow, e.g. design differences between IT and OT. • Improved understanding of cyber security risks and management for the NCS digital transformation. • Competence building of across disciplines, value chains and operators. • Reusable and transformable data models with open, secure and interoperable solutions enabled by technology capable of modeling data quality and user access at variable levels .

4.3 ENVIRONMENT AND GREENHOUSE GAS EMISSIONS

The prioritized technology and knowledge areas for TG1 are:

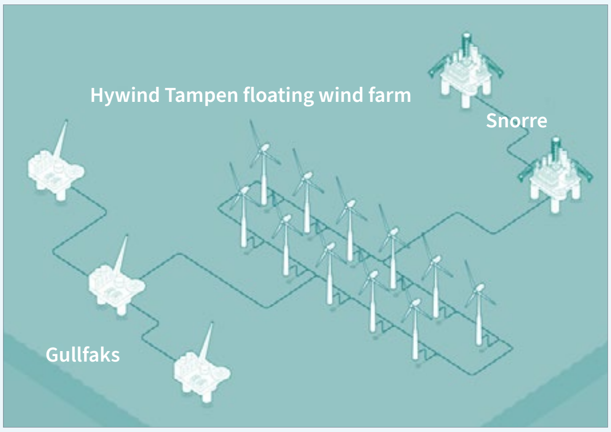
- Energy efficiency in offshore operations.
- Reduced cost of electrification.
- Offshore carbon capture, utilization and storage (CCUS).
- Lifecycle assessments.
- Leak detection and mitigation.
- Environmental risk assessment and management.
- Oil spill contingency.
- Environmental performance data.

The first three are addressing the need for reducing CO_2-emissions from the NCS, described in Section 3.3; whereas lifecycle assessments look at assessing environmental impacts beyond the NCS geography (supply chain etc.). The next three are related to the "zero harm" vision and drive for continual improvement described in Section 3.1 and 3.2. The final point looks at the coverage of and access to data which describes environmental performance.

Technology development includes development of knowledge. The technology strategy emphasizes the need for improved knowledge, improved risk understanding, and corresponding mitigating actions to ensure a sustainable effect on the environment from the oil and gas activities.

Implementation of new technologies might affect risk. Technology development within the environment and greenhouse gas emission perspectives will need to consider its possible impact on safety by ensuring an integrated risk assessment of possible technology solutions.

HYWIND TAMPEN: THE WORLD'S FIRST RENEWABLE WIND POWER FOR OFFSHORE OIL AND GAS



Hywind Tampen is an 88 MW floating wind power project intended to provide electricity for the Snorre and Gullfaks offshore field operations in the Norwegian North Sea.
It will be the world's first floating wind farm to power offshore oil and gas platforms.

It will also be the world's largest floating offshore wind farm and an essential step in industrializing solutions and reducing costs for future offshore wind power projects.

Hywind Tampen will be a test bed for further development of floating wind, exploring the use of new and larger turbines, installations methods, simplified moorings, concrete substructures and integration between gas and wind power generation systems.

The floating wind farm will will consist of 11 wind turbines based on one of Equinor's floating offshore wind technologies, Hywind. The wind farm will have a combined capacity of 88 MW and is estimated to meet about 35% of the annual electricity power demand of the five Snorre A and B, and Gullfaks A, B and C platforms. In periods of higher wind speed this percentage will be significantly higher.

The wind power solution will help reduce the use of gas turbine power for the Snorre and Gullfaks offshore fields, while also offsetting 200,000 tons of CO_2 emissions and 1000 tons of NOx emissions per year.

The final investment descision (FID) was taken in October 2019 and key contracts for the NOK 5 bn project were awarded the same month.

HYWIND TAMPEN FACTS

The Hywind Tampen project will contribute to further developing floating offshore wind technology and reducing the costs of future floating offshore wind farms, offering new industrial opportunities for Norway, the licences and Norwegian supplier industry in a growing global offshore wind market.

- Equinor together with its partners are developing the world's first floating offshore wind farm supplying renewable power to offshore oil and gas installations.
- Aiming at partially powering the Snorre and Gullfaks offshore oil and gas fields with floating wind.
- 11 units w/ combined capacity of 88 MW.
- Located approximately 140 km off the Norwegian coast.
- Water depth at the wind farm site ranges between 260 m and 300 m.
- Considerable CO_2 emissions reductions, estimated 200,000 tons per year.
- Mounted on floating concrete spar substructures with shared anchors supplied by Kvaerner.
- Equipped with 11 Siemens Gamesa SG 8.0-167 DD turbines.
- With a 167 m-diameter rotor and 81.5 m-long blades, each turbine of the wind farm will have a swept area of 21,900 m.
- The wind turbines will be connected in a loop by a 2.5 km-long, 66 kV dynamic inter-array cable system.
- Enova has approved an application for funding of up to NOK 2.3 billion to support the Hywind Tampen project.
- Due to start up in the third quarter of 2022.

ID.	TG1 PRIORITIZED AREA	PROBLEM STATEMENT / CHALLENGE	SUPPORTING TECHNOLOGY & KNOWLEDGE INNOVATIONS[3]
#1	**Energy efficiency in offshore operations** The ambition is to reduce operational greenhouse gas emissions by 50% in 2030 vs 2005 levels, and to near zero by 2050 (Konkraft, 2021). Over 90% of the NCS' present CO_2 emissions relate to the generation of energy (NOROG, 2020). Improved efficiency in the demand and supply of energy is critical to meeting these targets.	Water injection is a common drainage philosophy on the NCS, where produced water and/or seawater replace produced volumes to maintain the reservoir pressure. The energy demand to pump water to injection pressure is usually very large, and the NCS as a mature basin continues to see growth in its water-to-oil ratio (NPD, 2019). Preventing formation water from leaving the reservoir or removing water from the well stream as close to source as possible, would significantly reduce the energy demand for fields supported by water injection.	• Reservoir technologies for less water production. (see water management in section 4.4). • Well completion technologies that reduce water production. (see water management in section 4.4). • Downhole or subsea water separation and reinjection.
		Subsea tie-backs to existing topside facilities are projected to be the dominant means of producing new volumes on the NCS (NPD, 2019). Longer distance tie-backs will incur higher temperature and pressure losses along the flowlines, which are typically reintroduced at the host facility. Flow assurance issues (hydrates, wax) usually become more challenging with lower temperatures/ pressures, and the solutions typically add to the energy demand or result in increased flaring.	• Subsea boosting. • Cost-competitive flowline insulation techniques. • Low emission flow assurance philosophies. (e.g. low dosage hydrate inhibition, cold-flow technologies).
		New topside facilities will be few and far between; existing topsides will be utilised and life-extended. Brownfield modification of major energy consumers and suppliers is often challenging in terms of layout, weight and cost.	• Increased efficiency of local power generation. (e.g. combined cycle gas turbines, dual fuel engines). • Low/zero carbon fuels (e.g. hydrogen, ammonia, blends). • Heat integration (recovery of heat within the process systems) without bulky piping or heat exchangers (e.g. heat pumps). This is an enabler for electrification (below).

3 These are examples. Other solutions addressing the prioritized technology areas should also be sought and developed.
4 Noting that chemicals which are eventually discharged to sea also represent an environmental impact.

<table>
<tr><th>ID.</th><th>TG1 PRIORITIZED AREA</th><th colspan="2">PROBLEM STATEMENT / CHALLENGE</th><th>SUPPORTING TECHNOLOGY & KNOWLEDGE INNOVATIONS[3]</th></tr>
<tr><td rowspan="5">#2</td><td rowspan="5">Reduced cost of electrification
Electrification has to date been the preferred approach for large scale removal of upstream CO_2 emissions; favoured since it does not interfere with the reservoir or processing systems, and carries low risk. It is, however, often a costly mitigation and continues to face technical and physical limitations.

Here, electrification refers to import and production of power either from shore or from other offshore sources.</td><td rowspan="2">Minimising the need for topside equipment to support electrification would improve the viability of electrification, in particular for brownfield applications.</td><td>Direct current (DC) transmission is most suited to longer cable lengths (typically >200 km depending on load and cable design) or higher loads (>200 MW), but requires power converters at either end of the cable which are large and heavy.</td><td>• Subsea HVDC converter.
• Floating HVDC facility, noting that this incurs some of the dynamic cable issues discussed below.
• Wet-mate high voltage connectors to reduce the complexity of installing subsea equipment.
• Pressurised power electronics.</td></tr>
<tr><td>Alternating current (AC) transmission avoids power converters, however it continues to see limitations in its transmission capacity and distance.</td><td>• Increase the viable range (cable length) by:
- mid-point compensation.
- low frequency transmission.
- series capacitor.
• Place electrical equipment subsea (frequency converter, transformers, reactors).
- Wet-mate high voltage connectors to reduce the complexity of installing subsea equipment.</td></tr>
<tr><td colspan="2">The static cable(s) between the power source and the offshore facility are often the largest contributor to capital expenditure for electrification projects.</td><td>• Wet design high voltage cables currently qualified up to 36 kV.
Areas of research include:
- Degradation by water treeing.
- Water condensation in the insulation at reduced load.
- Water diffusion along the cable into connecting components.</td></tr>
<tr><td rowspan="2">The dynamics associated with floating facilities present further challenges for electrification.</td><td>Dynamic cables (between static cables/equipment on the seabed and the floating topside facility) are currently qualified for 145 kV / 100 MW (per cable) AC transmission.</td><td>• Qualify dynamic cable for HVDC:
- Termination from subsea static to dynamic section.
- Dynamic influence on space charge / field inversion.</td></tr>
<tr><td>For turret-moored (weather vaning) facilities there are currently swivels qualified up to 52 kV power transfer.</td><td>• Qualify space-efficient swivels for higher voltages.</td></tr>
</table>

ID.	TG1 PRIORITIZED AREA	PROBLEM STATEMENT / CHALLENGE	SUPPORTING TECHNOLOGY & KNOWLEDGE INNOVATIONS[3]
#2 cont.		Most electrification schemes in operation or under development supply power to an individual facility or field. In principle, electrification hubs serving several facilities/fields, or even a region, would be more cost-efficient and reduce technical and physical limitations. Furthermore, larger grid systems improve the potential for the integration of renewable power sources and energy storage systems. The mixture of frequencies (50/60 Hz) used at differing facilities must be overcome, where applicable.	• Improved understanding of practical issues that affect the overall viability of hubs: - Collate key data characterising individual NCS facilities (forecast load profiles, frequency etc.) that can be used for preliminary technical assessment. - Research the organizational viability (multiple licenses, cash flow, cost allocation, ownership etc.). - Integration of renewable energy sources (e.g. wind) and gas power with carbon capture and storage (see below). - Energy storage opportunities (e.g. batteries, fuel cells).
		Electrification from low carbon or renewable power production offshore can be a supplement to, or a replacement of, conventional offshore power generation or power from shore.	• Technologies for alternative energy sources offshore.
#3	**Offshore carbon capture, utilization and storage (CCUS)** CCUS is widely recognised as group of technologies that will have a significant role in the energy transition, notably serving 1) fossil-fuel grid power, 2) blue hydrogen and 3) sectors with hard-to-abate emissions (IEA, 2020). Each of these three groups could be represented offshore. (for sequestration of CO_2 captured outside of upstream activities, see section 4.4)	Exhaust gas capture technologies are not yet proven offshore, but are available in the market using conventional technology at abatement costs which have been found to be competitive against power from shore. Nonetheless, current capture and CO_2 injection modules require a sizable footprint, height and weight, and are therefore highly challenging for brownfield applications. Injected CO_2 reaching production wells (known as "back-production") is a significant risk due to corrosion – enhanced material selection is expensive.	• Reduced size, weight, and cost to further improve competitiveness. • Improved understanding of the behaviour of injected CO_2 in the reservoir. • Cost-effective techniques for storage/utilisation of CO_2 (in the order of 10^5 tonnes per year) which does not involve the producing reservoir.
		Gas is expected to continue to increase its share of NCS production while the regional demand for gas is predicted to fall (Rystad Energy, 2021). Alternative techniques to monetise gas resources in a low carbon society could be performed offshore with the help of carbon capture and local storage.	• Offshore blue hydrogen production (see also section 5 discussing new energy markets). • Offshore gas power generation, exporting power to the onshore grid (also known as "gas-to-wire").

ID.	TG1 PRIORITIZED AREA	PROBLEM STATEMENT / CHALLENGE	SUPPORTING TECHNOLOGY & KNOWLEDGE INNOVATIONS[3]
#4	**Lifecycle assessments** LCAs enable environmental impacts beyond only the operational phase of an asset to be evaluated in design. LCAs need to enable a broad range of environmental indicators. For emissions, Scope 3 aspects should also be included.	Upstream facilities are complex in their components and supply chains and rely on specialist yards and vessels. Early design phases offer the greatest opportunity to affect key decisions which might influence lifecycle environmental impacts, but the least information upon which an LCA could be based.	• Toolkit aimed at the early design phases of upstream facilities to enable coarse LCAs to be established, commensurate with the information that is available. • Methods for risk assessment related to handling of contaminated waste from obsolete offshore materials (e.g. decommissioning),
#5	**Leak detection and mitigation** Unplanned releases of hydrocarbons or chemicals to the marine environment erodes trust in and the reputation of the industry. Improved detection of leaks is therefore important to reduce business risk as well as environmental risk.	Conventionally, sensing devices are static and are limited to covering either a point source (e.g. a valve) or an area (e.g. ambient seawater surrounding a subsea facility). Remote and rapid pin-pointing of a leak point within a complex/congested facility is hence challenging, and likely to limit the effectiveness of the immediate response.	• Sensors mounted on autonomous mobile devices (e.g. AUVs, drones) permanently stationed at the facility may allow fewer sensors to be used for greater coverage/accuracy. • Further effort is needed to demonstrate and implement available sensor technologies, to reduce cost of the technologies, and to understand how the technologies can be utilized and optimized for different purposes (i.e. environmental risk factors in general)
		In design, it is often challenging to justify measures for the detection and (where relevant) containment of leaks. This is particularly true for, but not limited to, smaller leak scenarios (typically which do not carry a significant safety or asset risk).	• Develop a framework for performance standards and/or functional requirements to support the selection of leak detection strategies for smaller leak scenarios.
		In operation, it can be challenging to quickly detect smaller leaks using process (in-pipe) instruments, especially where there are frequent changes in process conditions.	• Detection techniques which accurately monitor the ambient environment, to complement process instrumentation. • Artificial intelligence, data-analytics and physical models for faster and more reliable detection. • Review whether there are opportunities for better calibration data (in test facilities or in-situ) to help tune the above tools.

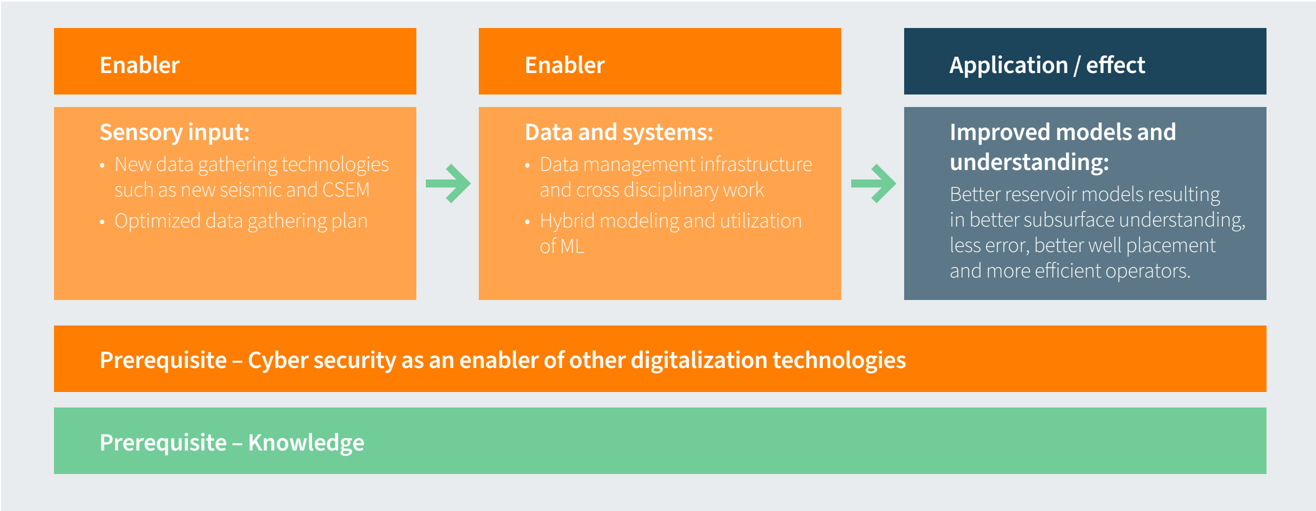
ID.	TG1 PRIORITIZED AREA	PROBLEM STATEMENT / CHALLENGE	SUPPORTING TECHNOLOGY & KNOWLEDGE INNOVATIONS[3]
#5 cont.		Lack overview of reported NCS leak events which can be used by the industry for experience transfer and could in the future form the basis for statistical analysis supporting risk assessments.	• Along the lines of the UK's Hydrocarbon Release Database (HCRD) (UK HSE, 2020), Norwegian authorities are recommended to publish a leak database detailing the fluid type and properties, volume, rate, duration, cause etc. This should cover chemicals as well as hydrocarbon fluids. • Better understand the connection between fracture mechanisms and leakage rate to better predict the risk of leakage as well as leakage rate development over time.
#6	**Environmental risk assessment and management** Discharges to the marine environment from petroleum activities are risk assessed using the DREAM model to predict the Environmental Impact Factor (EIF). This predominantly covers discharges with produced water, injection water and drill cuttings. All natural compounds (from oil and gas production) and added chemicals are included. Chemicals are classified into colour-coded groups according to their properties (i.e. environmental hazards). These properties are an input to the EIF model.	EIF models are considered to have been highly successful at minimising the impact/risk from discharges to the marine environment. However the industry may be overlooking the holistic risk provided by EIF models and instead focusing on reducing individual chemicals' hazards (by substitution). Substitution is one tool to minimise the environmental risk of discharges to the marine environment, but it is not the only solution. Managing the holistic risk is foreseen to offer a better environmental performance compared to managing the hazards of individual chemicals.	• Wider-spread use of EIF models/results for decision making (both in design and operation) and for periodic regulatory reporting. • Improved knowledge/understanding of techniques which avoid chemical injection, or target reduced injection volumes (e.g. chemical combinations, low-dose chemicals). • Improved information availability/sharing concerning chemical properties (e.g. partitioning and toxicity) – collaboration between vendors and operators, inclusion in chemical databases.
		Future production on the NCS is expected to be characterised by new wells and IOR techniques within existing fields, whereas the numerous smaller discoveries are likely to be developed as tie-backs to existing facilities.	• Discharge philosophies/practices for drilling of production/injection wells. • Chemical development should focus on the industry trends (e.g. drilling, IOR chemicals, hydrate inhibitors, corrosion inhibitors, drag reducers, chemicals supporting produced water treatment and techniques to treat injected seawater). • Compatibility issues created by mixing produced waters from different fields.
		A prerequisite for the O&G industry is to demonstrate sustainable activities for the regional fauna and ecosystems. This is particularly important for vulnerable areas.	• Improved knowledge, models and tools supporting good effect and risk evaluation of environmental impact on marine ecosystems.

ID.	TG1 PRIORITIZED AREA	PROBLEM STATEMENT / CHALLENGE	SUPPORTING TECHNOLOGY & KNOWLEDGE INNOVATIONS[3]
#7	**Oil spill contingency** It is a prerequisite for the industry that oil spills are avoided. However, if they occur, they must be detected early and the consequences need to be minimized through efficient oil spill response.	Subsea dispersion of oil reduces the environmental impact by decreasing the concentration and increasing natural decomposition. It also reduces the risks for response teams attempting to work at the surface near the spill site. However, there is limited experience of these techniques at full-scale.	• Further technology development and large scale testing of subsea dispersant injection (SSDI) and subsea mechanical dispersion (SSMD) to lift to higher TRL level.
		The efficiency numbers used for different oil spill response technologies, in oil spill response analysis and planning, are often questioned. Especially for mechanical recovery.	• Increased knowledge and documentation on efficiency and effects for different oil spill response technologies is needed.
		Oil spill response equipment and techniques may not be suitable for the cold climate in the high north.	• Test conventional equipment and techniques in winterized conditions. • Adapt equipment and techniques where required. • Train response teams to understand the different equipment and techniques required in cold conditions.
		Tools used for spill modelling and response rely on accurately predicting the fluid's behaviour. Wax rich crude oils and condensates with high pour point may not be accurately predicted with the tools used today.	• Further development of modelling tools to compensate for reduced initial spreading and increased oil thickness for oils that may solidify on the surface in≈contact with cold sea water.
		Shoreline clean-up knowledge and tools are typically based on heavy fuel oils which will behave differently to NCS fluids (crude oils and condensates).	• Increased knowledge and documentation on behaviour of different crude oil types in contact with different shoreline substrates. • Improve the basis for estimation of resources requirements adapted to crude oil releases. • Improvement of shoreline clean-up technologies for crude oils.

ID.	TG1 PRIORITIZED AREA	PROBLEM STATEMENT / CHALLENGE	SUPPORTING TECHNOLOGY & KNOWLEDGE INNOVATIONS[3]
#8	**Environmental performance data** Increased public scrutiny of the petroleum industry's environmental impacts should be proactively met by offering enhanced transparency.	A significant amount of information is publicly available, offering an insight into historic volumes of pollutants at field-level. However, the information is dispersed and generally inflexible (not centralised or in a format to allow ease of interrogation), and there is significant room for improved disaggregation of data.	• A single-source, publicly accessible environmental data hub which can be flexibly interrogated and exported. - Facilitates maximum available disaggregation (e.g. by facility, emission equipment, chemical functional group etc.). - Functionality to collate data by processing hub[5]. - Includes production/injection data for normalisation.
		There is no overview of upstream energy consumption, which is crucial to support strategy and research which targets greenhouse gas emissions.	• Annual reporting of energy (GWh) which separates between: - Demand by main use (e.g. oil separation, gas compression, water injection etc.). - Supply by type (electrical, mechanical, thermal) and source (e.g. turbine, engine, boiler, WHRU, imported power etc.). • Fuel consumed by source (gas, diesel).
		Data are collected on emissions and for environmental monitoring. A significant amount of data is available but not sufficiently coordinated across different platforms and needs for optimal total utility.	• Utilize all available emission and environmental data for improved prediction of effect of activities on ecosystems and biodiversity.

5 For example, emissions/discharges from Field X support production from Field Y in addition.

Figure 43. Data acquisition and management enable improved subsurface understanding and models



4.4 SUBSURFACE UNDERSTANDING

The prioritized technology and knowledge areas for TG2 are:

- Offshore CO_2 storage and late life deposits.
- Data acquisition for subsurface understanding and models.
- Data management for subsurface understanding and models.
- Subsurface understanding and models.
- Water management.

The “data acquisition” and “data management” technology areas, described in detail on the next pages, are enablers for the “subsurface understanding and models” technology area. This is shown in Figure 43.

The TG2-prioritized technology areas are important for all the competition indicators described in Section 3.

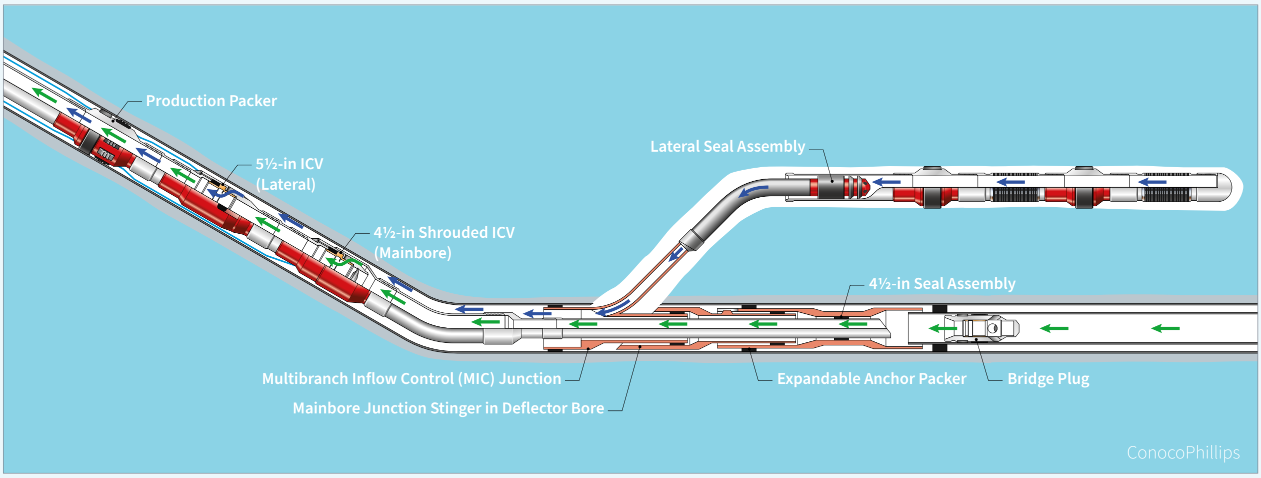
For instance, the improved subsurface understanding and models, building on data acquisition and the management related to it, will provide the fundament for:

- Finding and maturing new resources.
- Cost-efficient reservoir drainage.
- Safe and cost-efficient drilling.

Offshore CO_2 storage has, in addition to receive and store large amounts of CO_2 from industry sources in Norway and abroad, the potential to extend the lifetime of fields beyond the cessation of O&G production.

Improved water management will lead to significant reductions in water cycling, and thereby lower emissions from power generation. It is also expected that improved water management will accelerate HC production and yield higher resources by a more efficient reservoir drainage, as well as savings related to less energy consumption for processing of both injection and produced water.

RETROFIT MLT AND TROUGH TUBING DRILLING -TTD



Retrofit Multilaterals RMLT and TTD Through Tubing Drilling are technologies allowing added, low cost, drainage or injection points from existing wells. While maintaining access to production or injection from the existing well bore these methods are converting single bore wells to dual or multiple lateral wells.

The savings related to TTD is to avoid removing and reinstalling the completion string and no drilling of top-holes sections. For Retrofit it is improved slot usage, reduced drilling of top-hole sections and keeping the x-mas tree installed throughout the drilling process. Both technologies offer access to smaller targets which may not be viable by drilling single dedicated wellbores, or from a sidetrack when the old wellbore is shut off and remaining production is abandoned. Both technologies increase the recovery and may extend the platform life.

Maintaining the access and production or injection from the main bore is crucial, and the development of the hollow or removeable whipstock has been the major breakthrough to enable the technology. Several operators have used the technology on the Norwegian Shelf, and there are ongoing developments to further refine and optimize both technologies.

ID.	TG2 PRIORITIZED AREA	PROBLEM STATEMENT / CHALLENGE	SUPPORTING TECHNOLOGY & KNOWLEDGE INNOVATIONS[6]
#9	**Offshore CO_2 storage and late-life deposit** After an oil or gas field is depleted, CO_2 injection for storage can commence. This will effectively store large amounts of CO_2, as well as postpone the de-commissioning and could have a positive effect on the field's NPV. Life-extension challenges would be the same as for other life-extension projects.	The old installation and its equipment topside, at the seabed and subsurface are likely not designed for handling CO_2. Integrity must be ensured through-out the CO_2-injection phase, and for subsurface equipment also after the field has been abandoned.	• Anti-corrosive processing equipment. • CO_2 injection pump technologies. • Leverage renewable energy sources nearby. • Modelling tools to ensure safe CO_2 injection, seal rock integrity and maximized utilization of CO_2 storage capacity.
		Injected CO_2 will have to be stored without leaks permanently. Any leaks must be identified early.	• Long term reservoir monitoring capabilities for containment assurance .
#10	**Data acquisition for subsurface understanding and models** Subsurface data provide the basis for success-ful exploration and efficient field develop-ment.and operations. Access to sufficient amounts of high-quality data at reasonable costs is an enabler for im-proving subsurface knowledge and developing and implementing better subsurface tools.	Exploration and reservoir management is associated with a high degree of uncertainty. To reduce uncertainty there is a need for improved sensors and data acquisition equipment that will improve data quality and enable better imaging of the subsurface.	• High resolution broadband seismic data. • Further mature OBN-acquisition / streamer systems. • Improved borehole seismic data. • 3D resitivity imaging. • Better datapoints for each well (inflow tracers, permanent downhole gauges, well rate measurements, DTS and DAS (acoustic and temperature)). • Automated accurate well monitoring capabilities.
#11	**Data management for subsurface understanding and models** Subsurface data provide the basis for success-ful exploration and efficient field develop-ment and operations. Access to sufficient amounts of high-quality data is an enabler for improving subsurface knowledge and developing and implement-ing better subsurface tools. Efficient handling/ management of the data is the step after data acquisition.	Data handling and management is often time consuming and cumbersome. The inefficiency is partly related to interoperability and format issues, data quality, and inefficient infrastructure for storing and distributing data.	• Data management protocols and maintenance systems. • Standardized data storage systems. • DISKOS –improvements in effective data usage and data type expansions • NPD's CO_2 storing ATLAS. • Rock image / cuttings database. • Industry collaboration initiatives like OSDU.

6 These are examples. Other solutions addressing the prioritized technology areas should also be sought and developed.

ID.	TG2 PRIORITIZED AREA	PROBLEM STATEMENT / CHALLENGE	SUPPORTING TECHNOLOGY & KNOWLEDGE INNOVATIONS [6]
#12	**Subsurface understanding and models** Improved subsurface understanding and better subsurface models are key to improve the NCS competitiveness: it's the basis for more efficient exploration, better well placement and safe drilling, improved reservoir drainage, and less energy use and CO_2-emissions.	Improved models and modelling approaches, e.g. integrated models utilizing advanced data analytics / AI / ML, could enable faster model updates providing a more comprehensive specter of potential outcomes.	• More knowledge related to seals, overburden and chemical composition. • Basin models incorporating migration pathways and reservoir history. • Improved 4D analysis techniques. • Improved understanding of the source of production. • Integration of more data analytics, AI and ML in models. • Hybrid models where AI integrates with physical models. • Improved tectonic models. • AI techniques for model generation, matching and predictions.
#13	**Water management** Water management is fundamental for cost-efficient drainage of the reservoirs. Water processing and injection is power demanding and it is a main driver for CO_2-emissions from the NCS.	Water injection is essential for efficient reservoir drainage. Water fingering and break-through leads to less efficient sweep and higher than necessary water cut, and measures to prevent this are sought after. Water used for improved sweep needs to be treated. More cost- and energy efficient ways of water treatment are sought.	• EOR measures such as foams, polymers and gels that improve sweep and reduce water production. • Develop effective "green" chemicals with little environmental risk potential. • Subsea water treatment.
		Water is being produced from the reservoirs. The water cut is often low in the early days of a field, and increases over time. Processing the water takes up processing capacity topside. Re-injection of produced water is preferred over discharge-to-sea, and the re-injection is energy demanding. Technologies to reduce water production and/or separating the water on the seabed, are therefore important for reducing power consumption.	• Improved inflow control devices (AICD) to reduce water production from reservoirs. • Down-hole water separation and re-injection. • Seabed water separation and re-injection.

4.5 DRILLING, COMPLETIONS, INTERVENTION, AND P&A

Although drilling performance has improved substantially over the last 6 years, Drilling & Wells is still the main cost element on the NCS, representing 28% of estimated expenditures on the NCS for the 2021-2040 time period (Rystad Energy, 2021).

The prioritized technology and knowledge areas for TG3 are:

- Data gathering and optimization of drilling operations.
- Improved drilling equipment.
- Advanced well construction and methodologies.
- Subsea well intervention technologies.
- Recompletion and multilateral technologies.
- Challenging reservoirs.
- More efficient P&A.

All TG3-priorities have the potential to cut costs on the NCS significantly (see Figure 42). In addition, most would contribute to adding significant volumes. Most of the priorities would also have a potential positive impact on CO_2-emissions.

"Challenging reservoirs" are with current technologies associated with higher CO_2-emissions than conventional reservoirs. Considering the large volumes on the NCS in such reservoirs, the R&D efforts should be aimed at reducing CO_2-emission to at least the same level as for conventional reservoirs. We believe such reservoirs could potentially be drained with technologies that are not necessarily very energy consuming, e.g. more mechanical technologies can be developed, and fluid pumping methods could be advanced.

Common for most of the evaluated TG3 priorities is that they can be adopted fast – often they would yield saved costs or added volumes within a year from investment decision. This make such technologies especially attractive in a business environment where fast returns are favored and may explain why such technologies had a relatively high adoption rate during the petroleum recession period 2014-2018.

We have seen some technology development for rig equipment over the last years, but there is still scope for further improvements. Making use of sensor data and Artificial Intelligence (AI) to improve automation and make the rig operate more towards optimum performance every time, will improve the efficiency and as such minimize the carbon footprint of the operation. This combined with improved and modernized drilling equipment has a considerable potential.

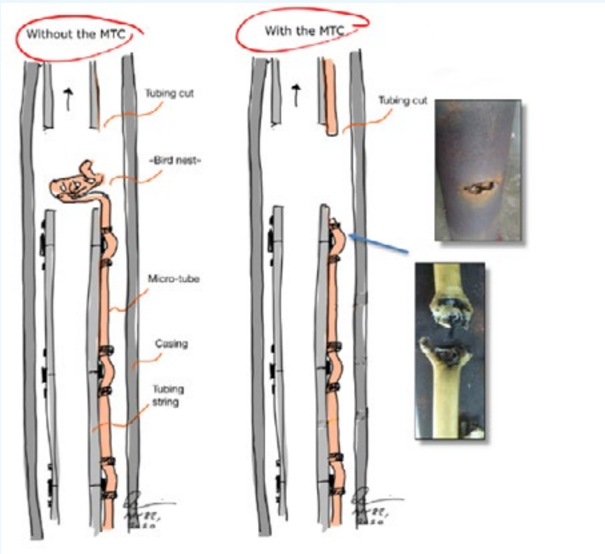
When it comes to well construction, new drilling methods and optimized well design combined with intelligent utilization of existing wells have been demonstrated by some of the operators on the NCS. There are however several new technologies where the full potential is still not harvested. Further development and adoption of such technologies could reduce the number of days per well, and facilitate cost and volume optimized wells, i.e. maximizing the value of each well.

P&A of wells on the NCS is a considerable challenge ahead. We need step change technologies to make these operations as effective as possible to minimize future expenditures. The market volume is increasing, and several service companies are very creative in this arena and should be stimulated to advance these technologies to minimize rig days, emissions, and costs.

DO WE HAVE TO USE RIG FOR P&A OPERATIONS?
DO WE HAVE TO PULL THE TUBING, OR CAN THE TUBING REMAIN IN THE WELL?

WHAT AARBAKKE INNOVATION'S MTR-TECHNOLOGY ENABLES:
Allowing the production tubing to remain in a well after P&A is currently only wishful thinking – a wonderful scenario of well P&A at the end of a field life. It would save significantly both with respect to safety, emissions, and cost.

If control lines are removed, the production tubing can be plugged with cement and left in hole permanently. The need for significant crane power (hence; rig need) is eliminated, and thereby also safety risks are minimized. Last but not least: Large savings are achieved (cost and environment), as pulling/transport/deposit is eliminated.



Estimated savings: CO_2 = 6:1, NOx = 5:1 and SO_2 = 4:1

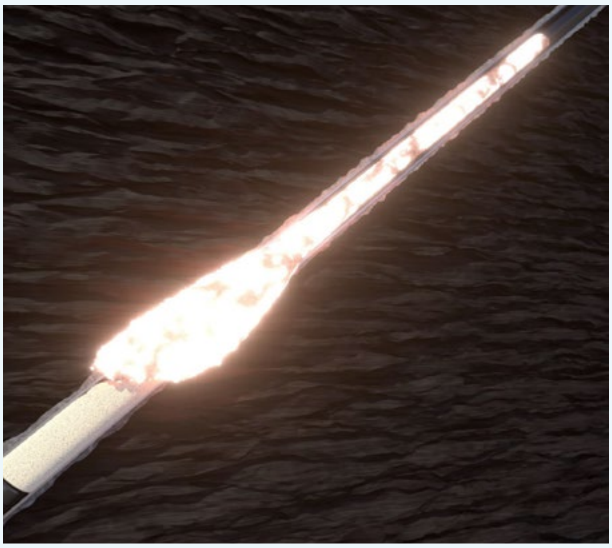
"..if the MTR was a "off the shelf tool" we would change our P&A methodology going forward..."

P&A Engineering Supervisor, Well Operations.

Aarbakke Innovation is developing a downhole (wireline) tool that can lock itself in place (anchor), detect the position of lines in the annulus outside the tubing (ultrasound), machine out a hole, grab and cut the lines, and thereafter remove the lines from annulus in desired interval(s). The tubing may thereafter be cemented without the lines as a potential pathway for HC. The ambition is to perform this operation with a prototype in a pilot well in 2022.

This tool may also prove itself valuable combined with other complementary P&A technologies, and potentially in a wider scope (EOR, Slot recovery). A wireline «swiss army knife»?

WHAT INTERWELL'S «ROCK SOLID»-TECHNOLOGY ENABLES:
Rock Solid" utilizes a highly energetic chemical composition deployed on wireline. It melts the cross sectional well elements and solidifies to form an everlasting gas tight barrier. Through 2021 an extensive field trial program has been conducted in cooperation with several operators. The prototype deployed in field trials has shown that there is a challenge to retrieve downhole data from the combustion and barrier placement due to heat influence. Downhole data is vital to validate key indicators, which in term will qualify that the



reaction has occurred according to plan and to verify barrier formation process. A new generation of deployment tool kit aims to enable Interwell to evolve and expand application envelope; to improve barrier quality, and; to ensure key performance data from barrier setting for final verification.

These elements provide key information to support the technology qualification and enables Interwell to target more demanding wells and stringent regulatory requirements in the offshore market.

ID.	TG3 PRIORITIZED AREA	PROBLEM STATEMENT / CHALLENGE	SUPPORTING TECHNOLOGY & KNOWLEDGE INNOVATIONS [7]
#14	**Data gathering and optimization of drilling operations** A considerable step has been taken in drilling performance the last few years, but still there is room for further improvement in efficiency and eliminating non-productive time (NPT). There is a need for improved predictability when drilling new plays. In addition, the regular quality and accuracy of formation data should be improved to deliver optimum wells in development drilling and getting more accurate assessments of exploration wells.	The prioritized area covers the full digitalization chain: data gathering- >data management / systems - > data application. Data gathering in drilling and completion operations can be split into operational data from the drilling operation itself, formation evaluation data, and production data after putting the well on stream. The first data set can be used to optimize the drilling operations including automation and repetitiveness. This has the potential to reduce drilling time and non-productive time (NPT), and therefore reduce drilling costs and emissions significantly. In combination with formation evaluation data (MWD/LWD) it would provide better control and earlier detection of anomalies, and therefore reduce NPT, improve safety and mitigate major accident risks. Data gathering and interpretation while drilling is important for real time operations, improving the chances for landing production or injection wells in the most optimum place, as well as for improving reservoir models. Providing power downhole will simplify the drilling assemblies (BHA) and make them more compact. It will also aid in developing future sensor technologies and push BHA limits. The downhole measurement of the production flow to manage the reservoir and minimize the energy consumption of the well (see ID#1 above) is essential. The right tools for measuring temperature, pressures and composition can make a considerable difference and in combination with downhole control/ steering, the reservoir can be managed in the most optimum way for value creation and minimized emissions.	• Automated drilling operations with next generation sensor technologies, artificial intelligence and physical models. • Further robotization of rig operations. • New sensory input like measurement-while-drilling / logging-while-drilling, improved look around and look head perspectives. • More efficient data transfer like wired pipe with downhole power supply. • Development in data interpretation and display results. Utilize AI also here. • Wireless technologies for downhole production monitoring. • Improved interoperability and connectivity between systems. • Electrification of downhole components. • Inflow control devices (ICVs). • AICV development and development of interpretation models and reservoir models to simulate the effect on volumes. • Digital tools for safe and efficient simultaneous operations. • See also ID#10-13 above.

7 These are examples. Other solutions addressing the prioritized technology areas should also be sought and developed.

ID.	TG3 PRIORITIZED AREA	PROBLEM STATEMENT / CHALLENGE	SUPPORTING TECHNOLOGY & KNOWLEDGE INNOVATIONS [7]
#15	**Improved drilling equipment** Development of rig equipment is conservative and rig contractors are reluctant to take bigger investments after the difficult times they have been through. But the time is here to take a closer look at the next generation rig equipment and the operational and energy efficiency improvement required.	Less complex and more reliable equipment would reduce non-productive time, "invisible" lost time and maintenance time, which are significant contributors to drilling costs. Monitoring wellhead fatigue and having tools improving well-head fatigue is essential for having enough operating days for drilling, completion, and P&A of subsea wells. Power systems on offshore rigs are designed for peak loads, and most of the time they run at low thermal-efficiency loads. Hybrid system could improve efficiency and reduce GHG emissions.	• Electric BOP. • Improved monitoring of BOP. • Hybrid technologies and batteries. • Modelling of sea movement. • Systems and methods for mitigation of wellhead fatigue. • Systematic use of improved wellhead monitoring for fatigue. • Energy management systems.
#16	**Advancement in well construction and methodologies** Better well construction can increase recovery by making un-drillable wells drillable. It can also have significant cost and emission effects by reducing the time of the drilling operations as well as through enabling the use of less materials, e.g. through reduced casing and mud use or by avoiding additional subsea production system (SPS) equipment.	Reduce drilling time: Cost estimates in Section 3.5 suggest that drilling will contribute with almost a third of NCS investments over the next two decades. 85% of this is time dependent. Reducing productive as well as non-productive drilling time will hence contribute significantly to overall cost-reductions. Problematic wells are prone to unplanned/invisible lost time caused for instance by need to circulate mud or drilling side-tracks. Downtime (NPT) is also caused by equipment failure and drilling trouble such as stuck pipe, kicks and mud loss.	• Expand planning tools from automation of engineering to incorporate all planning (drilling, completion, intervention, well integrity monitoring and P&A). • Improved managed pressure drilling (MPD) for subsea wells on the NCS. • Improve rotating control device (RCD) technology for optimized dual gradient drilling. • Better fluid design for wellbore stability and lower friction. • Improve technologies mitigating risk of not reaching target depth in extended reach wells. • Riserless drilling post BOP installation. • Improved AICD modeling and simulation methodology for improved understanding of the effect of this tool. • Improve batch drilling methods, and utilization of dual and offline activity rigs.
		Increase recovery: 1. Drill problematic and "un-drillable" wells, e.g. inhomogeneous reservoirs with varying pressure zones. 2. Improve completion	Same as above, in addition: • Further develop autonomous inflow control devices (AICD).

ID.	TG3 PRIORITIZED AREA	PROBLEM STATEMENT / CHALLENGE	SUPPORTING TECHNOLOGY & KNOWLEDGE INNOVATIONS[7]
#17	**Subsea well intervention technologies** Technologies for cost-efficient and safe maintenance of subsea wells. The main effect of more cost-efficient subsea well intervention is added volumes from improved well productivity. Conducting subsea well interventions without heavy rigs could also save emissions.	The intervention ratio for wet wellheads on the NCS is about 70% lower than for dry wellheads. The reason is mainly the large costs of conducting well interventions on subsea wellheads relative to dry wellheads – typically 5-10 times higher from a rig than from a fixed platform. In addition, subsea well interventions are often postponed due to poor weather conditions.	• Simpler standardized well intervention systems. • Remote on seafloor devices and technologies. • Dedicated floater with operational motion characteristics for all year operations.
#18	**Recompletion and multilateral technologies** The priority "Recompletion and multilateral technologies" consists of technologies and knowledge needed to re-utilize existing wells partly or fully. The priority is also part of improved reservoir management. This priority also covers the potential volume effects of improved technologies within P&A. Opportunities within utilization of existing wells that pertains to improved water management is covered in TG2 within the opportunity "Water management". Furthermore, opportunities within utilization of existing wells that pertains to subsea well interventions is covered in TG3 within the opportunity "Subsea well interventions".	Utilizing existing wells in a better way could: (i) reduce costs and emissions by reducing the number of drilling days and the need for materials; and (ii) enable new volumes as improvements in such technologies will make more resources technically and economically recoverable.	• Multi-lateral technologies with better control over each wellbore. • Technologies for sidetracking and retrofitting. • Further develop through-tubing-rotary-drilling (TTRD) and coiled-tubing-drilling (CTD). • Technologies for improved control for each wellbore. • Improve monitoring and management of production and injection in multi-lateral wells (MLW). • Well construction with life-time perspective, e.g. for later use for CCUS.
		Utlizing P&A technologies: This could enable new wells that would otherwise be viewed as uneconomical and enable new marginal volumes.	• Improved slot recovery.

ID.	TG3 PRIORITIZED AREA	PROBLEM STATEMENT / CHALLENGE	SUPPORTING TECHNOLOGY & KNOWLEDGE INNOVATIONS[7]
#19	**Challenging reservoirs** The opportunity "Challenging reservoirs" consists of technologies and knowledge associated with recovering tight and/or inhomogeneous reservoirs (permeability less than 10 millidarcy (mD)). Such formations often call for the use of unconventional technologies to achieve profitable development.	An NPD study suggests that 12.5 billion barrels of oil equivalents could be realized from tight reservoirs on the NCS. Costs could be high and recovery from tight reservoirs could also lead to high CO_2-emissions. Research and technology development should aim at producing such reservoirs with CO_2-emissions at least as low as conventional reservoirs.	• Improved completion technologies and stimulation. • Multi branch wells with fracking in each branch. • New fracking methods – e.g. straddle or large-scale versions of existing technologies such as Fishbone. • Mud/Polymer technologies. • Zonal control to enable production from both tight and highly productive formations in the same wellbore. • Knowledge transfer from other petroleum provinces. • Improved modelling.
#20	**More efficient P&A** P&A on the NCS is currently done with rigs. This is costly and time-consuming. More cost-efficient and at least equally safe methods should be sought to minimize the scope required to be performed with the rig. More efficient P&A should be achieved also by developing downhole tool technologies for optimized P&A that don't relate to rigless, where there still is significant room for improvements.	P&A operations have a significant cost, and it is a large well inventory that needs to be plugged on the NCS. Within P&A, the potential to minimize rig scope and leave as much metal in the ground as possible, is identified as giving the lowest CO_2-footprint and the most cost-efficient P&A. To achieve a more efficient P&A of wells, a stepwise approach is needed: • Improve the understanding of P&A Barrier integrity risk to be able to challenge the current standards (D-010). • Improved understanding could enable new alternative plugging methods. • Alternative plugging methods could enable rigless P&A, e.g. light intervention vessels equipped with wireline or coiled tubing units.	• Slot recovery. • Improve understanding of P&A barriers. • New barrier solutions, e.g. active stimulation of shale swelling. • New metal plugging techniques (e.g. Bismuth). • Tubing slicing via wireline / micro-tube removal tool (e.g. Aarbakke). • Multiple string removal technology and bond logging. • Casing removal through improved jacking solutions utilizing vibration techniques and roller expansion. • Alternative energy solutions e.g. laser and plasma. • Multiple string bond logging. • Expandable tool and solutions for improved annulus well bore sealing. • Cleaning and flushing systems for decommission of subsea wellhead and manifold systems. • New well construction design for more efficient P&A operations. • Technologies enabling a future low carbon emission and cost-efficient rig-less P&A.

4.6 PRODUCTION, PROCESSING, AND TRANSPORT

Remaining contingent resources on NCS as presented in Figure 2, are almost equally distributed between contingent resources in existing fields and contingent resources in the NCS discovery portfolio. Average size of discoveries is decreasing, but most discoveries are within tie-back distance to existing fields, as shown in Figure 29.

The NCS is characterized by very efficient infrastructure which is the main reason behind favorable operational costs and break-even prices presented in Figure 32 and Figure 33. However, as production declines from existing fields, costs per barrel increase unless more resources are produced.

Cost-efficient continued development of the NCS is therefore dependent upon two success factors in particular:

- Efficient utilization of the existing infrastructure to realize contingent resources in the areas.
- Realization of discoveries through tie-backs to existing infrastructure.

Making a step-change in cost effectiveness for subsea solutions will enhance tie-in economy and hence provide a great impact on the ability to lift additional volumes from near-field discoveries and prospects. With the high number of potential tie-in projects going forward, there is a great advantage to standardize on new subsea technologies to enable wide implementation with reduced unit costs.

Safe lifetime extension of existing installations is contingent on cost-effective documentation of present state with adequate quality. In this context, efficient development and implementation of sensors and tools, both physical and software, is important across NCS. Robotics with increased level of autonomy and advanced analytics including Artificial Intelligence can prove vital tools for documentation of condition, but also safe and efficient production while in operation.

Value of data is realized when used to update a risk picture, integrate into optimization schemes, or inform decisions to be made. Further, efficient data-collection will bring most value when systemized and coupled with domain knowledge on e.g. degradation mechanisms and prediction of future load and response. Such knowledge on both capacity and load side of offshore structures is important. Technologies improving management of information across all project development interfaces (research communities, contractors, suppliers, service providers, partners, manufacturers, integrator) is needed to improve efficiency in engineering, construction, operation/maintenance. This calls for standardized digital twin solutions.

Extent of modification scope needed on existing infrastructure to accommodate tie-backs is important for viability of new tie-in prospects. Swift modification and hook-up are important also for production efficiency of the existing production. Ability to choose subsea processing technology may ease topside modification scope, reduce cost and project execution time and thereby enhance overall economy of such projects. Several subsea processing technologies matured to project ready level is hence needed to capitalize on these opportunities.

For long tie-back distances, multiphase flow technology development competes with subsea processing and unmanned installations to provide the best development solution for a given prospect. Use of unmanned installations, floating or fixed, will increase the ability to process well stream to transport quality. Using existing infrastructure onshore as well as offshore for further processing can prove cost efficient. Further development of unmanned systems needed to improve brownfield as well as open greenfield opportunities is essential to harvest the full potential and define the NCS petroleum future.

The prioritized technology and knowledge areas for TG4 are closely linked to the success factors. The TG4 priorities are:

- Material condition detection and degradation mechanisms.
- Digital sensory and technologies for facilities.
- Data management for facilities.
- Digital tools for improved monitoring and better understanding.
- Unmanned facilities and subsea processing.
- Standardized subsea templates.

ALL-ELECTRIC SUBSEA – A GAME-CHANGING TECHNOLOGY GOING FORWARD

All-electric subsea technology is the transition from electro-hydraulic actuation of subsea valves to direct electric driven actuators. Electric actuators have been used subsea for 20 years, the next step is to control safety functions in the subsea system with electric battery powered actuators.

"This is a great step towards more efficient development of tie-back fields, and it will enable cost efficient solutions for CO_2 injection wells."

Dan Pedersen, Chief engineer SPS in Equinor.

A simpler subsea control infrastructure saves cost. Operations and maintenance are more efficient without hydraulic power unit topside. Reduced high-pressure testing and improved well barrier monitoring increases safety. Less discharge to sea of hydraulic fluid benefits the environment. The system facilitates condition monitoring and digitalization.

Development is based on broad industry cooperation between research institutes, the Norwegian Research Council/Demo 2000, main SPS suppliers and O&G Operators. A joint operator specification is developed. Technology qualification for fully electric actuated XT's is at the final stage. Work to build and test pilots are initiated.

TechnipFMC, eVXT

ID.	TG4 PRIORITIZED AREA	PROBLEM STATEMENT / CHALLENGE	SUPPORTING TECHNOLOGY & KNOWLEDGE INNOVATIONS [8]
#21	**Facility integrity and lifetime extension of fields** The high-quality, efficient infrastructure on the NCS is key to the current and future competitiveness. Maintaining integrity while keeping costs down, will be important for realizing remaining reserves and contingent resources in fields, as well as for developing resources in the vicinity. Improved knowledge on materials and material condition detection and degradation mechanisms could lead to improved operations and regularity, improved safety, and a better knowledge basis for life extensions and integrity assessments. Integrity of existing installations could also improve development opportunities further away in combination with unmanned platforms.	Access to sufficient, high quality data, is fundamental for understanding integrity of facilities. Condition monitoring could be difficult due to e.g.: lack of sensors; limited physical access; limited availability to historical data series and failure data on equipment and structures. Documentation of present condition could involve considerable offshore scope of work which is time consuming and costly.	• Knowledge sharing between operators and between operators and suppliers on critical equipment and structures. • Use of robots and drones for inspection. • Improved sensory and cost-effective tools for documentation of technical condition (e.g. detection of corrosion under insulation, erosion).
		To fully understand integrity, it is imperative that degradation mechanisms are understood.	• Improve tools for material conditioning and degradation analysis. Include data analytics, AI/ML. • Develop knowledge and tools to analyze dynamics of electrification cables. • Develop knowledge and tools to analyze integrity of flexible risers. • Knowledge of and development of new materials that could replace or be used in combination w/existing.
		Improved access to data and the better understanding of degradation mechanisms should be leveraged to improve cost-efficiency and safety. Risk-based approaches would focus the attention to equipment and structures that are critical to safe operations and high regularity.	• Risk-based identification of critical equipment and structures. • Condition based maintenance. • Predictive maintenance.
		A more efficient inspection and maintenance approach would also include improvements in spare parts logistics.	• 3D printing of spare parts. • Drone delivery of critical equipment. • Industry collaboration on critical spare parts.

8 These are examples. Other solutions addressing the prioritized technology areas should also be sought and developed

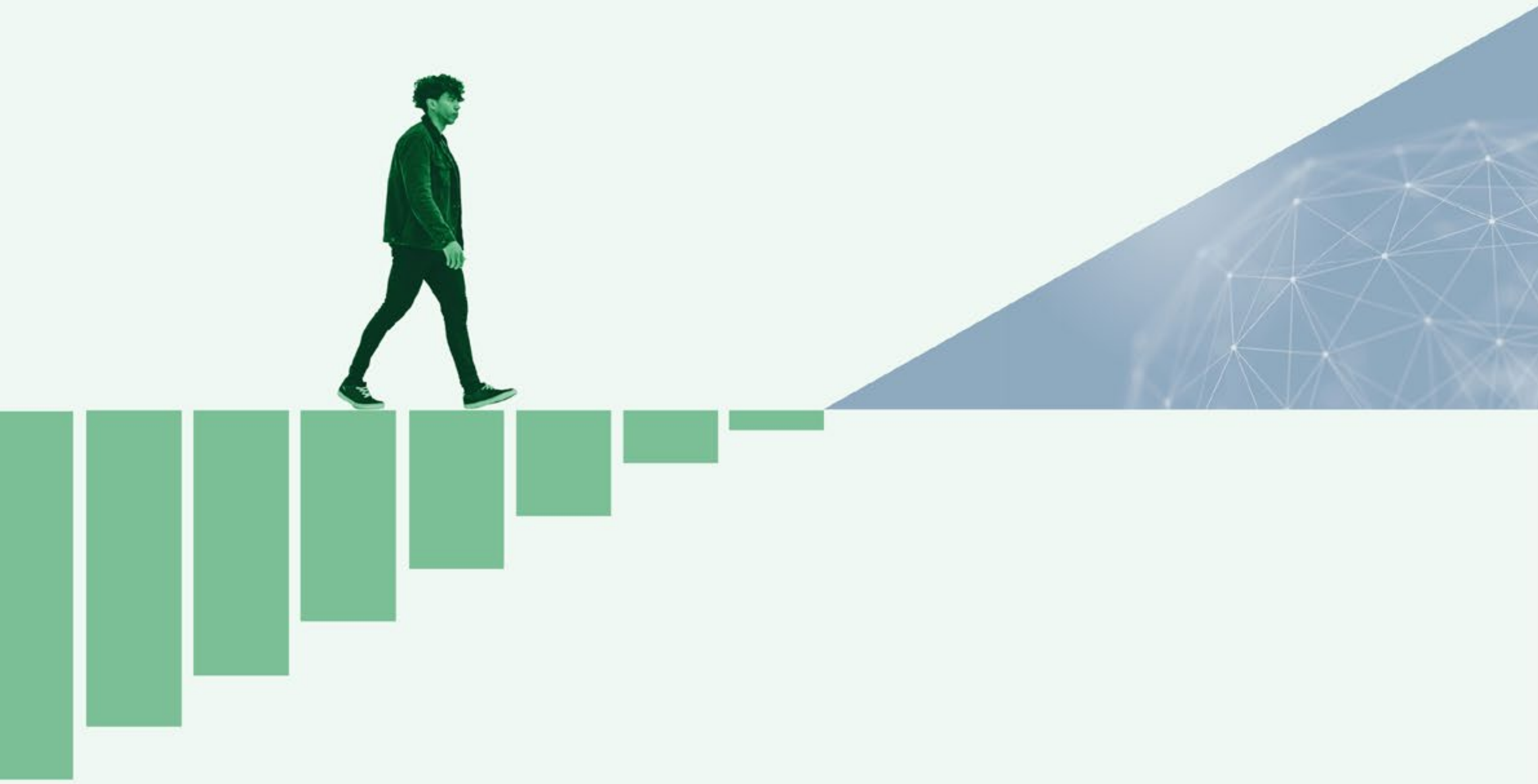
ID.	TG4 PRIORITIZED AREA	PROBLEM STATEMENT / CHALLENGE	SUPPORTING TECHNOLOGY & KNOWLEDGE INNOVATIONS [8]
#22	**Data collection for facilities** New digital sensory technologies like robots, AUVs, drones and sensors for monitoring and inspections can improve monitoring and maintenance of offshore facilities. It forms the basis for predictive maintenance, which can improve regularity. These technologies allow for people-less operations, reduced manual inspection, reduced maintenance costs and improved safety.	Access to sufficient, high quality data, is fundamental for operations and understanding integrity of facilities. Inspection and monitoring could be difficult due to e.g.: lack of sensors; limited physical access; limited amounts of historical data series and failure data on equipment and structures. Documentation of present condition could involve considerable offshore scope of work which is time consuming and costly.	• Robots, drones and AUVs for inspections. • Increased level of autonomy. • Digital sensory for monitoring and detection with sufficient quality. • Data “eco-systems” that include data platforms with improved data access, data structures and possibilities for interoperability.
#23	**Data management for facilities** New digital platforms and software for data management could improve data access and enable new possibilities for use of available data. It could improve use of data to enable integrity monitoring, maintenance planning, improve data quality etc.	Data handling and management is often inefficient, time consuming and cumbersome due to lack of standard formats, poor interoperability, and lack of data management tools. Data tools and digitalization can improve efficiency by automation of manual work tasks like data treatment and analyses to find patterns, optimize processes and improve understanding of a system. This can also allow smaller service suppliers to get more easily established among operators. Standardized interfaces for communication will also make it easier for operators to start using new technology. Improved data access and systems which in a standardized way could treat all types of data could be beneficial to improve efficiency in all organizations, as data overload is a common issue.	• Standardized Digital Twin solution based on the Industry 4.0 concept supporting engineering, construction and operation/maintenance processes. • Software tools with AI and ML algorithms. • Software for communication between different sensor platforms. • Software for improved data handling. • Software for maintenance planning. • Standardized communication protocols for sensory to enable easier use of new sensory technology.

ID.	TG4 PRIORITIZED AREA	PROBLEM STATEMENT / CHALLENGE	SUPPORTING TECHNOLOGY & KNOWLEDGE INNOVATIONS [8]
#24	**Digital tools for improved monitoring, better understanding and more efficient operations**	The efficient infrastructure on the NCS is a main reason for the competitive cost level. It is essential for realizing reserves in the fields, contingent resources in the field, and for realizing a majority of the contingent resources in the discovery portfolio that would need tie-back to a host to become economically viable. Keeping control of integrity through cost-efficient inspection and maintenance will be important in the decades to come, among others for life extension of installations and/-or re-deployment and re-use of installations. Digitalization is however relevant through the complete oil and gas value chain, as it can provide improved efficiency, better understanding of processes and systems, automate and optimize operations and by that contribute to increased volumes, cost savings, emission reductions and improved safety.	• Improved methodology and analytics tools for condition-based, predictive and risk-based maintenance. • Software for maintenance planning that provide better understanding and better control of material condition and degradation mechanisms. • Data management software. • Autonomous and normally not manned operations topside (like subsea).
#25	**Unmanned facilities and subsea tie-backs** The discovery portfolio on the NCS is dominated by relatively small discoveries, and the trend is that the average discovery size is decreasing. Cost-efficient development of small to medium sized fields is therefore important for the future of the NCS.	The dominant solution going forward to realize resources in smaller discoveries is to tie the resources back to existing infrastructure / hubs. Flow assurance and subsea processing technologies can increase possible tie-back distances and therefore unlock new volumes from discoveries which today are considered too far from existing infrastructure and not economical as a stand-alone development. Subsea all-electric is a promising opportunity that in addition to subsea processing and power solutions, also include drilling and wells technologies. Receiving hubs needs to be able to handle comingled production efficiently, which require tools for process simulation and optimization. Unmanned facilities could also be a solution for developing smaller fields, either tied back to hubs or as stand-alone installations. Many of the digitalization technologies described above would be needed in addition to other types of technologies.	• Subsea toolbox: matured subsea technologies to enable configuration of optimal system solutions. • Standardized subsea equipment modules and interfaces. • Standardized subsea sensory interfaces. • Standardized test and qualification requirements. • Extended reach for multiphase transport. • Multiphase pumps. • Subsea separation technologies. • Subsea produced water treatment. • Subsea All-electric e.g. production systems, x-mas trees, blow-out preventers, downhole safety valves, compression systems. • Unmanned production facilities. • Power and communication distribution technology for long-range tie-backs. • Process simulation and optimization w/ automatic control or real-time guidance on process optimization.

ID.	TG4 PRIORITIZED AREA	PROBLEM STATEMENT / CHALLENGE	SUPPORTING TECHNOLOGY & KNOWLEDGE INNOVATIONS [8]
#25 cont.		Common for both is that a range of subsea technologies ("subsea toolbox") should be matured to enable optimal configuration of system solutions (topside and subsea) to fit specific field development needs to realize resources. Standardized subsea templates and interfaces is important to reduce unit cost: • The trend on the NCS is more emphasis on infrastructure-led exploration and discovery sizes are decreasing. Standardization of subsea satellites could (i) decrease costs, and (ii) shorten lead time on new developments which improves competitiveness on lead times and improves value due to earlier production. • Standardization may require operators to accept for instance lower recovery rates as less field-specific adjustments are made; cost/benefit considerations may still favor standardization. • Savings are expected in the engineering and installation phase due to fewer interfaces between SPS and SURF. Procurement cost might also decrease if standardization leads to "less steel".	• Condition based maintenance. • Remote operations. • Automation, autonomous systems and robotics.

5

ENABLERS FOR INNOVATION AND BROAD IMPLEMENTATION



5.1 A NEED FOR TECHNOLOGY LEADERSHIP

The value of new technology and knowledge is realized when it is applied. A study by OG21 showed that technology adoption takes too long time (OG21, 2018).

The study concluded that there is a tendency of over-emphasizing technology risks over the opportunities the technology offers. The tendency is exacerbated by risk-averse decision makers in oil companies and production licenses that add their perceived risks to technology investment decisions. The final decision makers in a production license tend to have a narrow objective of optimizing the value for the license, rather than for a portfolio of production licenses at company or national level.

OG21 believes the combination of risk management tools that fail to consider value creation opportunities, technology risk aversion among decision makers and a lack of portfolio thinking, lead to over-cautious technology decisions unless enterprise culture, leadership, objectives, and incentives drive a different behavior. (OG21, 2018).

Recommendation:
Industry enterprises should have visible "technology champions" at the executive level. Technology responsibility should start at the executive level and be distributed throughout the organization. Executive level technology managers should make sure that technology opportunities are identified and communicated to potential technology providers in a timely fashion.

5.2 AN EFFICIENT INNOVATION SYSTEM WITH PUBLIC STIMULATION OF R&D&I

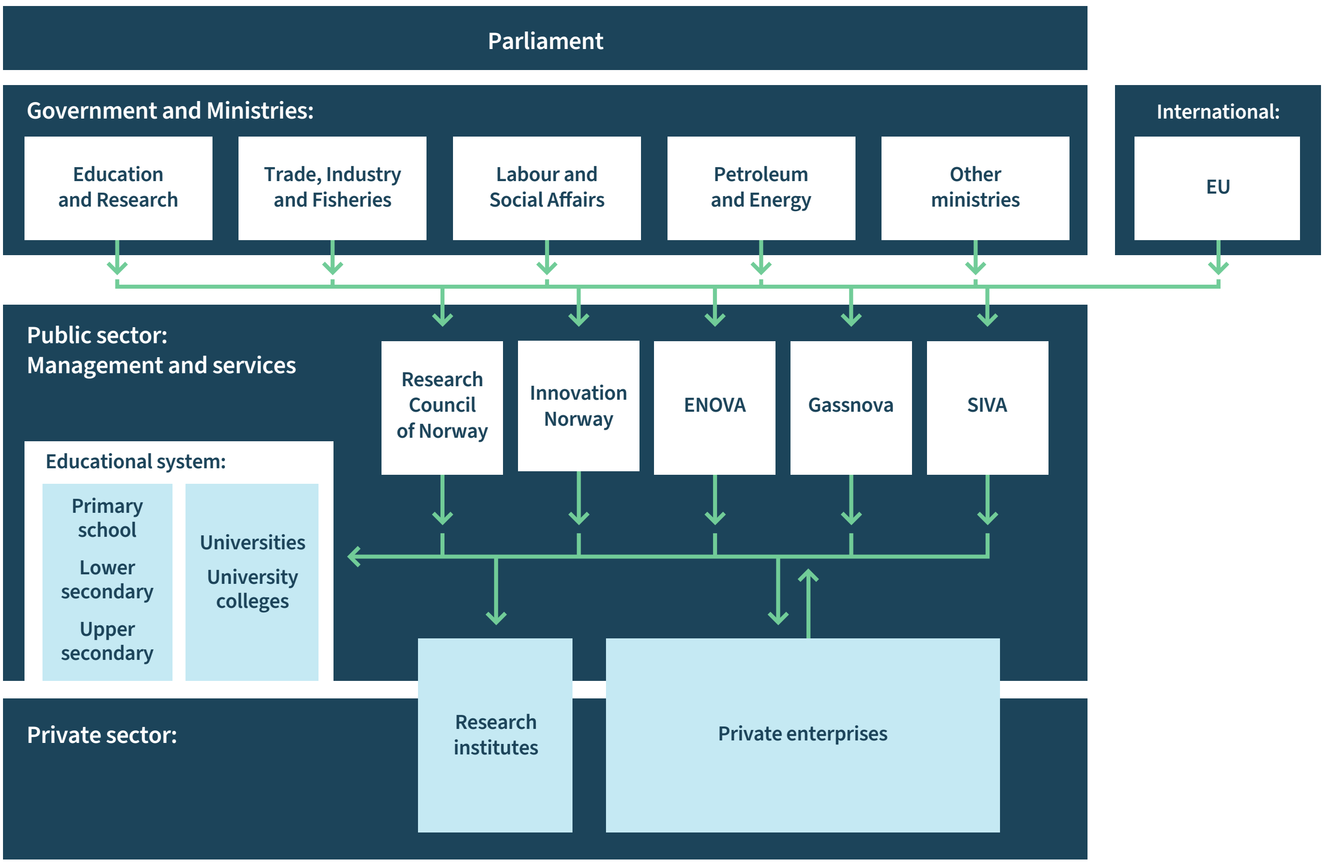
5.2.1 A sectoral approach to innovation in Norway

The innovation system in Norway follows a sectoral principle where individual ministries govern and coordinate R&D&I investments within their responsibilities, see Figure 44. The "21-processes", such as OG21, support this structure by providing guidance on R&D&I priorities within the sector, often based on a bottom-up approach.

The approach has some obvious benefits, e.g. that R&D&I investments target specific challenges within an industry, and that it is easy to obtain alignment between industry, academia and the ministry on objectives and priorities. The approach has proven efficient to produce results with significant impact as a study commissioned by the RCN on effects of petroleum R&D, clearly indicates (Rystad Energy, 2020).

The sectoral principle also has some weaknesses, as alluded to by OECD in a recent report (OECD, 2021): lack of a high-level agenda setting mechanism; weak holistic coordination; and a fragmented policy landscape. OECD proposes that a mission-oriented innovation policy (MOIP) could address the

Figure 44. The R&D and innovation system in Norway (Adapted from Indikatorrapporten, 2018)



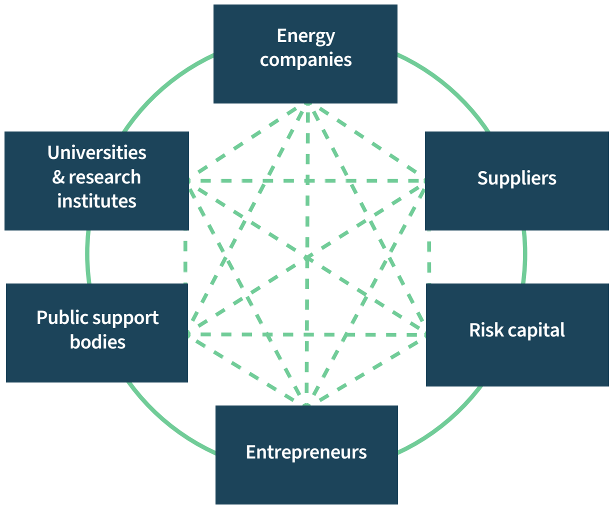
short-comings and be a supplement to the current system and practices.

Recommendation:
OG21 supports the idea of supplementing the well-established and efficient sectoral approach to R&D&I, with cross-sectoral "missions" to guide R&D&I efforts on societal challenges reaching across sectors.

5.2.2 A shared responsibility for R&D&I
The industry, academia and governmental bodies have a shared responsibility for R&D&I. OG21 encourage all R&D stakeholders including industry enterprises, universities, research institutes and public funding bodies, to reflect the OG21 priorities in their R&D&I plans and programs.

OG21 is of the opinion that efficient innovation occurs through collaboration and close connections between many competent stakeholders as depicted in Figure 45. In this picture, public R&D&I bodies play an important role both for bringing stakeholders together and for providing economic risk relief.

Figure 45. Stakeholders necessary for efficient innovation



5.2.3 Governmental R&D&I support instruments relevant for the petroleum sector
Even though the responsibility for R&D&I is shared between private enterprises, academia and the society, governmental R&D&I incentives and funding are important to adjust for externalities and market failures such as:

- New knowledge and technology resulting from R&D becomes available in the market, which makes it more attractive to be an adopter of new solutions rather than the developer.
- Some technologies may offer high rewards, but struggle to attract R&D investments due to high development costs, high economic risks, or too small application scope within single enterprises' project portfolios.
- Some R&D offer high societal rewards, but do not provide sufficient return to private enterprises.
- System critical research could struggle to attract funding from private enterprises within the industry sector.

A recent study on drivers of transformation in the Norwegian oil and gas industry, focusing on climate-related research, confirms several of the R&D challenges listed above. Based on a survey among participants in the OG21 network, it finds that low profitability and long payback times are among the most important hurdles preventing companies from conducting more climate-related research. Other important hurdles mentioned in the study include lack of regulatory requirements and lack of competence (Karlstad, 2021).

Governmental R&D&I funding is also a possible and important counter-cyclical measure. This was demonstrated in 2016 and 2020 when increased R&D funding contributed to offset parts of the R&D investment decline that followed activity reductions in the Norwegian petroleum sector.

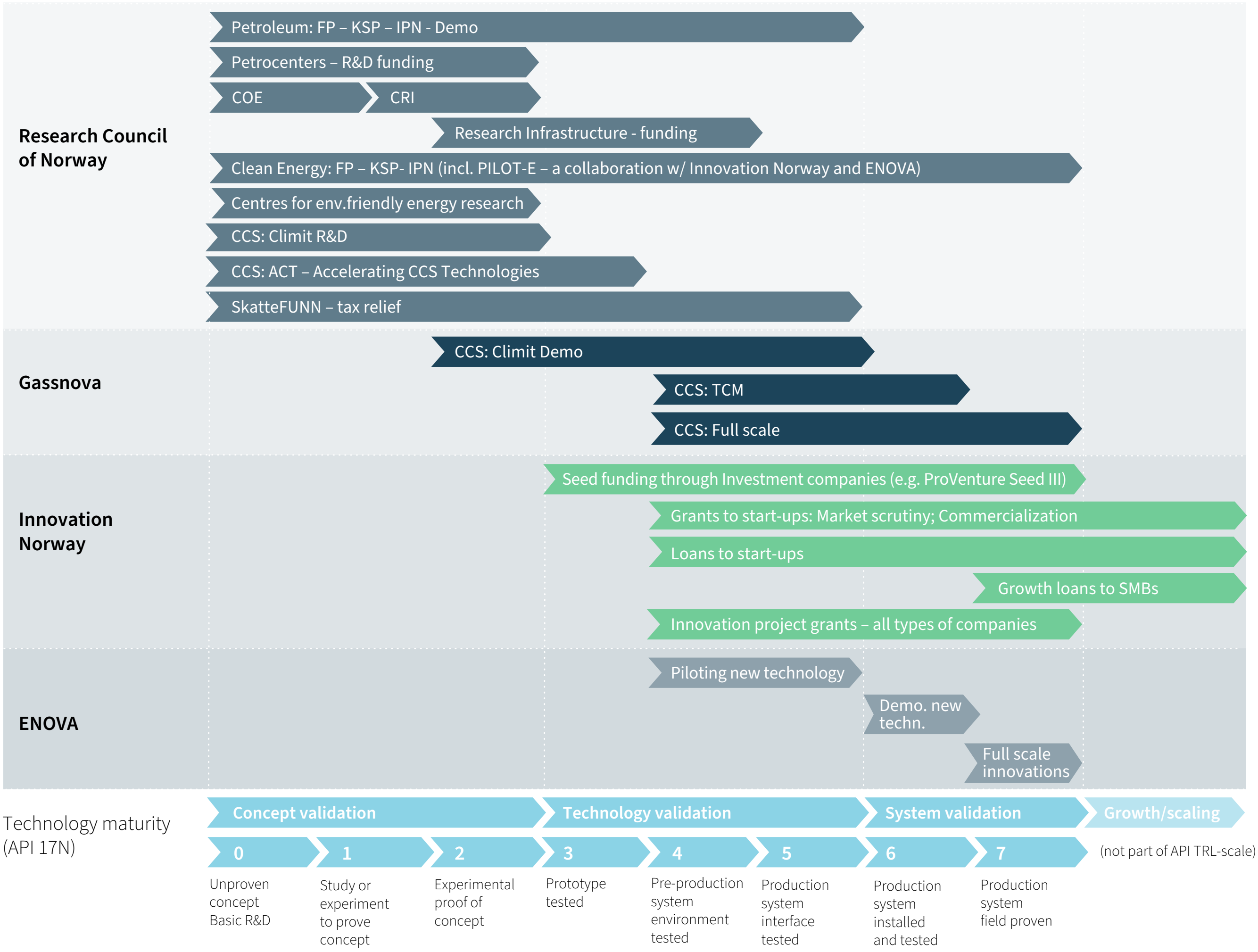
The most important R&D&I instruments managed by governmental R&D&I bodies in Norway, relevant for enterprises and organizations within the petroleum sector, are shown in Figure 46.

OG21 is of the opinion that the Governmental R&D&I financing instruments serve the petroleum industry well, and that they have contributed to creating world leading petroleum clusters. The instruments include:

- The sector specific petroleum R&D program, including FP, KSP, IPN and Demo projects (also known as Petromaks2 and Demo2000).
- Petrocenters, multiple-year funding of research partnerships, which address topics of particular importance for the petroleum industry sector.
- Open R&D arenas where petroleum sector enterprises compete with other industries, e.g. Centers of Excellence, Centers for research based innovations, and Infrastructure.
- SkatteFUNN, an R&D tax deduction program.
- Industry Innovation Norway supported projects, seed funding as well as industry cluster programs.
- ENOVA funding of energy efficiency and climate technology projects

CCS is a key technology for Norway to reduce CO_2-emissions, secure future petroleum markets, and develop new industry. To make CCS attractive, costs need to be reduced and well-functioning value chains need to be established. Climit is an R&D program managed by Gassnova and the Research Council of Norway. It supports technology development within CO_2 capture, transport, injection, and storage.

Figure 46. R&D&I financing instruments relevant for petroleum managed by RCN, Innovation Norway, Gassnova and ENOVA.

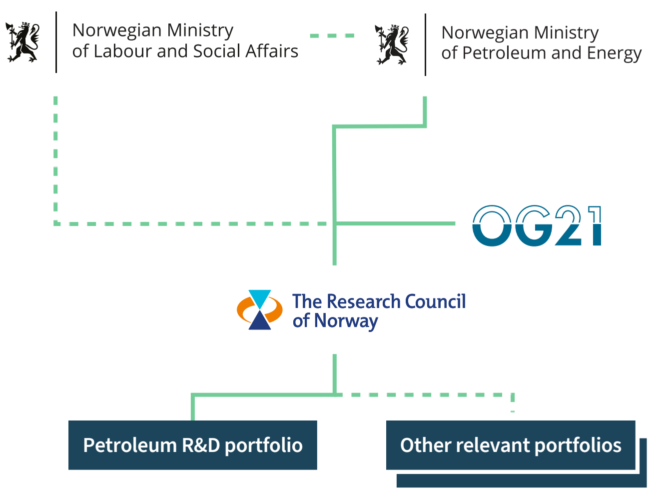


FP: Research project **KSP:** Collaberative and knowledge building project **IPN:** Innovation project for the industrial sector
Demo: Demonstration project for the industrial sector **COE:** Center pf Excellence **CRI:** Center for Research Based Innovation

Gassnova manages the CO_2 capture demonstration project at Technology Center Mongstad (TCM), as well as the full scale "Longship" project with the aim of demonstrating the full CCS value chain from capture to storage.

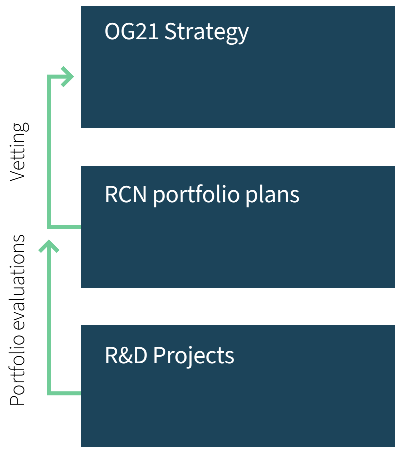
OG21's technology priorities are operationalized, among others, through research projects administered by the RCN, see Figure 47. The OG21 strategy provides recommendations and suggested technology priorities to the Ministry of Petroleum and Energy (MPE), which is then reflected in the annual allocation letter from the MPE to the RCN. In 2021, the OG21 scope was extended to also include safety and working environment, which is the responsibility of the Ministry of Labour and Social Affairs. The petroleum portfolio of research projects is the main vehicle in the RCN for operationalization of the OG21 strategy but depending on the type of technologies and knowledge recommended by OG21, the RCN may choose to implement parts of the strategy also in other relevant project portfolios.

Figure 47. OG21 influences public R&D funding and priorities



The implementation of the OG21 strategy in the RCN project portfolios is monitored through two steps as shown in Figure 48: OG21 reviews relevant portfolio plans, and RCN monitors that the project portfolios reflect the portfolio plans through regular portfolio evaluations.

Figure 48. Implementation of the OG21 strategy through RCN R&D portfolios



OG21 believes that the established R&D structure and organization support the close collaboration philosophy. For instance, the RCN petroleum portfolio board has a broad industry representation, and the project evaluation processes and criteria reflect industry needs. The competition for funding and the project selection process results in high quality R&D projects providing high returns for the Norwegian society (Rystad Energy, 2020).

R&D funding from the RCN is allocated through competition. The traditional and well-recognized approach is to issue calls for proposals with set deadlines, evaluate proposals and allocate funding within the budget available to the projects that receive the highest score on evaluation criteria. This linear approach works well for many types of R&D projects where time to impact is not critical. For other projects where time to impact is a determining factor for competitiveness and/or relevance of the results, e.g. digitalization projects within areas with a high transition pace, other approaches that could speed up the innovation cycle should be evaluated. The identification and evaluation of new approaches could be informed by practices used in the industry as well as approaches evaluated or used earlier in the RCN.

Recommendation:
The RCN should evaluate new and more agile approaches to R&D funding to complement the established approach and identify for what types of projects and calls such new approaches could be applied. New approaches could for instance be open-ended calls (no proposal deadlines) or parallel funding of competing projects/concepts up to a selection gate after which only the better project(s) receive funding.

Recommendation:
To better understand the value of new technologies and how technologies depend on system integration, petroleum research programs should encourage holistic R&D approaches, including system perspectives.

Recommendation:
Collaboration across disciplines such as engineering, physics, and social science spur innovation. OG21 encourages cross-discipline R&D collaboration when relevant.

5.2.4 Significant investments in energy R&D

NIFU biannually collects and publish data on R&D investments in Norway split on sectors and types of enterprises, see Figure 49. Petroleum R&D investments are the largest followed by energy efficiency, renewable energy, and CCS. Petroleum R&D has seen a small decline from 2017 to 2019, whereas R&D investments in the other sectors have increased. (NIFU, 2021).

A much larger portion of the total R&D is funded by the industry in the petroleum sector as compared to the renewable energy sector and the CCS theme. An important driver for the industry to invest in petroleum R&D is the FOT agreement, a mechanism that allows the operating oil companies to charge their partners in production licenses for R&D expenses, given that the R&D is relevant for the NCS, see details in section 5.2.5.

As discussed in Section 3, the future competitiveness of the NCS is dependent upon the ability to reduce GHG emissions from the production, as well as through the value chain for natural gas. In such a context, integration of the petroleum systems with renewables to provide green power to the production, and applying CCS to de-carbonize natural gas, are both highly relevant for the NCS.

5.2.5 Petroleum R&D funding and prioritizations

The Research and Technology arrangement ("FOT-ordningen") is possibly the most important national mechanism for stimulating petroleum R&D. It allows production license operators to charge the production licenses, and thus their license partners, a certain %-age of the licenses' revenue for R&D. The R&D needs to be relevant for the NCS, but there is no requirement of relevance to the specific licenses that are being charged and there is no requirement for disclosure to the license partners of what the R&D funding has been invested in.

NCS operating companies reported nearly 4 billion NOK R&D investments in 2019, see Figure 50. It decreased to 3.4 billion NOK in 2020, probably due to R&D investment cuts resulting from the Covid-19 pandemic. 77% of R&D investments, or 2.6 billion NOK, reported to the RCN in 2020 was charged to the licenses. 23%, or 0.7 billion NOK, was not charged to the licenses, which indicate that some NCS operating companies invest significantly more in R&D than the limits for what the companies can charge their partners. On the other hand,

Figure 49. Energy R&D investments in Norway (NIFU, 2021)

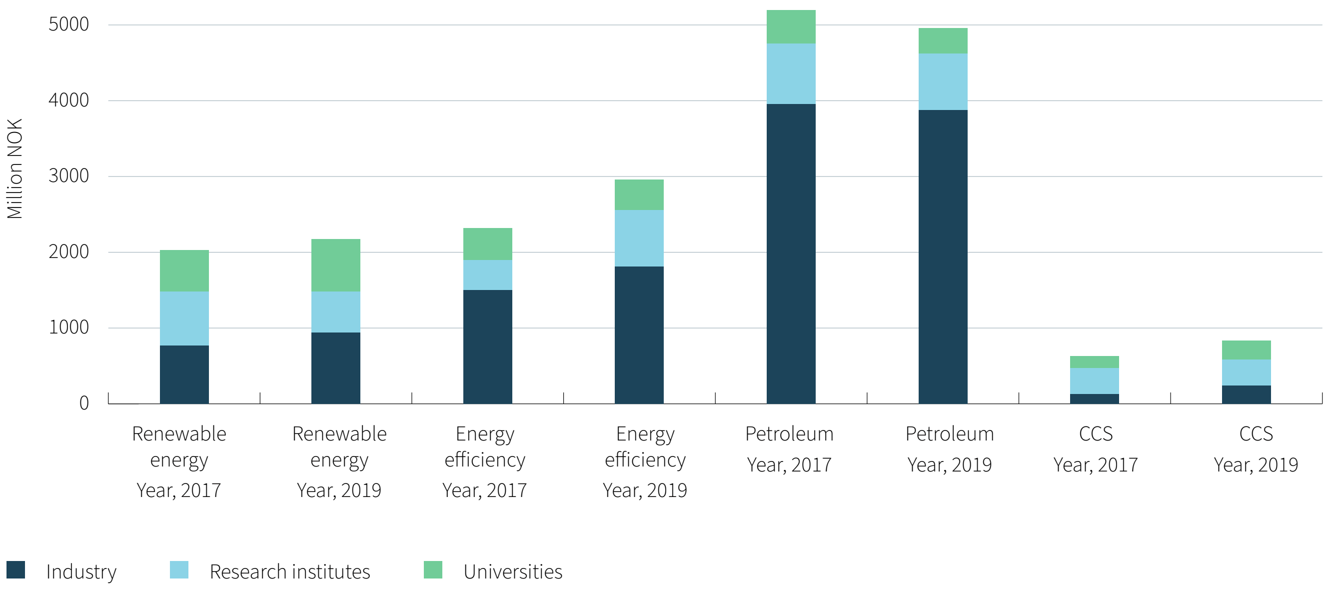
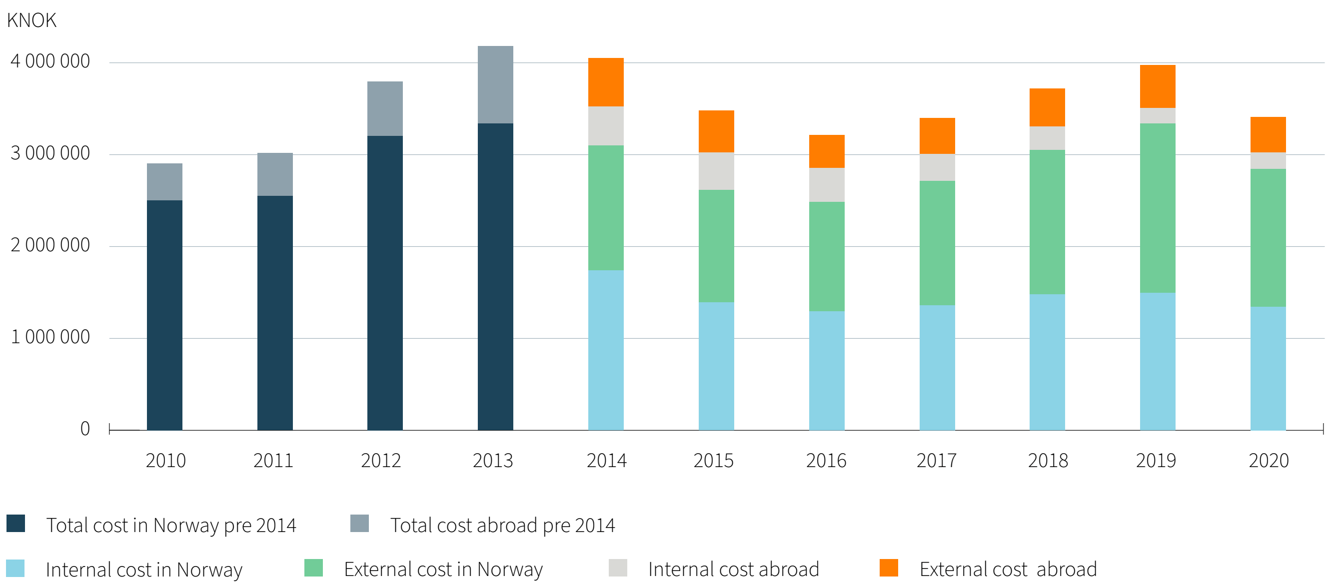


Figure 50. R&D investments through the FOT arrangement (RCN data)



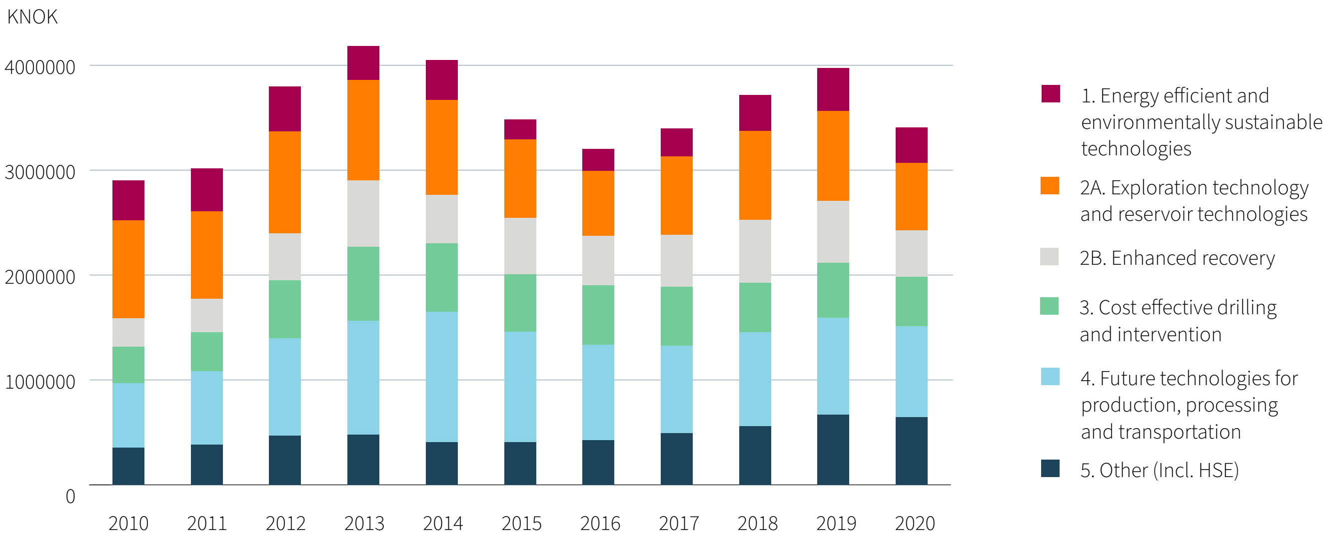
the potential limit for what operators could have charged their partners, aggregated over all licenses, amounts to 3.5 billion NOK in 2020 as compared to the 2.6 billion NOK that was charged. This indicates that some operating companies do not leverage the full R&D potential that the license arrangement offers. The gap could be explained by a lack of organizational capability to initiate, conduct, and follow up R&D projects. It does, nevertheless, represent a lost innovation opportunity for operating companies and the society.

60% of the operating companies R&D investments reported through the FOT-reporting, are done externally in the R&D market.

The external investments in Norway, corresponding to 1.5 billion NOK in 2020, are very important for activities and competence development in research organizations such as research institutes.

The R&D investments are well spread on themes aligned with the scope of the various OG21 technology groups. Subsurface, including exploration, reservoir, and enhanced recovery, is the larger one, but all themes see significant investments.

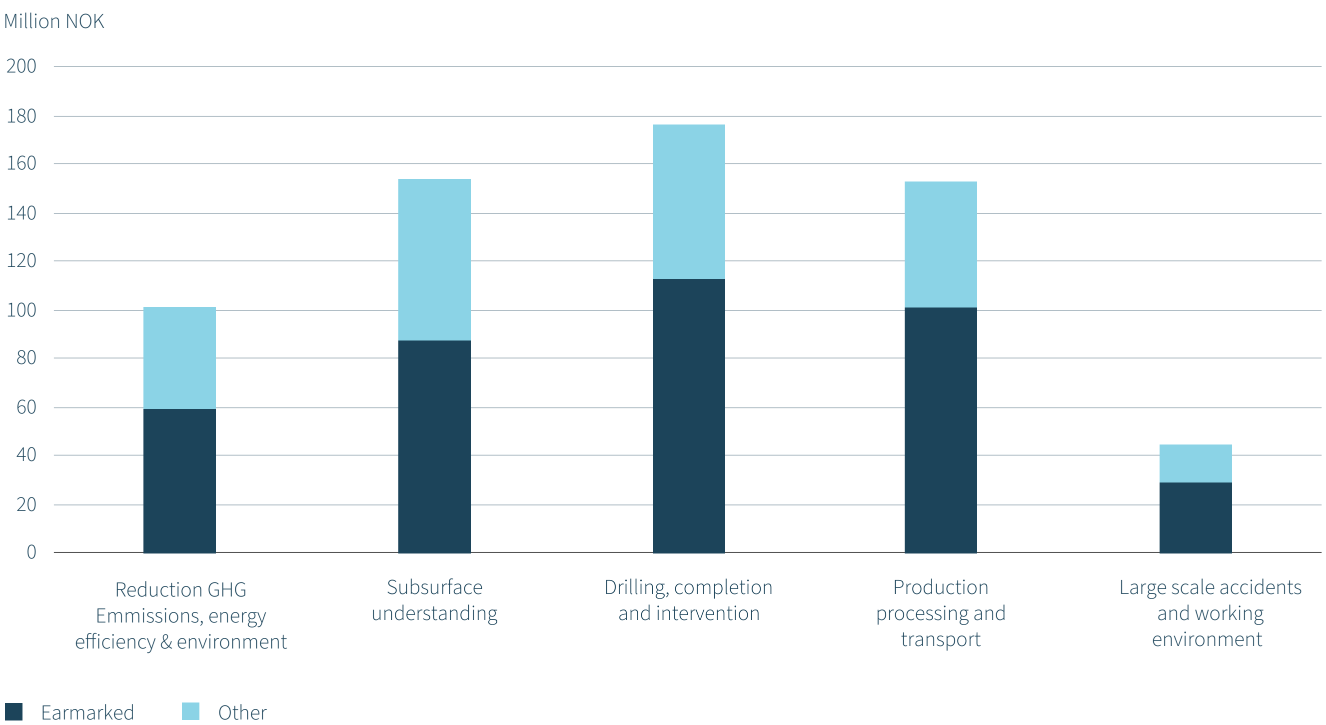
Figure 51. FOT-investments distributed on disciplines (RCN data)



The public R&D investments through the Research Council of Norway (RCN) totaled 630 million NOK in 2020, distributed on disciplines as shown in Figure 52. Investments earmarked for petroleum contributed with 62% of the total. It included investments through petroleum programs such as Petromaks2, Demo2000 and the Petrocenters. "Other" are the open investment programs and schemes where applicants from all sectors compete for funding, e.g. through calls for new research centers and calls for research infrastructure projects. The large portion of "other" shows that petroleum related organizations are relatively successful in the competition for funding through the open arenas, which suggests that they deliver high quality and convincing project applications.

The petroleum R&D funding through the RCN is targeted at suppliers, research institutes and universities. Oil companies are encouraged to participate as research project partners, but they cannot apply for research funding themselves in the petroleum R&D project calls.

Figure 52. Direct public petroleum R&D investments through the RCN in 2020 (RCN data)



Moving forward, public R&D incentives and funding in Norway are as important as ever to adjust for externalities and market failures discussed in Section 5.2.3.

- Reducing GHG emissions will be crucial to attract project investments, maintain society acceptance and curb global warming. Even with increasing CO_2-costs as described in the Government white paper on climate strategies (Meld.St.13 (2020-2021)), technology for reducing GHG emissions offers low economical returns, at least on the enterprise level.
- The NCS is maturing, and the average field size is decreasing. This reduces the financial capability of individual licenses to carry R&D investments.
- Improved oil recovery is important for a maturing NCS, but often such projects are marginal and new IOR/EOR technologies could struggle in the competition for funding internally in oil companies.
- The NCS attracts new types of oil companies, often smaller with a strategy of applying market proven, low risk technologies, and with little appetite for developing and applying new technologies.
- Petroleum from the NCS is competing with supplies from other regions in the world. Staying competitive requires improved productivity and lower cost solutions.
- The global competition for attracting technology clusters is increasing.

A report commissioned by the RCN, shows that petroleum research creates high value for the society, and that research can also contribute to solutions that help Norway achieve its climate commitments. The report estimates that for every NOK the Norwegian society invests in petroleum R&D, it gets a 30-fold payback, (Rystad Energy, 2020).

Public petroleum R&D funding contributes to value creation through development of competence and solutions in academia and research institutes and by stimulating industry R&D and innovation. Figure 53 and Figure 54 illustrate that many more high-quality R&D projects could have been conducted if more public funding had been available. The graphs show the accumulated Petromaks2 and Demo2000 awards split on the project evaluation scores where 7 is the highest. If all high-quality projects (grade 5 or higher) should have received funding, the allocations would have had to almost double for Demo2000 and increase three-fold for Petromaks2.

Recommendation:
OG21 recommends that public funding through Petromaks2 and Demo2000 is increased. Historic data suggest that there is sufficient research capacity and high-quality R&D project ideas to accommodate a significant increase of the annual budgets.

Figure 53. Petromaks2 awards 2016–2020 split on evaluation grade (RCN data)

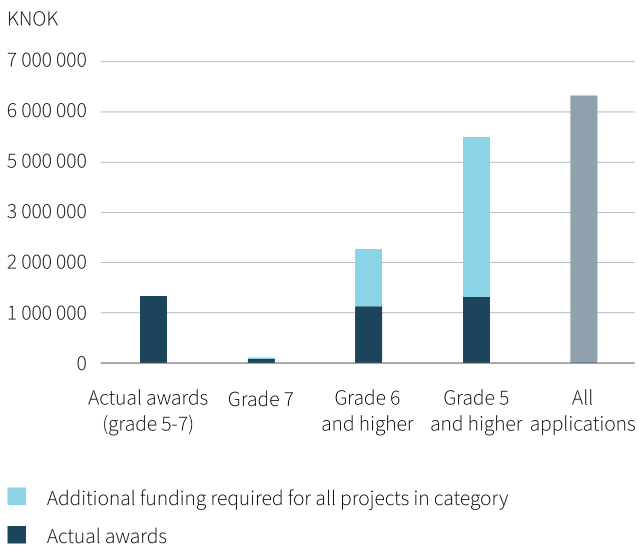


Figure 54. Demo2000 awards 2016–2020 split on evaluation grade (RCN data)

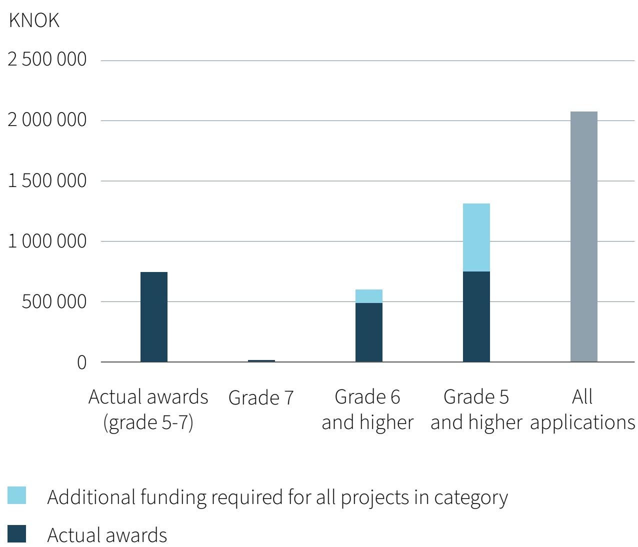


Figure 55. The organization of the Horizon Europe R&I program

5.2.6 Opportunities within the EU research and innovation system

EU will over the years 2021-2027 invest a total of 95 billion € in R&I through the Horizon Europe program. It is organized into three pillars as shown in Figure 55. The "Excellent Science" pillar covers basic research, whereas Pillar II on "Global Challenges and European Industrial Competitiveness" is centered around applied research with the potential for fast adoption of results. "Climate, Energy and Mobility" is one out of 6 clusters organized under Pillar II of the program. Approximately 28% of the pillar's budget, or more than 15 billion €, is allocated to this cluster.

The energy scope of Horizon Europe is aimed at de-carbonizing the energy system to meet EU's target of climate neutrality by year 2050. It includes energy topics such as renewable energy, CCUS and energy systems, power grids and energy storage. Petroleum is not included – nevertheless Horizon Europe provides enterprises and institutions that historically have operated within the petroleum industry and that now want to make the transfer into low-carbon energy industries, opportunities for R&I support.

Successful applicants for EU R&I funding are characterized by:

1. Project proposals that demonstrate R&I excellence and solutions with high impact and job creation in Europe.

2. This must be achieved through strong partnerships that combined can muster the competence and skills to cover the complex challenges of the calls.

3. A strong understanding of EU's R&I objectives, and a convincing demonstration of the partnership's capability of contributing with tangible results and impacts.

There are several R&I priorities specifically mentioned within the cluster "Climate, Energy and Mobility", that align well with the competencies and capabilities of many Norway based enterprises and institutions that historically have worked for the petroleum industry, e.g.:

- Earth system science.

- Global leadership in renewable energy, e.g. geothermal and offshore energy production.

- Energy systems, power grids and energy storage.

- Carbon capture, utilization and storage.

There could also be many opportunities within other clusters, e.g. in Cluster 4, "Digital, industry and space", where for instance advanced materials, AI and other data analytics, and robotics are included.

In addition to Horizon Europe, other EU initiatives where Norway participates, also provide R&I opportunities:

The EU *Important projects of common European interest* (IPCEI) address specific strategic topics such as batteries and hydrogen. Norway is co-funding the hydrogen IPCEI and Enova manages the Norwegian participation. The selection of Norwegian projects for further matchmaking with projects from other countries was done in March 2021. Innovation Norway has the responsibility for coordinating future IPCEIs.

An EU *Clean energy transition partnership* (CETP) is being developed. Norway will be participating through the RCN, and calls are likely to include topics such as CCUS, renewable energy and energy systems.

EU is setting up 10 new *European partnerships* where industry clusters and the EU collaborate for a green and digital transition. Relevant partnerships for Norwegian industry include “Key digital technologies” and “Clean hydrogen”.

The *EU Innovation fund* is funded with revenue from the European Trading System (ETS). It funds the commercial demonstration of new low-carbon technologies such as CCUS, renewable energy and energy storage solutions. Innovation Norway manages the Norwegian participation.

Norway also participates in the the *Digital Europe Programme*. The program will provide strategic funding to projects in five key areas: in supercomputing, artificial intelligence, cyber-security, advanced digital skills, and ensuring a wide use of digital technologies across the economy and society, including through Digital Innovation Hubs.

Further information on the Horizon Europe and other opportunities for Norwegian organizations in the EU R&I system, can be obtained from National Contact Persons in the Research Council of Norway and Innovation Norway:
https://www.forskningsradet.no/eus-rammeprogram/horisont-europa/ncp/

https://www.innovasjonnorge.no/no/tjenester/snakk-med-en-radgiver/eu-finansiering/

5.2.7 International collaboration on R&D

Since petroleum R&D is not part of the Horizon Europe scope, the Norwegian national petroleum research programs as well as research collaboration efforts between Norway and other countries with petroleum production, become particularly important for the petroleum industry.

Norway currently has bilateral agreements on petroleum research, technology development and higher education with among others the USA and Brazil. Further collaboration agreements should be evaluated based on the strategic R&D priorities for the Norwegian petroleum industry described in this OG21 strategy.

5.3 PRIVATE EQUITY INVESTMENTS IN TECHNOLOGY DEVELOPMENT

Enterprises in the petroleum sector in Norway in 2020 attracted 2 790 million NOK in private equity investments (NVCA, 2021). The majority of this, 2 730 million NOK, was invested in enterprises in the “buy-out” phase, a phase relatively late in the technology development when the technology is available in the market. In the earlier “seed” and “venture” phases when the technology is still being developed and little revenue is made, private equity investments are modest. In 2020 seed investments amounted to 20 million NOK whereas venture investments were 40 million NOK, see Figure 56.

Figure 56. Norwegian private equity investments in petroleum for the early development phases of enterprises
(Seed typically TRL4-6, venture typically TRL7 on the API-scale) (NVCA, 2021)

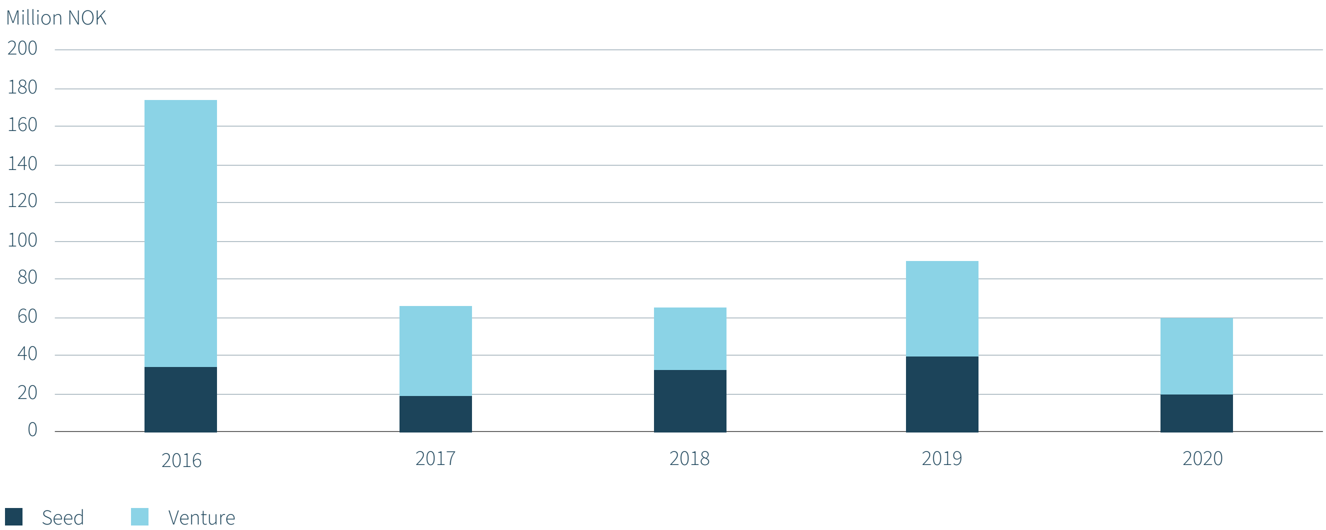


Figure 57. Prioritized technologies mapped into a digitalization value chain model (Rystad Energy, 2021)

	Prerequisite	Enabler: Sensory input	Enabler: Data and systems	Application	Effect
TG1	TG5 Cyber security as an enabler of other digitalization technologies	New digital sensors for environmental surveillance and leak detection Measurement tools for discharges and better control of emissions	Data management systems for environmental risk assessments Analysis tools to improve long term potential discharges from wells and shared management tools for biodiversity.	Faster oil spill detection Faster leak detection Unmanned/people less facilities Visual detection of spills Subsea leak detection Detection of small leaks	People less operations Better control of emissions and content of discharge flows Reducing emissions Improve environmental impact and safety
TG2		New data gathering technologies such as new seismic and CSEM Optimizing data gathering plan what data, when and at what frequency.	Data management, infrastructure and crossdisciplinarity work. Hybrid modelling combining physical models with ML. 3D distribution of porosity, automatic fault interpretation.	Better reservoir models resulting in better subsurface understanding. Improved data flow across departments.	Less errors More efficient operations Better well placement Most recent knowledge utilized
TG3		Technologies for optimizing downhole data gathering and transport. Utilizing real time data when drilling.	Automation and digitalization to improve efficiently. Incorporate data from wells to aid the automation and decision support. Connectivity	Automated drilling operations Better understanding of drilling operations. Improved process understanding of rig operations. Better models and tools	Faster, better and safer drilling operations, resulting in increased volumes and reduced cost and emissions.
TG4		New sensors for detection of vibration, acoustics, sniffers and imagery	New software using artificial intelligence and machine learning algorithms in data modelling to improve uptime, lifetime extensions and secure integrity Digital twin tools	Material condition detection Condition based monitoring on e.g. electrical cables Risk based monitoring, inspection and maintenance Autonomous operations	New software using artificial intelligence and machine learning algorithms in data modelling to improve uptime, lifetime extensions and secure integrity Digital twin tools
TG5		Sensoring of integrity issues or potential hydrocarbon leaks Sensory to perceive impending collisions between vessels and structures Sensory to provide access to remote areas of facilities	Software to improve situational awareness Artificial intelligence to detect integrity breaches before they occur Software for better overview of vessels to prevent collision	Increased situational awareness Continuous and improved leak and integrity detection Increased overview of and routing of offshore vessels	Better crisis management Fewer collisions Less human exposure to leaks or integrity issues

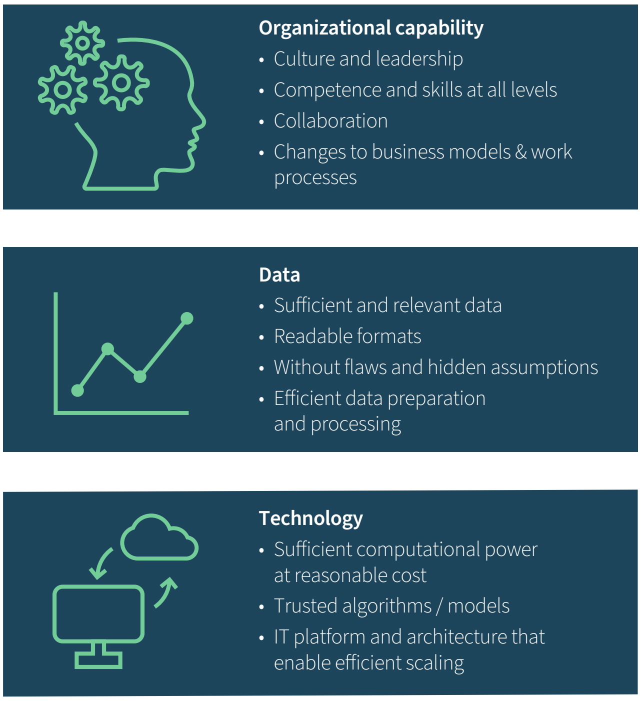
Source: Rystad Energy research and analysis

The seed investments level in petroleum related enterprises in Norway of 20-40 million NOK per year is much less than the public funding through the Research Council of Norway and Innovation Norway. This underpins the importance of RCN and IN in the development of new entrepreneurial enterprises.

5.4 DIGITALIZATION AND EFFICIENT DATA UTILIZATION

Most of the technology areas prioritized by the TGs and discussed in Section 4, include some elements of digitalization. Some examples from the TG priority tables are presented in Figure 57, categorized into a model where cyber security is a prerequisite, data collection and data management systems are considered enablers, and the specific physical or data analytics tools are called applications (Rystad Energy, 2021).

Figure 58. Digitalization success require maturity in organizational capability, data collection and management, and technology (OG21, 2020)



Gathering and processing the right data is often a cumbersome and time-consuming task. Data might not be on the right format, it may be locked into applications, it might not be known to the user because it sits in other departments, or it may need to be manually checked for flaws. High data quality is fundamental for creating trust in data and therefore for realizing full digitalization and autonomous systems. Systems and sensors that can correct for data errors is an important part of providing high quality data, but high-quality data is also dependent upon safe and efficient data transfer. The full data value chain must be considered to build trust, starting from sensors, through data transfer, communication and storage, all the way to and including the use of data in applications.

In an industry where the amounts of data are growing exponentially, it will be important to develop technology, systems and work processes that enable efficient data gathering and processing as well as efficient data sharing between parties.

There are many examples of good collaboration on data gathering and exchange in the petroleum industry. The “Subsea Wireless Group” (SWiG) is an example of an international industry collaboration on data gathering and transfer, where one o the objectives is to promote interoperability for subsea wireless communications.

Another example is “DISKOS”, an industry database for the NCS with seismic data, well data and production data. “Digitalt grunnfjell” is a third example where information on drill cuttings from 1500 NCS wells is digitized and made available for analyses.

With the many collaboration initiatives going on and the considerable opportunity for more collaboration going forward, the oil companies on the NCS have come together in a digital collaboration initiative, managed by the Norwegian oil and gas association, with the purpose of coordinating such initiatives to the best for the whole industry.

Recommendation:
The industry should collaborate on developing procedures and standards that enable data interoperability and efficient data sharing.

5.5 THE IMPORTANCE OF COLLABORATION

The petroleum industry in Norway must be prepared for tightened competition in the future, where the producers with low costs and low CO_2-emissions are likely to be the winners. OG21 believes more collaboration between players in the Norwegian petroleum industry will be essential to succeed.

We have a long tradition for collaboration on petroleum R&D in Norway. The industry organizes its own Joint Industry Projects, and many of the projects that get public funding are required to engage co-funding partners in the industry. This practice has several advantages: It secures dissemination of knowledge in the industry cluster; it makes the R&D in the research organizations relevant for the industry, which is motivating for the researchers; and it provides the industry access to state-of-the-art research.

The average field size on the NCS is decreasing and the average production license has less economic incentive and time window for technology development than some of the large discoveries developed earlier. Many licenses do however share the same challenges which new technology could solve. It is therefore imperative that the industry succeeds in viewing technology implementation at scale and across portfolios of projects.

Recommendation:
The larger oil companies need to have a portfolio rather than a project approach to new technology, Petoro should advocate for technology collaboration across the wide range of licenses they are involved in, and the NPD and the PSA should leverage their influence on technology development and adoption in licenses.

5.6 COMPETENCE – ATTRACTING TALENT COULD BECOME A CHALLENGE

The application statistics to higher education in Norway show that M.Sc.-studies are popular and that they even experience an increased interest in 2021 from the year before (KD – Samordna opptak, 2021). Oil companies, oil service companies and other suppliers to the petroleum industry recruit from a broad range of technology studies, and the recruitment basis appears solid provided that the jobs offered are attractive. The statistics do however also show that the petroleum specific studies are becoming less popular: To the petroleum M.Sc. study at NTNU with a capacity to enroll 20 students, only 26 people applied for the study as their first choice in 2021. An even lower interest was shown for the petroleum M.Sc. studies at the UiS where 21 people had the study as their first choice as compared to a maximum enrollment capacity of 20.

Whether the low interest in petroleum specific studies reflect a reduced support for the petroleum industry among young people, is uncertain. A poll in December 2019, conducted for Klassekampen, revealed that 49% of the people interviewed supported the opening of new areas, whereas 28% were against. 23% had not decided. Among the 18-22 year age group, 58% supported the opening up of new areas. A study from Cicero (2019) suggests that 30% of Norway's population wants to reduce the oil production, whereas 40% are against reducing the production. The low application numbers to petroleum studies could therefore have other explanations, e.g. a perception of insecure jobs after several hiring and firing cycles over the last two decades.

Some universities find innovative ways to attract people to petroleum studies. The BRU21 initiative at the NTNU is a telling example of how new approaches can boost the interest in petroleum relevant studies (see textbox).

The BRU21 case example from NTNU illustrates a general observation related to Ph.D. studies in technology disciplines. In 2020, 64% of technology Ph.D students in Norway were non-Norwegians (RCN, 2021). This provides unique opportunities for establishing international networks and for cultural exchange and awareness. The risk is that highly skilled people leave Norway to return to their home country or other countries. Numbers from NIFU (2013) suggest that around 50% of foreign Ph.D. students remain in Norway after finalized studies. Foreigners with a technology Ph.D. from a Norwegian university are less inclined to leave Norway after finalized Ph.D. studies as compared to the average for all disciplines (37% as compared to 50%) (NIFU, 2013).

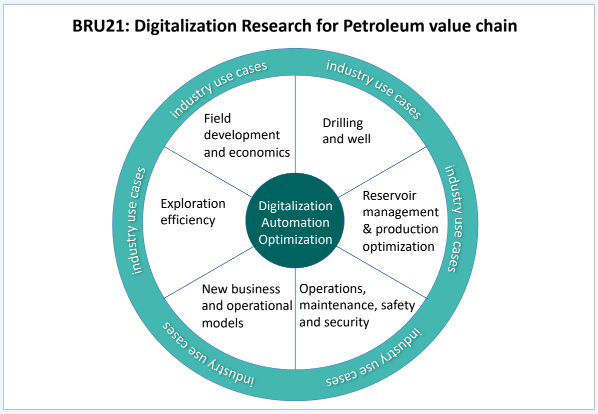
The petroleum R&D project portfolio at the RCN is very important for educating people to high competence positions in academia and the industry. Combined the Petromaks2 projects and the Petrocenters have had around 80 full-time Ph.D positions annually over the last three years, engaging more than 100 people annually with Ph.D. studies.

The workforce in the Norwegian petroleum industry is aging as Figure 59 on next page shows. Around 30% are expected to retire over the next decade. With the "great crew change" looming in the petroleum industry, it is important that the industry can offer stable, meaningful, and attractive jobs to young talents. If not, lack of competence and skills could become a bottleneck in the further development of the NCS in the years to come.

The digital transformation that the Norwegian petroleum industry is going through, requires new competencies and skills within areas such as artificial intelligence, robotics, cyber security, and more. The availability of people with such skills could become scarce, e.g. a study by Mark (2019) indicated a potential undersupply of 4100 cyber security experts in Norway by 2030.

THE BRU21 INITIATIVE

The BRU21 initiative on the NTNU currently engage 30 Ph.D. students and 3 post-docs, of which 10 Norwegians and 23 foreigners from 17 countries. The initiative has been successful in attracting talent partly because it recruits already experienced people from the industry that want a career boost, partly because it recruits from a diverse set of academic backgrounds, and partly because it offers projects that combine digital and domain disciplines. Another success from the initiative is the close collaboration with the industry, where the students are engaged to solve concrete challenges (use cases). This is motivational for the students and it provides real value in return for the funding that the industry partners provide.



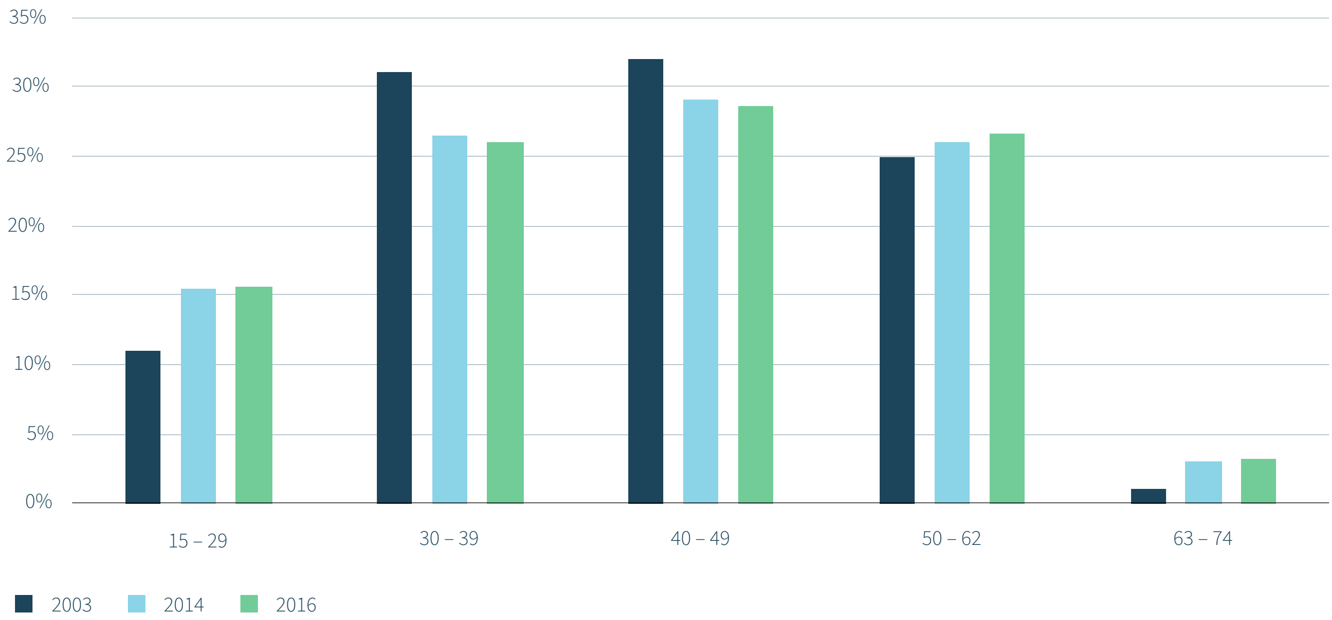
BRU21 program focuses on value creation in 6 areas of petroleum value chain. It conducts research and educates future specialists in the overlap of petroleum and digital domains, which include automation, big data, artificial intelligence, machine learning, digital twins, autonomy and robotics, cyber security, organization, optimization and other areas.

"We regard BRU21 as an innovative and exciting model for collaboration between the industry and NTNU.

We participate in educating the next generation of petroleum technologists with digitalization «under their skin» on top of addressing critical challenges for the future. Digitalization is a necessary enabler inherent in most future value creation. Our fields of interest range from sub-surface technology to risk-based maintenance, remote operations, future operation models and cyber security. Through our participation in BRU21 we contribute to competence development and innovation and thus high value creation in the future."

Tor Ulleberg
Equinor, Senior Advisor Innovation and Collaboration

Figure 59. Age distribution of workforce in oil companies, pipe transport, oil service, petroleum onshore bases and yards. Year 2003, 2014 and 2016. (SSB, 2017)



Going forward, we could therefore expect a competition for professionals with computer science backgrounds. To secure sufficient competence, the industry not only needs to become more attractive to young professionals, it also needs to educate its existing workforce in digital technologies. Some universities have started to offer continued education courses within data science, like for instance the "From data to insight" program at the University in Oslo (see textbox).

Recommendation:
The industry needs to improve its attractiveness to young professionals. They need to be offered exciting and meaningful jobs, and be convinced therough tangible results that the industry takes climate change seriously.

Recommendation:
To harvest the value of digitalization the work force must understand the technology, its opportunities, and its limitations. Such competence development is a life-long endeavor, and the industry therefore needs to educate and train its employees to master and adopt new digital technologies. Industry enterprises should as part of this look for ways to collaborate with universities to develop their staff.

FROM DATA TO INSIGHT

"From data to insight" is an educational program offered by the University of Oslo to professionals working in various industries. It provides the students with relevant state-of-the-art knowledge within data science, machine learning and computation. The program provides a broad introduction, with some deep dives, of the process from data collection and representation, to knowledge extraction and the use of new technologies based on data.

6

INTEGRATED ENERGY SYSTEMS AND NEW INDUSTRIAL OPPORTUNITIES

6.1 THE NORWEGIAN PETROLEUM INDUSTRY PARTICIPATES IN THE ENERGY TRANSITION

The Norwegian petroleum industry's contributions to the energy transition and a zero-emission society include three elements:

- De-carbonatization of the petroleum production phase as described in Konkraft's roadmap (Konkraft, 2020), (Konkraft, 2021), see Section 3.3.
- De-carbonization of petroleum value chains, which in addition to abating CO_2-emissions, also could contribute to securing the future market for natural gas.
- Participation in and transfer of competence and solutions to emerging low-carbon industries.

The three elements combined will strengthen the competitiveness of the petroleum industry and contribute to offset potential consequences of possibly reduced production and investments in the industry.

6.2 PETROLEUM AND INTEGRATION WITH THE POWER SYSTEM

Electrification is a key measure to meet the petroleum industry's ambition of 50% reduction of GHG emissions by 2030. It will require 11-13 TWh of electrical energy, which is less than the normal surplus energy of the Norwegian energy system today (normal demand is 135 TWh as compared to the current 153 TWh capacity). Other new energy-intensive industries such as battery factories and green hydrogen production, as well as a continued electrification of the transport sector, will however also create a higher energy demand, and by 2030 the total demand could reach 170-190 TWh. (NHO/LO, 2021).

The increased demand for energy will not only require investments in new production capacity, it will also create the need for de-bottlenecking and investments in the electricity grid system.

OG21 fully supports the call from NHO and LO in their "Common energy and industry political platform" on an energy policy that stimulates ambitious industry development, and a holistic electrification strategy that combine industrial opportunities, climate goals and improvements in the power system. (NHO/LO, 2021)

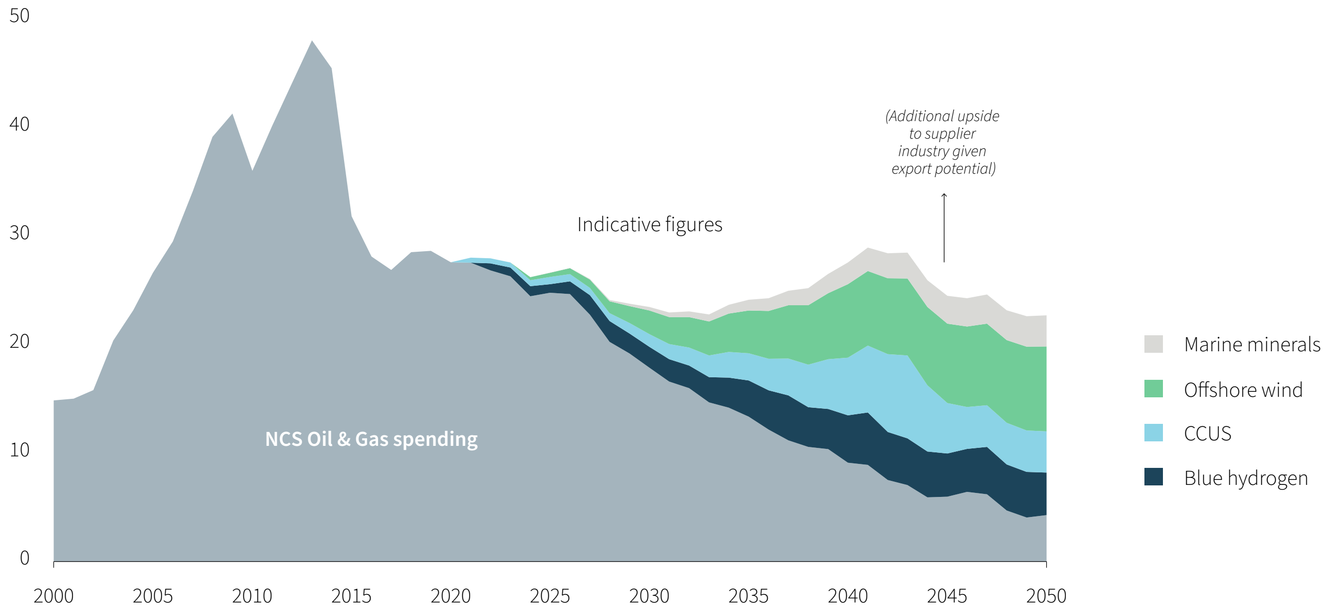
The Governmental White Paper on the Norwegian energy resources (Meld.St.36 (2021-2021)) includes such a holistic electrification strategy. It addresses among others the need for power from shore to electrify offshore installations, and the need for evaluation of the power grid system in the light of the increasing electrification of industries and the society.

Recommendation:

OG21 presents in Section 4.3 of this strategy a number of ideas and measures that should be considered when evaluating electrification of offshore installations:

- *Develop offshore grids that connect offshore facilities and enable power exchange with onshore systems.*
- *Integration with offshore renewables such as offshore wind.*
- *Offshore CCS to de-carbonize operations.*
- *"Gas to-X" technologies, such as hydrogen production and power production combined with CSS.*

Figure 60. Estimates on potential investments (billion USD) in new industries as compared to the expected investment level* on the NCS (Rystad Energy, 2021)



*Includes both capital and operational expenditures, in addition to historical exploration costs and assumed future exploration costs
Source: Rystad Energy research and analysis; Rystad Energy UCube

6.3 PETROLEUM COMPETENCE AND SOLUTIONS – A STEPPINGSTONE FOR NEW INDUSTRIES

Although the Norwegian petroleum industry will remain important for the Norwegian society in the decades to come, its relative importance is likely to decline. The basis estimate of the white paper "Perspektivmeldingen" is that the Norwegian petroleum production will fall by 65% from now and until 2050, and that the production increasingly will be dominated by natural gas. This would result in reduced revenue to the Norwegian society, and also to a loss of jobs. In the basis estimate with an oil price of 50 USD/bbl in 2030, the number of direct and indirect employees in the petroleum sector will decline from 190 000 in 2019 to 140 000 in 2030, whereas in the less likely low oil price scenario (30 USD/bbl in 2030) the number of jobs declines to 70 000 in 2030. (Meld.St.14 (2020-2021).

It is therefore a pressing need to create new industries which can create activity and new jobs. Estimates from Rystad Energy (2021) suggest that none of the new potential industries hydrogen, CCUS, offshore wind and marine minerals, alone could reach the historical activity level of the petroleum industry, but that they combined could offset the likely activity decline and corresponding loss of jobs in the petroleum sector.

Figure 61. Mapping of petroleum industry competencies relevance for a selection of potential new industries (Rystad Energy, 2021).

Norwegian competence				Commodity industry relevance				
Norwegian geographical cluster	Field of industry competence	2019 Norwegian employment *[# employees]*	Examples of relevant players*	Oil and gas	Hydrogen (1)	CSS (2)	Offshore wind (3)	Marine minerals (4)
Eastern Norway	Seismic (TG1)	2 500	TGS, emgs, roxar, allton, PGS, magseis fairfield	●●●	●●●	●●●	○○○	●●●
	Geology (TG2)			●●●	●●●	●●●	●○○	●●●
	Enginering (TG4)	9 500	moss maritime, Dr. techn. Olav Olsen, Global Maritime	●●●	●●●	●●○	●●○	●●○
	Subsea (TG4)	16 500	AkerSolutions, TechnipFMC, subsea 7	●●●	●●●	●●●	●●○	●●○
West coast	Marine operations	9 000	DeepOcean, DOF, Østensjø Rederi, Solstad Offshore	●●●	●●●	●●○	●●●	●●●
	EPC- and shipyards (TG4)	15 000	aibel, VARD, Kværner, Kleven, Ulstein	●●●	●●●	●●○	●●○	●●●
	Drilling (TG3)	10 000	Transocean, Seadrill	●●●	●●●	●●○	○○○	●○○
South coast	Drilling rig- and topside equipment (TG3)	22 000	Schlumberger, ABB, mhwirth, NOV, Wärtsilä	●●●	●●●	●●○	●○○	●●○
Country Wide	Automation and digital technologies (All)	26 000	Sekal, Eelume, Cognite, Kongsberg	●●●	●●●	●○○	●○○	●●●
	Other, incl. maintenance services (TG3)		DNV-GL, Axess, IKM, Jotun	●●●	●●●	●●●	●●●	●●●

Many of the listed oil field service companies perform work within several fields of competence, logos placed based on their main activities
Source: Rystad Energy research and analysis; Brønnøysundregistrene; Statistics Norway; Norwegian Petroleum

○○○ *Relevance degree - from high (3 filled) to low (1 filled)*

Competencies and solutions from the petroleum sector are highly relevant for potential new industries as the mapping in Figure 61 indicates.

The EU, the UK and other countries have ambitions of taking a leading role in one or more of the new, green industries. For Norway to obtain a first mover advantage, it is imperative to move fast. OG21 therefore supports NHO and LO in their calls for urgent action on developing energy policy and strategies that stimulate such ambitious industry development, and relevant support instruments.

7

SUMMARY OF RECOMMENDATIONS

Details on technology and knowledge priorities are provided in Section 4. The 30 priorities can be summarized into **8 prioritized technology areas**:

1. **Improved subsurface understanding** and tools are fundamental for the attractivity and competitiveness of the NCS. The technology area has important ties to all disciplines: it will improve identification of opportunities and exploration for resources; improve well positioning and aid in the completion of wells; improve drainage of reservoirs; reduce water production which is the main contributor to energy use and GHG emissions on the NCS installations; and reduce safety risks associated with drilling. It is also fundamental for efficient carbon capture and storage (CCS).

2. **Cost-efficient drilling and P&A** address two major cost elements of offshore operations. More cost-efficient drilling requires improved methodologies and tools for well construction, more efficient drilling technologies for subsea wells, improved completion solutions, and better subsea well intervention technologies. In addition to reducing costs, such methodologies and tools could also reduce emissions and improve recovery from challenging reservoirs. Plugging and abandonment of wells (P&A) represents a potential high future cost for oil companies and the Norwegian state, and it is a pressing need for development and application of significantly more cost-efficient technologies.

3. **Utilizing existing infrastructure** efficiently will be key to produce remaining reserves in the fields and to realize contingent resources. Contingent resources could be in fields, in the NCS discovery portfolio, and in new near-field discoveries. Existing infrastructure should also be evaluated for re-purposing when approaching end of production, for instance for late-life deposits of CO_2 in relation to CCS. The technology area includes technologies and knowledge for process optimization and integrity management, for instance: improved process simulators, condition monitoring, risk-based maintenance and improved understanding of materials and material degradation mechanisms.

4. **Unmanned facilities and subsea tie-back solutions** include technologies such as flow assurance models to extend the possible tie-back distances, subsea processing technologies, and unmanned production facilities.

5. **Energy efficiency and cost-efficient electrification** are of paramount importance to meet the industry's ambitious GHG emission target of 50% reduction by 2030. Electrification from shore and use of offshore renewables are the most important technologies to reduce operational GHG emissions. There are many costly technical challenges to be solved such as power transfer through FPSO turrets, subsea HVDC converters and long-range AC transmission. Electrification hubs and large grid systems could also reduce costs. Energy efficiency can be improved for instance with technologies to reduce water production, water processing downhole or subsea, combined cycle gas turbines, and the use of low carbon fuels in gas turbines.

6. **Carbon capture and storage (CCS)** is a key technology area to reduce CO_2-emissions. Firstly, CCS provides an opportunity to de-carbonize natural gas either onshore or offshore (gas-to-X where X could be either blue hydrogen or electrical power). Secondly, an opportunity to apply CCS directly to offshore gas turbines to reduce operational emissions, should be explored. In addition, CCS represents an industrial opportunity for broad multi-industry application.

7. **World leading HSE and environmental** performance is a fundamental value for the industry and a pre-requisite for society acceptance. It includes improved knowledge to understand and mitigate risks related to adoption of new technologies and new business models, better tools for understanding major accident risks and uncertainties, improved management of cyber security risks, and the continual effort to understand and reduce working environment risks.

8. **Digitalization** spans across all disciplines. The technology area is fundamental for improved and faster decision processes, which will reduce costs, increase the resource base, reduce GHG emissions and improve safety. The development and application of new tools and solutions such as artificial intelligence, robotics and drones, and digital twins, are key to achieve a digital transformation of the industry. To get there, there is a need for acquiring and processing data more efficiently, a need for more collaboration on data access, data formats and data quality, and a need to change work processes and business models to fully utilize the potential of new technology.

Section 5 provides several **policy and leadership** recommendations as summarized below:

- Industry enterprises should have visible **"technology champions" at the executive level**. Technology responsibility should start at the executive level and be distributed throughout the organization. Executive level technology managers should make sure that technology opportunities are identified and communicated to potential technology providers in a timely fashion.

- OG21 supports the idea of supplementing the well-established and efficient sectoral approach to R&D&I, with **cross-sectoral "missions"** to guide R&D&I efforts on societal challenges reaching across sectors.

- The RCN should evaluate new and **more agile approaches to R&D funding to complement the current system** and identify for what types of projects and calls such approaches could be applied. New approaches could for instance include open-ended calls (no proposal deadlines), and parallel funding of competing projects/concepts up to a selection gate after which only the better project(s) receive funding.

- To better understand the value of new technologies and how technologies depend on system integration, petroleum research programs should encourage **holistic R&D approaches**, including system perspectives.

- Collaboration across disciplines such as science, technology, engineering, mathematics, and social science spur innovation OG21 encourages **cross-discipline R&D collaboration** when relevant.

- **Public funding through Petromaks2 and Demo2000 should be increased**. Historic data suggest that there is sufficient research capacity and high-quality R&D project ideas to accommodate a significant increase of the annual budgets.

- The industry should collaborate on developing **procedures and standards that enable data interoperability and efficient data sharing**.

- The larger oil companies need to have a **portfolio rather than a project approach** to new technology. Petoro should advocate for technology collaboration across the wide range of licenses they are involved in. The NPD and the PSA should leverage their influence on technology development and adoption in licenses.

- To harvest the value of digitalization the work force must understand the technology, its opportunities, and its limitations. Such competence development is a life-long endeavor, and the industry therefore needs to **educate and train its employees to master and adopt new digital technologies**. Industry enterprises should as part of this look for ways to collaborate with universities to develop their staff.

- The industry needs to **improve its attractiveness to young professionals**. They need to be offered exciting and meaningful jobs, and be convinced therough tangible results that the industry takes climate change seriously.

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ABBREVIATIONS

ABEX	Abandonment expenditure
AC	Alternating current
AI	Artificial intelligence
AICD	Autonomous inflow control valve
AUV	Autonomous underwater vehicle
bbl	Barrels
boe/d	Barrels oil equivalent per day
BHA	Bottomhole assembly
BOP	Blowout preventer
CAPEX	Capital expenditure
CCUS	Carbon capture, utilization, and storage
CETP	EU clean energy transition partnership
CO_2	Carbon dioxide
COP	Conference of the parties
CTD	Coiled tubing drilling
DFU	Definerte fare- og ulykkes-situasjoner (defined hazards and accident situations)
EGD	European Green Deal
EIF	Environmental impact factor
EOR	Enhanced oil recovery
EPC	Engineering, procurement and construction
ETS	European trading system
EXPEX	Exploration expenditure
FAR	Fatal Accident Rate
FID	Final investment decision
FOT	Forskning- og teknologi-ordningen
FP	Forskerprosjekt
FPSO	Floating production, storage, and offloading system
GHG	Greenhouse gas
HC	Hydrocarbon
HCRD	HC release database
HSE	Health, safety and environment
HVDC	High voltage direct current
ICE	Internal combustion engine
IEA	International Energy Agency
IPCEI	Important projects of common European Intrest
IMR	Inspection, maintenance and repair
IN	Innovation Norway
IOGP	International organization of oil and gas producers
IOR	Improved oil recovery
IPN	Innovasjonsprosjekt for næringslivet
ICT	Information and communication technology
IT	Information technology
KSP	Kunnskapsprosjekt for næringslivet
LCA	Lifecycle assessment
LNG	Liquified natural gas
LOHC	Liquid organic hydrogen carrier
LTIR	Lost time injury rate
LWD	Logging while drilling
ML	Machine learning
MMbbl/d	Million barrels pr day
MMO	Maintenance, modifications and operations
MODU	Mobile offshore drilling unit
MPD	Managed pressure drilling
MPE	Ministry of petroleum and energy
MWD	Measurement while drilling
NAM	North America
NCS	Norwegian continental shelf
NPD	Norwegian petroleum directorate
NPT	Non-productive time
NPV	Net present value
NZE	Net zero emission scenario
O&G	Oil and gas
OPEX	Operating expenses
OT	Operational technology
P&A	Plugging and abandonment
PDO	Plan for development and operations
PSA	Petroleum safety authority
R&D&I	Research and development and innovation
RCN	Research council of Norway
RNNP	Risk level on the NCS
RRR	Reserves replacement ratio
SWiG	Subsea Wireless Group
SPS	Subsea Production System
TG	Technology group (OG21 has 5 TGs on specific disciplines)
TPED	Total primary energy demand
TRL	Technology readiness level
TTRD	Through tubing rotary drilling
UN	United Nations

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APPENDIX

APPENDIX A – OG21 MANDATE (IN NORWEGIAN ONLY)

Formål med OG21

OG21 skal arbeide for en effektiv, sikker og miljøvennlig verdiskaping fra norske olje- og gassressurser. Dette skal skje gjennom et samordnet engasjement i petroleumsklyngen innenfor utdanning, forskning, utvikling, demonstrasjon og kommersialisering. OG21 skal inspirere til utvikling og bruk av ny og bedre kompetanse og teknologi tilpasset et energisystem i endring og målet om reduserte klimagassutslipp.

Hovedoppgave for styret

OG21-styret skal utarbeide en helhetlig nasjonal teknologistrategi i petroleumssektoren som skal være retningsgivende for næringens og myndighetenes samlede teknologi- og forskningsinnsats.

Strategien skal bidra til:

- Effektiv, sikker og miljøvennlig verdiskaping på norsk sokkel.
- Kompetanse og industri i verdensklasse
- Petroleumsnæringens deltakelse i omstillingen til lavutslippssamfunnet

Gjennom å koble myndigheter, næringsliv og forskningsmiljøer sammen skal strategien gi en forsterket innsats for petroleumsrettet FoU og kunnskapsutvikling.

Strategien skal bidra til å utvikle internasjonalt konkurransedyktig kompetanse og næringsliv innenfor petroleumssektoren.

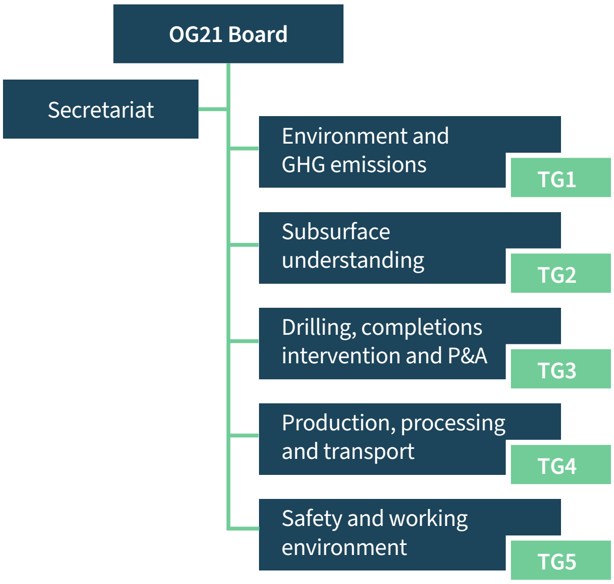
Styrets oppgaver for øvrig:

- beskrive framtidens muligheter og utfordringer for verdiskaping på norsk sokkel i et perspektiv som inkluderer økonomiske, klima- og miljømessige, helse- og sikkerhetsmessige og samfunnsmessige forhold.
- definere prioriterte innsatsområder, etablere arbeidsgrupper på disse områdene og sørge for at arbeidsgruppene spisser og handlingsretter strategien.
- definere hvilke teknologiutfordringer og teknologigap norsk kontinentalsokkel står overfor.
- identifisere virkemidler for å lukke teknologigapene og øke eksportverdien av norsk petroleum og næringens teknologi og kompetanse.
- kartlegge den internasjonale konkurransekraften til norske kunnskaps- og teknologimiljøer, definere teknologi- og kunnskapsområder hvor petroleumsnæringen i Norge bør ha ambisjoner om å være verdensledende og identifisere virkemidler som skal til for å nå ambisjonene.
- samarbeide med tilgrensende og relevante "21-prosesser", f.eks. Energi21 og Maritim21, for å sikre helhetlige vurderinger av: (i) verdikjeder for petroleum (ii) utslipp av CO_2 og andre gasser som påvirker klima (iii) energisystemer hvor petroleumssektoren inngår (iv) tverrfaglige og tverrindustrielle teknologigap og -prioriteringer
- kommunisere og forankre strategien hos relevante aktører og stimulere til samhandling i petroleumsnæringen.
- bidra til operasjonalisering av strategien gjennom samarbeid med utførende organer som Norsk olje og gass, Norsk Industri, Innovasjon Norge, NORWEP og Forskningsrådet.
- gi råd til OED i henhold til OG21-strategien og peke på områder hvor offentlig finansiering er avgjørende.
- jevnlig vurdere framdrift og oppnådde resultater så vel som relevans av strategien.
- identifisere hva som skal til for at Norge blir et attraktivt vertsland for teknologi- og kunnskapsutvikling innenfor områder hvor vi har ambisjoner om å være verdensledende.
- revidere strategien ved behov, typisk hvert 5. år.
- arrangere en årlig konferanse for å formidle OG21-strategien, prioriterte innsatsområder og OG21s anbefalinger (OG21-forum).

APPENDIX B – OG21 PARTICIPANTS

Technology opportunities and challenges have been identified, described and prioritized by technology groups (TGs) within the themes shown below. The TGs have members from oil companies, universities, research institutes, suppliers, regulators and public bodies.

Figure 9. Organization of OG21



An overview of board members and TG members is provided on the OG21 website. None of the board and TG members are compensated economically for their participation in OG21.

As per August 2021, the following individuals participated in OG21:

The OG21 Board:

Elisabeth Kvalheim, *Board leader, Equinor*
Arne Jacobsen, *Norwegian Petroleum Directorate*
Christina Johansen, *TechnipFMC*
Finn Carlsen, *Petroleum Safety Authority*
Lars Sørum, *Sintef*
Merete Madland, *University of Stavanger*
Morten Jensen, *Schlumberger*
Roy Ruså, *Petoro*
Siri Helle Friedemann, *Research Council of Norway*
Tove Lie, *Lundin*
Vibeke Andersson, *Aker Carbon Capture*
Torgeir Knutsen, *Ministry of Petroleum and Energy, observer*

THE TECHNOLOGY GROUPS:

TG1 – Environment and GHG emissions:

Luke Purse, TG-leader, *AkerSolutions (until August 2021)*
Inge Brandsæter, TG-leader *(from August 2021)*
Alfred Hanssen, *University of Tromsø*
Andreas Tomasgaard, *Norwegian Petroleum Directorate*
Axel Kelley, *Lundin*
Christian Collin-Hansen, *Equinor*
Eilen Arctander Vik, *Aquateam*
Eirik Sønneland, *Validé*
Ivar Singsaas, *Sintef*
Jannecke Moe, *Neptune*
Martin Jensen, *Shell*
Ove Sævareid, *NORCE*
Per Omar Melilla, *Kongsberg Maritime*

TG2 – Subsurface understanding:

Ole Eeg, TG-leader, *ConocoPhillips*
Ane Lothe, *Sintef*
Cathrine Ringstad, *Sintef*
Eirik Møgedal, *Axis Well Technology*
Eirik Kaarstad, *BakerHughes*
Gorm Liland, *Halliburton*
Jan Inge Faleide, *University of Oslo*
Jarle Haukås, *Schlumberger*
Laila Pedersen, *DNO*
Lars Jensen, *Norwegian Petroleum Directorate*
Mariann Dalland, *Norwegian Petroleum Directorate*
Peter Eilsø Nielsen, *Equinor*
Pål Haremo, *Neptune*
Rolando Di Primio, *Lundin*
Tim Head, *Vår Energi*
Ying Guo, *NORCE*

TG3 – Drilling, completion, intervention and P&A:

Jan Roger Berg, TG-leader, *Lundin*
Anne Bergsagel, *BakerHughes*
Birgit Vignes, *ConocoPhillips*
Eirik Møgedal, *Axis Well Technology*
Gerhard Våland Sund, *Neptune*
Hans Magnus Bjørneli, *Schlumberger*
Jan Butler Wang, *Norwegian Petroleum Directorate*
Jan Einar Gravdal, *NORCE*
Johan Kverneland, *Total*
Karim Saffaran, *Vår Energi*
Kent Allan Dahle, *Halliburton*
Knut Steinar Bjørkevoll, *Sintef*
Marianne Høie, *Equinor*
Pål Skogerbø, *MHWirth*
Rune Hatleskog, *Shell*
Sigbjørn Sangesland, *NTNU/Bru21*
Stein Tonning, *DNO*
Tore Endresen, *Petroleum Safety Authority*

TG4 – Production, processing and transport:
Kjetil Skaugset, TG-leader, *Equinor*
Anne Minne Torkildsen, *Norwegian Petroleum Directorate*
Anngjerd Pleym, *Siemens*
Bjørn Søgård, *DNV GL*
Carsten Ehrhorn, *Shell*
Charlotte Skourup, *ABB*
Dag Eirik Nordgård, *Sintef*
Eirik Duesten, *Petroleum Safety Authority*
Elin Klemp Schmidt, *Neptune*
Elisabeth Alne Hendriks, *Gassco*
Joar Dalheim, *Vysus Group*
Jose Plasencia, *Baker Hughes*
Kjartan Haug, *Kongsberg Digital*
Kristian J. Sveen, *IFE*
Marie Holstad, *NORCE*
Ole Thomas McClimans, *TechnipFMC*
Stein-Erik Hilmersen, *Lundin*
Trine Boyer, *Total*
Øyvind Hellan, *Sintef*

TG5 – Safety and working environment:
Espen Forsberg Holmstrøm, TG-leader, *Research Council of Norway*
Berit Sørset, *Norsk Industri*
Frank Børre Pedersen, *DNV*
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Many stakeholders of OG21 have also participated in workshops and documents reviews during the development of this OG21 strategy, including representation from:

- The Norwegian oil and gas association.
- Norsk Industri.
- Gassnova.
- Innovation Norway.
- The Low-emission center at Sintef.
- The Research Council of Norway.
- Enova.
- Energi 21.
- Maritim 21.
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