BRU21

Better Resource Utilization in the 21st century

NTNU Strategy for Oil and Gas

What are the major challenges for the O&G industry on the Norwegian Continental Shelf in the future and the contribution from academia for solutions

NTNU
Norwegian University of Science and Technology

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Photo front page: With the courtesy of SIEMENS

1.0

Introduction by NTNU's Rector

Gunnar Bovim

The oil and gas activities on the Norwegian Continental Shelf are a very important part of the Norwegian economy. Excellence in building long-term competence, research and development has been central in this process and will continue to be so in the future.

The activities in the petroleum industry demand the best skills that are available in order to solve future challenges. This is so across the entire value chain from exploration, field development, production and exploitation to the final stage of decommissioning.

One of the goals of NTNU is to contribute to national value creation on the Norwegian Continental Shelf and to the internationalization of the Norwegian petroleum industry. In order to achieve this goal, NTNU will deliver long-term educational expertise as well as leading-edge technical and scientific R&D solutions.

In the years ahead NTNU will contribute to develop the Norwegian Continental Shelf with environmental care and a minimum CO_2 footprint with low carbon technologies. The recent Paris agreement forecasted the need for oil and gas in the global energy mix as part of the 2-degree solution for many years ahead.

The BRU21 Project facilitates multidisciplinary solutions to important problems in the petroleum sector by using technologies like Big Data, information and communication technologies (ICT), and cybernetics and artificial intelligence (AI).

In addition, the BRU21 conferences are important arenas for the discussion of strategic issues and the technologies of the future with the petroleum industry. These meetings are part of the vital network between scientists at NTNU and representatives from oil companies, service companies, organizations and the authorities.

As the Rector of NTNU, I am positive to offer my full support to the activities and processes in the BRU21 Project.

Norwegian University of Science and Technology

NTNU Knowledge for a better world

Vision

NTNU is to use its science and technology capacity to enhance the O&G sector by "better resource utilization" (BRU) and contribute to find solutions for greenhouse gas reductions with a zero emission vision.

Objectives

The BRU21 objective is to address "technologies of the future" for the petroleum sector including safety aspects and a minimal CO_2 footprint.

NTNU will identify technologies and solutions to assure future petroleum activities at low oil prices (break-even price of 30 USD/bbl) and develop petroleum assets in the future with the highest safety standards that are environmentally friendly.

BRU21 "Better Resource Utilization" stands for improved economic efficiency by increased income (resource recovery/production) and reduced costs relevant for both existing O&G fields in mature areas ("brown fields") and new petroleum fields in old and new areas ("green fields").

NTNU has also adopted the OG21 objectives from its recent strategy report:

- Maximize resource utilization
- Minimize environmental impact
- Improve productivity and reduce costs
- Develop innovative technologies
- Attract, develop and retain the best talents

3.0

Fact-findings meetings

In order to update the NTNU's strategy for research and education and listen to advice from the industry and the authorotiies, the BRU21 team organized a fact-finding meeting program during 2016. NTNU visited oil companies, service companies, OG21, NOROG, PTIL, NPD and MPE to roundtable meetings at their premises.

The objective was to address "technologies of the future" for the petroleum sector including safety aspects and minimal CO_2 footprint. The discussion points for the meetings were:

- Major challenges for the O&G industry on the Norwegian Continental Shelf in the future
- Break-through technologies and solutions in order to build future petroleum fields safely and environmentally friendly at a break-even oil price at 30 USD/bbl
- NTNU's contribution to deliver education, future technologies and solutions for the O&G sector

Table 3.1: Fact-finding meetings

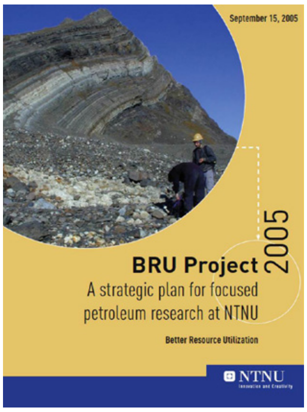
Oil Companies	Service Companies	Organizations/ Authorities
Statoil	GE	OG21
DetNorske (AkerBP)	FMC	NOROG
Petoro	Kværner	OD/NPD
TOTAL	CGG	PTIL
Lundin	DNV-GL	OED/MPE
ConocoPhillips	Technip	
Shell	IKM	
ExxonMobil	Halliburton	
Centrica	Schlumberger	
BP (AkerBP)	Teekay	
ENI	Odfjell Drilling	
Maersk Oil	Siemens	
VNG	Reinertsen	
ENGIE	Aker Solutions	
Hess	BakerHughes	
Wintershall		
DEA Group		
Repsol		
OMV		
OKEA		
Petrobras		

The team organized 41 meetings during 2016. The program of visits was most valuable. NTNU had very positive, constructive and creative dialogs with the petroleum cluster. The initiative of holding the meetings during a period of low oil prices and transition in the industry was welcomed. NTNU experienced strong support for the objective and organizing roundtable meetings to discuss joint challenges and future solutions for the petroleum sector to handle low oil prices in the future and a mature continental shelf. The topics are important for the oil industry, the academic community and society at large. Table 3.1 gives an overview of the meetings.

In addition to these companies and organizations during 2016 we contacted several other companies for later follow up.

NTNU carried out a similar process with fact-finding meetings and strategy discussions in 2005 and published the results in "BRU2005", a report that outlined the R&D focus on major areas. The BRU2005 report is a comprehensive review of key technologies that are still quite relevant. The report concluded with four focus areas:

- BRU Program 1: Finding and producing
- BRU Program 2: Drilling and subsea technology
- BRU Program 3: eField and integrated operations
- BRU Program 4: Arctic technology



The most direct result of BRU2005 was the establishment of the "Center of Integrated Operations for the Petroleum Industry" (IO Center) which qualified as a Center of Research-based Innovation (SFI) with funding from the Research Council of Norway and industry. The IO Center was based on cooperation between 14 oil companies and service companies, SINTEF, IFE and NTNU, with NTNU as host from 2006 to 2015. SINTEF and NTNU were the drivers to establish the DrillWell Center in 2010 with IRIS in Stavanger as host. The two other areas resulted in similar R&D activities and centers at NTNU.

BRU21 is an updated strategy review adjusted to the business challenges with the recent low oil prices combined with a significant transition from a relatively high investment level in recent years of about NOK 220-240 billion/year to about NOK 150 billion/year for the future. This transition from a high level to a lower sustainable level is an additional challenge for industry and society.

Industrial fact-finding meetings

During the BRU21 process we have received a comprehensive review of technologies and future solutions. We have discussed core petroleum technologies in the value chain: exploration, drilling, reservoir, production, improved recovery and decommissioning and plugging and abandonment. We have further discussed cross-over technologies between disciplines and between industries, and environmental issues and new business models.

Based on the discussions in the fact-finding meetings and the priorities in the OG21 strategy, BRU21 has laid out a technology road map to focus on the following multidisciplinary business segments:

- **BRU21 Program 1:** Digitalization in O&G industry
- **BRU21 Program 2:** Technology challenges in the Barents Sea
- **BRU21 Program 3:** Field development and area strategies
- **BRU21 Program 4:** Environmental friendly O&G production
- **BRU21 Program 5:** New business models for oil companies and suppliers
- **BRU21 Program 6:** Late life challenges and decommissioning

In addition to these six program areas the BRU21 process has also included two other general topics from the meetings:

- **BRU21 Activity 1:** Advice for petroleum education in the future
- **BRU21 Activity 2:** Niche R&D topics identified in the fact-finding meetings not covered by the 6 Program Areas. These areas will be processed internally as follow up

Companies & Institutions Visited by NTNU – 2016

The motivation for the six selected areas

BRU21 PROGRAM 1
Digitalization in O&G

The importance of this topic was clear feedback from most of the fact-finding meetings. Both society and industry are in a technology transition and technology revolution related to the implementation of digital solutions including automation, robotics, artificial intelligence, machine learning, use of big-data for decision support and automatic independent decisions. The O&G industry still needs to catch up with this development and exploit the opportunities evolving in other industries. We strongly believe that "digital and automation solution" will be a significant contributor to the O&G industry-related management of risk, margins, safety and environmental footprints. Implementation of digital solutions will enhance safety and reduce environmental impact at the same time that the economic efficiency and risk management will improve.

BRU21 PROGRAM 2
Technology challenges in the Barents Sea

The opportunities in the northern areas and the Barents Sea have changed in recent years. A major change came with the agreement between Norway and Russia about the delineation in 2011. The new added area for exploration is looked upon with great interest and with increased petroleum resource opportunities. Further we have experienced very promising exploration results in recent years. The NPD Resource Report 2016 gives an excellent status of the expected resource potential in the Barents Sea. The Barents Sea had the largest increase in estimated resources in the last report in 2016. With the new update by April 2017 doubling the resources in the Barents Sea, the Barent Seas now represent 65 % the total undiscovered resources on the NCS. There are in addition several technology challenges in exploration, drilling and production in the Barents Sea that were highlighted during our fact-finding meetings.

BRU21 PROGRAM 3
Field development and area strategies

Smart and robust field planning and development is essential to ensure the profitability and success of future fields under low price scenarios and challenging environments. From our fact-finding meetings it is clear that the industry is currently facing multiple challenges that might hinder the exploitation of prospective resources in the NCS. We believe that a combination of key technical and human elements will help progress towards the widespread development of lean production systems. Some keywords are: to assimilate and develop relevant technology in all E&P disciplines, improve current field planning methodologies using digitalization and implement common goals and strategies for regional areas. In addition, current and future generations of engineers working in this area must exercise and embrace multidisciplinary thinking.

BRU21 PROGRAM 4
Environmental friendly O&G production

There is a clear understanding in the industry and academic life that we need to reduce the CO_2 footprint in the O&G business and preserve the biological diversity in the areas the business operates in. Reduction of climate gases is an international goal and we have to find radical solutions in the value chain from production of hydrocarbons to the market place. The O&G industries have the strategy to contribute to the new "green economy" and use their considerable technology capabilities to do this. This program highlights environmental friendly O&G production.

BRU21 PROGRAM 5
New business models for oil companies and suppliers

Future success for the Norwegian oil and gas industry will depend on the ability to follow two tracks. The first is to work with continuous improvement in the different fields of exploration and production. The second track is the route to improving business models or developing new business models. An important contribution to improving existing business is to be able to redefine the relations between oil companies and suppliers, by fostering new alliances and developing new contract strategies. New business models imply either searching for ways to utilize existing technologies and competencies, or to take part in the growth of innovative, digitalized business ecosystems. In all cases, an important precondition is to develop organizations that increase their capabilities both for innovation and change.

BRU21 PROGRAM 6
Late life challenges and decommissioning

NCS has a 45 year production history and we have several mature areas in the North Sea and the Norwegian Sea with aging platforms and infrastructure. There are several challenging issues related to late life field management including options for field extensions and the preparation of decommissioning. A prerequisite for life extensions is optimal use of maintenance resources hand in hand with systematic risk control in a demanding operational context including modifications, reconfigurations and staff reductions. The decommissioning includes also plugging and abandonment of more than 3000 wells on the NCS. The cost aspects are huge and the technology solutions are challenging. Decommissioning across the Norwegian and UK shelves is seen as a new industry opportunity.

4.0

Global energy demand and the climate challenge

KAMEL BEN NACEUR, Director Directorate of Sustainable Energy Policy and Technology, International Energy Agency (IEA)

4.1 Introduction

The COP21 Paris Agreement entered into force in November 2016 and was a milestone in the international effort to tackle climate change. Energy production and use account for two thirds of the world's greenhouse gas (GHG) emissions, highlighting the role that the energy sector has in reaching the ambitious targets set in the Paris Agreement. The agreement will also sustain the growth of the world economy, boost energy security and bring energy access to the billions that lack it today. Beyond the successful outcome of climate negotiation, a variety of key energy indicators signal that progress is being made towards the global objective.

1. A preliminary analysis made by the International Energy Agency (IEA) indicates that worldwide energy-related emissions remained flat, a clear sign of a decoupling of the previously close relation relationship between economic growth, energy demand and energy-related CO_2 emissions.
2. Capacity addition of renewable electricity has reached a record 150 GW in 2015, exceeding the capacity from all other sources, including coal, gas, oil and nuclear.
3. Electricity prices from long-term auctions around the world have been in a rapid decline over the last 4 years, decreasing from USD 120/MWh to less than USD 30/MWh for solar PV, and from USD 80/MWh to USD 30/MWh for onshore wind.
4. Energy efficiency investments have exceeded USD 220 billion, and sectoral coverage by efficiency policies have increased three-fold in the last 15 years.
5. Due to the excess in production capacity, oil prices have been at much lower levels than at the beginning of the decade, leading to a significant decrease in upstream oil & gas investment. For the first time in over three decades, there have been two consecutive years of investment reduction (-25% in 2015, and -24% in 2016). Such a magnitude in investment drop, if not reversed, will have significant implication on oil supply security in the medium term.

4.2 The IEA's World Energy Outlook

The IEA's 2016 World Energy Outlook (WEO) considers a number of scenarios for energy markets. The Current Policies Scenario (CPS) or business-as-usual assumes no changes in countries policies; the New Policies Scenario (NPS), used as a baseline, takes into account the pledges made by the Governments at COP21, while the 450 Scenario sets out an energy pathway consistent with the goal of limiting the global increase in temperature to 2°C by limiting concentration of greenhouse gases in the atmosphere to around 450 parts per million of CO_2 (Figure 4.1). In 2016, the WEO also considered a scenario that would be in line with well below the 2 degree target.

In the NPS, world energy demand will expand by 30%, with the consumption of all modern fuels continuing to grow until 2040, and the largest increase amongst fossil fuels coming from natural gas (50% growth, overtaking coal). Oil consumption will continue to grow (by 12%) between 2015 and 2040, with the largest growth coming from the petrochemical sector, followed by aviation, shipping, and trucking, offsetting a decline in oil use in power generation and buildings. Light duty vehicles would double, but, because of the electrification and progress in fuel efficiency, oil consumption from such vehicles will remain stable. Renewables are the largest source of growth for energy supply. Nearly 60% of the capacity additions between now and 2040 come from renewables, which by 2030 will become the largest source of electricity supply.

In the NPS, there is a significant decrease in the rate of growth (from 2.4% to 0.5% in 2040), energy-related emis-

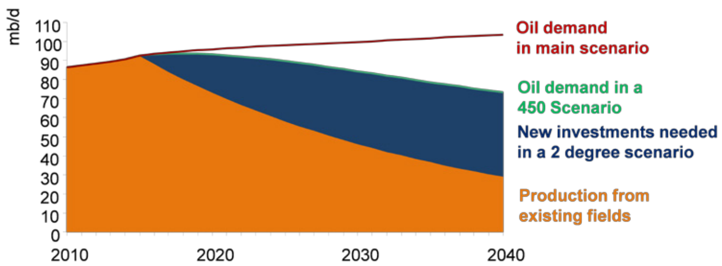


Figure 4.1: Future oil demand in 2040 will be mostly from fields that are not producing today

sions will continue to grow reaching 40 gigatonnes per year by the middle of the century.

The IEA's 450 Scenario, energy-related CO_2 emissions peak before 2020, and drop around 15 gigatonnes by the middle of the century. Emission reductions will be achieved through a combination of technologies (efficiency – 32%, renewables – 32%, followed by CO_2 capture and storage (CCS), nuclear and fuel switching. The sectors that will see the largest decrease are power, industry and transport, followed by buildings. In the power sector, the additional reduction of emissions intensity is facilitated through increased prices and extended policy support to low carbon generation, leading to an increase in renewables generation by 40% in the 450 Scenario vs the NPS, with the largest increase made in solar and wind generation. CCS will also rise rapidly in the power generation sector (coal and natural gas), as well as in industry. In the transportation sector, electric cars would reach one third of the global car stock (710 million) by 2040 in the 450 Scenario.

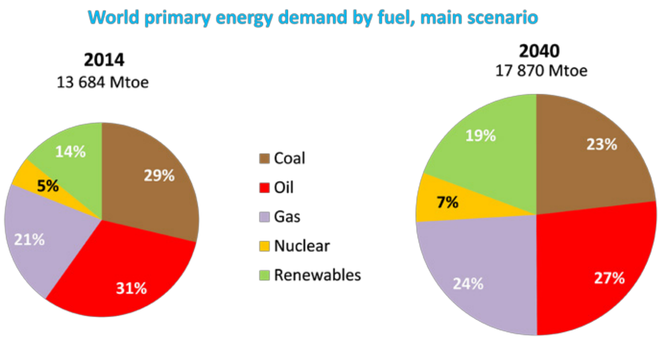


Figure 4.2: In the NPS Scenario, oil and gas share is 51% in 2040

4.3 Role of oil and gas towards 2050 in the transition to low carbon society

Fossil fuels currently represent 81% of the primary generation sources, and have been accounting for more than 80% for the last decades. In the NPS, the share of fossil fuel would decrease to 74% by 2040, with oil and gas representing over 50% of the total sources. In the 450 Scenario, the shares of fossil fuels and oil and gas drop significantly to 58% and 37 % by 2040. With the production decline from currently operating oil and gas fields, it is expected that their oil output would decline from 95 million bpd (mbpd) to 33 mpbd in 2040. In the NPS, new oil and gas production sources of 70 mbpd would have to be discovered, appraised or developed (Figure 1). Even in the 450 scenario, new fields with a capacity of 40 mbpd will need to be developed. For natural gas, current gas fields would be producing 1.5 trillion cubic meters (tcm) in 2040, and an additional 3.7 tcm will have to be developed (more than today's total current output). Even in the 450 Scenario, an additional set of fields with a production of 2.5 tcm per year will have to be started. The share of oil and gas in the primary fuel mix remains at 51% in 2040, with gas increasing from 21% today to 24% (Figure 4.2). It is therefore primordial in all the scenarios to maintain a sufficient level of investment in oil and gas, either in anticipation of the increase in demand, or compensation for the production decline.

Figure 4.3 shows a comparison of the level of investment required for the NPS and 450 Scenarios. In the NPS, investments in fossil fuels need to remain at the same level as in the 2000-2015 period, while in the 450 scenario, nearly USD 700 billion is required annually. WEO 2016 raises an alarm about the dramatic drop in conventional crude oil resources receiving approval worldwide, which have now reached the lowest level since the 1950s.

In addition to stimulating the required investment level, the oil and gas industry has an important role in the energy transition, through:

- A reduced environmental footprint (operational efficiency, methane emission reductions, carbon capture utilization and storage, including advanced EOR schemes)
- Stress testing strategies and business models against decarbonization scenarios
- Seeking out opportunities to harness industry skills and expertise to the energy transition (offshore renewables etc.)

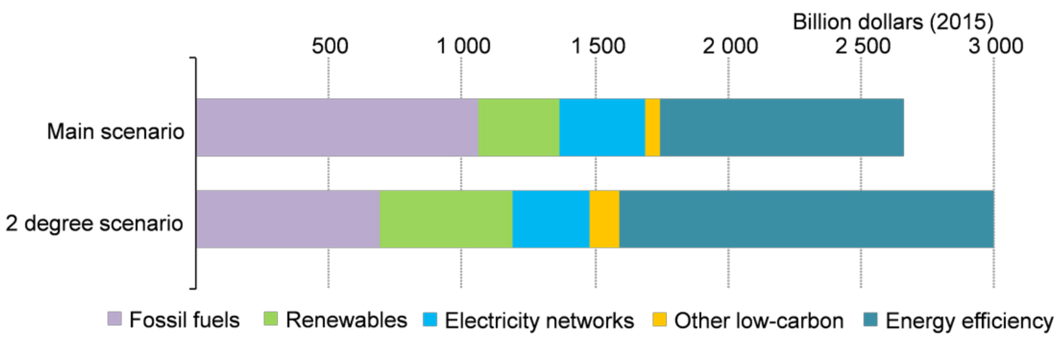


Figure 4.3: Average annual investment in energy by scenario (2016–2040)

5.0

Long-term aspects for O&G on the Norwegian Continental Shelf[1]

ARILD N. NYSTAD, BRU21 Coordinator (Ph.D)
Former Petroleum Resource Director at NPD

5.1 Introduction

The Norwegian Continental Shelf (NCS) has a 45 year successful production history and can expect at least another 45 years of potential production. The public petroleum resource and safety management is efficient and world class. The NCS is resource rich, a technology leader and close to gas markets in Europe. The public management and the petroleum industry give top priority to safety and environment (HSE) and are continuously working for better solutions in the future.

5.2 Sedimentary basins and licensing

The NCS covers about 2 040 000 square kilometers and is six times larger than mainland Norway. Two-thirds of this area comprise sedimentary rocks that could have a potential for petroleum. The areas currently opened for exploration amount to 570 000 square kilometers, with some 130 000 square kilometers awarded as production licenses (10% of the areas with sedimentary rocks). See Figure 5.1.

The NCS has been opened for petroleum activities grad-

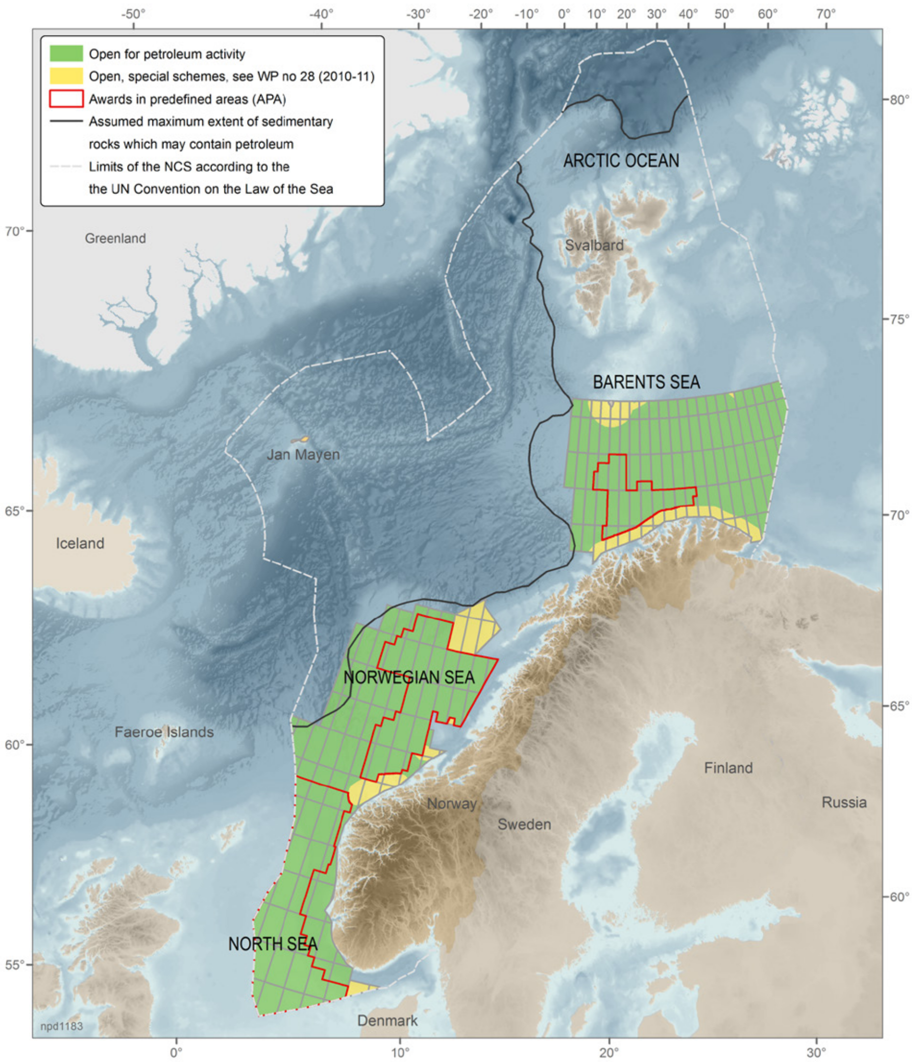


Figure 5.1: Norwegian Continental Shelf. (Ref. NPD)

1 This chapter use information and illustrations with the courtesy of the Norwegian Petroleum Directorate (NPD)

ually since the first licensing round in 1965. The first blocks in the Norwegian Sea and Barents Sea were awarded between 1981 and 1989. Deepwater areas in the Norwegian Sea and part of Nordland VI area off Lofoten were opened for petroleum activities in 1994. Two decades then passed before Barents Sea southeast was opened in 2013.

The Norwegian Authorities have had prudent step-by-step announcements and awards in order to gain information from one step to the next. An extensive set of policy instruments has been developed on the NCS to take account of other industries and the environment in all phases, from the opening of new areas, through awards, exploration, development and production to decommissioning.

Policy implication: There are still vast unexplored areas with sedimentary rocks on the NCS. G&G competence, exploration technologies together with innovative companies and exploration teams are crucial to produce future discoveries on the NCS.

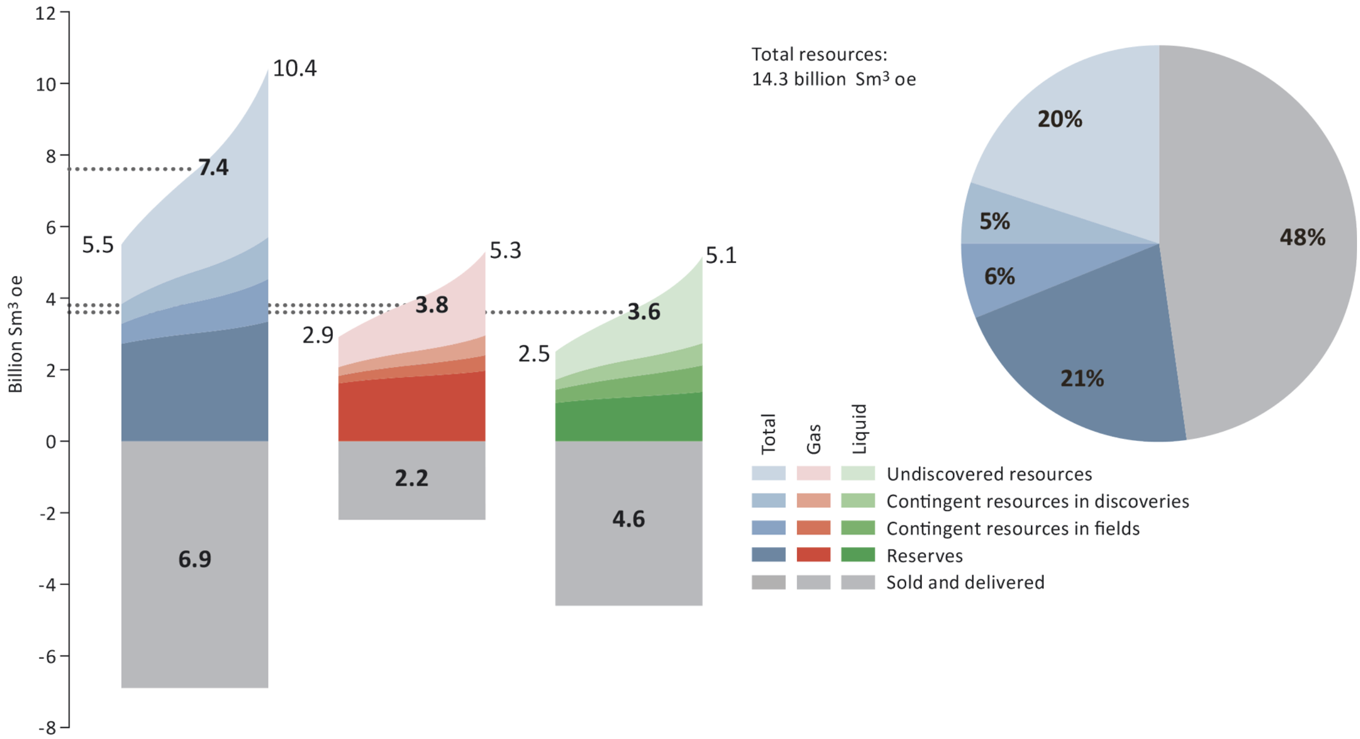


Figure 5.2: Total recoverable resources. (Ref. NPD)

5.3 Recoverable petroleum resources

The NPD's resource accounts provide an overview of total expected recoverable resources, including those remaining to be discovered and form the basis for the production forecast. See Figure 5.2. Total recoverable resources on the NCS are estimated to be 14.3 billion scm o.e. of which 58% is liquid and 42% is gas. The original hydrocarbons in place might be about 30 billion scm o.e.

Total recoverable resources were estimated to lie within an uncertainty range from 12.4 to 17.3 billion scm o.e., with 14.3 billion scm o.e. representing the expected value. These resources incorporate the whole NCS, with the exception of the Barents Sea northeast area defined by the boundary treaty between Norway and Russia. The higher number of 17.3 means statistically that there is a 10% probability that it is at least 17.3 billion scm o.e and on the other hand there is a 90% probability that it is at least 12.4 billion scm o.e.

Remaining resources are estimated to 7.4 billion scm o.e. The uncertainty range goes from 5.5 to 10.4 billion scm o.e. There are still 52% of originally expected recoverable resources remaining for future production.

Policy implication: NCS is only half way resource depleted even after 45 years of production. Technologies and competencies within the entire value chain and across all disciplines are needed to develop future petroleum fields on the NCS in order to develop the remaining value even with low oil prices.

5.4 Undiscovered resources on the NCS and in the Barents Sea

Total undiscovered resources by 2016 are estimated to be 2920 million scm o.e (18 billion bbl oe). This number is included in the previous total resource account. Undiscovered resources are estimated to be between 1350 and 5490 million scm o.e. The estimates for undiscovered resources are very uncertain as is reflected in the difference between the high and low assessments.

About half of the total undiscovered resources are expected to be in the Barents Sea, with the remainder divided roughly equally between the North Sea and Norwegian Sea. The largest recent change in estimated resources is in the Barents Sea, with an increase of roughly 125 million scm o.e. See Figure 5.3

According to the Norwegian Petroleum Directorate's new calculations by April 2017, the undiscovered oil and gas resources in the Barents Sea are twice as large as previously assumed. The major increase originates from the eastern part of the northern Barents Sea – an area of about 170,000 square kilometres. A large part of this is located in the previously disputed area, and most of the new information has been collected after the demarcation line agreement with Russia entered into force in the summer of 2011. The share of undiscovered resources in the Barents Sea has thus been increased from 50 to nearly 65 per cent of the total undiscovered resources on the Norwegian shelf. The resources in the new area are estimated at 1.4 billion standard cubic metres of oil equivalents (about 9 billion bbl). This is equivalent to 14 Johan Castberg fields, and more than five times the Snøhvit field. See Figure 5.4

Policy implication: Barents Sea contains the major expected undiscovered resources and the highest uncertainty and should have clear focus in the years ahead.

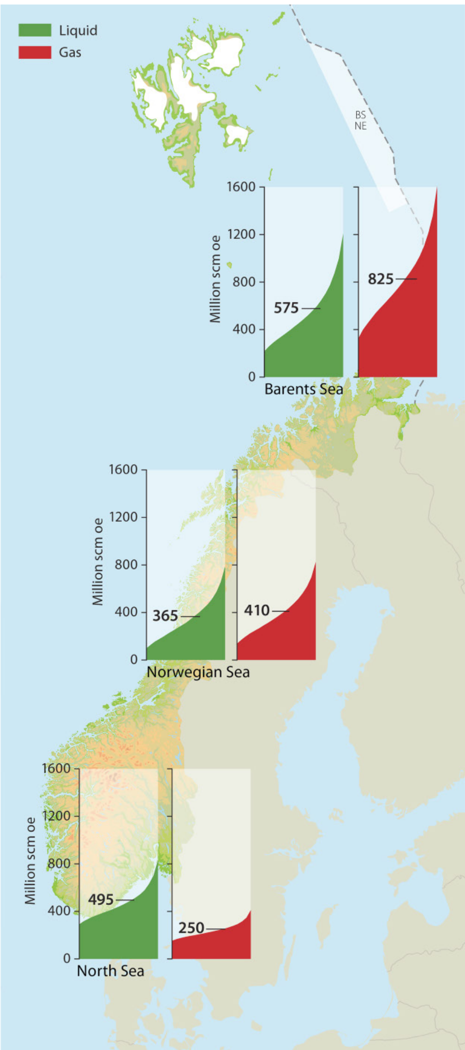


Figure 5.3: Recoverable undiscovered resources 2016. (Ref: NPD)

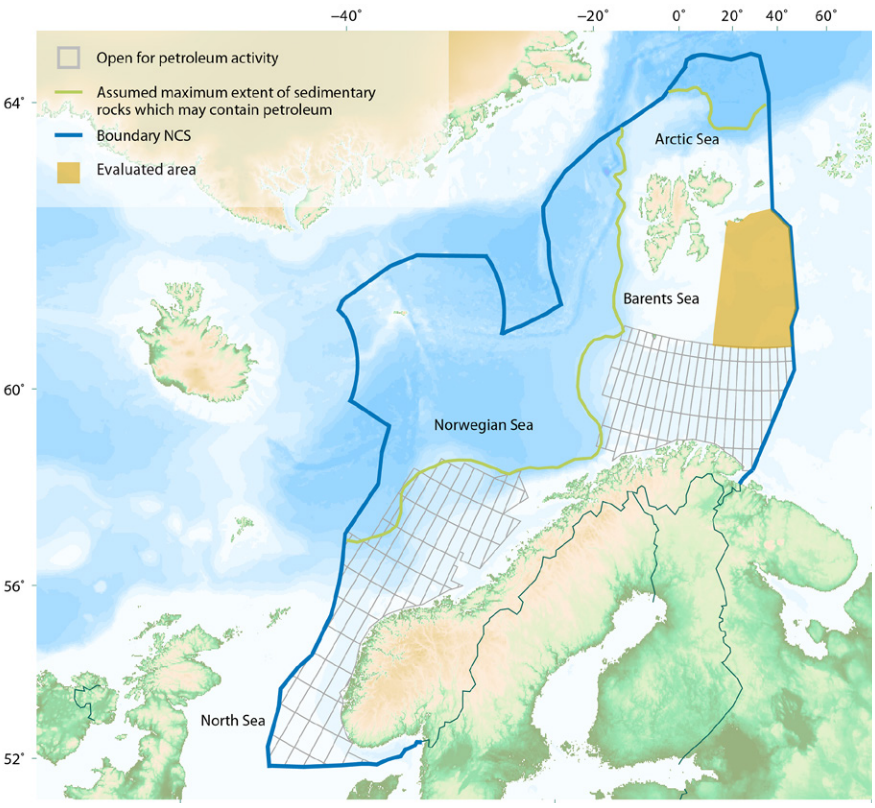


Figure 5.4: Barents sea update April 2017 of recoverable undiscovered resources (Ref: NPD)

5.5 Technology to assist recovering the large volume of remaining resources is crucial

Remaining resources in the reservoirs (in place) at planned cessation according to approved plans are to be a target for future technologies and has a huge upside potential. This refers to the remaining oil in place in the major "old" oil fields: Ekofisk, Troll, Snorre, Eldfisk, Valhall, Statfjord, Heidrun, Oseberg, Gullfaks and several smaller fields.

NPD reports these numbers in light green in Figure 5.5. NPD estimates the remaining oil in place after planned production in the 25 largest oil fields to be about 4 billion scm (25 billion bbl) oil. About 10% of these resources are already included in the numbers for "contingency resources in fields" in Figure 5.2. But still there is a significant amount where exploitation is not yet decided. This is an ultimate target for future technologies. A possible goal might be to develop 25% - 35% of these additional resources "not decided to produce" with game-changing technologies. We are thus talking about significant resources in well-established producing fields and with installations in place ready to be used. This may require development that is critical in terms of timing.

Policy implication: Investments, technologies and competences target improved recovery methods, drilling and wells are needed to assure that these resources that are critical in terms of time are depleted while the the platforms and facilities still are available.

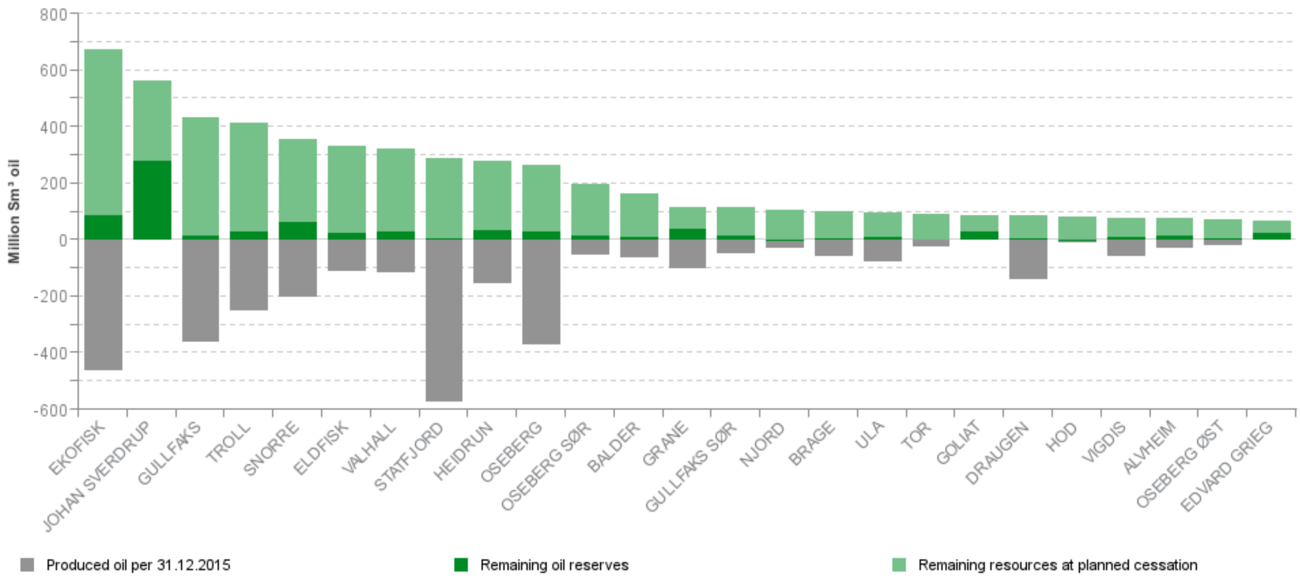


Figure 5.5: Oil reserves and resources for the largest fields. (Ref: NPD)

5.6 Long-term challenges

NPD refers to the following aspects in order to capture the remaining value on the NCS:

- Exploration
- Long-term investments
- Cost reduction and improved efficiency
- Improved technology solutions

The exploration activities in both mature and new areas need to gain momentum in the years to come in order to assure that the undiscovered resources can make use of the established infrastructure on the NCS.

Long-term investments are needed to capture marginal resources in smaller separate fields as well as marginal resources in producing fields. Coordination of several fields sharing joint infrastructure will be important. Further development of recovery methods and drilling of many wells will be needed to capture proven recoverable reserves as well as the proven resources not yet planned to exploit.

Cost reduction and improvement in efficiency need to continue and gains obtained need to be permanent.

Policy implication: The introduction of new technologies and solutions need to be implemented in order to assure remaining values.

6.0

Oil and Gas for the 21st century – OG21 Strategy summary[1]

6.1 OG21 Strategy summary

OG21 summarizes in their 2016 Strategy Document "Oil and gas for the 21st century" the fact that new technologies and competencies to develop and adapt technologies will be key success factors in the further development of the Norwegian Continental Shelf.

The vision of OG21 is: "Technology and innovation for a competitive Norwegian petroleum sector". To achieve this, OG21 highlights that we need to maximize resource utilization, improve industry productivity, reduce cost and reduce greenhouse gas emissions. This is a challenging task, where the utilization of technology and innovation will be the key to success.

The vision is supported by five strategic objectives:

- Maximize resource utilization
- Minimize environmental impact
- Improve productivity and reduce costs
- Develop innovative technologies
- Attract, develop and retain the best talents

The new OG21 strategy sets the direction for the prioritization of technology development and gives recommendations about how to accelerate technology development and use.
The main priorities of OG21 are reflected through the choice of Technology Target Areas (TTAs):

- TTA1 Energy efficiency and environment
- TTA2 Exploration and increased recovery
- TTA3 Drilling, completions and intervention
- TTA4 Production, processing and transport

The technology that needs to be identified and prioritized through the TTAs (See Fig 6.1):

1. Improved energy efficiency: Technologies contributing to more efficient energy production and less energy consumption.
2. Zero carbon emissions: Technologies enabling renewable power supply to offshore facilities, electricity from shore, CO_2 storage, CO_2 use for enhanced recovery, and cost-efficient, de-carbonized hydrocarbon value chains.
3. Protection of the external environment: Systems and technologies that reduce operational discharges and emissions, improve the management of safety barriers and minimize the impacts of accidental spills.
4. Subsurface understanding: Technologies for better understanding geology and reservoirs.
5. Drilling efficiency and plugging and abandonment (P&A): Technologies that reduce the overall work effort for well construction and well plugging, thereby lowering the costs of exploration and production wells as well as P&A.
6. Production optimization: Processing, downhole and intervention technologies that increase the regularity, availability and productivity of wells and installations.
7. Improved subsea and unmanned systems: Technologies that reduce development costs and increase the capabilities of subsea and unmanned production systems.
8. Enhanced oil recovery: Offshore technologies that increase production of mobile oils and enable production of immobile oils.
9. Digitalization: Enabling automation, autonomy and ICT technologies for all petroleum industry disciplines. The technology needs to encompass data acquisition, data management, data quality, data integration, and decision support and data security.
10. High North: Technologies that address the particular challenges of the currently opened areas in the Norwegian parts of the Barents Sea, including shallow reservoirs, carbonates, long distances and logistics and protection of the environment.

The TTAs technology areas are illustrated in more detail in Figure 6.1.

6.2 BRU21 as a supplement to OG21

The BRU21 team has maintained contact with the OG21 management during the fact-finding meetings in 2016. The BRU21 team participated at OG21 Forum meeting on 24 November 2016 in Oslo. BRU21 and OG21 had a joint meeting with the Ministry of Petroleum and Energy in December 2016. In its work BRU21 has been inspired by the OG21 work during 2015-2016. We fully support the view that new technologies and competencies to develop and adopt technologies will continue to be a key success factor in the future development of the NCS. The main findings and priorities of BRU21 fit well with the priorities in OG21 and will be a supplement and support to the OG21 strategy.

OG21 prioritized technologies follow to a large extent the technology life cycle: exploration and increased recovery (TTA2), drilling, completion and intervention (TTA3), production, processing and transport (TTA4) and energy efficiency and environment (TTA1).

1 With the courtesy of OG21

The BRU21 technology road map focuses to a large extent on multidisciplinary business segments (in chapter 7):

- Digitalization in O&G (7.1)
- The Barents Sea (7.2)
- Field development and area strategies (7.3)
- Environmental friendly O&G production (7.4)
- New business models for oil companies and suppliers (7.5)
- Late life challenges and decommissioning (7.6)

The research approach for the future in BRU21 focuses on "digital and automation solutions" in the value chain and across the six different categories listed above. The aspects of "digital and automation solutions" are also represented across in the different TTAs in OG21. The NTNU initiative for an R&D program in this field will thus cover several of the TTAs in the value chain. NTNU will organize this in multidisciplinary collaboration between several departments and faculties on its campus. In addition there are also specific R&D topics listed in each of the six BRU21 categories.

The education approach for the future in BRU21 focuses on "research-based multidisciplinary subjects" with input from the six BRU21 categories. Cross-disciplinary research for education will include the social sciences. NTNU will continue to strengthen the core competencies.

The BRU21 strategy for research and education is aligned with the OG21 recommendations.

TTA1 – ENERGY EFFICIENCY AND ENVIRONMENT: PRIORITIZED TECHNOLOGY NEEDS			
Integrated environmental monitoring and modelling systems	Oil spill preparedness	Produced water management for EOR chemicals	Cost-effective subsea safety barriers
Improved efficiency of power and heat production	Improved weather forecasting High North	Improved communications High North	Technical safety barriers High North

TTA2 – EXPLORATION AND INCREASED RECOVERY: PRIORITIZED TECHNOLOGY NEEDS		
CO_2 for EOR and storage	Improved reservoir understanding and management	Understand and maintain well productivity, and smart well solutions
Improved HC-prospect identification	Water diversion and radical new EOR methods	Improved exploration technologies

TTA3 – DRILLING, COMPLETIONS AND INTERVENTION: PRIORITIZED TECHNOLOGY NEEDS				
Smart well solutions	Drilling and completion for challenging reservoirs	Drilling automation and autonomy	All electric subsea wells	Reduce intervention cost and increase reservoir exposure from existing subsea wells
Energy efficient rig power generation	Plugging and abandonment of wells	High North wellbore positioning and navigation systems	High North shallow reservoirs drilling solutions	

TTA4 – PRODUCTION, PROCESSING AND TRANSPORT: PRIORITIZED TECHNOLOGY NEEDS				
Life extension of fields	Produced water handling	Unmanned operations	Efficient marine operations	Integrated monitoring
Lean stand-alone field development concepts	Flexible field development concepts	Cost-efficient utilization of host platform by subsea developments	Autonomous components. systems and decision support	Energy generation and management
Process simulation and optimization	High North flow assurance	High North shallow reservoirs, subsea facilities incl. subsea compression		

Figure 6.1: OG21 TTA's Technology areas

Technologies of the future

NTNU research and education

7.0

Technology Road Map

Introduction

This chapter defines areas of research and technology development that NTNU should include in the years ahead in order to contribute to the overall objective of Better Resource Utilization of oil and gas.

These areas are the result of the fact-finding meetings that NTNU had during 2016. We had 40 meetings with oil companies, service companies, NOROG, OG21, NPD, PTIL and MPE.

BRU21 "Better Resource Utilization" stands for improved economic efficiency by increased income (resource recovery/production) and reduced costs. We address "technologies of the future" including safety aspects and minimal CO_2 footprint.

The objective is to identify technologies and solutions to assure future petroleum activities at low oil prices and build petroleum fields of the future that are environmentally friendly and have the highest standards of safety. We address both existing O&G fields in mature areas ("brown fields") and new petroleum fields in old and new areas ("green fields").

NTNU also adopts the OG21 objectives outlined in the previous chapter:

- Maximize resource utilization
- Minimize environmental impact
- Improve productivity and reduce costs
- Develop innovative technologies
- Attract, develop and retain the best talents

Both the recent strategy document from OG21 "Oil and Gas for the 21st century" and the KonKraft Report (2016-1) about a "Norwegian Continental Shelf in Change" (2016) with focus on the opportunities in the northern areas, have been additional important input for BRU21.

NTNU wants BRU21 to be a significant contribution to the industry and society in the O&G sector and be an "add-on" to the already established R&D/innovation in niche technology areas. We have selected six multidisciplinary business segments as the major areas to focus on in the future as the result of the BRU21 process and the fact-finding meetings:

- **BRU21 Program 1:** Digitalization in O&G
- **BRU21 Program 2:** The Barents Sea
- **BRU21 Program 3:** Field development and area strategies
- **BRU21 Program 4:** Environmental friendly O&G production
- **BRU21 Program 5:** New business models for oil companies and suppliers
- **BRU21 Program 6:** Late life challenges and decommissioning

In addition to these six program areas we have also included two other general topics from the meetings in the BRU21 process:

- **BRU21 Activity 1:** Advice for petroleum education in the future
- **BRU21 Activity 2:** Niche R&D topics identified in the fact-finding meetings not covered by the six Program Areas. These areas will be processed internally as follow up.

7.1

Digitalization in O&G

The BRU21 fact-finding meetings revealed that O&G actors perceive digitalization and automation as critically important for future competitiveness. This section is about digitalization of the O&G sector: the opportunities provided by digital technologies as well as directions for research and technology development following from the industrial challenges and needs identified during the fact-finding meetings. Section 7.1.1 provides a generic overview of digitalization and automation, whereas Section 7.1.2 elaborates on the corresponding research and technology development implications for the O&G value chain: exploration, drilling, production and subsea operations. Section 7.1.3 briefly presents relevant research resources at NTNU.

7.1.1 Digitalization and automation – O&G perspective

Backdrop

Digitalization is a megatrend which is transforming life, since digital tools with amazing new capabilities are becoming available. These capabilities do not originate from one line of innovations; but are a consequence of a broad spectrum of innovations that come together in powerful synergies and enable further rapid innovation. These include advances in software, computer hardware, the availability of data sets, sensors, networks and communication, visualization, robotics and automation, data analytics, and autonomy and cyber-physical systems. Of particular importance is the ease with which a diversified and large set of these technologies can work together to form systems which accomplish useful tasks. Examples include smart energy systems dynamically optimizing conventional and highly variable renewable electricity generation, distribution and consumption; fleets of drones performing a joint task; and assistance systems and auto-piloting in modern cars.

Industries are adopting digitalization as a means to become "smarter" through incremental and disruptive changes. A leading initiative is the German government's "Industrie 4.0" strategy for manufacturing industries where the goals are, among others, rapid innovation-to-production-line processes, resource input optimization and embedding intelligence in product life-cycles.

Even though technical artifacts tend to become increasingly autonomous, people are often a vital element. People and digital technologies collaborate, in for instance, advisory systems, where decisions are made by humans based on recommendations from a decision-support system. Further, technology facilitates collaboration within groups, integrated operations and social media being two examples and in concepts for human-machine interaction, where numerous technologies and platforms are surfacing.

A further observation of an ongoing trend is the strong belief that future teams will be more balanced between domain experts and data scientists than today. This trend is also observed elsewhere such as in the medical sector and has the potential to unlock considerable efficiency gains.

Digitalization clearly has a disruptive potential and the oil industry's take on this ranges from "wait and see" to a proactive approach. At the proactive end digitalization may be visualized by a vortex where all processes are transformed through some "digital center" by for instance digitizing business models and value chains to the maximum extent possible (Figure 7.1.1).

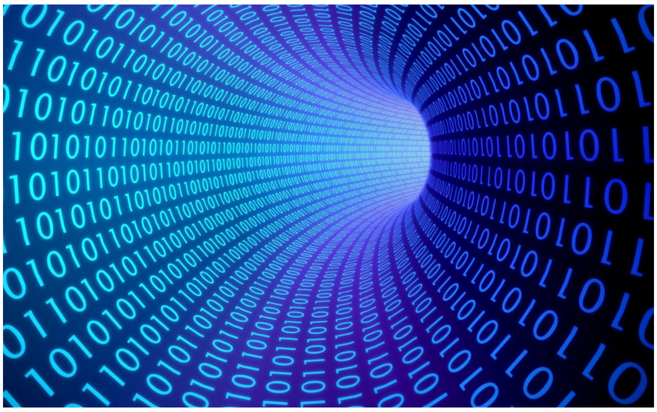


Figure 7.1.1: A digital vortex illustrates that digitalization transforms industries (Digital Vortex, 2015[1]).

The BRU21 fact-finding meetings revealed that O&G actors perceive digitalization and automation as critically important for future competitiveness. This holds for oil companies, service providers, and the authorities alike. Furthermore, there is a widespread belief that the O&G industry lags behind neighboring industries, in particular the downstream process industries and manufacturing industries, in employing digital and automation technologies. Thus, insights and lessons learned from other industries can and should be exploited and new digital and automation technologies tailored

1 Report is available on http://www.imd.org/uupload/IMD.WebSite/DBT/Digital_Vortex_06182015.pdf

for the oil and gas industry should be developed. The potential business impact of this can be huge.

Below we review some examples of digital technologies with significant potential for the O&G industry.

Big Data, Data Analytics and Cyber-physical systems
It is hardly surprising that Big Data, i.e. the management of large and complex data volumes, is perceived as important and expectations are high. This data tsunami creates impatience since companies have invested heavily in data infrastructure for collecting, storing and retrieving data. However, this data is not used anywhere close to its potential. Thus, there is a growing awareness of data analytics as a strategic technology. The O&G industry has traditionally focused on model-based techniques where physics is embedded into models, examples being seismic inversion models and reservoir simulation models. However, Big Data allows for a wider range of methodologies, in particular data-driven analysis either as a standalone methodology or in combination with model-based techniques. There is a range of applications within exploration, field development, drilling and operations. To illustrate this we present a drilling example and an operations example. They both rely on real-time data analytics. First, new technologies for look-ahead geosteering are emerging. This novel real-time data stream can be used, together with other information, for geosteering to modify the well trajectory while drilling, and even perform completion redesign under strict time-constraints as the drilling operation ends. Second, daily operation creates an ever-increasing data stream from sensors in addition to other information sources. To elaborate, a typical offshore platform can have 30 000-50 000 data tags. This information is an excellent candidate for real-time data analytics – for monitoring and optimizing the utilization of equipment and production facilities.

Cyber-physical systems (CPS), in which physical components and software components are highly intertwined, enable two key capabilities; automation and autonomy. This is enabled when physical components are equipped with sensors, embedded computers and self-correcting mechanisms. CPS appear on all spatial scales from sensors to large systems like production facilities onboard an offshore platform. Large CPS are based on networks of smaller systems, which can be considered an instance of the Internet of Things (IoT). The opportunities are immense, particularly related to unmanned platforms and subsea systems, cost-efficient operations, e.g. timely and predictive maintenance, and fully automated drilling operations.

The concept of Integrated Operations (IO) has been used to tie teams and organizations together through use of appropriate visualization technologies, design of physical workspaces, design of workflows and cultural adaptation. IO takes a structured top-down approach as a means to facilitate interaction and teamwork. However, digital technologies enable new forms of interaction and collaboration, like social media, which can be viewed as a bottom-up approach: collaboration emerges through numerous formal and informal channels within a company and beyond its boundary. These ways of technology supported collaboration have obvious gains both for daily problem solving and longer-term innovation.

Cyber security is a particular challenge, since the consequences of hostile activities can be immense. It is clearly a prerequisite for the above as automation and especially any degree of autonomy can only be performed in trustworthy environments where anomalies and possible attacks are detected and mitigated sufficiently early. This is a major challenge in CPS where environmental conditions, faults and operational decisions may be hard to distinguish from sophisticated attacks.

Digitalization methodologies and subsequent technologies apply a data scientific perspective where the data itself provides the bulk of information. There are many examples of how this approach has successfully transformed technologies in various industries. However, it can be dangerous to transfer this directly to O&G applications without taking into account the specifics of the O&G domain. It will be important to merge the strengths of digitalization technologies with domain knowledge to capitalize on the digitalization advances. Thus, domain knowledge, i.e. intimate knowledge of the relevant aspects in the O&G domain, should be a key component in all applications of digital and automation technologies to the O&G value chain.

7.1.2 Digitalization and Automation – O&G Value Chain

Exploration
Marine seismic exploration is characterized by the considerable areal extent of sources and streamers being towed behind large seismic vessels. The typical length of the receiver cables is up to 10 km and the typical width of a swath is up to 1 km, see Figure 7.1.2. This means that this constitutes the largest moving object on the earth's surface (if we neglect continents that move by a velocity of cm per year). These cables are normally towed at a depth of 30-50 m and the towing speed is around 5-8 knots. This acquisition process is automated to a certain degree: Air gun arrays are automatically fired based on navigation, and the number of data points and illumination of the subsurface is automatically updated during the survey. For 3D seismic surveys it is important to keep track of the number of traces (measurements) that contribute to the illumination of a given location at the seabed. This number should be as high as possible in order to increase the signal-to-noise ratio. The positions of each source element

and each receiver (might be several thousands) is automatically stored in the navigation file.

For seabed seismic data acquisition, there is a current drive especially for the nodal technology to automatically pick (from a rack) individual nodes and automatically put them on a rope on the seabed. This technology is limited to water depths less than 1 km. There have also been suggestions[2] about using Autonomous Underwater Vehicles (AUV) that automatically dive to the seabed, record seismic data and come back to the mother ship again. Currently, the price tag for individual AUVs is too high to make this realistic. However, by relying on progress taking place outside the petroleum industry, like the defense and space industries, reasonably priced AUVs with the needed specifications will become available in the future. This will open the way for a wide roll out of AUVs for automation of seismic data acquisition.

Presently there are four major fields offshore Norway that are equipped with Permanent Reservoir Monitoring receiver arrays. The receiver cables are trenched into the seabed (approximately a meter) and the seismic signals are tied back into a recording unit on the platform. The acquisition and processing of such data are automated to a certain degree. A shooting vessel is used to create a high number of shot points on a regular grid, while the rest of the process is automated. Typically, the field is covered by seismic shots every half year. In addition, the buried receiver array can be used in a passive mode, recording data similar to those measured on a seismograph. The next steps for further developments with regard to automation are the handling of the vessels and automated assistance systems for the handling of the towed seismic streamer arrays. Automation is a technology that can increase accuracy and reduce the cost of the exploration data acquisition.

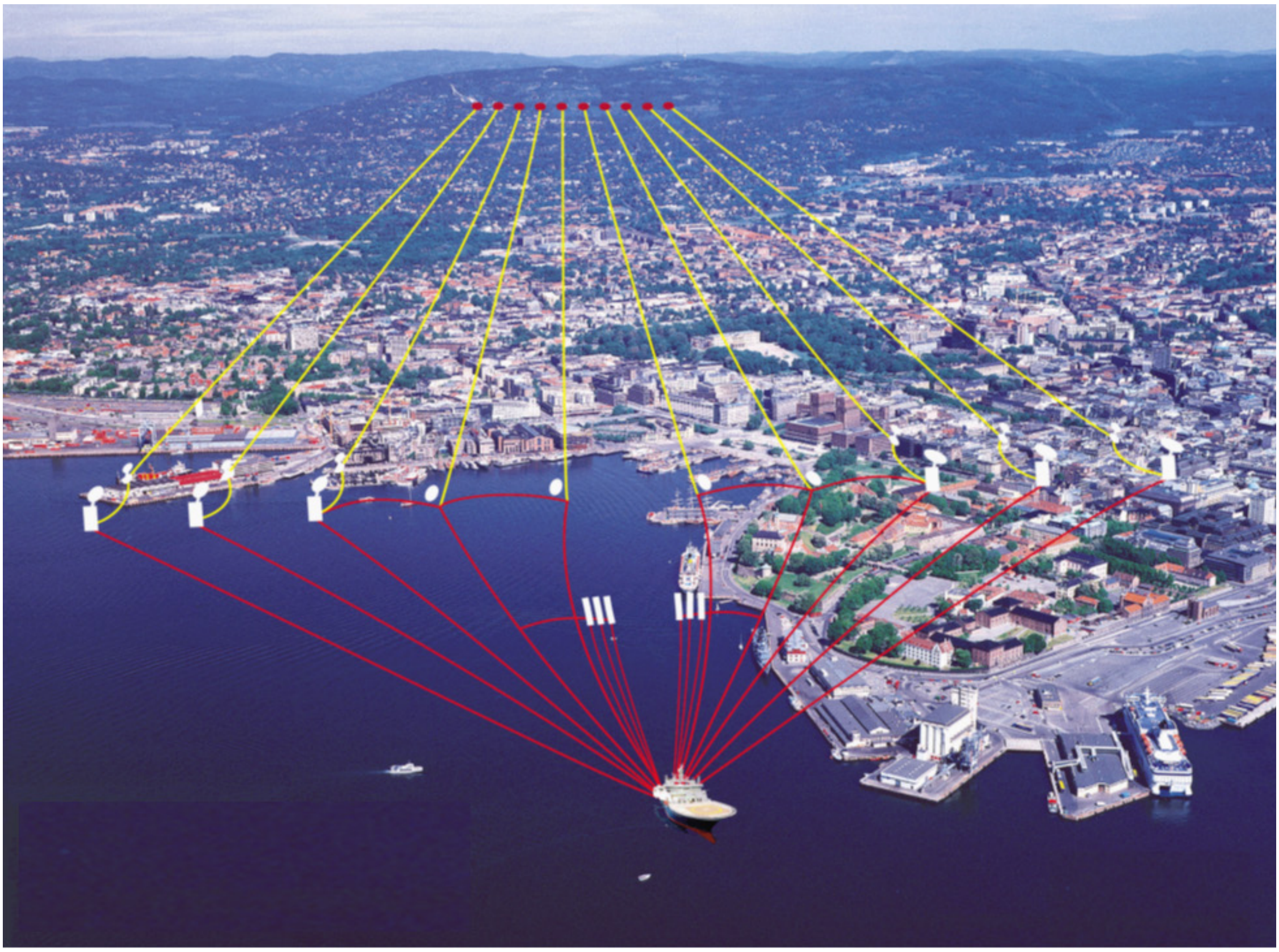


Figure 7.1.2: The size of marine seismic acquisition. In this example 10 receiver cables are towed behind two source arrays (each array consists of three white rectangles (subarrays) that are towed closer to the seismic vessel in front). The streamers are displayed using a photo of Oslo as background to illustrate the size. (Courtesy WesternGeco)

2 Amundsen, L. and M. Landrø, 2008, Seismic imaging part IV, GeoExpro, Volume 5, Number 5, 2008

Drilling

The drilling process is characterized by high cost, fragmented operation with many parties involved and many interfaces and high uncertainty especially with respect to the underground conditions, such as the pore pressure and fracture gradient. Approximately 50% of field development costs are related to offshore drilling and well activities, and 80% of offshore well cost is time related. Thus, the high cost of well drilling and construction is perceived as important by oil companies. The expected answer to this, by the same actors, is increased autonomy of drilling operations through automation and extensive use of data- and digital technologies for optimization of drilling and completion operations.

Higher levels of digitalization and automation for the drilling process will imply broader use of data from sensors for advisory and automation systems. The amount of valuable information available from sensor data streams during drilling is still to a large extent limited by the existing sensor, communication and data processing technologies. For example, as follows from the BRU21 fact-finding meetings, there is still a need for high quality, highly reliable, high frequency, reasonably priced communication link between the bottom hole assembly (BHA) and the rig floor; better sensor and data processing solutions for top-side measurements, e.g. high accuracy mud volume totalizer; new solutions for drilling data analytics. The further development of technology in these directions will lead to higher availability of accurate and reliable information for automation systems and decision-making processes, and thus contribute to safer and more efficient drilling and completion operations.

In recent years we have witnessed increased automation of single functions, such as automated pipe-handling, automated drilling fluid systems, and downhole pressure control. Larger gains can be expected if one builds integrated systems that automate across functions to achieve higher-level efficiency and safety goals rather than simply replacing manual operations, such as automated hole cleaning, or fully unmanned drill-floor operations.

Based on experience, it is clear that successful adoption and use will depend on automatic solutions being easy to use with a limited need for configuration and very limited need for experts on the rig to support the operation. There must be a sufficient data infrastructure providing automatic control systems with frequent real-time measurements with limited time lags, good accuracy and repeatability. This is an important observation, as many measurements on existing drilling vessels are designed for manual control and thus do not satisfy these requirements. Standards should be developed, so that different vendors of automatic solutions can easily interface with the various control systems, and solutions should be fault tolerant and coordinated. Support systems interpreting the measurements both from downhole and on the rig should be developed and used to help the driller detect events earlier. Real-time interpretation of drilling data should be used to evaluate the downhole conditions. Figure 7.1.3 illustrates the flow of information to the drilling control system.

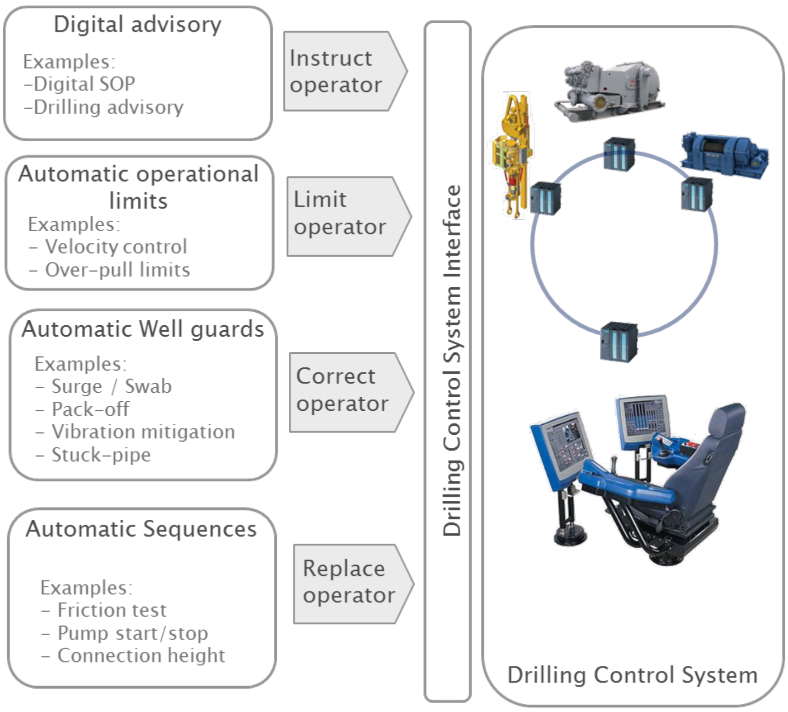


Figure 7.1.3: Flow of information to the drilling control system

Currently, despite increased automation, the drilling process requires a high degree of manual interaction and specialists offshore during operations. Several companies provide input both during planning and execution, and the interfaces are typically provided through Word documents and spreadsheets. In order to take full effect of automation systems regardless of vendors, digital workflows between onshore planning and offshore execution will be required, as well as digital standardized interfaces between parties, for instance between the well planner and operator.

The list of technologies and operations where digital and automation solutions will play an important role also include Automatic events detection based on real-time drilling data; Logging while drilling (LWD) combined with Seismic while drilling (SWD); Tools for look around and look ahead; Hammer technology; Systems for continuous circulation; Managed Pressure Drilling systems; as well as Drilling operations in depleted reservoirs, long reach wells and ultra slim drilling.

Extensive drilling automation and digitalization will represent a major shift in the way the industry is run, and, thus will depend on changes in contract strategies and operating models.

Production optimization

Better sensors combined with data analytics can help engineers to manage complex operating situations since it is impossible, even for skilled teams, to fully understand all interactions and thus optimize production efficiency. Therefore, there is much to be gained by adopting technologies and experience from the downstream industries where data analytics and model-based optimization are in widespread use. New production optimization tools, which exploit data analytics in real time, will undoubtedly surface that will offer better leverage of Big Data and thus improve utilization of equipment to increase production, increase energy efficiency, optimize maintenance, and of course increase recovery.

An ever-increasing real-time data stream is generated from increasingly instrumented offshore fields. However, the industry is struggling to find out how to efficiently utilize this data. To elaborate, there is considerable potential in the use of machine-learning techniques to transform historical data and real-time production data into actionable advice in daily operations, also denoted short-term production optimization. Online-calibrated models may also be combined with mathematical optimization in a decision-support system for production engineers where advice could include adjustments of subsea chokes, gas-lift allocation, or re-sequencing of well tests. Such decision-support systems may be used to maximize oil production while honoring safety and operational constraints. A notable feature of such digitalization is the cost, which is virtually zero, since infrastructure in terms of sensors, information networks, storage and retrieval capabilities is typically available. Thus, decision-support systems for production engineers are a matter of extracting information from data and making it available to the users. These are functions which are implemented solely in software. Other similar application areas are logistics and maintenance planning, and environmental monitoring.

The digitalization shift in the oil industry has enabled extensive deployment and use of "digital twins", i.e. numerical and computerized representations of the real system. This further facilitates and promotes applying and implementing production optimization on virtually every level of the value chain.

Reservoir management relies on large physics-based reservoir models and the use of these for long-term production optimization (years), including drainage strategies and well placement decisions. Exploiting tons of data, as was stated in the fact-finding meetings, is challenging, in particular how to align this with the traditional reservoir simulation analysis paradigm. A systems-based approach using the concept of closed loop reservoir management, which has been developed during the last decade, provides a framework for accomplishing this. To exemplify, methodologies for systematic calibration of reservoir models with uncertainty and aligning these with geomodels are emerging.

For successful adoption, implementation and use, digital and automation solutions within production optimization should

- Accurately reflect the most important variables, objectives and constraints, yet avoid overcomplicating the problem.
- Reduce or explicitly address uncertainties. This is especially applicable to the case of reservoir models.
- Be sustainable, which includes ease of use and maintenance, scalability, and proper ownership by the industrial partner.
- These requirements should be addressed at all levels of the R&D pipeline from academic research to industrial implementation: during research and development, through proper commercialization solutions and through communication, follow up and feedback between industrial and academic partners.

Cultural barriers or "silos", which promote suboptimal behavior in different camps, in particular related to daily operations and reservoir management, were identified as an E&P challenge in several BRU21 fact-finding meetings. The convergence that digitalization brings about in terms of infrastructure, terminals and functions, in addition to underlying algorithms, holds promises for improving these situations even though this cannot be fully mitigated without attention to work culture and incentives.

Subsea processing

Oil companies point to unmanned field operations and the importance of digitalization in this context. Unmanned alludes both to unmanned surface structures, which may be manned from time to time, as well as subsea solutions, which by necessity are unmanned. History tells us that separators have been placed on the seabed since 2000 (Troll Pilot) while the first subsea compressors were commissioned quite recently (2015). There is a strong drive towards placing more complex processing structures subsea, by moving topside facilities functionality subsea, as a means to reduce cost. This requires automation and monitoring capabilities beyond current standards, and improved intervention techniques.

Subsea field solutions require a high degree of autonomy and the ability to reliably and securely provide remote monitoring capabilities. Performance monitoring includes the monitoring and calculation of system variables like temperature, pressure, fluid composition, fluid properties and efficiency of equipment, while condition monitoring includes tracking equipment parameters like material degradation, wall thickness, fouling, scale and wax deposition, vibration, and leakage. A new topic, which has been rapidly developing in the last years, is prognostics and health management (PHM). This links equipment state and failure mechanisms to system lifecycle management. Future subsea facilities will provide a wealth of real-time data for realizing monitoring, automation and autonomy.

Subsea solutions require efficient intervention techniques for the installation and retrieval of modules and components, inspection, maintenance, and repair work carried out subsea, since intervention is a strong cost driver. Autonomous underwater vehicles (AUV) represent a key technology for cost reduction, a concept that relies on a high degree of automation.

Many of the systems that enable subsea solutions are composed of components and services provided by a large number of suppliers that need to interoperate, but may at the same time be reluctant to divulge commercially sensitive information. A key element in realizing many of the above aspects is therefore a trustworthy information and communication systems environment in which selective and timely information sharing and exchange is enabled leading to effective incident management. At the same time, breaches and faults in any component or subsystem may jeopardize security and safety of larger systems, resulting in a duty and imperative to detect issues early and provide effective mitigation strategies without which the ambitions outlined here would pose unacceptable risks.

7.1.3 NTNU contribution in Digitalization for the O&G industries

NTNU, as Norway's largest university with a key profile in science and technology, is well positioned to take on the industrial digitalization challenge and thus contribute to industrial change. Of particular importance are the strategic research areas NTNU Energy, which covers renewables and O&G, NTNU Ocean, which includes a wide spectrum of ocean-related research and NTNU Digital, which covers the complete range of information and communication technologies.

As one of the results of BRU21, NTNU now organizes broad cross-discipline research cooperation between the Faculty of Engineering and the Faculty of Information Technology and Electrical Engineering with relation to "Digital and automation solutions for the Oil and Gas industry". This collaboration will be based on the expertise and experience in Petroleum Engineering, Cybernetics, ICT (including Cyber Security) and other relevant disciplines from the two faculties and affiliated research centers.

7.2

The Barents Sea

7.2.1 Exploration[1]

The Barents Sea is a large area covering approximately 1.4 million square kilometers, approximately the double size of the North Sea. With the new update by April 2017 doubling the resources in the Barents Sea, the Barent Seas now represent 65 % the total undiscovered resources on the NCS.

Figure 7.2.1 shows a map of the Norwegian part of the Barents Sea, with the Skrugard and Havis discoveries, presently denoted the Johan Castberg field, and the Snøhvit Field. One of the greatest challenges in the Barents Sea is the sealing potential of reservoirs; this applies particularly to possible Jurassic reservoirs. The Johan Castberg structure consists of rotated fault blocks of Jurassic age (145-200 Ma).

The seismic data from the Skrugard discovery, which now belongs to the Johan Castberg license represent an excellent example of how seismic data can be used to de-risk an exploration project.

Interest in the Skrugard block was almost non-existent until 3D seismic was acquired in connection with the Norwegian 20th licensing round in 2009. This new data showed 'direct hydrocarbon indicators' more clearly, particularly two 'flat spots' interpreted as reflections of gas-oil and oil-water interfaces (Figure 7.2.2). Combined with positive results from electromagnetic surveys, several companies were attracted to evaluate the prospect. This discovery opened up a new oil province in the Barents Sea, with significant additional exploration resource growth potential.

Well 7220/8-1 in 2011 proved hydrocarbons in the porous sandstone rocks. This discovery was a significant milestone for hydrocarbon exploration in the Barents Sea, and positively confirmed the geoscientists play model and prospect

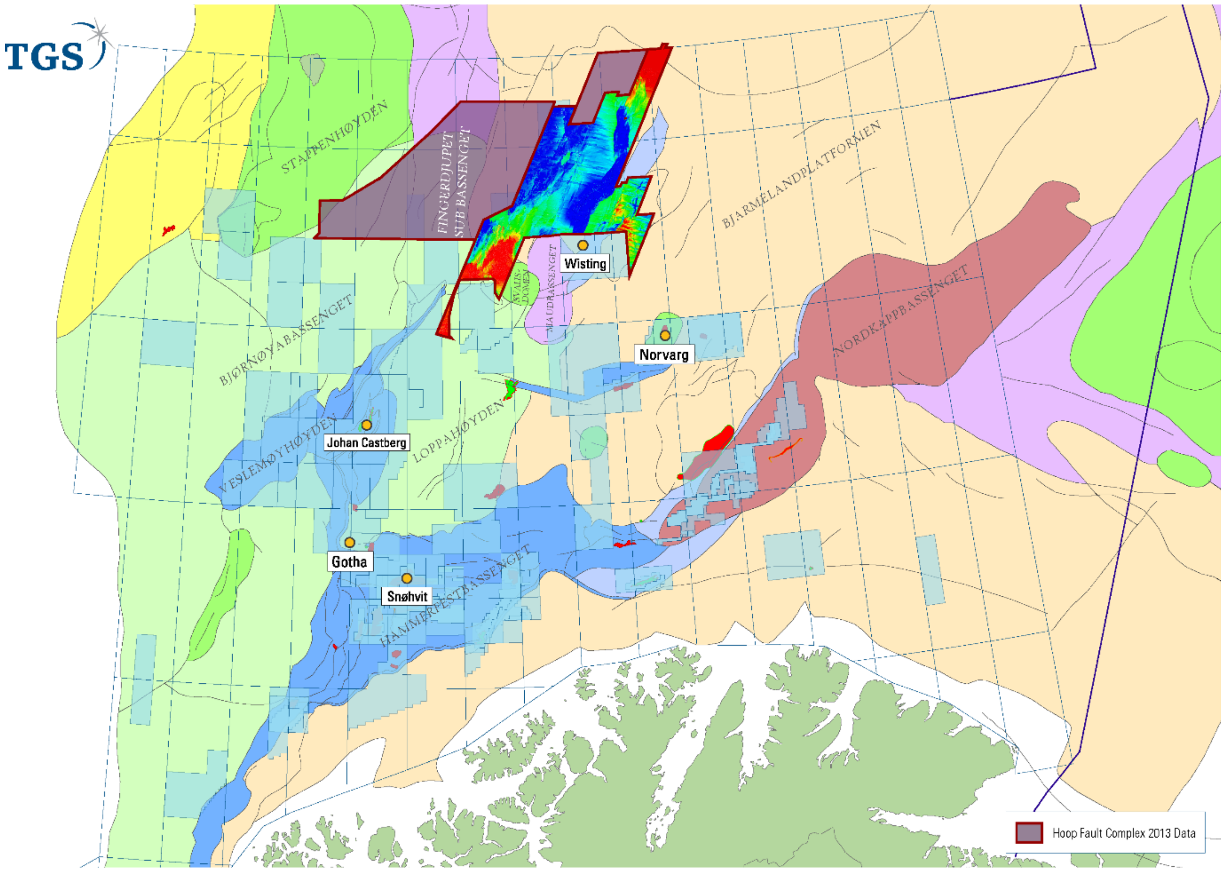


Figure 7.2.1: Location map and structural elements in the Norwegian Barents Sea. The Snøhvit, Gotha, Norvarg and Johan Castberg fields are shown by yellow circles together with the Wisting prospect. (Courtesy of TGS)

1 Part of this chapter is taken from "Introduction to exploration geophysics with recent advances" by Martin Landrø and Lasse Amundsen, to be published in 2017.

evaluation. The two flat spots seen on the seismic map were good hydrocarbon indicators and, as expected, they proved to represent a gas-oil contact (GOC) and an oil-water contact (OWC). The well, in approximately 1250 m of water, encountered a 33 m gas column and an 83 m oil column. The first flat spot results from the increase in acoustic impedance when the gas-filled porous rock (with a lower acoustic impedance) overlies the oil-filled porous rock (with a higher acoustic impedance). The second flat spot likewise results from the increase in acoustic impedance between the oil-filled porous rock and the brine-filled porous rock beneath. They stand out in the seismic image because they are relatively flat and thus contrast with the surrounding dipping strata reflections. Generally, however, there are a number of other possible causes for a flat spot in a seismic image. Consequently, flat spots do not necessarily indicate hydrocarbons. In the seismic section, the flat spots have been enhanced by a data processing technique called optical stacking, where multiple seismic sections are summed together to see the flattish reflectors clearly.

Another very interesting exploration example from the Barents Sea is the Wisting discovery made by OMV and partners in 2013, 310 km north of Hammerfest, and is the northernmost oil discovery in Norway. The reservoir is extremely shallow, only 250 m below the seabed. See seismic profile showing the Wisting structure in Figure 7.2.3. The shallow reservoir depth opens new challenges for both exploration and production. The estimated recoverable reserves are between 200 and 500 million barrels of oil equivalents.

The combined use of seismic and CSEM (Controlled Source ElectroMagnetic) data shows promising results at the Wisting prospect. Especially the use of high frequency CSEM data pinpoints clear anomalies that can be used to map the reservoir extent in a 3D sense, as illustrated in Figure 7.2.4.

Detailed 3D imaging of shallow reservoirs needs adjustments and new approaches to seismic data acquisition. P-cable data using short cables and short distance between source and receivers is one option. Another interesting development is to tow streamers deep and use an extra shooting vessel to shoot above the deep-towed streamers. CGG and Lundin have tested this concept, and the first commercial seismic survey of this type will be acquired in 2017.

Some major challenges related to geophysical mapping in the Barents Sea region are:

- Improved imaging of shallow geology
- Mapping of karsts in carbonate rocks
- Imaging around and beneath salt structures

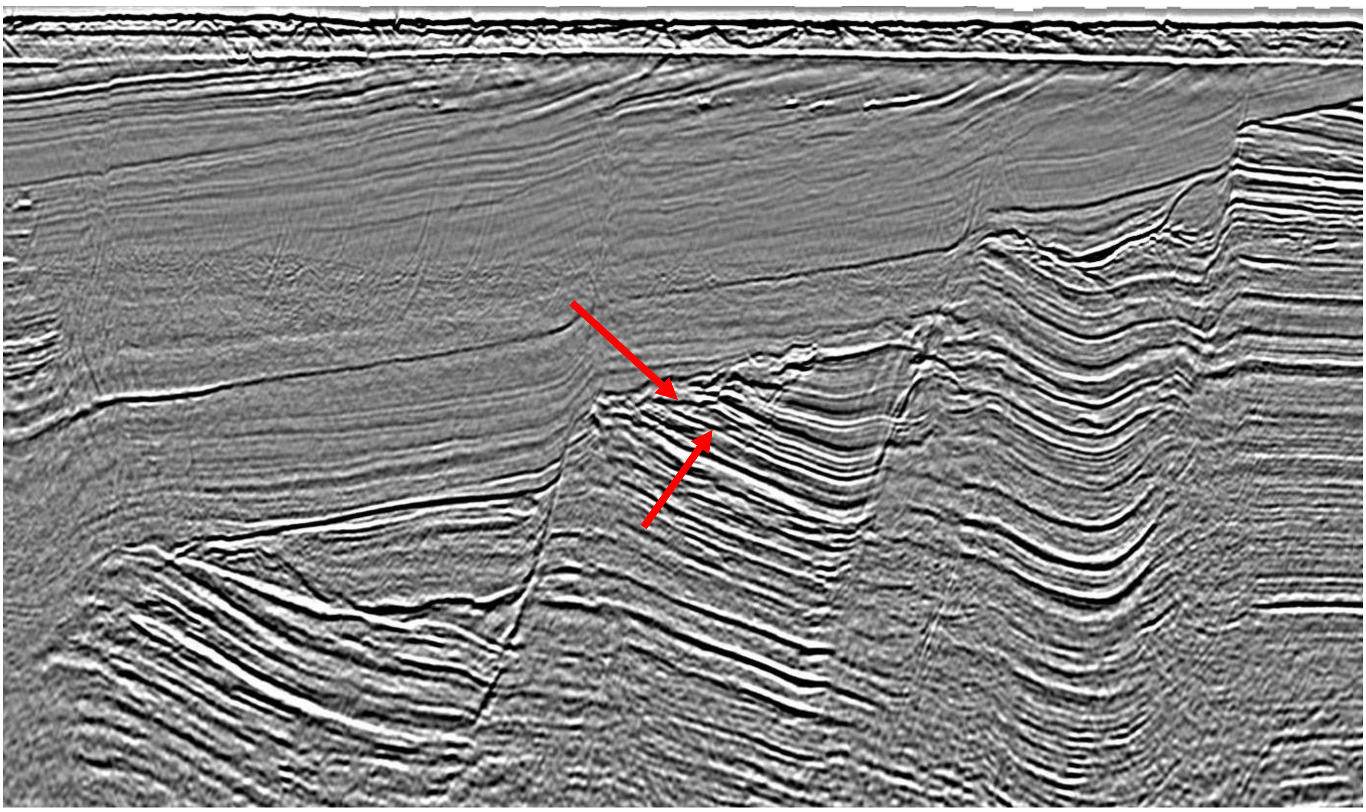


Figure 7.2.2: 2D vertical section showing the Skrugard structure, and the double flatspot (marked by two red arrows). (Courtesy of Statoil)

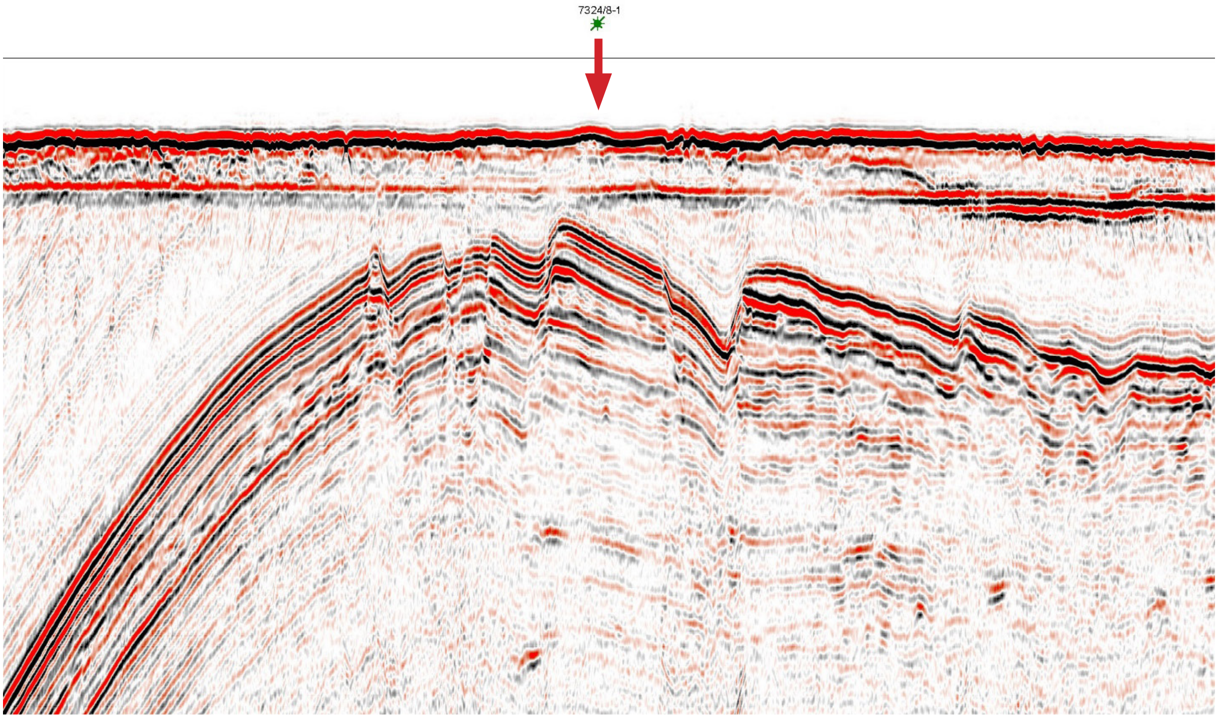


Figure 7.2.3: Seismic profile showing the Wisting discovery. (Courtesy of TGS)

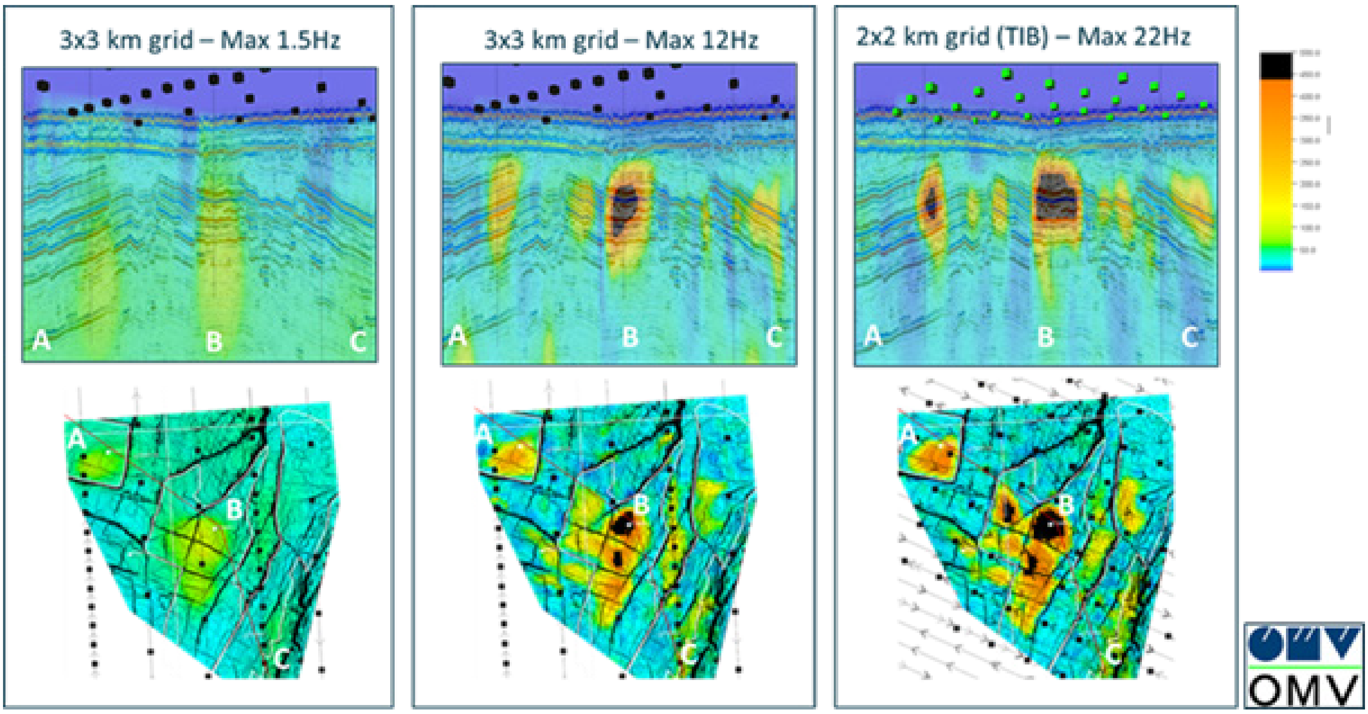


Figure 7.2.4: The extra information from CSEM data using higher frequencies. Left: 1.5 Hz; middle: 12 Hz and 22 Hz to the right. The CSEM responses are shown as color-coded areas overlying the seismic data in the background. (Courtesy of OMV)

7.2.2 Drilling aspects

General
The long distance from shore, darkness in wintertime, icing on structures and cold climate, potential oil spill and other environmental considerations make drilling operations in the Barents Sea or High North more challenging compared to drilling operations in the North Sea. However, it is important to note that the weather (including severe storms) in the Barents Sea is not worse than further south. Geologically speaking, there are other specific challenges related to drilling shallow reservoirs and karstified carbonate reservoirs.

Shallow reservoirs
Wisting is an example of a shallow reservoir with low temperature (17°C) and low pressure (72 bar) located 250–300 m below the seabed. The water depth (400 m) and the low temperature may cause hydrates to form, resulting in drilling and well control problems. The strength and the sealing capability of the cap rock above the reservoir are not well understood, and therefore, the pressure in the well may be restricted causing operational limitations.

Drilling horizontal wells is more challenging due to the high build-up rate needed to reach the horizontal well section. Experience has shown that these types of wells can be drilled.

However, there are issues which are more critical such as drilling a relief well for the interception of a blowing well. The shallow depth makes it difficult to drop off the relief well for homing in (standard method) when approaching the blowing well (Figure 7.2.5). An alternative approach is trial and error which may be time consuming. In cases where no casing string or drill string is present in the section for interception in the blowing well, conventional magnetic ranging tools cannot be used. In general, the standard magnetic survey tools have increased uncertainty in the High North.

On the other hand, the short distance to the reservoir allows a simplified and slimmer casing program to be used. This involves reduced size of the subsea wellhead, BOP and marine drilling riser, and consequently, a lower grade and less expensive drilling vessel may be used.

Carbonate reservoirs
The Gotha field is an example of a carbonate reservoir. Carbonate reservoirs often contain karsts (vugs and caves). Drilling through karstified carbonate reservoirs may cause bit drop, severe mud losses resulting in well instabilities. In order to reduce these problems, new and improved logging tools for looking ahead and looking around the bit, such as seismic while drilling (SWD) may be needed for optimized well bore positioning and reduced drilling problems. New or improved drilling methods, like controlled mud cap drilling (CMCD) or pressurized mud cap drilling (PMCD) may be needed to overcome the problems with lost circulation and well control.

7.2.3 Flow assurance

In subsea developments, flow assurance may be a challenge. The main concern focuses on the maintenance of the flow network to maximize the production potential of the field. Nevertheless, this simple task may lead to several challenges depending on the characteristics of the fluids produced. Thus, depending on the gas fraction, water cut, and fluid composition the appearance of waxes, hydrates, scales and asphaltenes may be inevitable. The precipitation rate and deposition of these different components depend directly on the nature of the phenomenon, and on the temperature and pressure of the flow stream for a given fluid composition. Nevertheless, the management of the problems is relatively similar and alternatives such as thermal control, chemical injection, and mechanical removal are part of the flow assurance strategy.

Furthermore, multiphase flow transport is susceptible to flow transient phenomena, where the seabed topography, flowline layout, start-up and shut-in, pigging operation, among others can generate large fluctuations in the flow (slug flow). Hence, flow assurance activities also must include the prediction and control of the slug flow phenomenon, both during the design stage and in normal operations.

Planning further subsea developments in the Barents Sea has been on the Norwegian agenda for some time now. Barents Sea projects represent an extra challenge for the industry, mainly because of the long tie-back distance, very low temperature and harsh environmental conditions. In addition, there is limited access to the production facilities (both surface and subsea) due to the remoteness. From the flow assurance point of view, very low temperature and long tie-back distance suggest more complexity for the multiphase flow transport. Not only because such harsh conditions will potentially increase the severity of the phenomena, but also because the strategies for prevention control and correction are more difficult. Some of the technology used nowadays could be inefficient and much more expensive for field developments in the Barents Sea province than elsewhere. Some challenges that may face the industry for a given development include:

Thermal management
The long tie-back distance will significantly increase the exposure time of the fluids to the cold environment, requiring more cost-efficient solutions for temperature control. Passive thermal control may not be enough for long distance and low temperatures such as expected in the Barents Sea. On the other hand, active heating systems are very expensive especially if they are to be applied over extended distances. The method used today for the heating of insulated subsea pipelines is based on electric power. Other options for heating may potentially include heat pumps and combustion stations located along the pipeline. Nevertheless, active heating is effective not only as a prevention strategy but also to dissolve

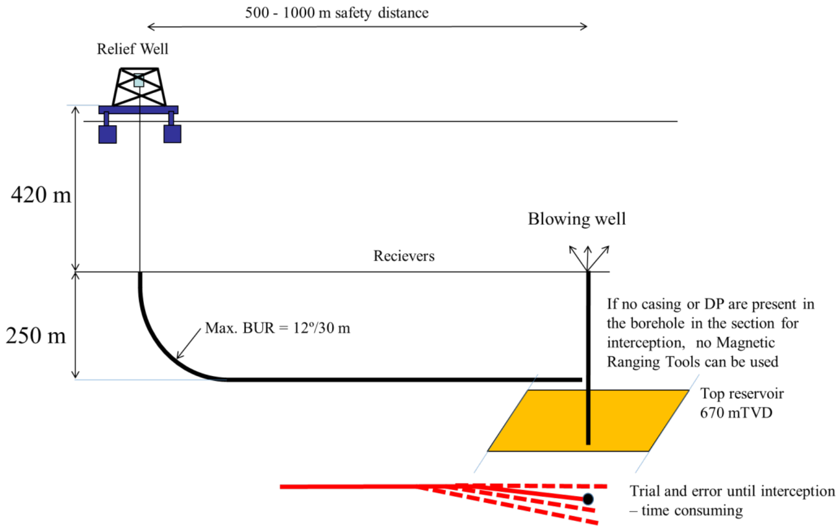


Figure 7.2.5: Dropping off the well path and homing in before interception of a vertical blowing well in a shallow reservoir is challenging. An alternative method is trial and error.

solid accumulations in the line(s). Other strategy denominated "cold flow" suggests allowing precipitation of solids in a controlled manner and avoiding particle deposition and material accumulation. This last alternative has not been proven in the field and may require further studies.

Chemical injection

Depending on the driver for the chemical injection, different flow assurance strategies can be developed. The strategy design may include chemical selection, injection points and injection dosage. For continuous injection systems, the degradation process, in terms of chemical and thermal stability, of products used nowadays can be affected by large temperature fluctuations and extensive resident time in long umbilical lines. Hence, it is necessary to improve methods for flow characterization, evaluation of chemical degradation process under such conditions, and be able to rely on computational tools for thermodynamics analysis and flow behavior prediction. Other approaches for chemical injection may require subsea storage of the different chemicals and local distribution of the products. Such technology has not been applied yet, but may bring some benefits in terms of umbilical size reduction, and boosting system. Nevertheless, a drawback is that the storage system will require a more dedicated monitoring and periodic refills of products. The difficult access and harsh environmental conditions may represent a limitation for this last alternative.

Flow transients

The proper design of cost-effective solutions regarding flow transients phenomena relies on the capacity to understand the multiphase flow transport dynamics and on the capability of numerical models to predict the real physics of the phenomenon under such environmental conditions. Therefore, it is crucial to account for accurate and reliable computational codes for the system design, and for operational strategies.

Fundamental aspects of the multiphase transport

Development in the Barents Sea area will require extremely reliable systems, which calls for continuing studies and advances in the understanding of multiphase flow. For instance, improvements on liquid-liquid system predictions are necessary in terms of the flow characterization, dispersion models, emulsion formation and dynamics of the phases in long pipelines. Emulsions, in fact, represent an important challenge for both flow transport and flow separation. Emulsion formation affects the fluid radiology, induces higher pressure-drop than expected, and can require longer resident time during separation.

Water management

The produced water plays an important role in many of the common flow assurance issues: hydrate formation, scale, emulsion, corrosion, etc. Subsea separation together with re-injection, and/or local disposal to the sea will potentially optimize the hydrocarbon transportation. The gain will be translated into the improvement of conditions for these flow assurance aspects, less pressure drop along the pipelines, reduction of the flowline requirements, and reduction on processing requirements at the receiving facility. The challenge is to advance towards the proper technology to achieve the water quality required for both direct disposal to sea and re-injection for pressure support.

Pressure support

For very long pipelines as the case of the Barents Sea area, it will be necessary to have pressure boosting systems to convey the production fluids from the reservoir to shore or a closer surface facility. Subsea processing systems integrated with multiphase boosting and wet-gas compression may be the key to optimize production in the area.

7.3

Field development and area strategies

7.3.1 Introduction

The design of an optimal development plan for an offshore hydrocarbon field aims to maximize its economic value to the stakeholders while producing the resources in a safe and environmentally responsible manner. At the same time this is done while it is subjected to a variety of socioeconomic, political and regulatory constraints. The challenge is that most factors contributing to the value of the project are dynamic and are continuously changing over the lifetime of the field. The evolution and behavior of the physical system (e.g. reservoir and production system) can be predicted but other factors, related to regional and global issues might change abruptly and unexpectedly as evidenced by historical trends. Some examples of such factors are cost, consumption, revenue, demands (quantity and quality), political climate and socioeconomic development.

The goal of the field-planning phase is to define the following:
- The offtake strategy of hydrocarbon fluids from the reservoir
- The number of wells required and their location
- The technical solution to transport the fluids to the processing facilities
- The technical solution to process and stabilize the fluids
- The pressure support strategy for the reservoir.

The goal of the field design process is to define a detailed execution plan with realistically expected execution times, requirements and costs, quantifying their associated uncertainty. Additionally it must establish a contract framework, evaluate and select contractors.

During the field design phase several development alternatives are thoroughly evaluated and important decisions that entail heavy investment and expenditure must be taken. The available data is limited, especially about the reservoir, collected mainly by geophysical and seismic surveys and a few exploration and appraisal wells.

Figure 7.3.1 presents the typical lifecycle of a hydrocarbon field focusing on the field design phase. Initially, the value chain model is established, consisting of several critical components that are of concern for the particular case (for simplicity, only a few are shown in the figure). All components are usually interdependent but the subsurface (reservoir) is central. There are some components where physical models are defined and used to compute their behavior with time with some particular input (e.g. production profiles). There are other components where some key parameters must be defined (scheduling, topside structures). There are also components (e.g. financial issues) where calculations are performed based on the input from other components and making assumptions of some required factors (e.g. oil price).

During early phases of field planning some components

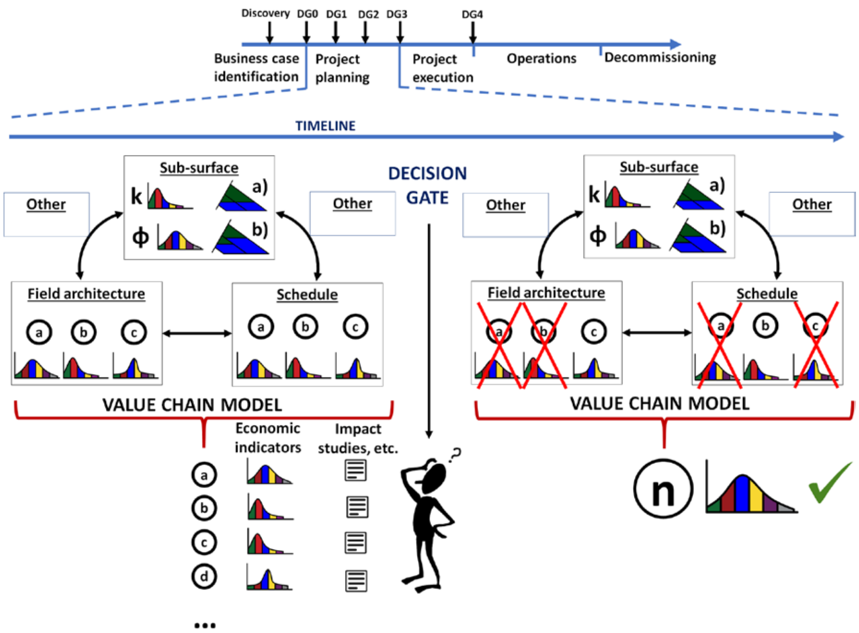


Figure 7.3.1: Field development timeline and the evolution of the value chain model after decisions are made

will have several possible alternatives (e.g. offshore structures, scheduling) that in turn will affect other components. Additionally, most parameters will have an associated uncertainty (that is often described statistically). With the value chain model it is possible to establish all development options and further calculate their associated economic indicators, impact and risks. The field design process progresses by gradually discarding non-attractive alternatives and narrowing the alternatives, factors and details for each individual component. This is typically done through decision gates (DG).

The field design process aims to find an optimal balance between flexibility and cost for the particular asset under study. High flexibility is desirable to cope with future changes, field expansion, market fluctuations; however, it usually comes at a very high cost. For example oversizing the processing facilities to allow production ramp-ups entails large investments that are likely to negatively affect the net present value of the project. Low flexibility means lower costs but could make the system very rigid to absorb future changes. The optimum lies somewhere in between.

The decision-making process within field design should be done leaving an appropriate amount of flexibility and options open at each stage. This allows adaptations to new information gathered at a later stage and has the possibility to execute changes when necessary. It also should carry all relevant uncertainties that could impact the value of the project.

The field design phase officially culminates in the delivery of the Plan for Development and Operations (PDO) to the authorities. However, this does not mean that the planning and design process is over, as eventual comments and observations to the PDO have to be addressed and often require small or large adjustments and amendments to the original development plan.

During the execution phase new information about the subsurface is acquired through the drilling of production and injection wells. This information is reviewed and assimilated into the subsurface models and it might cause significant changes in the drilling and completion plan originally proposed. However, most of the other elements in the production system have already been decided and commissioned, thus it is usually very expensive to make changes.

7.3.2 Challenges

Nationally and internationally, many oil and gas development projects often end up costing more than what was originally budgeted and planned and involve significant delays. This does not necessarily mean that the total economic value of the project decreases as often the total recoverable reserves or initial oil or gas in place end up being higher than expected.

The main culprit frequently pointed out is flaws during the planning process, e.g.: too short time dedicated to planning, incomplete studies, decisions made too early, under-defined quality requirements, improper pre-qualification of contractors and subcontractors. Deficiencies have also been pointed out during the execution phase, in for example: assimilation of new information about the subsurface, timely and close follow-up and cooperation with contractors and sub-contractors, timely check-up of the quality level of the product delivered by the contractors.

A proper field development plan is an essential component for exploiting new resources on the NCS in an efficient and safe manner. The exploitation of most of these new or future resources will be challenging partly because of their remote location (e.g. Barents Sea), their marginal size and the transport of hydrocarbons to the market. Technological advances and improvements in current planning processes are therefore required to ensure profitability and success of such challenging resources.

The current situation regarding field development can be compared to the start-up of the oil industry in Norway in 1969: huge potential and many opportunities but considerable challenges and uncertainties. Nowadays, however, there

ECONOMIC	MANAGEMENT	INTEGRATION	TECHNOLOGY	HSE
• High costs (drilling, operational, subsea) • High costs due to transportation of personnel. • Current economic models are too simplistic • Limited understanding of the drivers for economical value	• Managing and quantifying effectively uncertainty and risk in all stages of the project • Dealing with design errors and wrong decisions • Decision timing • Excessive documentation and paperwork • Including reliability in abandonment models • Reduce decommissioning time • Reduce development time	• Silo mentality in human knowledge and computational resources • Limited inter-discipline communication	• Drilling shallow reservoirs • Dealing with marginal resources • Long tie-backs • Perform water injection effectively • Make wet gas compression more affordable • Reduce weight of offshore structures • Avoid excessive water and gas production • Standardization – Difficult and costly to achieve	• Improve and maintain HSE record • Time demanding and ineffective requirements • Excessive documentation and paperwork • Delays in execution due to HSE regulations

Figure 7.3.2: Main current challenges in field development of offshore fields grouped by categories

is a well-established oil and gas community with a wealth of knowledge and technology that is familiar with the problem. This might nevertheless have a negative impact; people are conservative and careful in finding solutions to problems which might hinder innovation.

There are several challenges that affect the development of new resources on the NCS. There are some challenges that historically have always been present such as high costs and dealing and quantifying uncertainty and risk. There are some others that are relatively new and consist of technical problems that are common in future prospects: long tie-back distances, marginal resources, drilling shallow reservoirs. There are some challenges that originate from the increase in complexity in working processes and in the tools used by oil and gas companies such as information silos and the lack of a holistic perspective over the whole value chain. Lastly, there are some challenges that keep the "status quo" in increasingly difficult and more demanding environments (e.g. maintaining and improving the HSE record).

Figure 7.3.2 presents the most critical challenges grouped in five main categories: economic, management, integration, technology and HSE.

7.3.3 Solutions and enablers

Figure 7.3.3 describes proposed solutions and enablers for reaching the final goal of "optimal and cost-effective field development planning" thus developing a "lean" production system for the case under study.

The second floor presents two main enablers that are crucial for reaching this goal: technical solutions and improved project planning.

"Technical solutions" refer to development and assimilation of new or existing technologies that are deemed critical for future developments. The development of new technology and maturation and the adoption of existing technology is also crucial for unlocking reserves considered uneconomic in order to reduce costs and maintain and improve the HSE record. Some technologies worth mentioning are robotics for drilling, surveillance and maintenance, cold flow, subsea processing, unmanned platforms, wireless systems and all-electric subsea systems. An overview of relevant technical solutions is given in Figure 7.3.4.

During the last few decades there have been relevant advances in integrated operations, integrated asset modeling and digitalization in general. While many of these technologies have been successfully implemented in operations, so far they have not been fully adopted in the field development workflow. They are considered critical to ensure effective interdisciplinary cooperation, work team synergies and holistically analyze the whole value chain of the project. Some emerging technologies such as machine learning, artificial intelligence and big data analytics will probably play an important role in the future.

"Improved project planning" involves changes and upgrades in paradigms and methodologies currently used in field planning. New design philosophies to be adopted and included in the field development workflow are: including and considering area development, attributing value to flexibility and simplicity, planning decommissioning ahead, employing numerical optimization and developing "smarter", less conservative, flow assurance management (such as risk-based flow assurance).

Optimal and cost-effective field development towards the lean production system			
Technical solutions	**Digitalization** • Digital twins • Platforms, tools and methods for resource integration • Big data analytics • Machine learning • Artificial intelligence	**Existing solutions** • Subsea processing • Cold Flow • Integrated Uncertainty Management • Standardization • Smart Inflow Control Devices	**New solutions** • Casing while drilling • Robotics for drilling, surveillance and maintenance • Unmanned platforms • Cable deployed ESP • Wireless systems • All electric subsea systems
Improved project planning	**New design philosophies** • Think big – area development framework • Attribute value to system flexibility and simplicity • Consider decommissioning in the design • Numerical optimization for field development • "Smart" flow assurance management	**Assimilate existing methodologies** • Multi-level, integrated uncertainty management • Increase integration vendor-operator-authorities • Increase integration among disciplines • Integrated asset planning (IAP)	**Complex economics** • More advanced models: Real information theory, stochastic mathematical modeling • Include the effect of market variability and demand

Figure 7.3.3: Enabling technologies to address challenges in field development

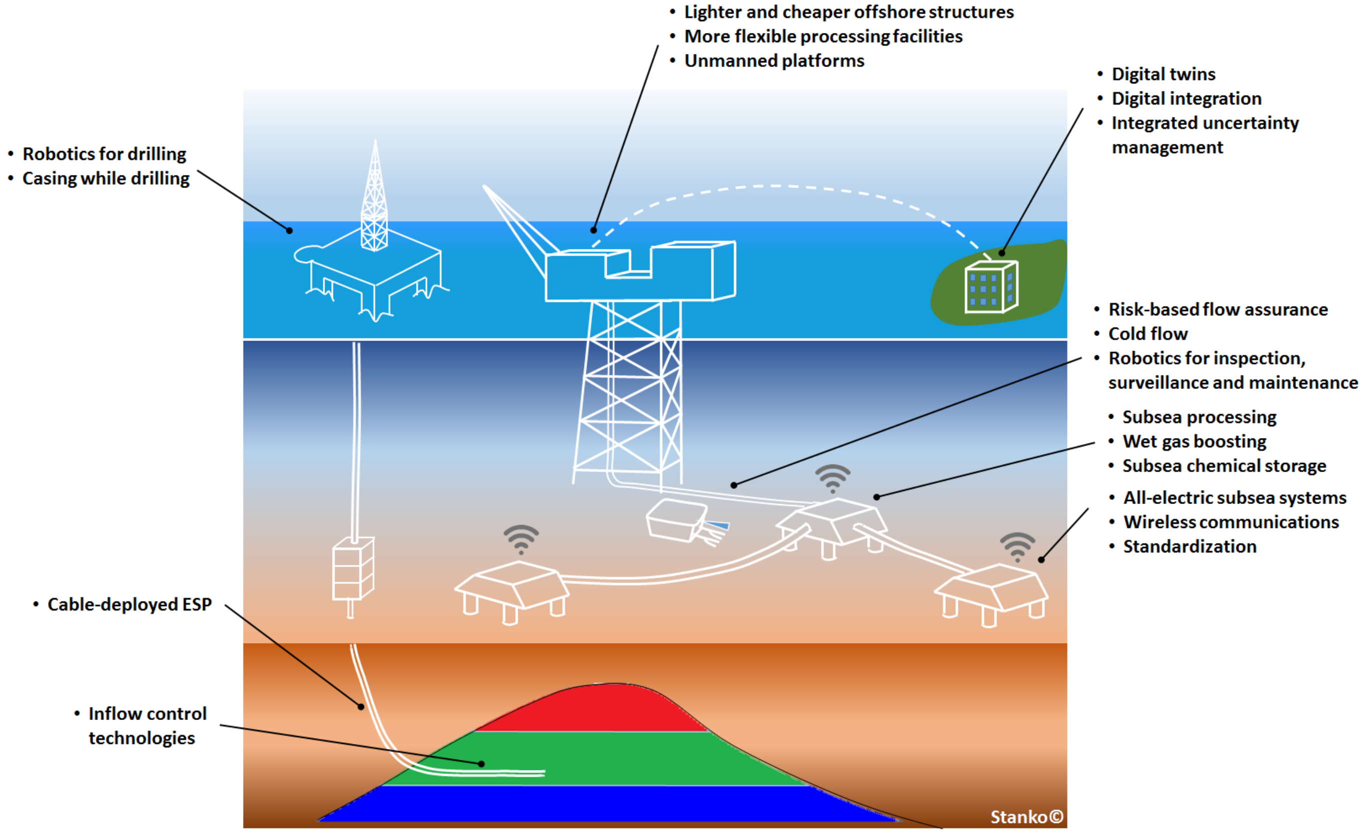


Figure 7.3.4: Technical solutions towards the "lean" production system

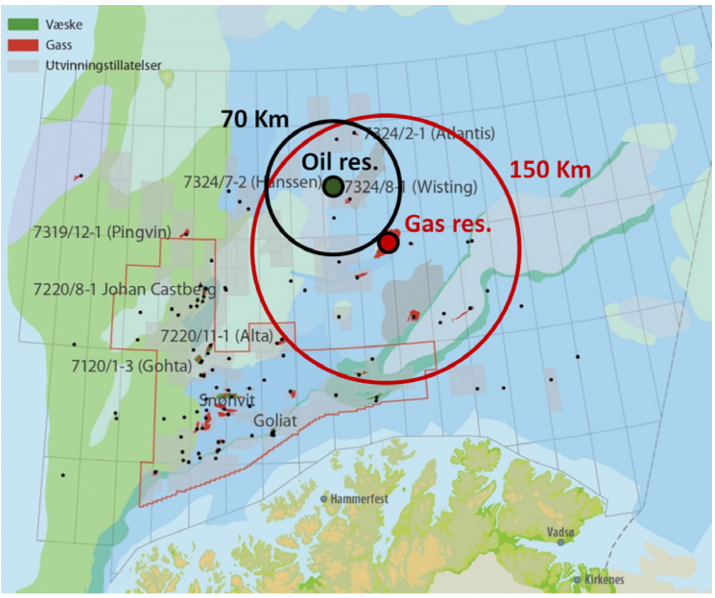


Figure 7.3.5-a: Current records in subsea tiebacks of oil and gas fields anchored to oil and gas discoveries in the Barents Sea

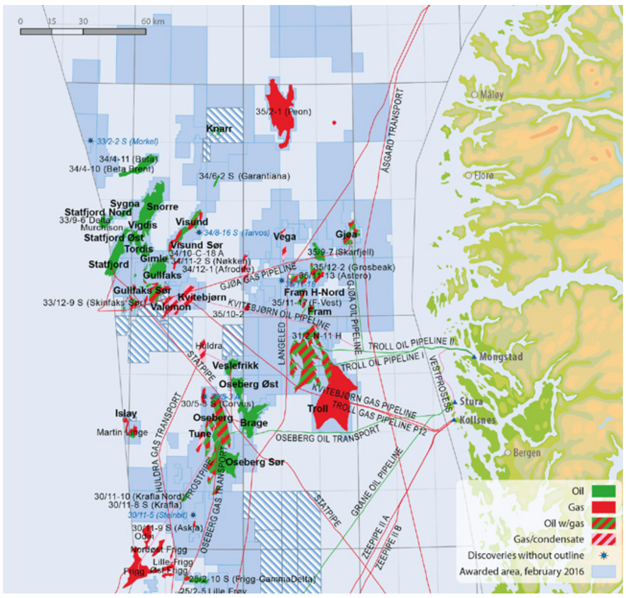


Figure 7.3.5-b: Potential tiebacks of oil and gas fields in the Tampen area

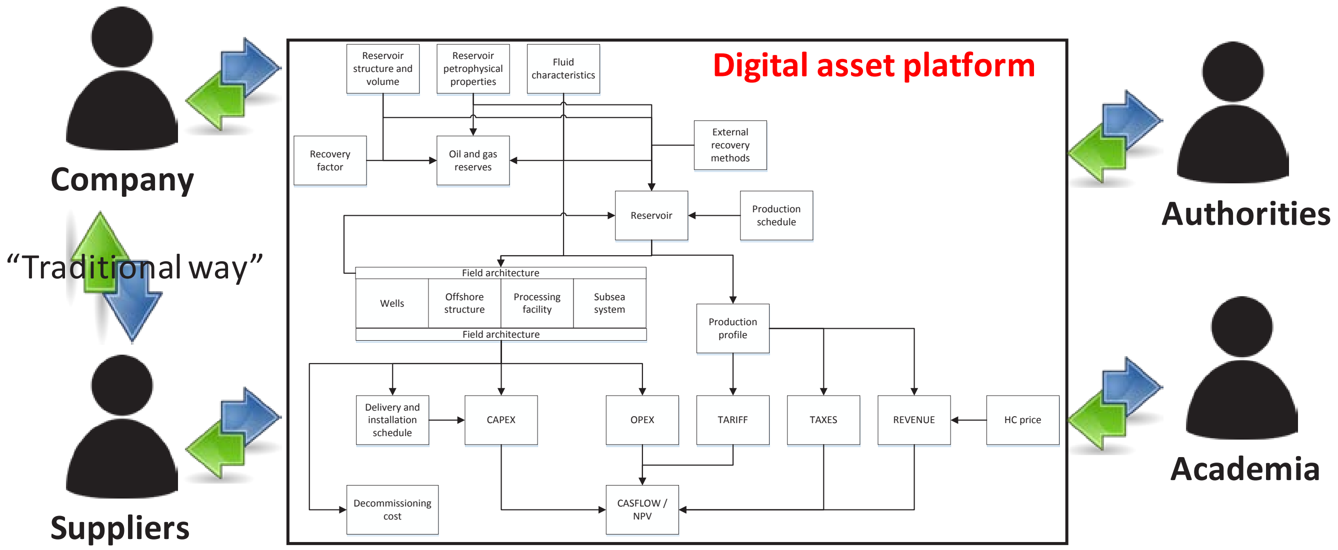


Figure 7.3.6: Digital platform for field development to integrate company, suppliers, authorities and academia

For example, operators should perform field planning considering the "big-picture" surrounding their individual fields and licenses. Figure 7.3.5-a shows an oil and a gas reservoir in the Barents Sea with two circles that depict the record tie-back distances for oil and gas fields. Theoretically, it could be possible to tie-in existing marginal reserves or future discoveries located inside the circles to the facilities of the future oil and gas fields (which are likely to dramatically increase the value of the original project). However, the uncertainty associated with future discoveries and the different ownerships hinders the establishment of common development projects and the flexibility in the individual projects for future expansion.

A solution to this issue is for authorities and regulating entities to establish area-strategies and goals, common development frameworks, platforms and incentives that are relevant to be considered by the companies during the field planning process. This is likely to increase the economic viability and profitability of the region and consequently, of the individual fields.

This issue is also relevant for mature areas, such as the one shown in Figure 7.3.5-b (North Sea). Small-size and marginal discoveries could potentially be tied-back to mature assets and platforms thus making their development profitable.

An area perspective on operations can provide flexibility at area level that removes the need to build in flexibility in every asset. This can be a major cost saver, but requires planning tools that can support both the uncertainty present from a field perspective and flexibility at an area perspective. This is relevant, especially considering that often the actual amount of hydrocarbons recovered from fields is sometimes larger than originally expected.

Planning methodology should to a larger degree capture the uncertainty present at all levels of field development (reservoir uncertainty, technological uncertainty, concept uncertainty, cost uncertainty, market uncertainty). While a thorough study of uncertainty is often made at each stage in the process, more of this should be channeled to the next level in the analysis, in order to promote flexible and robust field and area development. This requires new stochastic tools for economic analysis and risk analysis, being able to capture uncertain information from all the mentioned levels.

The planning process should also fully embrace existing methodologies that are based on digital integration of resources, for example multilevel integrated uncertainty management. This is done to fully deploy the "Integrated Asset Planning" vision, promote integration among disciplines and cooperation between operators, vendors and regulating authorities during the design and execution phase. In addition, this quantifies uncertainty and risk at all levels and stages of the process thus improving and adding robustness to decision making. Digitalization and the establishment of common digital platforms where all parties can interact (company, vendors, authorities and potentially academia) might be a major enabler for this goal.

During the field development process (see Figure 7.3.6) the company has the crucial role to look at the solutions proposed by the vendor, verify their purpose and determine their relevance and applicability for the particular case. Pre-packaged standardized solutions that have high flexibility and multiple components are easier to handle from the contracting point of view but they might cause extra expenses that affect negatively affect the economic value of the asset. Closer cooperation between company and vendor and performing third party "fit for purpose" reviews are ways to ensure that the solutions offered are applicable and necessary for the particular field development. The digital platform described above could enable this process.

Lastly, more complex economic models should be employed in the field planning process including stochastic modeling, real information theory and considering the variability of the final destination market.

The enablers presented here entail some major changes to the current "status quo" of field planning methodologies and they imply maturing and placing trust in some emerging technologies. However, this should ensure the profitability of challenging new prospects that will increase the profitability of "standard" projects and add robustness in general to developments to thrive under future price swings and crises.

7.3.4 Field development, R&D and education

Field development is an area that will be very active in future years and be mostly led by oil and gas companies. However, academia and research institutes have a crucial role in supporting this process by studying and developing a large part of the solutions described above and proposing novel enablers and technologies. Future research projects involving industry-academia-government will ensure timely and constant innovation in the topic.

Academia has also the role of educating and training future professionals that are not only proficient in their individual specialization but that are aware of the overall picture. Moreover, this will need professionals skilled in integration, digitalization, quantification and management of uncertainty and risk, to list a few areas. These professionals will be able to lead and contribute positively to the field planning process. Some actions to ensure this goal are to continue offering the existing courses on field planning, to include field planning tasks in existing courses (such as Experts in Teamwork) and in master's theses and specialization projects.

Lastly, this R&D area is closely related and intertwined with the other research areas presented: fully automated oil and gas field, Barents Sea province, environmental friendly O&G production, new business models for oil companies and suppliers and field extensions and decommissioning. Most of the findings, observations and the way forward described in the above sections should be taken into account in the field development framework.

R&D TOPICS

In Focus - topics for further work

- Reinforce and expand education in field planning (promote interdisciplinary thinking among students).
- Activate cooperation between academics from different departments and industry in common educational settings related with field planning.
- Expand research on model-based optimization for the field design process considering uncertainty.
- Expand research on integrated uncertainty management.
- Expand research related to promising technologies: improved drilling, robotics, wet gas compression, risk-based flow assurance, subsea processing.
- Expand and continue research related with the digitalization of the value chain model during field design: Improvement and integration of individual models.
- Further research on the inclusion of more complex economic models in the field design process and the utilization of alternative economic indicators

7.4

Environmental friendly O&G

7.4.1 Introduction to R&D area

In an emerging low carbon economy, it will become increasingly challenging to argue that the continued exploitation of oil and gas resources is sustainable and therefore a continuous development path for the Norwegian economy. The oil and gas industry will have to prove that it is able to address environmental challenges on a different scale than today and support the development of a more sustainable future. This will require substantial technological change, digitalization, new multidisciplinary work practices, new mindsets and new risk mitigation practices for the industry as we move towards a low carbon economy. If not, the general public and the authorities may lose confidence in the oil and gas industry. It will become very difficult to recruit young professionals and conserve the present operating conditions.

> Environmental friendly oil and gas production will be a pre-condition for a license to operate on the NCS and for the future development of the oil and gas business in Norway.

We describe environmental friendly oil and gas production as the integration of three research areas that mutually influence each other: real-time environmental monitoring, increased energy efficiency of new technology, and the development of technology and governance mechanisms that enable the development of a commercial CO_2 value chain.

7.4.2 Real-time environmental monitoring across the lifecycle of a field

In an environmental friendly oil and gas production regime environmental monitoring is a key activity in core area development, field development, drilling, operations and plugging and abandonment. This means that each phase will have its own strategies for data collection and risk mitigation.

In what follows we separate the long-term monitoring of the environment (i.e.: produced water and the fate of EOR chemicals), vs. oil spill preparedness in relation to containment of acute oil spills. Advances in ocean science, sensor platforms/landers and methods and standards development open up for more flexible and real-time sensor-based monitoring which can be tied closely to daily operations in the oil and gas industry; from exploration to plugged abandonment. This type of monitoring is important when moving towards more environmentally sensitive areas in the High North.

Let us begin with the long-term tracking of the environment. In the early phase of an area development, there is need for basic ecosystem dynamics knowledge, such as oceanographic and environmental data to establish a baseline for natural variation. Gathering temperature and current data, surveying and tracking the conditions on the seabed and water column will be important to understand the species distribution, biomass and diversity dynamics in a given area. It will also be important to detect and document the initial state of the habitat before oil and gas exploration starts. In this phase, surveys with vessels and local sensor networks on the seabed/water column will gather this type of background information. This sensor-based system detects the basic environmental and oceanographic parameters and collects data offline for local storage or is connected via a buoy on the surface of the sea. In the future it is likely that permanent submerged AUVs operating from docking stations can be the sensor platforms and do much of this environmental surveillance. It will be possible to configure the AUVs with the sensor package needed in this particular area for identification, mapping and monitoring objects of interest.

During exploration and production drilling there will be a more sophisticated sensor network that monitors the consequences of drilling operations, from leak detection to dispersion of drill cuttings from the top-hole section. In this situation environmental data are sent via a buoy, the transponder infrastructure of the rig or via a fiberoptic connection if this is installed at site. This makes it possible to integrate and develop better online discharge and risk modeling of the drilling process consequence for the corals and associated organisms. The online modeling value chain includes data transfer (acoustic, wireless and/or cabled), online drilling log data, assimilation feeding data to hydrodynamic modeling and release and transport modeling from which results are gathered and fed into the risk assessment tool. The risk picture will be visible at the desktop of the operators giving a common operating picture of operational and environmental data together with biological responses. This will influence the existing work processes and risk understanding during drilling. Both Kongsberg Maritime and DNV GL have new products and services in this domain.

In the operational phase of the field there will most likely be a permanent sensor network that measures the same basic parameters. This sensor network can be mounted on a subsea template, a separate lander connected via the subsea system or on the floating installations or permanent infrastructure. AUVs (combined with a subsea docking infrastructure) can be used as a moving sensor platform to monitor particular parameters, whether they are operational such as leakage detection from equipment and pipelines/flowlines or environmental such as CO_2 leakage monitoring similar purposes. This will be a mix of point sensors (measuring salinity, turbidity) and range sensors like echo sounders. Camera/still pictures and video can be used for pattern recognition to detect phenomenon and what species are around the sensor infrastructure. There is much ongoing sensor development in this area, from spectral imaging sensors to biological sensors (mussels) that can measure oil in water. The challenge is currently to integrate all these data sets that have different spatial and temporal dimensions.

All this calls for a real-time coupling of environmental data to process/production data. Improved predictive and decision models will be needed to enable this integration. Whether we monitor the production or CO_2 storage in the reservoir, a fixed or movable sensor platform is needed. The sensor package will differ but the same sensor network will probably be used.

After production, and after plug and abandonment, there will be a period of surveillance to document that the environment is handed back to the authorities in the same state as it was awarded. One should be able to track the fate of the most important environmental parameters across the lifecycle of the field. Mechanisms must be developed to track the integrity of plugged and abandoned wells and CO_2 storage leakages. It is likely that AUV and subsea sensor platforms will have a role in this final phase as well.

Oil spill preparedness will be an important capability in several parts of the lifecycle; exploration and production drilling, and during production. While the long-term environmental monitoring will address the long-term surveillance of a given habitat, oil spill preparedness will address the containment of acute spills. On the NCS we have a good system for oil spill preparedness undertaken by NOFO. When moving to the High North a number of new elements need to be incorporated into this capability to match the harsh environment of operations. There is a need to be able to contain oil drifting into ice infested waters and handle weathered oil. The harsh weather conditions call for a winterization of response equipment and response technologies that can handle high waves. More work is also needed in the use of dispersants and to understand the consequences of dispersants usage. There will be need for improved weather forecasting in the High North. This forecasting and simulation will need to monitor ice and icing and also be able to predict the sudden development of polar low pressures that can have profound implications for operational efficiency and safe operations. There will be challenges related to low temperature, darkness (polar night) and ice and a long response time regarding rescue operations.

Finally, we need more focus on technical safety barriers when entering the High North. It will mean safety barriers management and improved solutions for operations in ice. Floating ice is not a challenge in the Barents Sea, the greater problem is the accumulation of ice on the installation structures. In areas with ice better optimization between designing for loads and disconnecting systems must be developed. There will also be cultural/organizational management issues on decision support and actions that will be important to handle.

Real-time or right-time multisensor environmental measurements provide vast amounts of data, i.e.: oceanographic, echosound, video, benthic data, weather data, remote sensing data and spatial metadata. There is a need for different types of methodologies that can simplify the interpretation of these data sets across a temporal and spatial dimension (point source/range data) and develop more predictive models for use in research and operational activities.

One needs to know more about natural variation and have sufficient data with a proper granularity concerning the life on the seabed and in the water column. Integrating these data sets will depend on a range of models that detect phenomena in real time (pattern recognition algorithms), measure emissions over time (i.e. DREAM) and adapt risk models[1] to more com-

R&D TOPICS

Some research questions to be considered in this area are:

- Defining "environmental impact" and applying rules so that impact can be deduced?
- How can we model the environmental domain and environmental baselines so that measures of impact can be deduced?
- How to identify, map and monitor habitats for management and sound decision making?
- How do we develop acceptance criteria for operations using real-time environmental data?
- How do we see the sensor-platform development and integration of data-sets with different temporal and spatial dimensions?

1 https://www.sintef.no/en/software/dream/

Figure 7.4.1: Statoil Lofoten-Vesterålen ocean observatory, see love.statoil.com

plex eco-system models (SYMBIOSES)[2]. It is very likely that we will see increased openness related to the sharing of environmental data, Statoil's LoVe-portal is an example of this. Oil companies on the NCS are used to independent monitoring and 3rd party verification. The scientific community - and other 3rd parties - have an interest in receiving more environmental data.

NTNU's role in this field

NTNU has substantial competence in the field of marine biology using enabling technology to identify, map and monitor objects of interest. The data/computer science contribution is also critical here with modeling redictive analytics, machine learning, and the Internet of Things. Modeling competence with a solid background in mathematics and natural science will also be important. Finally, a general knowledge of oil and gas operations and instrumentation/sensor systems (i.e. AUVs) will be critical.

Digitalization, automation, sensor networks and autonomous systems will make it possible to develop more open platforms for sharing environmental and operational data. A more seamless and transparent integration of work processes, decision processes and data access is needed for environmental friendly oil and gas production.

NTNU has the possibility to drive this development. Most of the research in this area will be multidisciplinary, increasingly digitalized, and the need to be able to communicate across scientific boundaries will be substantial. There is also a role for social science/management disciplines in helping to define the risk management and governance structures around such a new environmental regime that will influence current operational models and mindsets. The recent discussion around the concept of the 'ice edge' indicates that this is not just an environmental/ technical question but is part of wider societal discussion in Norway. There are ethical and value rational issues in relation to the environment, technology and human intervention. Finally, it is also likely that this re-orientation and new focus will make the oil and gas domain more attractive to future students.

7.4.3 Energy efficiency

Energy efficiency is related to assessing the most energy efficient solution across the lifecycle of a field both for new fields and for brown fields with new tie-in infrastructure. Energy production must become more efficient with less energy consumption. Energy efficiency will also be a core property of area development. The gas turbines and combustion technologies used offshore for power generation have various degrees of production efficiency and utilization. We now see the development of fleet management practice that optimizes the performance of the machinery across the value chain and operational core areas using modeling and optimization systems. Just as important is the need to optimize logistics and its footprint, but here we will focus on offshore power generation. The authorities want to increase the electrification of the NCS to reduce carbon emissions, but connecting offshore installations to the onshore electricity grid has traditionally been more expensive.

The motivation for electrification of offshore installations by linking them to the onshore grid has been to reduce Norwegian CO_2 emissions. While this might be a consequence, it is unfortunately not the right objective. What matters in fighting climate change is reducing global emissions. Electrification from onshore will most likely have zero or negative effect on these efforts. In short, the reason is that both the petroleum sector and the power sector of Europe are included in the European Emission Trading System (EU ETS). Here the number of quotas is designed such that emissions will be reduced by 43% before 2030. Local efforts do not affect the number of emission permits traded, and hence have no effect on this number in either positive or negative direction. In addition, there is the negative effect of constructing and installing the cable and the possibly negative effect of more natural gas available for sectors not in the EU ETS. The electrification

2 http://barentssea.symbioses.no/

from onshore sources may have been justified if it is part of a permanent change or transition of society. This is not the case, as the installations are time-limited. Electrification of the NCS can only be justified if it is economically sound, not as a climate friendly effort. Today the difference between cost and savings makes it neither profitable nor climate friendly.

However, in this wider context there are alternative sources to offshore power supply such as fuel cells and wind turbines with battery storage. It is possible to see the development of wind farms that could supply offshore installations with power.

There is still skepticism about this among the oil companies (see Figure 7.4.2) because a steady and realible power supply is needed to maintain uptime and availability, and the power supply from wind turbines might come short with little or no wind. Batteries might compensate in the short run but there still a long way to go to make this solution technically feasible for this type of use. More research is needed to improve the combustion technologies (thermal energy efficiency/ compressors) effectiveness and how to make more energy production with less. Better simulation models, tools and methods are needed to understand how different energy sources can be combined in the lifecycle of an oil and gas field. A more energy efficient offshore fleet should be targeted using e.g. hybrid marine power plants by combining energy storage devices such as batteries in combination with combustion engines such as LNG and diesel engines. New incentives that make it profitable to invest in technology that reduces CO_x, NO_x and SO_x emissions should be implemented. In addition, the proper dimensioning of the fleet with respect to power ratings should be revised.

R&D TOPICS

The following are key research areas will be important in this domain:

- How can we make energy efficient production less carbon intensive via integration or replacement with onshore grid electricity or wind turbine/fuels cells batteries?
- The electricity grid operators and wind farms operations are very different from the oil and gas operators, how do we develop the necessary integration of technologies, control systems, operating and business models that will enable us to develop a more energy efficient and more carbon neutral power generation?
- How to design and operate hybrid power plants and propulsion systems on offshore ships using LNG, batteries and diesel engines reducing energy consumption and emissions by a fraction with 70-80% reduction of today's solutions?

Figure 7.4.2: Sheringham Shoal – Statoil (Photo Alan O Neill)

NTNU's role in this field

There are research opportunities in both technical and non-technical areas within this domain. The existing competence at NTNU from el-power generation will be important here, coupled up with ICT-smart grid capabilities that are emerging in the grid operator domain. The more generic Internet of Things and Big Data type of competence mentioned earlier will also be important in this domain. Finally, this change of power supply will also change the contract models, collaboration across boundaries and possibly new governance and market mechanisms that do not necessarily exist today. Social science and economics competence will be important to help in this transition process.

7.4.4 CO_2 value chain

We have already presented how the operational monitoring of CO_2 storage can be addressed in section 7.4.2. The future scenario on the NCS might be zero/low carbon emissions for new fields, where new offshore power supply solutions can enable offshore de-carbonized value chains. CO_2 emissions can be cut via CO_2 storage and by using CO_2 for EOR. There are heated discussions on the development of a new value chain for CO_2.

The NCS is a suitable storage location for the EU's and Norway's CO_2 , and our policies will be linked to the ambition of the EU. This will most likely be a large-scale business opportunity for Norway and we can become an important caretaker of EU's CO_2 emissions in addition to our own CO_2 emissions both onshore and offshore.

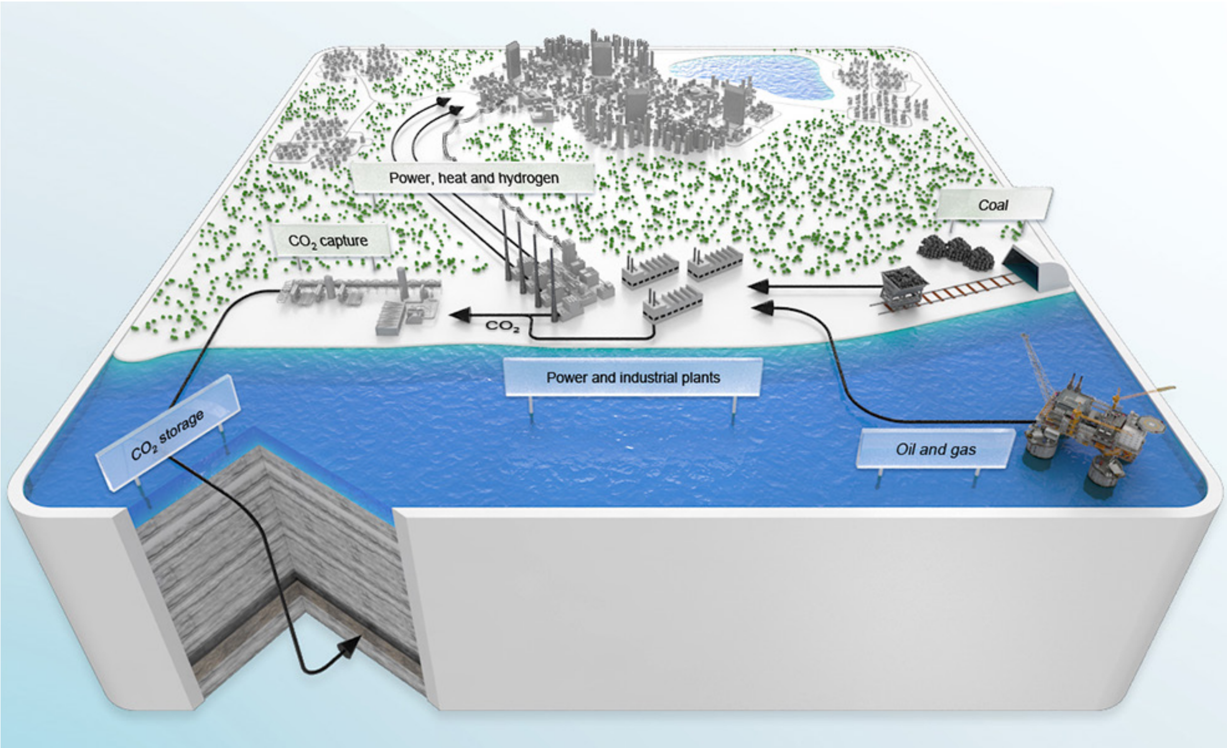


Figure 7.4.3: CO_2 Value Chain (NPD & Gassnova)

The commercial risk rests with the authorities and is pending. There is still large uncertainty concerning the realization of a future CO_2 value chain, but the Northern Light report[3] describes the technical feasibility of developing a full-size CO_2 processing and storage facility. In the current Northern Light solution, special ships will deliver liquefied CO_2 to the storage facility onshore. From there the CO_2 will be transported via a pipeline to a subsea installation and accumulated/captured in a liquid state in the reservoir. Such a CO_2 storage facility will not be especially complex; however, there is great potential for automation and digitalization. The risks will be different from a facility with hydrocarbons, the main safety hazards will be suffocation from CO_2 and fatigue due to extreme low temperatures of the equipment. Figure 7.4.3 illustrates the principle.

NTNU's role in this field

If a commercial model for a future CO_2 value chain eventually becomes viable, NTNU has relevant competence among existing faculty resources. Much of the same technology that has been used for oil and gas processing can be used in CO_2 processing and storage. The same domains that work in gas processing and transport, cybernetics, operation and maintenance, materials management, energy and environment at NTNU will be relevant here.

R&D TOPICS

The following questions should be addressed:

- Address the special consequences of CO_2 as a medium in a processing facility when it comes to operational requirements, material selection/fatigue, transport of liquids. New safety barriers need to be defined
- Modelling of core area strategies, business development of new CO_2 value chain. Financial model and profitability analysis of the new value chain.
- Financial, and operational analysis of key input factors in a profitable CO_2 value chain. This can range from optimization of the ships carrying the captured CO_2 to its storage location to developing more stable pipeline infrastructure to handle EU CO_2 emissions for storage on the NCS
- CO_2 storage and reservoir management for sealed storage and EOR

3 NPD 2016, Mulighetsstudier av fullskala CO2-håndtering i Norge: https://www.regjeringen.no/globalassets/departementene/oed/pdf/mulighetsstudien.pdf

7.5

New business models for oil companies and suppliers

7.5.1 Narrow and wide approaches

Business model development is a vital part of business strategy, and well-known business models are often used as "recipes" to be followed by managers.

The traditional definition of a business model describes how an organization creates, delivers and captures value. Joan Magretta (2002) divides the business model in two distinct parts: "Part one includes all the activities associated with making something: designing it, purchasing raw materials, manufacturing, and so on. Part two includes all the activities associated with selling something: finding and reaching customers, transacting a sale, distributing the product, or delivering the service". Either the driving force in a new business model may be to design a new product for a hitherto unmet need, or it may take the form of a process innovation: "a better way of making or selling or distributing an already proven product or service".[1]

The focus of a traditional business model is on a single organization, and as such can be characterized as "narrow". Experience from the last few decades, however, demonstrates that the business models of many of the most successful companies are better described as "wide," taking the form of network-based and digitalized business ecosystems where different players are interdependent, and where changes in one part of the system quickly can have consequences for other actors. A possible term is complex, adaptive, platform-based economic systems. Major players in such systems are Apple, Google, Facebook, Alibaba and Amazon. Other examples of fast-growing platform-based businesses are found in the "sharing economy", where direct linkage between suppliers and customers dramatically reduces transaction costs.

Both traditional ("narrow") and new ("wide") approaches may be useful for the development of new business models in the oil and gas industry. In both cases refining and developing existing business platforms stand out as a necessary precondition.

A basic issue in a traditional approach will be to search for new business opportunities, based on the industry's fundamental technological, geological, market and project management competencies. Relevant possibilities may be found within fields such as offshore wind, operation and maintenance of complex industrial systems, mining, geothermal heating, and the application of technologies from integrated operations for other purposes.

An example of a possible new, platform-based business model is to develop fully integrated CO_2 value chains, including capture, transport and storage, not only for the industry's own production facilities, but also for other industrial and public users.

The transformation towards digitalized and model-driven organizations is already to some extent under way, also in the oil and gas industry, even though much remains before the promising potentials of advanced integrated operations are fully exploited. There is probably unexploited potential both in Big Data and open data approaches, especially when it comes to discovering new resources. A well-known example is the story of Gold Corp, a mining company which published all of its geological surveys and maps on the Internet, offering a reward to those who could help them to find more gold. Stimulating geologists and academics worldwide to dive into the data, Gold Corp succeeded to increase its finds and profits. The authors of the book "Wikinomics"[2], who tell this story, argue that such an open source model can be applicable for many industries that possess large amounts of basic data.

7.5.2 New contract strategies

One important driver for better business models will be to redefine the relations between oil companies and suppliers, by understanding the organizational field as a network-driven economic ecosystem, and transforming the basic character of buyer-supplier relations from zero sum games to profitable partnerships. One of the most obvious targets stemming from this will be to develop new contract models for projects.

A prominent example of a new approach is the model used by Heathrow Airport Holdings Limited, formerly British Airports Authority (BAA) for the construction of the new Heathrow terminal 5 (T5), which consisted of two large terminal buildings, an air traffic control tower, road and railway transportation links, 13 km of bored tunnels, airfield infrastructure, a 4000 space multistory car park, and a hotel, with a total budget of USD 8.5 bn.

Before starting the project BAA surveyed most of the comparable development projects completed in Britain during the last few years, and found that common denominators were time delays and massive cost overruns. The conclusion from this survey was that existing industry practices in contracting and project management were unable to handle the complexity, scale and risk in the T5 project. Two key areas contributing to poor performance in large and complex projects were identified: Lack of collaboration between project partners, and the project owner's reluctance to assume responsibility for project risk. The new approach developed on basis of these

1 Magretta, Joan "Why Business Models Matter", *Harvard Business Review,* May 2002

2 Tapscott, Don & Anthony D. Williams (2006) Wikinomics: *How Mass Collaboration Changes Everything*. Old Saybrook: Tantor Media

insights was based on two core elements: integrated project teams and that BAA as project owner was willing to accept the economic risks.

BAA's insight was that despite efforts to transfer risk and responsibility, the client ultimately bears and pays for the risk when a megaproject runs into trouble. They therefore decided that a radically new approach was required. The T5 Agreement was then developed as a type of cost-plus incentive contract, in which the client pays the constructor the costs incurred plus a profit margin. Unlike other forms of cost-plus contracts, where the risks are shared between the client and contractor, BAA assumed full responsibility for the risk and worked collaboratively in integrated project teams with first-tier suppliers to create innovative solutions. This was the first time these principles were used in a large UK construction project. By removing the risk from the supply chain, avoiding adversarial relationships and offering incentives to perform well, the T5 contract was designed to encourage teams to work collaboratively to create innovative solutions, rather than seek additional payments or enter into legal disputes about scope changes. [3,4]

7.5.3 Innovation and change management

Innovation may be defined as *...a process of turning opportunity into new ideas and putting these into widely used practice*[5]. Innovations may come in the form of new or improved products, improved production or distribution processes, or as new ways to serve markets. Most innovations in established industries are of an incremental type, but we sometimes also witness innovations that are radical or disruptive. An important concept in all cases is "open innovation", which simply states that useful ideas and new knowledge can originate both from within and outside of a company, and that the decisive factor is to make the best use of both external and internal ideas. The general challenges in all cases are to find and nourish new ideas and to exploit these ideas for commercial purposes. This means that any large organization searching for innovations must develop its abilities to balance internal order and chaos. Order is necessary to plan, coordinate and finance activities, whereas elements of chaos are necessary in order to stimulate and give room for creativity and the growth of new ideas.

A prerequisite for innovation and for the development and exploitation of new business models is organizations with inbuilt capacities for continuous change and development. Such capabilities are dependent on three basic foundations: leadership, training and the overall functioning of the organization. Leadership may here be defined as: "the ability of an individual to influence, motivate, and enable others to contribute towards the effectiveness and success of the organizations of which they are members".[6] New ideas are often the outcome of cross-fertilization, drawing on inputs from different sources of expertise, which may reside in separate departments or parts of the organization. In such cases it can be relevant also to talk about collaborative leadership, which can be described as: "the capacity to engage people and groups outside one's formal control and inspire them to work towards common goals – despite differences in convictions, cultural values, and operating norms."[7]

Continuous success in bringing out new or improved products and processes is also a product of consciousness, experience transfer and training, in organizational settings where people learn how to stimulate and share ideas, and develop ideas into innovations. The ability to succeed in innovation is also dependent on the overall organizational capabilities for innovation and change, considering both formal and informal factors. A systemic and holistic approach to organizational development is therefore necessary. Similar approaches are also necessary to understand and manage the organizational preconditions for safety in operations.

A useful tool for approaching organizational analysis and development in a systemic and holistic way is to use a "pentagon model".[8,9] The pentagon model is an analytical tool that subsumes the most important organizational variables under five broad headings, covering both formal and informal dimensions. The headings are, respectively: formal structure, technology, culture, interaction, and social relations and networks. These five factors are closely interrelated and influence each other, but they may also be investigated separately. The relative importance of each of them varies, depending on the situation in the organization studied, and on what kinds of problem or challenge that are in focus.

R&D TOPICS

Four important future research topics:

- New business models in the petroleum industry
- New contract strategies for projects
- Organizational preconditions for innovation
- New business models and organizational preconditions for safety

3 Brady, Tim & Andrew Davies (2014) "Managing Structural and Dynamic Complexity: A Tale of Two Projects". *Project Management Journal 45/4* (21-38)

4 Tommelein, Iris, Ballard, Glenn, Rolstadås, Asbjørn and Per Morten Schiefloe (2011) *Megaprojects Leadership: Research Summary and Recommendations.* University of California, Berkeley: Project Production Systems Laboratory

5 Tidd, Joe & John Bessant (2013) *Managing Innovation: Integrating Technological, Market and Organizational Change*, New York: Wiley

6 House, Robert J., Hanges, Paul J., Javidan, Mansour, Dorfman, Peter W. & Vipin Gupta (eds) (2004) *Culture, leadership and Organizations.* The GLOBE Study of 62 Societies. Thousand Oaks: Sage

7 Ibarra, Herminia & Morten A. Hansen (2013) "Are You a Collaborative Leader? In HBR *On Collaboration*. Boston: Harvard Business Review Press (1-14)

8 Schiefloe, Per Morten et. Al (20025) *Årsaksanalyse etter Snorre A hendelsen 28.11.04 Stavanger:* Statoil

9 Rolstadås, Asbjørn, Iris Tommelein, Per Morten Schiefloe & Glenn Ballard "Understanding project success through analysis of project management approach". *International Journal of Managing Projects in Business*. 7/4 (638-660)

7.6

Late life challenges and decommissioning

7.6.1 Introduction to R&D area

For installations reaching end of life a major challenge is to avoid escalating maintenance cost and at the same time maintain the safety integrity and have acceptable production assurance. Although these are general research challenges addressed over decades, the BRU21 fact-finding meetings definitely indicate the need for *further* R&D to cope with these challenges.

Investigation of recent safety critical events in the North Sea demonstrates that the lack of safety critical maintenance is one of the greatest concerns when it comes to safety. The safety challenge may be categorized into technical safety integrity problems and safety *control* problems. An essential aspect of a control problem is to identify threats (early warnings) and be able to cope with them, i.e., prioritize resources. Model-based approaches, in the era of digitalization as emphasized in Section 7.1.1, is a prerequisite to cope with both of these problems. The core of model-based tools and approaches is automated processes for data acquisition, transforming data streams into meaningful information, and integration into model-based decision-support tools provided for the end user.

In addition to "safe navigation" in late life there is also an ultimate need to close production, and face the challenges of decommissioning. Decommissioning challenges relate to both technical issues as well as operations research approaches for handling the portfolio of decommissioning projects.

In the following four important areas from the BRU21 fact-finding meetings are presented in terms of research challenges.

R&D TOPICS

Research and development requirements

- General improvement of RUL estimation and prognostics combining signal processing/AI/Machine learning methods with probabilistic methods based on physical degradation.
- Tools and methods for maintenance planning synchronized with production and operations activities.
- Big Data:
  – Development of flexible data storage and retrieval systems that are easily adaptable to different production systems and scenarios.
  – Algorithms to analyze huge amounts of data: Transformation of Big Data to Smart Data.
  – Linking collected data to digital models of the corresponding production systems, components and sensors ("digital twin" connected by IoT and sensor technology).
- Easy but realistic economic models for cost-benefit analysis.

7.6.2 Maintenance optimization

Formal maintenance optimization methods become essential in tail production where margins are small and the uncertainties need to be handled systematically in order to minimize HSE and production risk. A case study of Norwegian railways has shown a potential of up to 30% savings in the total cost by using formal optimization methods. The potential for "safe" cost savings is seen both when it comes to implementation of classical optimization approaches and also when it comes to synchronization of maintenance and operations emphasized in e.g., Industrie 4.0 approaches.

Figure 7.6.1(a) shows traditional maintenance optimization where the objective is to determine the time interval between calendar-based preventive or inspection activities i.e., move from current situation, •, to the optimal situation, •. Figure 7.6.1(b) shows predictive maintenance optimization where focus is on determining the optimum execution point of time for activities triggered by the condition of the unit.

A fundamental assumption is that the cost of executing a "hard" maintenance task decreases with time because it is easier to synchronize the work with production. On the other hand, waiting too long represents a high risk of component breakdown. More precise residual useful life assessment and degradation modeling is essential in addition to be able to integrate production and maintenance planning. In the Industrie 4.0 concept this corresponds to creating virtual simulation models (digital twin of the real physical components and the production system) by means of sensor technology connected by Internet of Things (IoT) and manipulated by Internet of Services (IoS). Further big data and machine learning approaches are supplementing traditional physical-based degradation models.

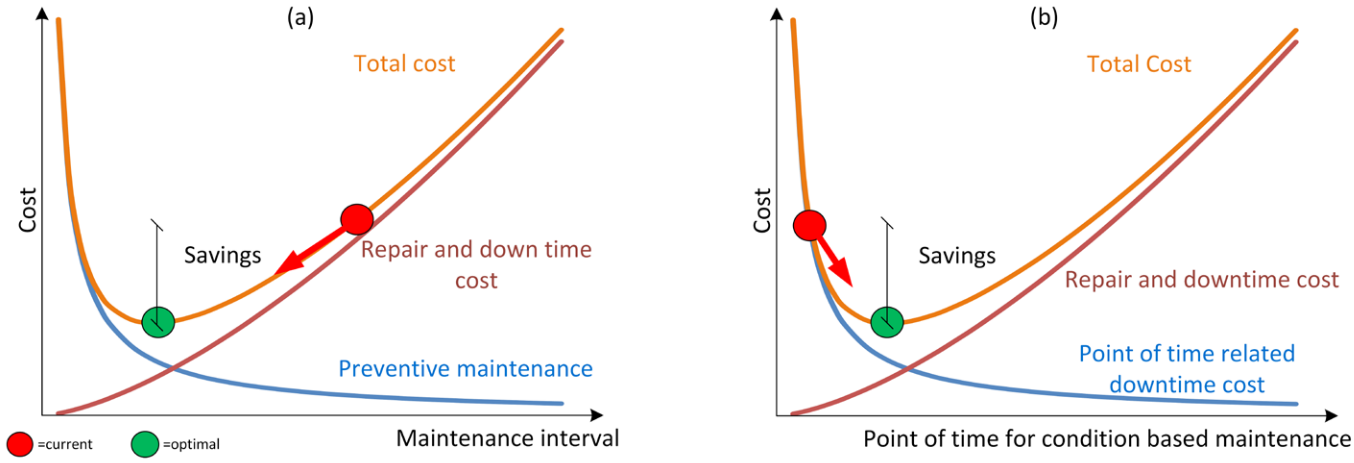


Figure 7.6.1: Traditional maintenance optimization (a) and predictive maintenance optimization (b)

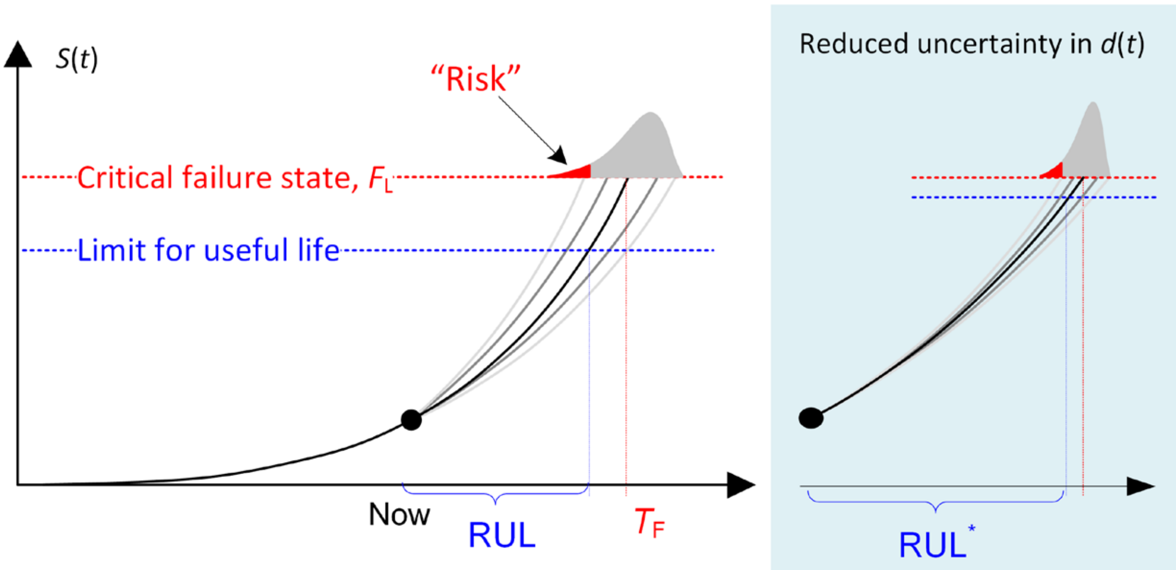


Figure 7.6.2: Extending residual useful life from RUL to RUL by reducing uncertainty in degradation speed, d(t)*

7.6.3 Structural integrity management in late life

To control the structural integrity of the installations is crucial for life extension. This relates in particular to concrete and steel substructures. Figure 7.6.2 shows a simplified degradation model. Large degradation uncertainty results in a *limited* residual useful life of the installation because we have to account for a possible fast degradation leading to a fast occurring critical failure. On the other hand, if we are able to control (i.e., reduce uncertainty of) the degradation we might extend the (safe) residual useful life.

This means that *knowledge as such* is essential to operate safely in the late life of an installation. It is further required to reduce degradation rate by e.g. smart coatings. Economists are people who love life extension not only because this extends the production period but also because it can postpone the huge decommissioning costs.

R&D TOPICS

Research and development requirements

- General improvement of RUL estimation is highlighted in Section 7.6.1, but emphasis is now on structural integrity where systematization of design/ as-built data, future "load profiles" and "current state" is crucial; Transformation of Big Data to Smart Data. Develop algorithms for material degradation.
- Develop a roadmap for degradation modeling as a basis for RUL estimation where the aim is to have a systematic approach to present "safety cases" for structural integrity.
- Development of smart solutions for lifetime extension e.g., coatings, mechanical clamps and condition monitoring techniques.

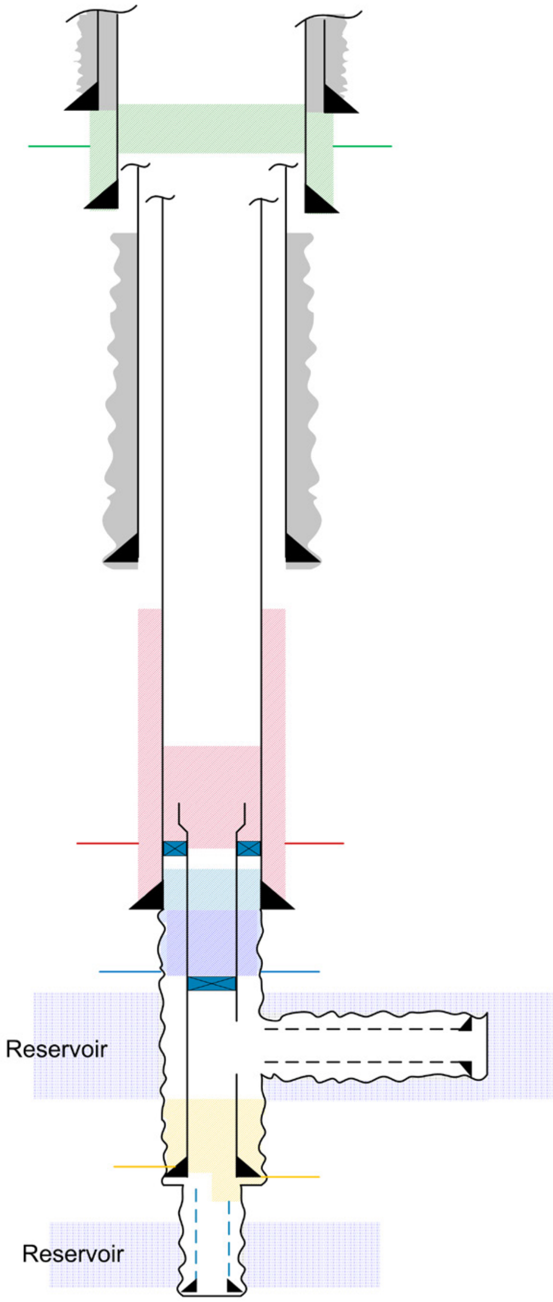


Figure 7.6.3: Schematic for the permanent plugging and abandonment (P&A) phase.
Reference to figure 7.6.3:
An Introduction to Well Integrity. Rev. 0, 04 December 2012.
http://www.norskoljeoggass.no/en/News/Successful-collaboration-with-universities/

7.6.4 Decommissioning

In the years to come, a large number of platforms, subsea pipelines and subsea equipment will be decommissioned. Specially designed vessels have been constructed to allow effective platform removal, e.g., the Yme platform deck was lifted off in one single operation and shipped to shore for total disassembly. More than 3 000 wells will have to be permanently plugged in the NCS. Well plugging is time-consuming, and requires heavy and costly rigs to perform the operations. For the next 20 years it is foreseen that 20 rigs will be working day and night to plug wells.

The technologies used for the plugging and abandoning of wells has not changed significantly over the years. Water-based cement slurries and drilling fluids are still the basic materials used to plug most wells. A permanent well abandonment has an eternal perspective. The permanent well

R&D TOPICS

Research and development requirements

- Develop a roadmap for new P&A technologies, e.g., facility cleaning and removal technology, cementing technology, shale creep around casing annulus, alternative materials / barriers, thermite technology, side-track drilling, PWC (Perforate, Wash and Cement), laser for cutting of multistring casings and rigless plugging.
- Numerical simulations of forming shale barrier and other quantitative approaches to verify that a solution fulfils the requirements.
- Monitoring methods, e.g. status of plugged wells and tools that can see through two casing strings.

barriers shown in Figure 7.6.3 are to be placed as close to the source of potential inflow as possible and at a depth which has as a minimum sufficient formation strength. As the wellhead and casings will be cut 5 m below the seabed as a part of the permanent abandonment, it will be very difficult or impossible to re-enter the well afterwards.

In order to ensure integrity it is crucial that the cement is bonded both to the formation and to the casing with integrity, as well as to the casing. A general and important principle for all barrier elements is that they are to be designed to withstand all the possible loads they can be exposed to during the lifecycle of the well.

Generally, systems and methods which can reduce the operational time and avoid the need for using large vessels will contribute significantly to cost reduction. Today, well design includes focus on more effective P&A operations. An optimized casing program based on extended use of liners with tie-back strings may ease the P&A operations since the tie-back string can be pulled without milling or cutting. NORSOK D-010 provides guidelines for well plugging. However, the operators have the full responsibility for the integrity of the wells which means that existing guidelines, rules and regulations have to be challenged: What is safe enough for a specific case?

7.6.5 Overall risk perspective

In order to navigate safely in the late life of an installation it is required to strengthen existing safety management procedures to cope with both known and unknown threats. Known threats are related to lacking and outdated documentation, physical degradation of structures and systems, lack of tacit knowledge due to downsizing and retirement of key personnel, running too many processes in parallel (cost cutting, modifications, safety programs etc.).

While an installation is still producing the main risk relates to hydrocarbon hazards and structural integrity challenges, whereas in the decommission phase threats in connection to marine and autonomous operations, reclassification, decoupling from producing installations, and occupational accidents need more focus.

R&D TOPICS

Research and development requirements

- Systematization of the relevant risk contributing factors affecting late production life.
- Systematization of the relevant risk contributing factors affecting the decommissioning phase.
- Develop tools and methods to aggregate risk contributing factors in appropriate risk barometers (dashboard) for easy visualization (drilldown capabilities operating on a so-called rich risk picture).

8.0

The way forward – NTNU strategy

8.1 Introduction

The findings from the industry meetings and the identified research areas presented in the previous chapters demonstrate the need for new technologies, operational methods and knowledge to ensure future viable and competitive energy production from petroleum reserves on the Norwegian Continental Shelf.

As indicated in the previous chapters, NTNU – the university that integrates solid foundations in science, technology, economics and humanities – has the right infrastructure, knowledge and experience base to meet these industrial demands either through internal resources or by hosting and coordinating larger research projects/programs involving external partners. Below we will take a closer look at the research areas identified in Chapter 7 from the perspective of NTNU strategy in research and education for meeting these industrial demands.

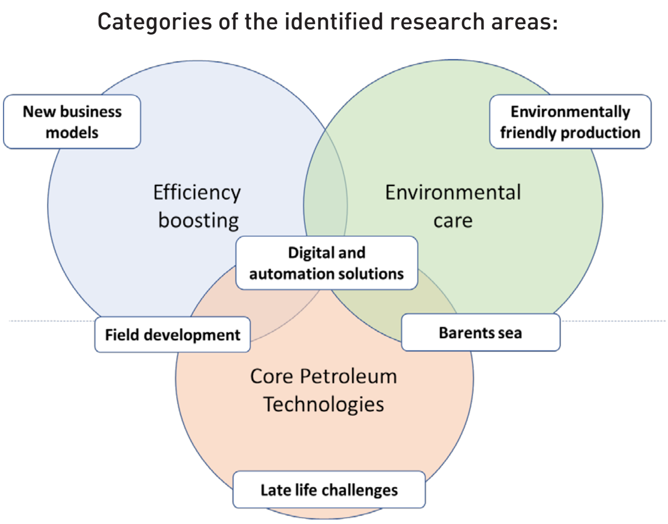


Figure 8.1: The research areas from chapter 7.

The category Core Petroleum Technologies represents technologies that enable production of petroleum resources on the Norwegian Continental Shelf. Efficiency Boosting Technologies focus on increasing efficiency of development, planning and operation with existing and emerging petroleum technologies. The category Environmental Care covers technologies and methods for environmental aspects of oil and gas production.

These three research categories, together with Safety and Security – necessary requirements for all oil and gas operations – give an overview of the key research incentives.

The Core Petroleum Technologies category is covered by various disciplines within Petroleum Engineering: Geology and Geophysics, Exploration, Drilling and Well, Production, Plugging of Wells and Field Decommissioning, and other relevant disciplines. Challenges in Late Life, Field Development and Barents Sea, which fall into this category, can be addressed by enhancing the knowledge base and educational efforts through the existing infrastructure for petroleum research at NTNU.

The Efficiency Boosting and Environmental Care categories correspond to highly interdisciplinary research. Here petroleum science intertwines with information and communication technologies, cybernetics, marine, environmental and management science. The interdisciplinary scope of these research areas requires integrated efforts across departments and faculties at NTNU to reach full value creation. Research and education in these areas will involve the Departments of Geoscience and Petroleum, Engineering Cybernetics, Information and Communication Technologies (ICT) including Cyber Security, Natural Sciences, Marine Technology, Biology, Industrial Economics and Technology Management, Sociology and Political Science, Center for Autonomous Marine Operations and Systems.

8.2 The proposed Research Program in Digital and Automation Solutions for the Oil and Gas Industry

The BRU21 fact-finding meetings revealed that O&G actors perceive digitalization as *critically important* for future competitiveness. This holds for oil companies, service providers, and authorities alike. The importance of digitalization comes from several facts. Firstly, the oil and gas industry has been lagging behind other industries, e.g. downstream process industries and manufacturing industries that adopted automation, robotics and digitalization technologies a long time ago, thus significantly increasing their efficiency. The economic potential of increased utilization of these technologies in the oil and gas industry is huge.

Secondly, automation and digitalization is nowadays a megatrend, which is transforming industries and everyday life as digital tools with amazing new capabilities are becoming available. These include advances in software, computer hardware, the availability of data sets, sensors, networks and communication, visualization, robotics and automation, data analytics, autonomy and cyber-physical systems. Digital and

NTNU STRATEGY

PROPOSED NTNU STRATEGY FOR RESEARCH AND EDUCATION IN OIL AND GAS

The role of NTNU in meeting the identified industrial needs is in

- **Research:** creation of novel methods, technologies and operational practices, with (potential) industrial value and sufficient level of maturity to be accepted by the industry for further development, commercialization and use.
- **Innovation:** active steps towards industrial implementation and commercialization.
- **Education:** training of specialists for the oil and gas industry
  – scientists and specialists for research, development, implementation, use and maintenance of high quality technologies in the identified research areas,
  – engineers and managers aware of the possibilities provided by the new technologies and thus ready to accept and use them in industry.

All the three objectives are essential for achieving high value creation for the oil and gas industry. To reach the Research, Innovation and Education objectives for the areas identified in Chapter 7, the following three actions are proposed:

- **Establish a new Research Program in Digital and Automation Solutions for the Oil and Gas industry** to address the most urgent yet fundamental industrial needs
- **Continue long-term research** with added focus on the identified research areas
- **Strengthen educational programs in petroleum- and petroleum-related disciplines** to respond to the identified industrial needs.

These actions are described in more detail below.

automation solutions based on these advances open significant economic opportunities at all levels and stages of oil and gas production and distribution.

Finally, automatic and digital technologies have a positive impact on HSE through improved process regularity, and the corresponding mitigation of environmental- and human factor-related risks, and through early detection and prevention of contingency situations in drilling and production processes as well as in offshore health and environmental monitoring.

Digital and automation solutions are the most urgent research areas identified through the BRU21 fact-finding meetings. These technologies usually do not incur large investments (mostly due to their software nature), yet they can bring significant value through increased efficiency of various processes in the oil and gas value chain. This fact makes this technology area essential for increasing efficiency of the oil and gas industry facing the reality of a low oil price.

We thus propose establishing a new research program in Digital and Automation Solutions for the oil and gas Industry. It will encompass the key research areas identified in Chapter 7 where the use of digital and automation technologies has been proposed.

The objective of the program is to *Boost efficiency and enable new technologies for oil and gas industry through digital and automation solutions*. The program will be developed in cooperation with key stakeholders.

It is proposed to have innovation and fast track implementation as important ingredients in the research program. NTNU will seek industry funding as well as input from public funds. This will establish a tight link with industry, which will facilitate fast track implementation through the participating companies and ensure focus on the most relevant research topics. Academic dissemination through publications will facilitate the accessibility of the research results and thus increase the availability of new technologies in the market.

The high-level research conducted in interdisciplinary academic teams in close collaboration with industry will also contribute (through PhD and postdoc research and research-based education) to the education of scientists, engineers and specialists who are needed to continue the digital and automation innovation process in industry.

NTNU is in the unique position for this interdisciplinary research program due to internal culture of cross-discipline research and innovation as well as top level knowledge base in Petroleum Engineering, Cybernetics, Information and Communication Technologies and other relevant areas.

R&D TOPICS

Digital and automation solutions. Key research areas:

- Data analytics and machine learning techniques for efficiency boosting, e.g. to improve operational efficiency
- Automated solutions, e.g. related to the drilling process
- Sensor and communication technologies, e.g. for drilling and environmental monitoring
- Increased autonomy, e.g. for subsea intervention and environmental monitoring
- Automated model updates, e.g. for reservoir monitoring and management
- Cyber security, e.g. in automated systems with wireless sensors
- Digital tools for efficient field development and operations planning
- Decision-support systems for HSE improvements, e.g. offshore health management

8.3 Long-term research in oil and gas

The long-term research in petroleum and petroleum-related disciplines is vitally important for competitiveness of the Norwegian oil and gas industry in the long run. NTNU should continue existing research within petroleum engineering and related fields and, at the same time, add the focus on the research areas identified during the fact-finding meetings:

- Technology challenges in the Barents Sea
- Field development and area strategies
- Environmental friendly O&G production
- New business models for oil companies and suppliers
- Late life challenges and decommissioning.

Particular proposals for research topics in these areas are presented in the corresponding sections of Chapter 7.

In this way NTNU will maintain and extend its knowledge base in the well-established research areas and adjust the research to respond to the identified industrial needs.

8.4 Strengthened educational programs in petroleum and petroleum-related disciplines

The areas of industrial challenges identified in Chapter 7, require not only research to create new technologies, but also education to prepare specialists for the oil and gas industry who are capable of further development, implementation, use and maintenance of the new technologies. To address these needs, it is suggested to strengthen the existing educational programs in petroleum and petroleum-related disciplines in the directions of the identified industrial challenges.

The strengthened educational programs will assure the vitality and competitiveness of petroleum assets on NCS through high level and up-to-date education of students and specialists for the oil and gas industry.

Educational needs within the Core Petroleum Technologies can be addressed through extension of the existing petroleum engineering and petroleum-related programs at NTNU. Education in the cross-disciplinary areas of Efficiency Boosting and Environmental Care will require integrated efforts across different departments and units at NTNU to achieve full value creation. Collaboration in research and education between relevant NTNU departments should result in establishing interdisciplinary courses and increased number of interdisciplinary master's projects addressing the identified industrial challenges and closely linked to ongoing research programs.

The strengthened educational program in petroleum and petroleum-related disciplines will create an educational interdisciplinary platform that can serve several industries and be of value for major focus areas at NTNU: Ocean, Energy, Sustainability and Health.

EDUCATION

The educational objectives will be achieved through:

- Enhancing the fundamental knowledge in individual disciplines
- Integrating disciplines (Petroleum Technology, Cybernetics, ICT, environmental and social sciences, economics, etc.)
- Introducing the digital and automation approach to Petroleum Engineering
- Addressing crossover technologies:
  – technology transfer from other industries to Petroleum and
  – from Petroleum to other industries
- Maintaining a tight link with the industry through
  – permanent communication channels with industrial partners to identify and deliver education on the most relevant topics,
  – continuous educational services delivered to industry at a post-graduate level
- Aligning education programs with ongoing research.

Technologies of the future

Industry topics

9.1

Reducing the break-even price per barrel at NCS

KJARTAN PEDERSEN

Economic sustainability for the oil & gas industry means that contracts are placed to (a) maintain producing fields and to (b) get new fields on-stream. The latter is heavily linked to the break-even price per barrel, and as a general rule contracts go first to the market segment with the lowest break-even price, see Figure 9.1.1.

The Norwegian Continental Shelf (NCS) is part of the "Offshore Shelf" market segment. The average break-even price for NCS is above USD 50 per barrel for new discoveries, with an exception for Johan Sverdrup. Johan Sverdrup has a break-even price below USD 25 per barrel for Phase I, and the discrepancy is primarily linked to its size.

The target of reducing the break-even price for NCS to USD 30 per barrel is ambitious but most likely required to be competitive with other regions and segments. If the break-even price per barrel at NCS is too high, investments and contracts will go elsewhere – not only into other regions and segments but also to other emerging energy markets such as renewables. The investment levels in renewables will also be influenced by the ongoing CO_2 debate and to which degree the oil and gas industry finds a suitable role in a low carbon future.

In order to reduce the break-even price we need to know what cost elements to include. One model is the "Full Cycle Costs" model which entails field specific development costs (exploration, development, production (incl. taxes), transportation), and company specific costs (cost of capital, overhead, other operating / investment costs). This is illustrated in Figure 9.1.2.

In the current business setup the suppliers deliver their goods and services to the major contractors and oil companies alike in a transactional manner; they sell, the buyer owns and takes over the responsibility for the goods / service. The major contractors are also involved in transactional offerings; there is a handover to the next involved party who also takes over responsibilities. Finally, the owners of the field are tasked with integrating and managing the interfaces between the transactions. When all costs in all entries in the matrix in Figure 9.1.2 are summed up, we get the field specific contribution to the break-even price per barrel.

The cost in each "matrix-entry" in Figure 9.1.2 is mostly a result of requirements (rules and regulations, specifications, etc.), general price level in region (supply & demand), effectiveness of project execution (suppliers and contractors), and cost of integration and inefficient transactions (incentives, business models, etc.).

In order to reduce costs, there are many things that can be done. New and "break-through" technologies, including modified requirements and specifications, will play a role. Better business models that create alignment between the various parties can certainly also have an impact.

A third way is to combine all good efforts when developing a field. At Aker Solutions we have developed an "Advanced Value Engineering" approach. In the study phase we use advanced parametric design tools and our comprehensive cost database to find the best overall field architecture. In the FEED phase, we challenge all specifications and standards to weed out non-value adding features. In the detailed engineering phase we use automated engineering, parametric design and lean and fit-for-purpose specifications towards suppliers to reduce engineering man-hours and cut procurement and installation costs. By using "Advanced Value Engineering" for the Johan Castberg field Aker Solutions together with clients and suppliers were able to reduce the break-even per barrel to a level that made Johan Castberg viable.

Our experience can easily be transferred to the rest of the oil and gas industry: At a national level, NCS specific rules and regulations should be revisited to modify those that do not give benefits that justify the additional cost. The same goes for operators; modify specifications that do not add value justifying the additional costs. This could entail a move towards more functional specifications which could open up for more innovative ways of solving problems.

Finally, the rapidly increasing capabilities within digitalization opens up new ways of controlling project execution, operating equipment, predicting facility condition, etc. This again opens up new ways of distributing responsibilities and risks which could incentivize the industry to move away from

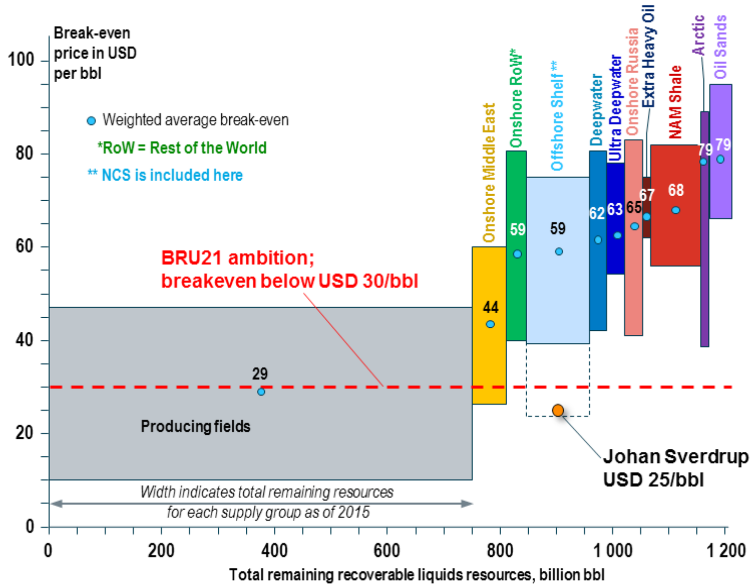


Figure 9.1.1: Break-even price per barrel

zero-sum game thinking to a more truly win-win environment. After all, by reducing the break-even price there will be more jobs for all as it becomes economical to maintain old fields and to develop new ones.

Aker Solutions provides products, systems and services to all offshore segments, all of which are under tremendous pressure to reduce costs as the oil price is believed to stay low. We are therefore highly devoted to do our share when it comes to addressing these challenges. We are working on how to incorporate digitalization into our business, how to increase our service offerings, how to innovate on value creation to customers, to mention a few. We do all this – in close collaboration with our customers and peers – with the intention to reduce the break-even price per barrel.

Academic institutions like NTNU could play a vital role in this effort. Mostly in working on the enabling technologies at the precompetitive stage: Smart products and sensing technology (e.g., condition-based maintenance), material science (e.g., lighter and stronger), cybernetics / SW development (e.g., algorithms for controlling and predicting), integrated operations (e.g., remotely control facilities), additive manufacturing (e.g., reliable and cost effective hardware), and system modeling and simulation (e.g., faster development and faster deployment), to mention a few.

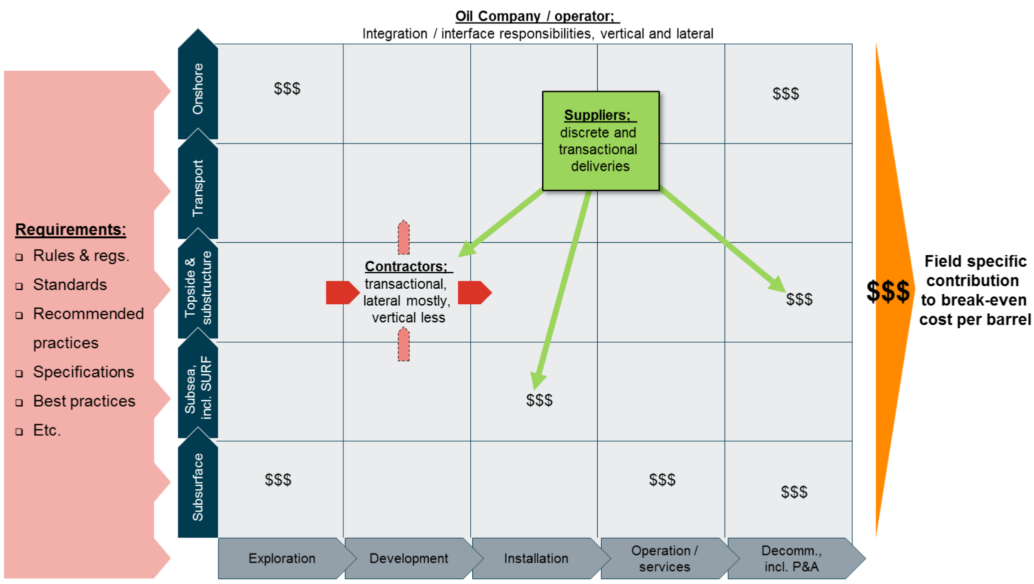


Figure 9.1.2: Field specific costs

9.2

The Nature of Exploration on the NCS

HANS CHRISTEN RØNNEVIK

Senior G & G adviser

Lundin Norway

Exploration is the continuous unfolding of reality by interactions. All the discoveries on the NCS have been considered impossible until proven differently by the drill bit. The behavior reference curve for the discovery process on the NCS is nonlinear and demonstrates that the main growth phases are related breakthroughs created more by actions than predictions. Early focusing on the known will always lead to self-fulfilling prophecies that there is nothing more to be found. A sustainable organic growth strategy to find petroleum must be based on drilling a diversity of play types both on a regional and local scale. A wide range of possible scenarios that can lead to new petroleum discoveries is needed at any time. A diversity of companies with different perceptions of reality is needed.

New perceptions of reality are introduced as historical novelties in nonlinear time irreversible patterns. Consciousness is the stored feedback process that results in a growing accumulation of understanding. The concepts, theories, tools and methods used are always incomplete. The work flows used will be under continuous change. Acceptance of incompleteness at any time is the prerequisite for continued generative learning and better practice. Modeling will always be tautological. The tools and methods must adapt to reality not the opposite. Facts can never be substituted by indirect methods. Conceptual integration by people using the basic principles of Hutton, Walter, Wheeler and Vail prior to advanced computing is needed to obtain good modeling

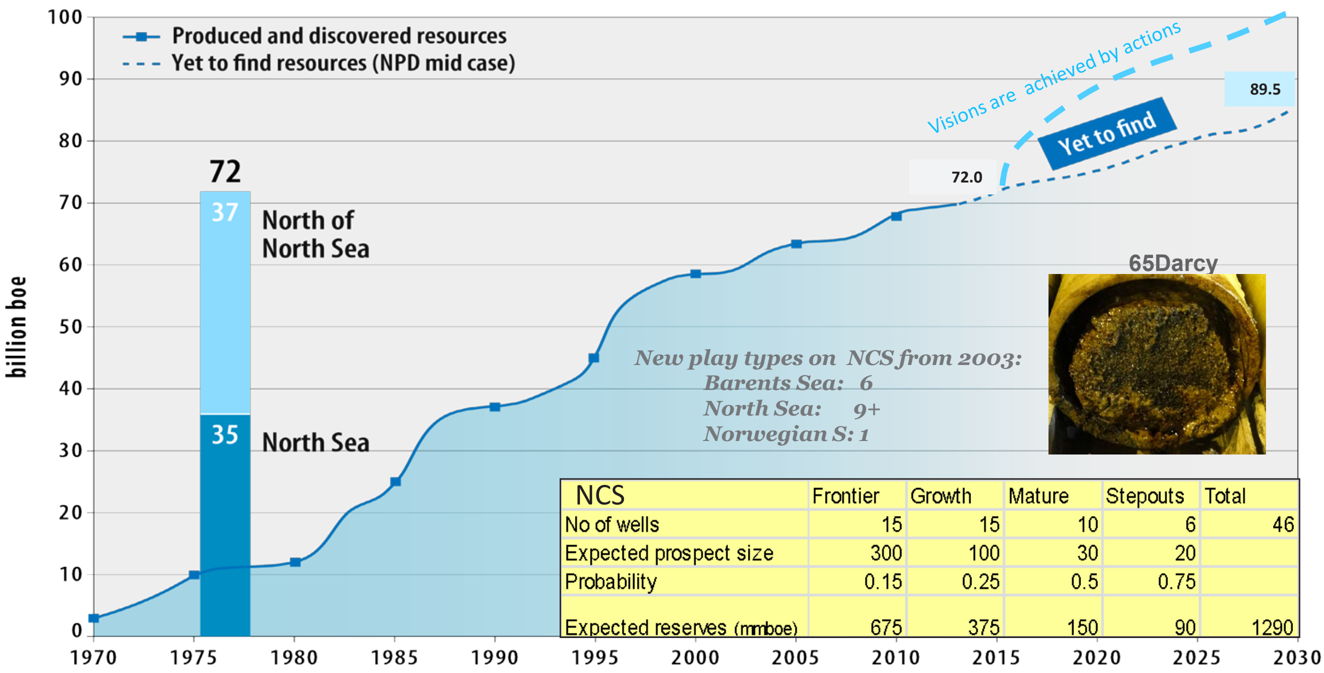
The resource potential of the NCS in the mid-1970s was estimated to be 72 billion barrels. This estimate was reached in 2016. The ultimate resource estimate for the shelf will remain uncertain. With balanced frontier, growth and mature exploration drilling it can reach more than 100 billion boe within a zero CO_2 discharge context. See: Figure 9.2.1.

The main reserve growth phase on the NCS from 1980 is related to the 4th concession round when it was decided to award several of the potential best blocks in the North Sea and opening up for activities in the Norwegian Sea and Barents Sea. The following decade was characterized by an acquisition and mergers strategy that led to fewer and more equal asset-based companies. Exploration drilling was focused around producing fields with a consequent underinvestment in drilling of breakthrough concepts. This led to a self-fulfilling prophecy that the NCS had reached a mature stage and that the time of large discoveries had come to an end.

The Norwegian authorities invited a diversity of new companies to secure a more balanced frontier, growth and mature exploration. This increased diversity was a success. Between 2000 -2006 five companies found 1 billion boe while from 2007 13 companies found 6 billion boe.

The new discoveries on the NCS are made in already explored areas and close to old fields and drilled dry wells. The discoveries can be related to 17 new play concepts. This clearly demonstrates that the NCS is not mature even in the most explored areas. In hindsight the discoveries could have been found earlier through more fact-based knowledge during operations. The best online adaptions to reality are always done by the people that formulated the exploration concepts.

Piet Hein's saying; "To know what thou knowest not is in essence omniscience", is the basis for all generative learning. The tools at hand will continuously improve without ever reaching the panacea status.



NCS	Frontier	Growth	Mature	Stepouts	Total
No of wells	15	15	10	6	46
Expected prospect size	300	100	30	20	
Probability	0.15	0.25	0.5	0.75	
Expected reserves (mmboe)	675	375	150	90	1290

Figure 9.2.1: Exploration is a nonlinear irreversible process driven by visions

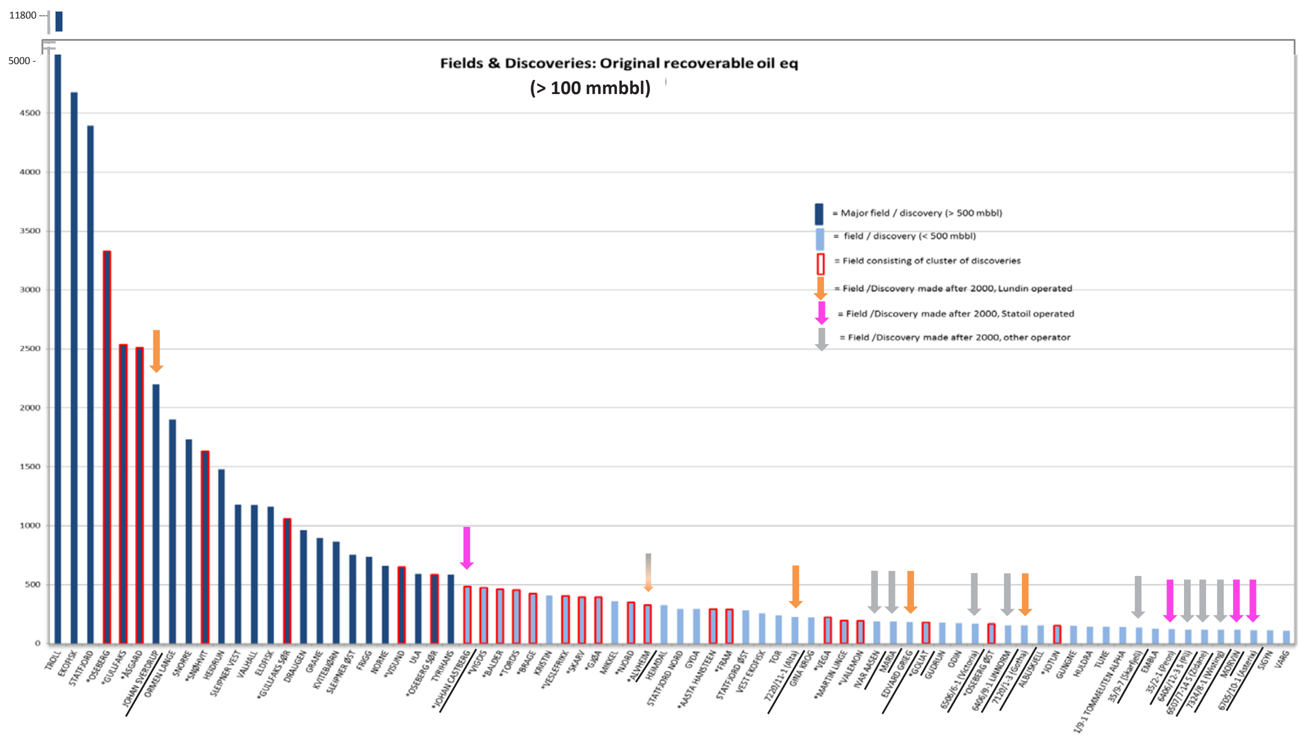


Figure 9.2.2: Growth by many diverse companies and use of old and new concepts

9.3

Digitalization of the O&G sector – ensuring trust in a connected physical and digital world

FRANK BØRRE PEDERSEN, Ph.D
Vice President
Programme Director, "Oil & Gas and Energy Systems"
DNV·GL

Digitalization and smarter use of data is increasingly among the top priorities of today's oil and gas companies. By exploiting opportunities offered by new cyber-physical systems, sensor data, machine learning, virtual- and augmented reality, and other technology enablers, the traditional capital value chain of the industry can be completely disrupted. More virtual testing, automation and autonomy offers cost reduction potentials in addition to safety improvements. The biggest disruption may however lie in completely new business models enabled by new technology and new platform models. Together this may create a new revolution for the oil and gas industry.

The rise of digital twins

Digitalization may improve both the efficiency of the capital value process itself and the products it creates. Virtual replicas of the real world – called digital twins – will be key in achieving such efficiency gains. The digital twin combines all available information and models of the object throughout its lifecycle. Within the digital twin environment, an endless variety of operations can be performed, including system design, efficient assurance and verification services, simulator-based testing and virtual system integration, and the generation of deep insights and predictions. And all of this can be done before any development decision has been made or any steel has been cut!

During operations of the asset the digital twin - fueled with sensor data - allows decision makers to react, if not in real-time, then within a decision interval that enables actions that still have value. Also, as more empirical evidence from the real-world operation accumulates, the model becomes more predictive, which enables greater proactivity to avoid risks and maximize profitability.

Technology innovation enabling process and business model innovation

The novel digital technologies enable innovation also on process level. Data analytics will be an increasingly important new discipline. We will see a shift towards more real-time performance and safety management as well as more condition-based maintenance. This will improve uptime and allow early detection of degradation before failure occurs.

The collaboration landscape will also change. Where companies before delivered products, they will increasingly be delivering performance. New business models will emerge as a result – all enabled by common digital platforms. The digital platforms allow sharing of assets such as data, algorithms and transactions with business ecosystems to match, create and exchange services. Unique and additional value can then be created through interactions between people, businesses, services and assets.

Ensuring trust in a connected physical and digital world

With the new digital opportunities, there also comes new challenges. Where we before focused on quality, safety, security and reliability of the physical asset, we must now also ensure similar trust in the digital assets. And since the digital platform model is all about sharing and collaborating across different actors, such trust is more important than before. In DNV GL we call this Trust 4.0

Three major challenges thus need to be addressed:

The complexity of the connected physical, digital and virtual worlds need to be understood and managed. Most of today's data is stored in fragmented systems, in various formats and not easily accessible to make real-time data analytics and timely decisions. To unleash the full potential of the data-rich reality, companies will have to aggregate data sets from various databases, standardize formats for easy analysis and make them available to the right people for decision making.

Ensuring quality in the software and data has proven to be one of the biggest barriers to the potential of digitalization. New data quality standards should be applied and novel ways of testing software quality like hardware-in-the-loop will be increasingly important. Data ingestion and cleaning will be key processes combining data analytics knowledge with deep domain knowledge.

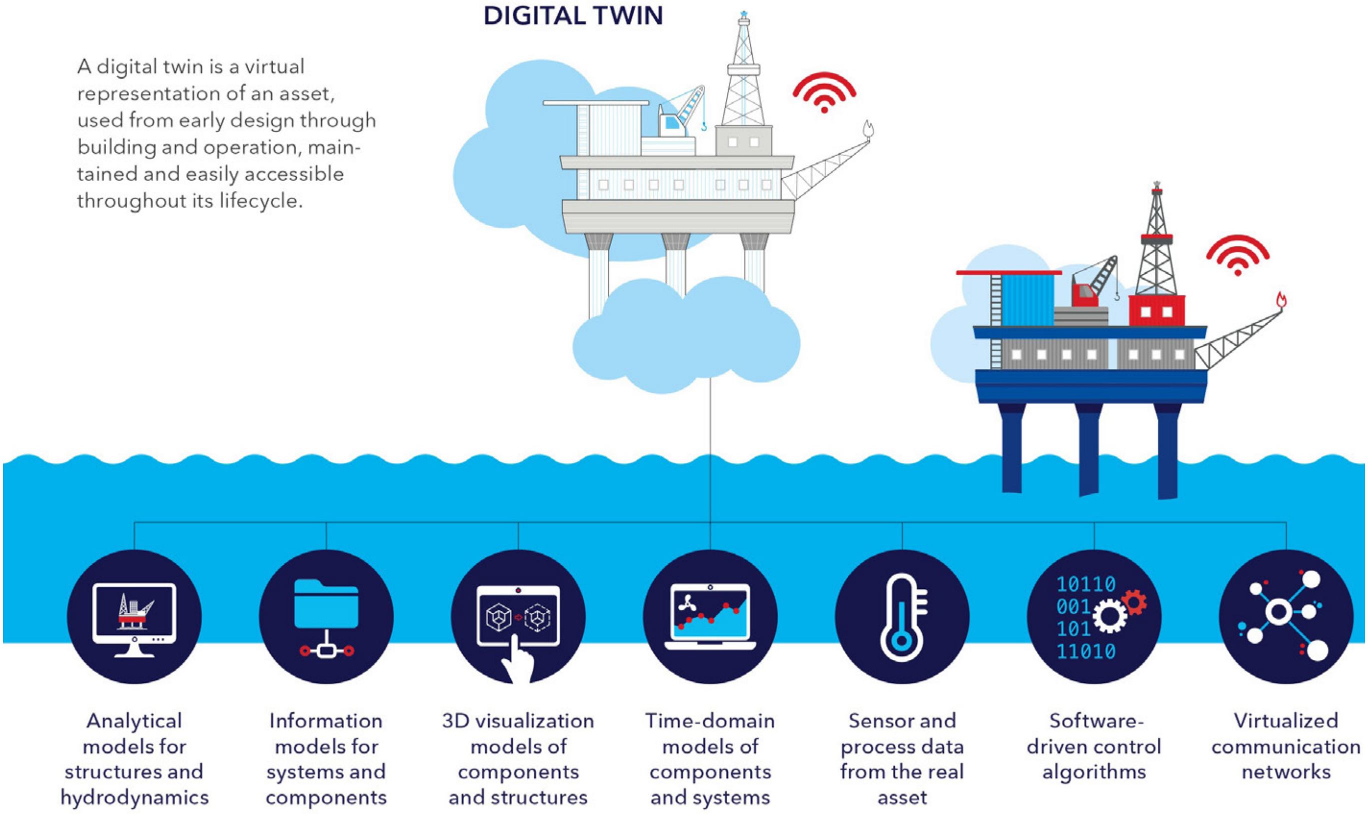


Figure 9.3.1: Digital twins

Security is paramount for rapid adoption of new technology. Business, field, reservoir and production data is business sensitive and operators demand uncompromising protection through rigorous security systems. Corporate IT and OT systems are being exposed to ever more external networks and devices through the Industrial Internet of Things, and as more assets become remotely supervised, controlled and maintained. Stringent security standards will be required to minimize security breaches and to enhance the flow of information within projects and with trusted partners.

The Veracity data platform

New DNV GL research shows that nearly half of senior oil and gas executives think they need to embrace digitalization to increase profitability. The oil and gas industry is increasingly recognizing the need to overcome data quality issues and manage ownership, control, sharing and the use of data. As a trusted third party, DNV GL is now launching an industry data platform - Veracity - to facilitate frictionless connections between different industry players, domain experts and data scientists.

DNV GL has for years worked with oil and gas companies on big data projects focusing on reduced downtime, improved safety, predictive maintenance, performance forecasting, energy efficiency and real-time risk management. A key learning from such projects is that data quality is a major barrier to overcome. A distinctive element of our new industry data platform is therefore that it combines domain expertise and data science to put quality assured data – the veracity of data – at the center and facilitate open, industry-wide collaboration and innovation. The aim is to not only build trust, but also boost knowledge and encourage collaboration. The industry needs to be successful at this to leverage the benefits of digitalization.

9.4

Our digital future

ROY RUSÅ
Vice President Technology

petoro

Petoro sees digitalization as the application of digital technology to enhance and improve asset management processes, resulting in improved asset performance. Petoro sees digitalization as a necessity, not an opportunity, to improve safety and assure competitiveness in our fields and in new business opportunities in the future. It covers all domains and every part of the E&P lifecycle.

We are generating data at an unprecedented speed. Digitalization has changed everything in industries like banking, commerce, retail and medicine. Even the car industry. Ordinary cars will generally stay as they were delivered. Modern cars, like Tesla, Mercedes etc., collect, analyze and learn based on their experiences. In addition, the cars share its experiences with others and are frequently updated with experiences obtained in other cars, wireless and without driver intervention. The experiences are used to both advise and assist the driver and maintain functionality and technical integrity. In addition lies a whole set of well proven automation technologies that take care of various processes in the car: From cruise control and automatic parking to automatic optimization of air conditioning system and automatic control of the engine and reduction of emissions.

Digitalization is really about data driven, high iteration learning. In our industry it opens for improved safety and a radical more efficient way of using past experiences in combination with real-time data to drill a new well, assure energy efficiency, assure efficient maintenance and effective utilization of actual process capacity. Your situational awarness is radically improved and you get access to relevant experience when you need it.

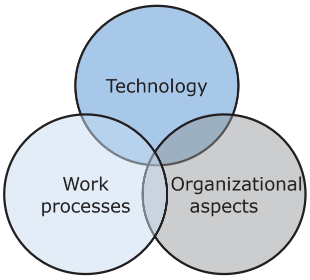
Digitalization of the oil and gas industry is not new. It started a few years into the new century. Developments in IT and early investment in a fiberoptic infrastructure made access to real-time data onshore. It opened for radical new ways of visualizing data and new work processes based on the improved communication between onshore and offshore. This characterizes the operating model today on the NCS. In the last few years, technology developments in computational technology, connectivity, digital platforms, advanced analytics, artificial intelligence and machine learning, mobility, robotics and additive manufacturing (3D) have been rapid. The technology development offers radical new opportunities and opens for a new wave of change.

In a business context, the data and analytics are used to find and eliminate own pockets of inefficiency either through "apps" that assist us in decision making or automation. The "apps" and work screens are designed for specific work processes in drilling, maintenance, production optimization etc. and set the agenda for what to focus, discuss and decide linked specifically to the user's need at the moment. It improves the quality or confidence of the information used as basis for decisions, whether it is to better understand what happened and why it happened, what may happen or being advised on remedial actions and the effect these potential actions may have. Commercial applications are available. Skeptics claim they are immature and are of course right in the same way as Windows 2.0 was less mature than Windows 10.0. The opportunities in low level automation can soon be realized. The oil and gas can draw on results from vast efforts of relevant R&D in other industries. This leaves the oil and gas industry as "followers" where the task is about adapting and integrating technology and insight into development of domain specific applications and redesign of our work processes.

The success factors for implementing the technology in our work processes require active participation and cooperation between academia, the large system suppliers, technology suppliers and technology startups, oil companies and authorities where business and domain insight are fundamental in order to ask the right trigger questions. It requires adapting our business models and competence. Further, it requires a pragmatic view on the business case, experimentation, challenging the previously successful work processes and meticulous evaluation of achievements. All in all, this is a challenging organizational development task and can only be achieved through guidance from a committed and visible top management, whether it is an oil company or supplier. It is not a technology or IT project!

While all companies use large words regarding use of dig-

Realization of the value potential are contingent on organization-specific factors



Factors include:

- The degree of executive sponsorship, support and accountability
- A "translator" appointed to manage and coordinate between operations, technical disciplines, IT and procurement
- Cooperation AND competition
- A focused and "purpose built" redesign of work processes
- Willingness to experiment, pragmatic approach to business case and meticulous evaluation of achievements

italization, the risk is the reluctance to act. The four critical hurdles are lack of confidence in the claimed potential, lack of confidence in technology maturity, resistance to the unavoidable, large and expensive change processes in a time where capital expenditure is critically prioritized and finally, lack of competence, especially at management levels.

The mountain of assuring competitiveness of fields and projects on the NCS is not going to be smaller and time is of the essence. It may be relevant to quote King Harald V: "It is being said that wisdom comes by age. My experience is that age often may come alone too". In this respect, wisdom is to act.

9.5

New business models – integrated approach to field development

MADS RØDSJØ and HÅVARD SKALDEBØ

A changing shelf and marketplace

Increasingly, the petroleum resources on the Norwegian Continental Shelf (NCS) are discovered in fields where oil in place is smaller than 10-20 years ago, and in more challenging formations impacting the achievable production rates negatively. The dramatic fall in the price of oil has once more reminded the market players about oil price volatility, it is a given feature that must be handled intelligently.

Tackling these challenges, unlocking the potential to produce these NCS reserves in a safe and economical way demands a new approach, mobilizing all the players in the value chain towards a common goal, the success of all the players, not only a few.

Early involvement of key players, the key

Integrating the key players in the value chain earlier into the project's decision and maturing process than the traditional execution model is the key. Any impact on later activities can then be identified, discussed, understood and agreed, mitigating any negative effect before they materialize. When the key players' competencies and skills are brought into the project earlier than traditionally, this enables discussion on the important risks and opportunities impacting the project success and taking the actions required.

Earlier involvement also enables the players to maintain concept flexibility longer than the traditional contracting approach; Concept Selection (freeze) and detailing solutions only when maturity is prudent, not governed by traditional contracting requirements.

Early "freeze" due to the traditional contractual mechanisms often requires major changes at a later stage with high cost, or one has to live with less than optimal facilities, eroding value creation. As shown in Figure 9.5.1, having long-term framework agreements and partnerships contract models will remove the need for late and costly project changes.

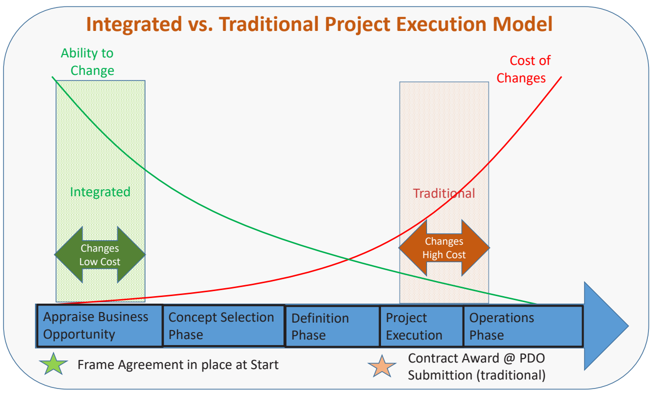


Figure 9.5.1: Integrated vs Traditional Project Execution Model

Setting the framework for successful cooperation

Enabling successful projects through cooperation between companies requires several pre-requisites. The key success factor is people, how they get along on both professional and personal levels is built on mutual respect and trust. When developing the contracts these aspects must be given adequate attention. Securing that the drivers are aligned to this end, typically requires:

- Common strategy, objectives and drivers for project
- Enabling environment for the project personnel driving innovation
- Common performance culture between all involved parties
- Complimentary skill sets within the wider team
- Shared risk and associated reward – Remuneration Model

The strategy needs to be aligned for all parties and all parts of the organizational model. This means that technology, people selection and ways of working shall adhere to the strategy agreed. Developing a culture to support this is the most important and also usually the hardest task. A lot of projects fail because the culture does not allow for the right mentality in the project. This is primarily the responsibility of the leadership team of any project.

9.6

Always safe, high value and low carbon

KJETIL SKAUGSET, Ph.D

Chief Researcher Upstream Technology

Statoil

Statoil is an energy company with the mission of *"Turning natural resources into energy for people and progress for society"*. We will develop our business portfolio to generate high value with a low carbon footprint. Technology and innovation are key enablers to succeed.

Green and brownfield oil & gas

On the Norwegian Continental Shelf (NCS) many installations will need extension of technical lifetime Examples of important efforts for continued tail-end production are; condition based maintenance, brownfield automation, cost-effective produced water treatment technologies, cost effective IOR measures and drilling & well productivity.

Development of frontier areas such as Barents Sea is vital to the sustained production on NCS. In more mature areas of NCS, tie-in of smaller discoveries is essential for the extension of economic lifetime of existing infrastructure. There is also a need for technology to provide cost-effective deep-water field developments. Finding the right plays, understanding subsurface to enable optimal drilling targets and improve reservoir predictability will be essential. Drilling efficiency and deep-water facility solutions will be important to reduce cost and CO_2 emissions.

Future Energy Systems

Statoil climate roadmap requires technology measures on energy efficiency, low carbon field development solutions and low carbon energy supply. For green-field applications, energy demand reductions could be provided by integrated and energy optimized subsurface and facilities design. New solutions for energy efficient power and heat generation are needed to further reduce carbon footprint.

New energy systems combining different sources of renewable energy and storage in a value chain is needed in a changing consumer market. Cost-effective technologies securing such integration and systems solutions should be developed. In addition, development of individual profitable renewable energy solutions will be vital.

Cross-discipline solutions and digitalisation

Cross-discipline solutions: Across industries and research institutions, organizations that facilitate and value collaboration between disciplines are more likely to provide new radical solutions with high value. Using a systematic innovation approach with specialist knowledge and open mind towards neighbouring disciplines, new solutions emerge on the border line between disciplines. A pre-requisite for this is however that deep knowledge within disciplines are utilized such that simplifications can be made acknowledging the difference between what really matters and what does not in a system.

Digitalisation: We believe digitalisation and automation will dominate technology development in the foreseeable future. Digitalization will drive integration of data, hardware, disciplines, value chains, industries and people. Within oil and gas, increased storage - and computing capacity, represents a game changer in how the use of data will support decisions and improve efficiency. This can however only take place if expert competence in relevant disciplines is fully integrated utilising theory and modeling capabilities on turning data into decision support.

9.7

Environmental O&G Development

JAN ERIK LYSTAD
Senior Vice President
Power Electronics Centre

SIEMENS

Due to a robust and cost effective state-of-the-art solution, the AC electrical power grid has for a long time been unchallenged by other technologies. For offshore grids, this is no longer the status. The reason for this is the increased focus on system efficiency, especially by including large energy storage systems in the power grid. Most of the energy storage systems have a DC voltage interface. Due to the nature of energy storage, DC distribution systems will be preferable in this context.

Installation of large energy storage systems together with DC distribution power grids opens up significant optimizing potential for energy consumption in offshore plant. Many of the loads are intermittent loads that force the engines and turbines into suboptimal operation modes. High levels of reverse load energy are burned in breaking resistors to ensure a stable operation of the AC power grid.

One of the biggest game changers by including energy storage systems in floating dynamic positioning installations is the possibility of introducing static spinning reserves. Class requirements are very conservative with regard to this topic, but since 2016 have opened up this possibility. This means that e.g. batteries can be used as backup power in case of failure in an engine. This reduces the need of active rotating machines working at poor efficiency due to low loading.

Electrical energy conversion systems have faced a large cost decrease in recent decades for all ranges of power. This advantage has been utilized by Siemens in oil and gas production, drilling and vessel propulsion. Especially due to the challenge of breaking DC current with mechanical breakers, the DC distribution system has just recently started to be attractive in large scale offshore systems. Since the silicon semiconductor components used for energy conversion have become low cost products, these can challenge the state-of-the-art AC breakers in cost and volume. The semiconductors still have some disadvantages due to losses compared to mechanical breakers, but they have other advantages such as ultrafast interrupting short circuit currents. When the fast breaking is combined with new ways of thinking protection philosophy for electrical systems, the result can be very attractive for offshore installations and vessels operating in critical modes.

When the vessel is not electrically connected through AC by synchronization of generators, engines and turbines can run with variable speed. This is utilized by Siemens in DC grid systems. The result is a new dimension for optimizing fuel consumption and environmental impact. The DC grid also opens up improved functionality for shore connection of offshore plants, but also interconnection between plants since a long AC cable connection very often is challenging with regard to stability and reactive power production. If alternative power sources as wind power are requested to be connected to an offshore plant, this can be done efficient only by a Siemens inverter. A combination of wind power and energy storages would result in a complementary solution for optimizing load consumption and available power from the wind.

The result of all of these changes opens a totally new possibility of optimizing operation of offshore installations and vessels. The main benefits of the changes are increasing power plant efficiency, reduced environmental impact, reduced operation hours for rotating equipment and increased operation safety.

Siemens has for a long period worked closely with the vessel and rig owners to come up with various energy storage solutions for ensuring spinning reserves during Dynamic Positioning and fuel saving concepts. Some of these projects are in the final design phase. In the latest concept studies, static machine rooms with batteries have replaced the standard machine room with diesel engines. The results are reduced installed diesel power demand, reduced OPEX due to more optimized operation and also reduced CAPEX due to less required peak power from standard rotating machines.

Figure 9.7.1: Digital layer

9.8

The CO_2 Value Chain

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CO_2 has proven to be very efficient to enhance oil recovery and has been used in commercial application especially onshore in the U.S. for decades. Currently the U.S. produces about 300 000 barrels of oil per day by this method and CO_2 is in this context regarded as a valuable raw material where the operators seek to minimize the consumption and reinject as much of the back produced gas as possible. The application of CO_2 for enhanced oil recovery (EOR) has recently attracted more attention since this method also involves permanent storage of CO_2 and as such represents a measure for greenhouse gas (GHG) mitigation.

The main elements in the so-called "CO_2 Value Chain" relevant for carbon capture and offshore use of the CO_2 for EOR or permanent storage is given in Figure 9.8.1.

CO_2 can be captured from an industrial onshore emitter and conditioned for ship or pipeline transportation. The gas can be injected directly into an aquifer for permanent storage or into an oil reservoir for EOR. Separated CO_2 from a gas sweetening process, like that in operation at Sleipner, can be injected for storage or used for EOR

Considerable oil reserves that would be recoverable by CO_2 EOR have been identified in various offshore regions. In the North Sea huge volumes have been identified both on the UK and Norwegian sides. There are various explanations about why these opportunities have not been exploited. One of these is the costly retrofit of existing topside facilities that would be mandatory to enable processing of the CO_2 rich well-stream from the flooded oil reservoir. However, new and emerging compact separation technologies and subsea solutions could enable the application of CO_2 for EOR offshore at a lower price.

It is also recognized that a depleted oil reservoir is useful as a permanent storage site for CO_2. Accordingly, the operator could convert the field from oil production to CO_2 storage in a post oil production state. Such an operating scenario would provide an extension of plug and abandonment costs and revenue from operating the field as a CO_2 storage site.

It has been challenging to establish a sufficiently good business case for the deployment of a CO_2 EOR value chain. In addition to the cost of retrofitting topsides, the cost of CO_2 securing a reliable logistic chain and legislation issues are elements that have prevented the complete industrial CO_2 value chain.

Considerable achievements have been obtained in new and more efficient capture technology. Still, compact separation and processing systems and understanding of reservoir mechanisms and new technology solutions are required to increase the attractiveness of the complete CO_2 value chain, including:

- Mobility control and sweep efficiency of the CO_2 flood to optimize use of CO_2 in the flooding
- Development and qualification of offshore gas handling systems (injection vessels)
- Development and qualification of compact and efficient well fluid separation systems
- Qualification of new materials and systems for P&A, monitoring, etc.

With successful achievements in these areas, Norway could get a leading position exporting technology solutions and play a significant role for securing a sustainable future for the oil and gas industry.

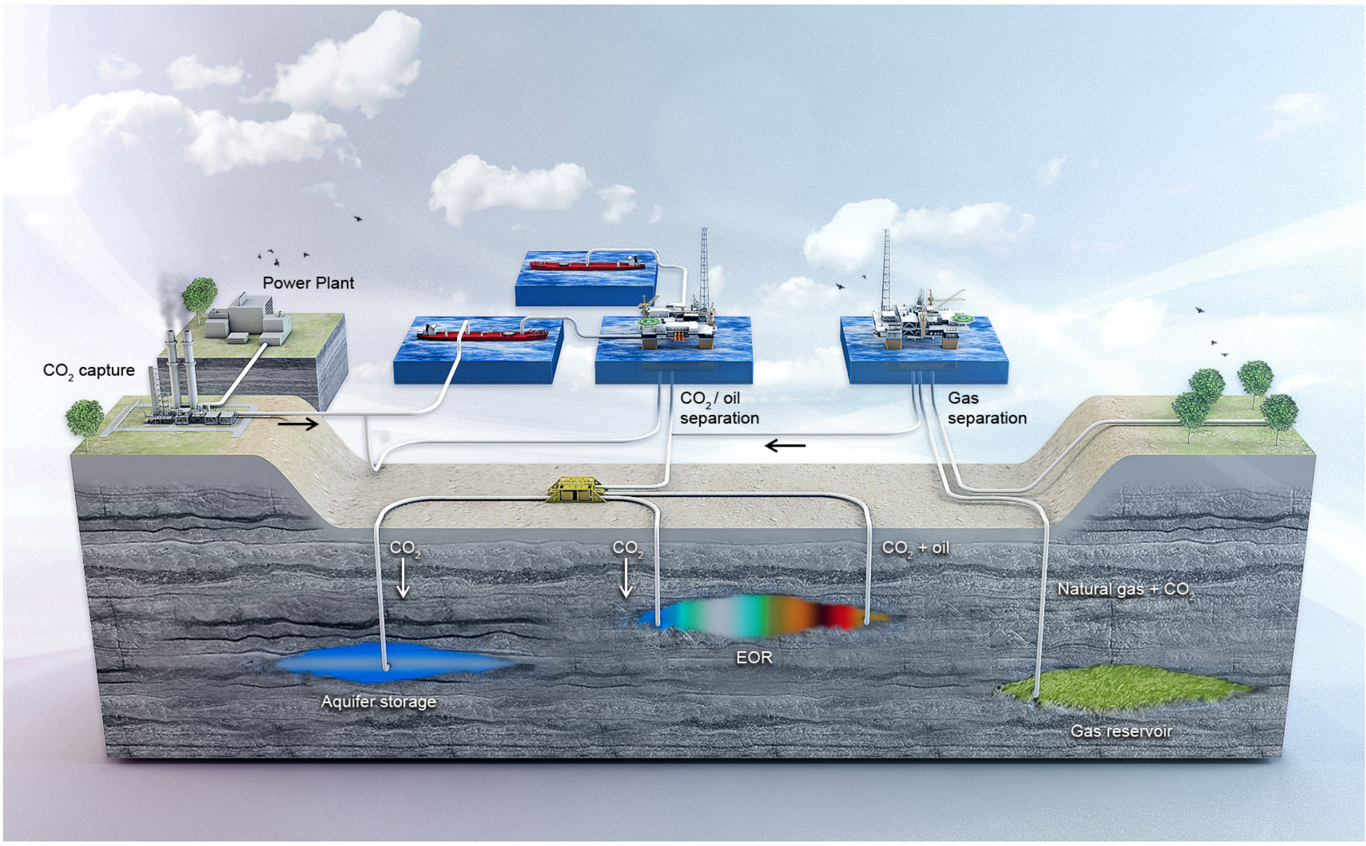
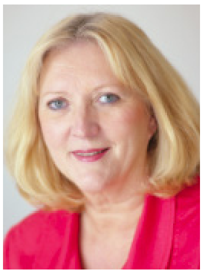


Figure 9.8.1: Illustration of CO_2 value chain. (Courtesy of Aker Solutions)

The Norwegian CO_2 Storage Atlas



EVA HALLAND

Norwegian Petroleum Directorate

NORWEGIAN PETROLEUM DIRECTORATE

The CO_2 Storage Atlas of the Norwegian Continental Shelf (NCS) has been prepared by the Norwegian Petroleum Directorate. The main objectives have been to identify safe and effective areas for long-term storage of CO_2, to avoid possible negative interference with the petroleum activity and to facilitate selection of sites that can be suitable for future CO_2 sequestration projects. This atlas is based on knowledge from more than 50 years of petroleum activity and from the ongoing CO_2 storage projects, Sleipner Vest and Snøhvit. The studied areas are located in parts of the NCS, which are opened for petroleum activity.

The Norwegian CO_2 Storage Atlas aims to document the distribution and properties of the aquifers having a relevant storage potential for CO_2 offshore Norway. Several storage options have been evaluated like structured aquifers, structural closures, dipping aquifers, abandoned fields and the possibility of storing CO_2 in combination with enhanced oil recovery (EOR).

Depending on their specific geological properties, several types of geological formations can be used to store CO_2. In total, 27 geological formations offshore Norway have been individually assessed, and grouped into saline aquifers together with several mapped and dry-drilled structures. Aquifers and structures have been characterized in terms of capacity, injectivity and safe storage of CO_2, but also evaluated according to the data coverage and their technical maturity. The storage mechanisms considered are both structural and stratigraphic trapping of CO_2.

An aquifer is a body of porous and permeable sedimentary rocks where the water in the pore space is in communication throughout. Aquifers may consist of several sedimentary formations and cover large areas. A good understanding of the geology and sedimentological development of the area is of uttermost importance. To be suitable for CO_2 storage, aquifers need to be at a depth where CO_2 can be stored in a supercritical state, have sufficient porosity and permeability and be overlain by an impermeable cap rock acting as a seal, to prevent CO_2 migration into other geological formations or to the sea.

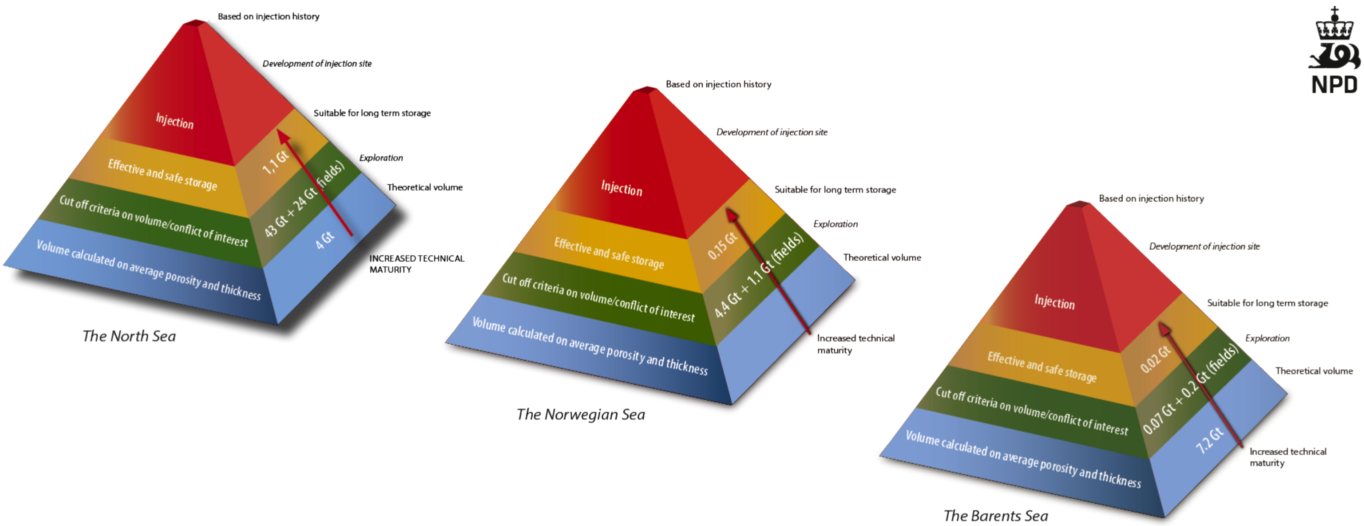


Figure 9.9.1: Maturation pyramides

The CO_2 storage capacity depends on several factors, primarily the reservoir pore volume and the fracturing pressure. The relation between pressure and injected volume depends on the compressibility of the rock and the fluids in the reservoir.

An overview of the results is illustrated by maturation pyramids for the North Sea, Norwegian Sea and southern Barents Sea, where the highest level in the pyramid represents the capacity of sites that are already used for CO_2 storage, while the lowest level represents theoretical capacity in lesser-known aquifers. See Figure 9.9.1. All areas have a significant potential for CO_2 storage, but as illustrated by the pyramid the three regions are quite different in maturity. See Figure 9.9.2.

Monitoring of injected CO_2 in a storage site is important for two main reasons: Firstly, to see that the CO_2 is contained in the reservoir according to plans and predictions, and secondly, that if there are deviations, to provide data that can update the reservoir models and support eventual mitigation measures. When injecting CO_2 it is important to ensure that there is no leakage to other geological formations or to the sea bottom. Evaluation of the sealing capacity, faults and fractures through the seal, in addition to old wells penetrating the seal, can provide important information on the sealing quality and the monitoring challenges.

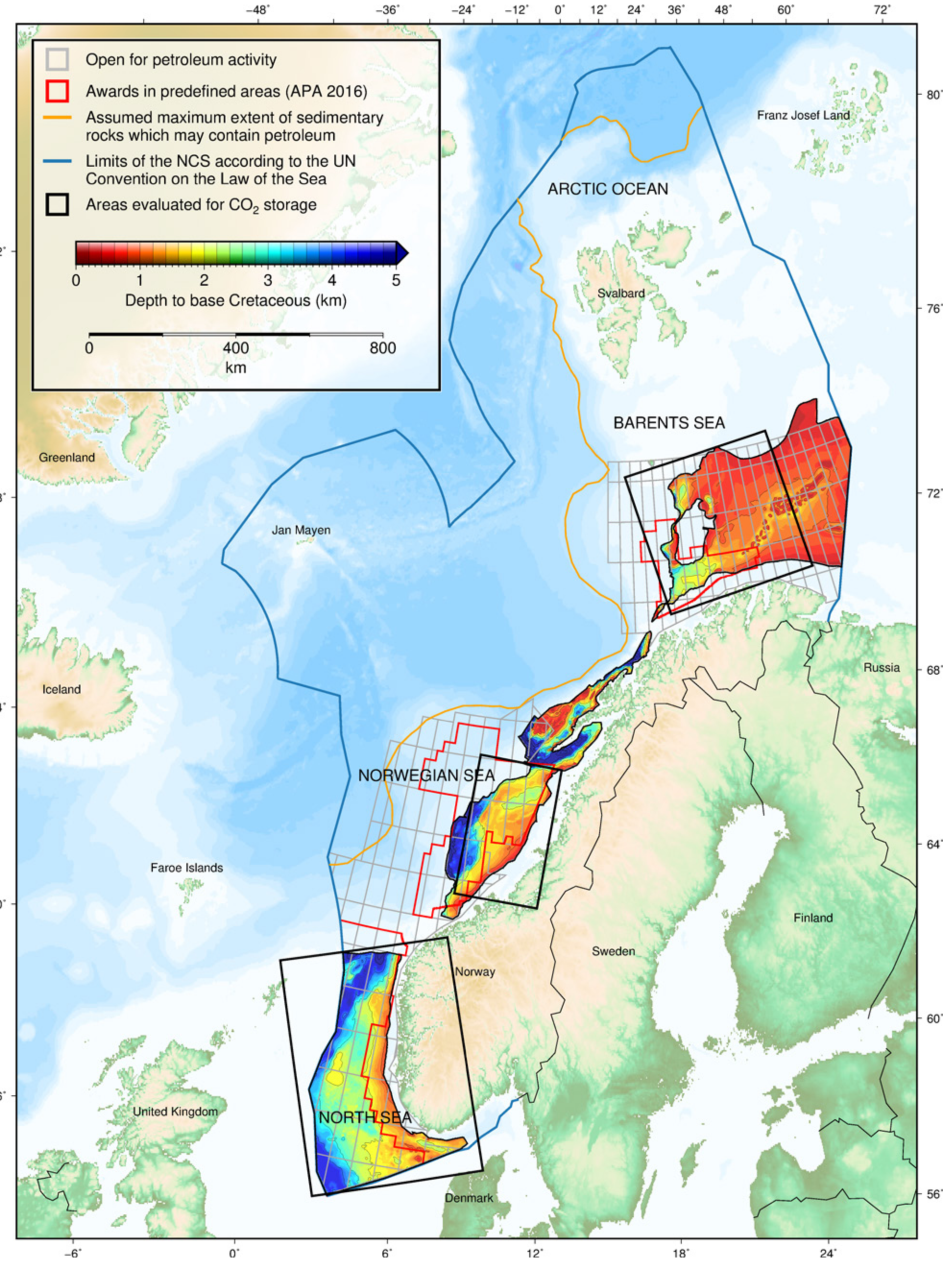


Figure 9.9.2: Geographical distribution of storage potensial with reference to the maturation pyramides

9.10

CO_2 emissions from global Oil and Gas Fields

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More than 90% of the CO_2 emissions from oil and gas (O&G) use take place when the fuel is combusted. Nevertheless, emissions related to O&G extraction also matter for the lifecycle emissions of these fuels. Emissions per unit of extraction vary substantially across countries or regions of the world, but also within countries. The International Association of Oil and Gas Producers (IOGP) publishes an annual environmental report showing inter alia average CO_2 emission intensities (emissions per unit oil and gas produced) in different regions of the world.[1] In 2015, the global average was 130 kg CO_2 per ton of oil equivalent (toe). However, the variation across regions is large, ranging from 53 kg CO_2 per toe in the Middle East to 210 kg CO_2 per toe in North America (see Figure 9.10.1). According to the IOGP, two thirds of the CO_2 emissions from global O&G extraction come from energy use, while almost one third comes from flaring.

The IOGP does not report numbers for individual countries. However, the Norwegian Oil and Gas Association publishes an annual environmental report,[2] showing average numbers for Norwegian O&G fields. According to that report, the emission intensity for Norwegian O&G extraction in 2015 was 53 kg CO_2 per Sm3, i.e., around 63 kg CO_2 per toe. Thus, CO_2 emissions from Norwegian O&G extraction are around half of the global average, but around 20% higher than in the Middle East.

The IOGP does not have information from all fields in the world, and thus it has been questioned whether the IOGP numbers are representative for e.g. the Middle East. However, the low emission intensities reported for this region is largely supported by Carnegie's Oil-Climate Index,[3] which presents emission intensities for selected oil fields around the world based on a detailed field-specific modeling of the oil production process. Two of the analyzed fields in Saudi Arabia are Ghawar, the biggest oil field in the world, and Safaniya, the world's biggest offshore oil field. Both these fields have emission intensities at or below 50 kg CO_2 per toe.[4] An important reason for the low emission intensities in the Middle East is that the energy use required to extract oil and gas from the ground is relatively moderate compared to O&G fields in other parts of the world.

When looking at emission and production figures for individual fields on the Norwegian Continental Shelf, it is evident that the emission intensity varies substantially across Norwegian O&G fields. Some fields have practically no emissions (e.g., Ormen Lange which is operated from land), whereas other fields have higher emission intensities than the global average (e.g., Veslefrikk). Gavenas, Rosendahl and Skjerpen (2015) have analyzed empirically the driving forces behind emission intensities in Norway.[5] A main finding is that emission intensities increase significantly as the field's production declines (see Figure 9.10.2). The empirical results suggest that emissions per unit extracted on average increase by two thirds when a field's production is halved compared to its peak level. The study also finds that Norwegian fields producing mostly oil have significantly higher emission intensities than fields producing mostly gas (even if so-called electrified fields are disregarded).

1 IOGP (2016). Environment Performance Indicators – 2015 data. IOGP Data Series: International Association of Oil and Gas Producers. http://www.iogp.org/pubs/2015e.pdf

2 Norsk olje&gass (2016): Environmental report 2016. https://www.norskoljeoggass.no/Global/2016%20dokumenter/NOROG%20milj%c3%b8rapport16_ENG%20(ORIG).pdf

3 http://oci.carnegieendowment.org/#map?yearSelect=2013

4 These numbers are not readily available on the web-site, but has been derived based on communication with experts involved in the Carnegie Oil-Climate Index project.

5 Gavenas, E., K.E. Rosendahl and T. Skjerpen (2015): CO2-emissions from Norwegian oil and gas extraction, Energy 90, 1956-1966.

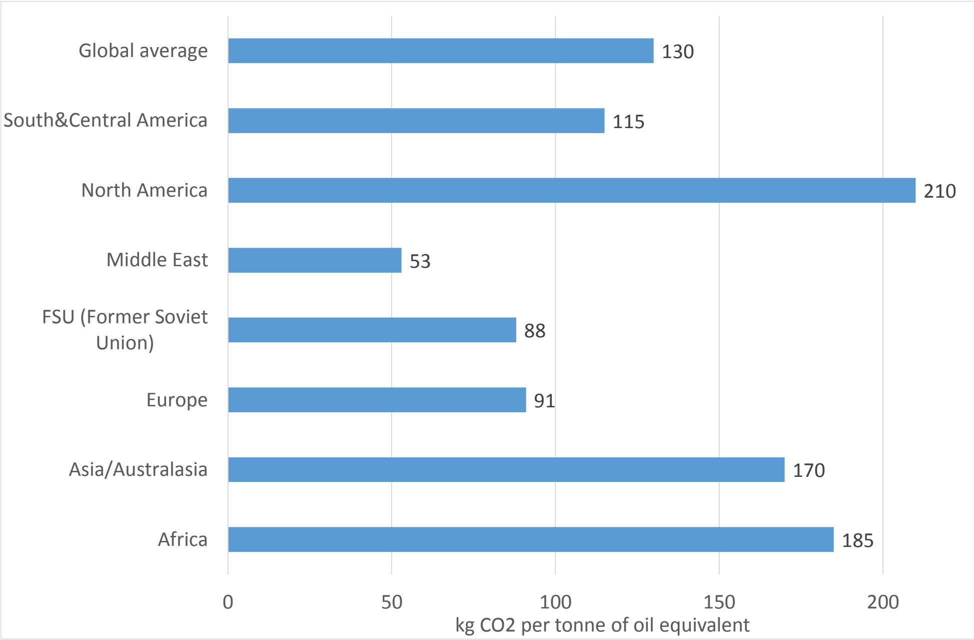

*Figure 9.10.1: CO_2 emissions per unit O&G production by region. Source: IOGP (2016)**

* Production with reported emissions relative to overall production is as follows: South&Central America 43%, North America 17%, Middle East 23%, FSU 10%, Europe 88%, Asia/Australasia 33%, Africa 61% (IOGP, 2016)

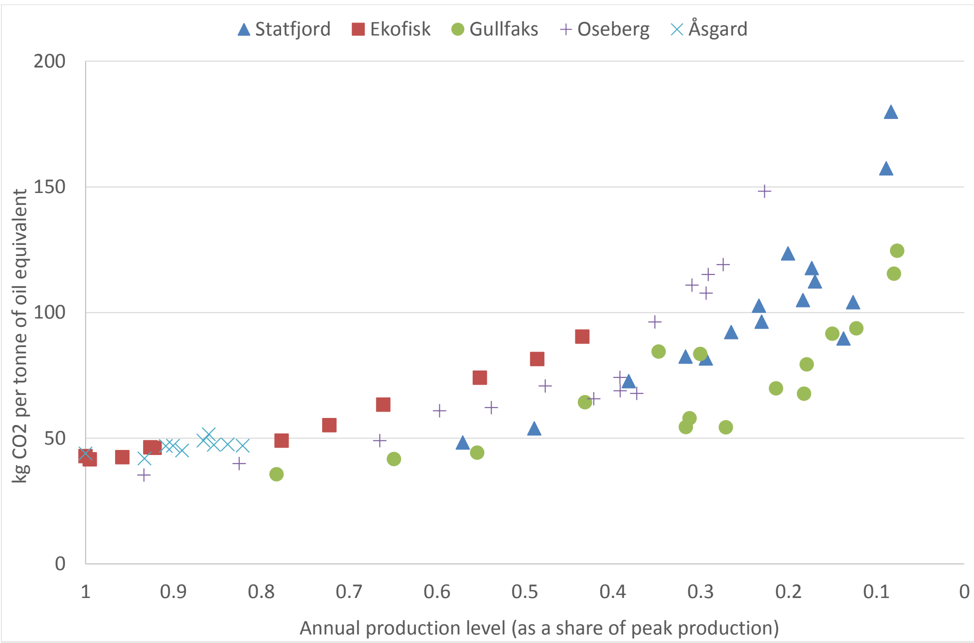

*Figure 9.10.2: Relationship between annual production level (as a share of peak production) and emission intensity for the five biggest non-electrified Norwegian fields in the years 1997–2012**

* Observations before peak production is reached have been omitted.

9.11

Greater Ekofisk Area Future Well Plugging and Abandonment Activity

TIM CROUCHER

Wells Excellence and Decommissioning Manager

ConocoPhillips

Well P&A Activity:
- Experience to Date: +/- 100 wells
- Medium-Term Plans: +/- 100 wells
- Long-Term Plans: > 200 wells

General P&A Challenges:
- Mature Subsurface Environment with large variability in pressure after 30 years of water flooding
- Dynamic Well Conditions with reservoir compaction and overburden subsidence
- Physical condition of ageing wells
- Surface / Platform Constraints

Future P&A Strategy

Two core focus areas:
- Ensure a robust subsurface barrier management philosophy
- Drive down future P&A cost through the development of new cost effective solutions

Future Solution Development – New Technology
- Understand key solution needs and opportunities
- Consider broad scope of alternative solutions
- "Out of the box" thinking / Open minded approach to solution development
- Communicate needs to the market
- How to improve market interest / understanding?
- How to accelerate development of North Sea P&A Solutions market?

Conclusions:
- Two core focus areas to drive improvements in future P&A
  – Acceptable subsurface barriers
  – Acceleration of development of new cost effective solutions
- There is an opportunity for a "Paradigm Shift" in P&A philosophy / strategy
- Need dramatic changes in both surface and downhole technical capability
- There is a huge long-term market and there is Win – Win market model!
- Long-term environmental risk assurance at a significantly reduced cost
- Guaranteed scope of work over a very long period
- Collaboration between Operators and the Market is vital

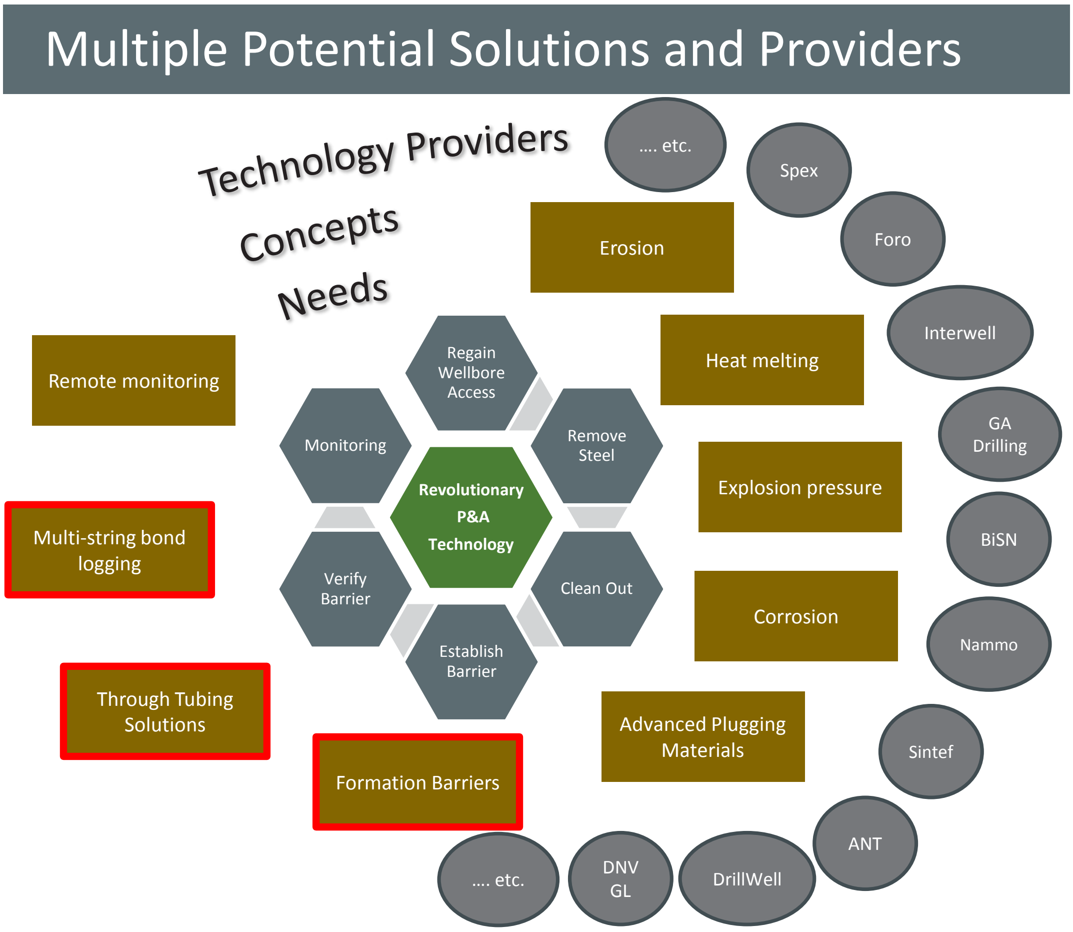

Figure 9.11.1: Plugging and Abandonment Activity

Figure 9.11.2: Ekofisk

10.0

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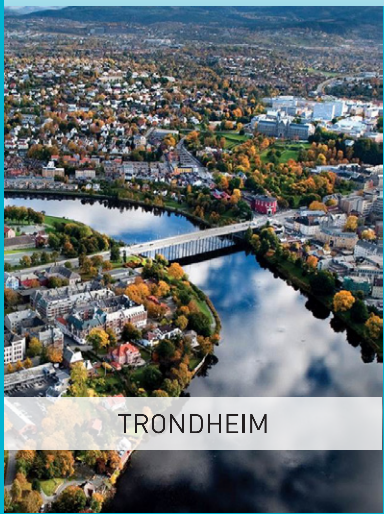

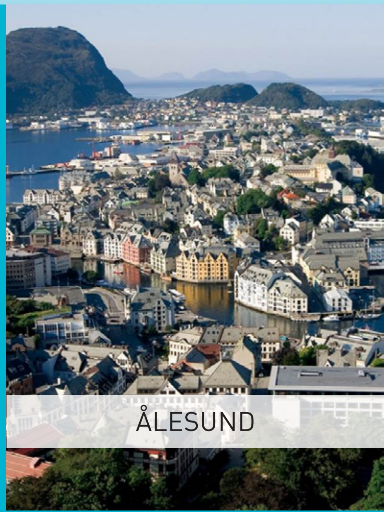

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