September 15, 2005

2005

BRU Project

A strategic plan for focused petroleum research at NTNU

Better Resource Utilization

NTNU
Innovation and Creativity

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

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 competence as well as long-term technical and scientific R&D solutions.

NTNU recognizes that the petroleum industry is a high tech sector which demands the best skills available in order to solve the challenges it faces. This is so across the entire value chain from exploration, petroleum field development, production and exploitation to the final stage of removal. This high tech dimension is also recognized over time when we see the major achievements obtained during the last 40 years on the Norwegian Continental Shelf. The oil and gas industry has had some remarkable results during this period related both to advanced technical solutions as well as in industrial engineering. It has established new enterprises and developed them into internationally competitive companies. NTNU recognizes the complexity of the petroleum industry, its need to utilize the latest advances in research and development and its need to recruit some of our very best students.

Torbjørn Digernes, Rector NTNU

As the Rector of NTNU, I am positive to offer my full support to the activities and processes within the BRU Project. This project is important to draw up a renewed strategy for the Norwegian Petroleum Cluster and facilitate cooperation across NTNU and SINTEF. I was pleased to participate at the BRU Seminar at NTNU on 22-23 August 2005 and discuss strategic issues with the petroleum industry. The seminar functioned as an important network meeting between scientists at NTNU/SINTEF and representatives from oil companies, service companies, organizations and the authorities.

BRU TEAM

The BRU team has been professors Jon Kleppe, Sigbjørn Sangesland, Martin Landrø and Bjørn Ursin at the Department of Petroleum Engineering and Applied Geophysics, NTNU assisted by secretarial work from Dr.techn. Arild N. Nystad in PetroManagement AS. The BRU Team started its work in June 2004. The objective was to come forward with a plan, strategy and recommendations for future R&D priorities in petroleum at the Department of Petroleum Engineering and Applied Geophysics. The direction of the work has been to define some key R&D "lighthouses".

The team decided that it would be important to ask for advice from the petroleum industry and organized a fact-finding mission to about 50 oil companies, service companies, relevant organizations and the authorities during the period November 2004 to April 2005. This turned out to be a most valuable and successful exercise. NTNU obtained invaluable insight, input and inspiration for the BRU Project. We felt that the entire Norwegian Petroleum Cluster appreciated this initiative. We openly discussed the future challenges on the Norwegian Continental Shelf and the needs and priority areas for each individual company. Further, NTNU strengthened and updated its network for all those involved.

The BRU team:
Professor Jon Kleppe, NTNU
Professor Sigbjørn Sangesland, NTNU
Professor Martin Landrø, NTNU
Professor Bjørn Ursin, NTNU
Arild N. Nystad (Dr.techn. and Managing Partner in PetroManagement AS)


Jon Kleppe


Sigbjørn Sangesland


Martin Landrø


Bjørn Ursin


Arild N. Nystad

Norwegian University of Science and Technology
Department of Petroleum Engineering and Applied Geophysics
S.P. Andersens vei 15 A
N-7491 Trondheim, Norway
Telephone: (+47) 73 59 49 25
www.petroleum.ntnu.no

Layout and print: Tapir Uttrykk
Language consultant: Stewart Clark
Svalbard photos: Helge Langeland

Summary of the BRU Project

Background for the BRU Project
The Board of NTNU decided to promote upstream petroleum activities to the status of Strategic Research Area and integrate them with the strategic area Energy and Environment. The new name of this research area is Energy and Petroleum. Here the entire energy value chain is organized in one program in order to obtain multidisciplinary synergy effects. Energy and Petroleum is one of six strategic research areas at NTNU. All of these have the objective of being among the international academic leaders of research in their field.

In connection with this, NTNU started an internal project to develop a new strategic plan for research and education in the upstream petroleum area. This is called the BRU Project (Better Resource Utilization). The driving force behind the project was that NTNU felt the need to focus and concentrate its resources in petroleum-related activities. This report is one of the main results from this project so far.

The objective of the BRU Project has been to define the future technological competences and areas for research at NTNU that need to be given high priority in order to solve the long-term challenges on the Norwegian Continental Shelf. The direction of the work has been to define a carefully selected number of R&D "lighthouses". The BRU Project will develop a strategic plan for focused petroleum research at the Department of Petroleum Engineering and Applied Geophysics in cooperation with other relevant departments at NTNU and SINTEF institutes/research companies. One goal of the BRU Project is to get an overview of activities from the different departments and institutes related to petroleum research and find means of integrating the results.

This report sums up the status of this work and the final section in this summary highlights the discussions and results from the BRU Seminar at NTNU on 22-23 August 2005. It is important to underline that this report is not intended to cover all aspects and activities in petroleum research at NTNU and SINTEF. It is important to have a continuous dialog with the entire Norwegian Petroleum Cluster in order to capture the needs and trends in the industry. This is why the BRU Project started with a fact-finding mission where the BRU Team had meetings with about 50 oil companies, service companies, relevant organizations and the authorities during the period November 2004 and April 2005. This was a successful initiative and produced valuable insight, input and inspiration for the BRU Project which was taken into account in the ten policy implications presented in this summary.

Review of the BRU Report 2005
Chapter 1 shows that the Government's objective is to facilitate profitable production of oil and gas in a long-term perspective. The parliamentary debate on the previous Report to the Storting on the Oil and Gas Activities (White Paper no. 38: 2001-2002) gained widespread support to work for the realization of a long-term scenario for the petroleum industry. This requires that all profitable petroleum resources on the Norwegian Continental Shelf are produced. It is an ambitious goal which will result in oil production from the Norwegian Continental Shelf for more than 50 years from now and gas production with a longer perspective.

Technology and competence have been the most important instruments during the last 15 – 20 years and have more than doubled oil production compared to the basis of the PDO Plans and investment decisions. Technology is still the most significant instrument to realize the long-term scenario in the next 15 - 20 years. NTNU will contribute with a research, development and competence strategy to enhance value creation on the Norwegian Continental Shelf and support the internationalization of the Norwegian petroleum industry.

Chapter 2 reviews the overall opportunities and challenges on the Norwegian Continental Shelf. The Norwegian oil and gas industry today has a very strong position in the Norwegian economy. It is industrially well developed, robust and internationally competitive. It is important to make sure that this situation lasts and that the Norwegian petroleum industry will continue to be competitive and contribute to future value creation. Long-term industrial management of the Norwegian Continental Shelf and the internationalization of the entire Norwegian Petroleum Cluster are important issues in this context.

After 40 years, the Norwegian Continental Shelf (NCS) is in a mature phase in many areas. There are still significant remaining resources and Norwegian waters experience a strong interest from the international petroleum industry. Many new oil and gas companies have established themselves in Norway and several are investigating the possibility of doing so. The opportunities reviewed in this chapter are:
- Exploration potential
- Mature fields and improved oil recovery
- Pipeline infrastructure
- Gas production and export
- Cross-border opportunities and the cooperation corridor between the UK and Norway
- Barents Sea and industrial opportunities for Russia and Norway in arctic technology
- Technology opportunities

Even though there are numerous future opportunities and the petroleum industry experiences high oil prices, there are some serious challenges:
- Too little added petroleum resources from exploration and improved oil recovery
- Significant increase in unit costs

These challenges are structural and the entire Norwegian Petroleum Cluster needs to focus carefully on these issues in long-term planning.

In order to meet these challenges we need a renewed technology focus in the Norwegian Petroleum Cluster. Technology and competence are the most powerful and cost-efficient instruments to solve a lot of the remaining and future challenges on the NCS. Technology has been one of the most important elements in contributing to improved efficiency on the shelf up to now. We need a total integrated technology strategy for further research, development and the testing of new solutions. This means significantly higher R&D budgets and closer cooperation in the Norwegian Petroleum Cluster. It is expected that this national focus will be a very profitable investment. We will see a good return from these investments on the NCS at the same time as the Norwegian Petroleum Cluster will improve its international competitiveness.

Chapter 3 presents the fact-finding mission to the industry mentioned above. The results are summed up in the policy implications included in this summary. These have been used to define the four BRU Programs that are briefly presented here and in detail in **Chapter 4**.

Chapter 5 reviews internal R&D projects at NTNU/SINTEF within relevant areas in petroleum research and describes the technology platform at NTNU/SINTEF. The Trondheim campus is one of the largest in Europe in terms of education and research in technology and the natural sciences. With a combined staff of 5 000 and 20 000 students, we are major players, not only in Norway but also on an international scale. Section 5.3 presents 13 papers on activities with specific relevance for OG21 and other areas. This shows why NTNU/SINTEF is a major supplier of technological competence and research to the petroleum sector.

Chapter 6 presents the international aspects and profile of NTNU. The University has developed a broad contact network with the international petroleum industry including National Oil Companies and regulatory bodies in many countries. It is believed that the present practice whereby Norway exports knowledge, skills and competence by offering university education in petroleum and related fields to graduates and staff from oil producing countries and National Oil Companies can be very important in the internationalization process. NTNU's international network and platform will be used in cooperation with the Norwegian Petroleum Cluster in the process of internationalization. Many of the new issues and challenges that the Norwegian oil companies and service companies meet in other geographical regions are already addressed in the curricula for scientific and engineering degrees at NTNU. Internationalization is an area where it is important for us to be in continuous dialog with the industry in order to capture future demands.

Chapter 7 contains 11 invited papers from the industry on important issues that were discussed in the fact-finding meetings:

- Integration of Seismic and Sea Bed Logging
- Ocean Bed Seismic
- 4D Monitoring and Improved Reservoir Simulation
- Cost-Efficient Drilling Methods
- How to Integrate the Seismic Pore Pressure Prediction into the Drilling Process
- Seismic While Drilling
- Subsea to Beach
- Advanced Intervention Technology for Subsea Applications
- Zero What? Water Management in the Norwegian Offshore Industry
- e-Operations – the Integrated Approach
- Fundamental Methods for IOR

Chapter 8 presents an overview of petroleum activities at NTNU/SINTEF. This chapter shows that most departments at NTNU, like their related SINTEF institutes, have petroleum-related activities in their portfolios. The chapter leaves little doubt about the innovative potential of the leading-edge petroleum R&D at NTNU/SINTEF. The challenge for the BRU Project is to structure and integrate this to achieve better resource utilization from Norwegian and global petroleum resources for the entire Norwegian Petroleum Cluster.

Policy implications

As a result of the fact-finding mission where the BRU Team had meetings with key representatives in the Norwegian Petroleum Cluster between November 2004 and April 2005, NTNU has made 10 strategic conclusions. These will contribute to the goals of better resource utilization through new step-changing technologies, strategic alliances and the multidisciplinary approach. Four BRU Programs are defined in the first four conclusions. These are described in more detail in Chapter 4.

Strategic conclusion 1:
Finding and Producing (BRU Program 1)

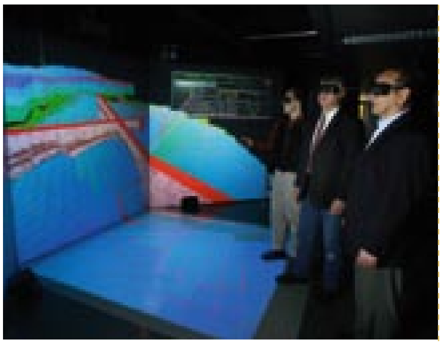
NTNU has decided to integrate the knowledge base within geophysics and geology together with reservoir description and reservoir management into BRU Program 1 that will focus on underground topics: "Finding and Producing" (Exploration and Production/Exploitation). The argument for this is the integration of the unique competence within geophysics and geophysical mapping together with the specialized areas within reservoir characterization and reservoir modeling and reservoir simulations. NTNU/SINTEF's combined expertise in these areas is world class. The multidisciplinary approach between geologists, geophysicists, and reservoir engineers is expected to contribute significantly to solve the future challenges required to unlock the value of the remaining petroleum resources on the Norwegian Continental Shelf.

Strategic conclusion 2: Drilling and Subsea Technology (BRU Program 2)

The second strategic conclusion was to integrate the expertise found at NTNU/SINTEF in drilling and well technology with interventions, subsea technologies and operational issues into BRU Program 2. This will also capture the challenges with tail-end production, tie-in of satellite fields and small field development. About 50 % of the annual operational costs on the NCS are related to drilling. In a new field development, the drilling and well costs are very important contributors to the total cost. We need to reduce the drilling costs significantly in order to handle the future resources in exploration and production. Low cost drilling, drilling for improved recovery, and subsea technology for improved recovery are all important elements in BRU Program 2.

Strategic conclusion 3: eField and Integrated Operations (BRU Program 3)

The next strategic conclusion has followed the industry's advice to develop a BRU Program 3 on "eField and Integrated Operations". This is



one of the more challenging issues in the petroleum industry and we foresee that this area will be the next efficiency step and a breakthrough for the entire global petroleum industry. To solve the challenges in this area, NTNU/SINTEF will need to integrate the combined expertise of about 7 - 8 different departments and institutes across both organizations. In this respect NTNU/SINTEF is in a unique situation because it has the required highly specialized expertise from different areas within its organizations and these people can be put together in project cooperation. NTNU/SINTEF will place high priority on this program and is committed to deliver valuable industrial solutions and long-term competence. This is also an area with considerable export potential in the long run which is an important reason for further strengthening the Norwegian Petroleum Cluster in eField and Integrated Operations.

Strategic conclusion 4: Arctic Technology (BRU Program 4)

NTNU has decided to establish BRU Program 4 on "Arctic Technology" integrating arctic exploration, environmental technology, gas technology, flow assurance and gas transportation into a special program. It is estimated that about 25 % of the remaining hydrocarbon resources in the world are located in Arctic areas. The Barents Sea has received renewed interest from the entire petroleum industry. Furthermore the Russians have focused priority on their continental shelf both in the Barents Sea and in the Pechora Sea. The Norwegian Petroleum Cluster has a golden opportunity to further develop the cooperation with the Russian oil and gas industry in this context.

Strategic conclusion 5: Step-change technology to improve recovery

Three of the BRU Programs: "Finding and Producing", "Drilling and Subsea Technology"" and "eField and IO" will use a common knowledge base to improve the recovery rate in oil and gas fields. The challenge is putting together research and development expertise across disciplines. This will involve close cooperation between seismic mapping, reservoir description, reservoir management and drilling in the different BRU Programs to develop a new paradigm in resource recovery by step-changing technologies. This work can make a significant contribution to the long-term goal of increasing recovery rates from all petroleum reservoirs.

Strategic conclusion 6: GEMINI Petroleum Center

NTNU and SINTEF have planned a GEMINI Petroleum Center. This Center was formally opened during the BRU Seminar 2005 by Thorhild Widvey, the Minister of Energy and Petroleum.

Strategic conclusion 7: Arctic Exploration Center

The three independent organizations NTNU, SINTEF and Norges Geologiske Undersøkelser (NGU) have agreed to join forces and seek support for an arctic exploration center. The initiative has been named EXTRA: "Exploration Technology Related to the Arctic".

Strategic conclusion 8: International university cooperation

NTNU has a well-established contact network with the major universities and educational competence centers in the petroleum sector around the world. NTNU is about to sign Cooperation Agreements with some of the best international players in each of the BRU Program areas. The objective is step-changing technological developments for the industry.

Strategic conclusion 9: R&D Focus and Scale

As a consequence of the BRU strategy, NTNU will establish focused and scaled R&D. NTNU will consequently focus its R&D funding, academic manpower and Ph.D. candidates towards the four BRU Programs.

Strategic conclusion 10: Organizational issues and networks within Energy and Petroleum

The organizational issues are vital to achieve the overall objectives in the BRU Project. NTNU and SINTEF are committed to implement a management structure for cooperation across the different departments, institutes and competence centers to support these objectives.

NTNU will develop a *knowledge base structure* which will be a virtual organization linked together in different network groups. These types of networks have been implemented within several of the international oil companies with great success. NTNU and SINTEF have many thousands of experts working in different departments and institutes who are directly or indirectly addressing areas that potentially may solve some of the challenges faced by the petroleum sector.

NTNU will organize a *global R&D scouting program* in order to have a updated overview of all R&D activities performed internationally. This will give the opportunity to utilize results and developments from activities performed internationally either at universities or in the industry. Further it will avoid performing unnecessary duplication of research.

NTNU will also set up an *industry scouting program* in order to have a clear understanding of the industrial needs on the short, medium and long terms. This will be a continuously organized activity. The fact-finding meetings during the BRU process were a good starting point here.

BRU Seminar 2005

The BRU Seminar 2005 was held at NTNU on 22-23 August. Attendance was good and about 120 delegates represented the oil companies, service companies, sectoral organizations, the authorities, external research institutes and representatives from NTNU/SINTEF. NTNU's new Rector, Torbjørn Digernes wished the seminar delegates welcome before Thorhild Widvey, the Minister of Petroleum and Energy opened the BRU Seminar with an introductory keynote speech. Here she focused on the Norwegian Continental Shelf, its importance and the need for R&D in the future.

She also officially opened the Gemini Petroleum Center between NTNU and SINTEF. SINTEF's President Unni Steinsmo explained the importance of the Center before signing the agreement with Jon Kleppe, NTNU. This was followed by an address by Erik Skaug, Director of the Research Council of Norway and a keynote speech by Gunnar Berge Director General of the Norwegian Petroleum Directorate and. During the seminar NTNU's Jon Kleppe and Arne Bredesen and SINTEF's Gunnar Sand presented their main areas of activity in petroleum research. Alfred Nordgård, Shell, who chairs OG21, showed what OG21 expects from NTNU and SINTEF in this area. The BRU prospective and discussion with industry involved Jon Kleppe, Sigbjørn Sangesland and Bjørn Ursin all NTNU, and Arild N. Nystad Petromanagement all from the BRU Team and, on the other hand, Jens Hagen, Hydro; Sverre Strandenes, PGS; Alan Burns, Total; Morten Loktu, Statoil; Kjetil Lenning, Odfjell from the industry. Yngve Theodorsen, Statoil presented some of the main international challenges to the industry and Tore Halvorsen, FMC Kongsberg discussed technological breakthroughs from the perspective of the Norwegian Petroleum Cluster. Internationalization was discussed by Jon Kleppe NTNU and Gulbrand Wangen, Intsok.

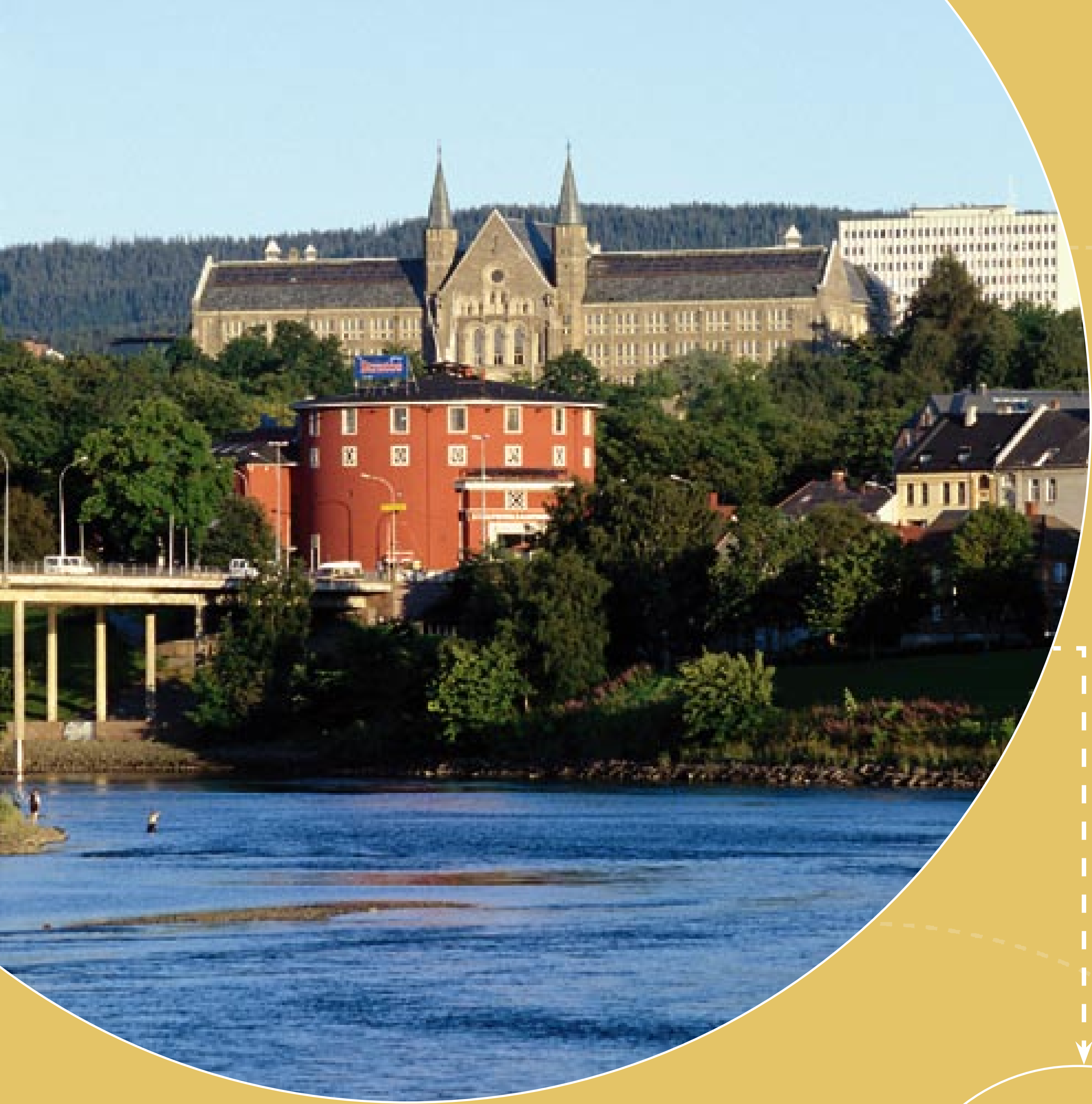
The BRU Seminar included a roundtable discussion on the importance of petroleum education in the long-term development of society. This discussion was chaired by the manager of Kon-Kraft Kjell-Arne Oppebøen. The panel consisted of two politicians, Trond Giske and Michael Momyr; Arild Selvig, FMC Kongsberg, representing the industry; and student Sigrun Mellemstrand and Rector Torbjørn Digernes representing NTNU. Finally the Seminar had a special session on eField and Integrated Operations where Trond Lilleng from OLF/Hydro gave an overview of industry trends and needs followed by a presentation by Jon Lippe about a relevant NTNU/SINTEF program. This was followed by a panel discussion where the BRU Team outlined their future plans for cooperation between NTNU/SINTEF and the industry in Integrated Operations. Most of the named contributors to this successful event are seen in the photographs from the Seminar.

NTNU/SINTEF received valuable and well-considered feedback during the presentations and discussions on the strategic plan for focused petroleum research at NTNU and the four BRU Programs.
Here are some of these highlights from this feedback:

- Challenge the industry with new thinking - do not try to be too similar to the industry
- Expand the cooperation and contact with the supply industry as well as the ongoing established contact with the oil companies
- Highlight safety issues
- Look into the possibility of transferring knowledge from other industries
- Concentrate the R&D on the long-term issues and challenges (the steps beyond ongoing development work in the industry)

The four BRU Programs were well received, but several delegates advised that the process of focusing these programs should be continued.
All these comments will be reviewed during the last quarter of 2005 when we will prepare these Programs in more detail. NTNU/SINTEF will set up an organizational structure for the management of the four BRU Programs. The first task for the Program management will be a more detailed specification for each Program and include the feedback from the industry.

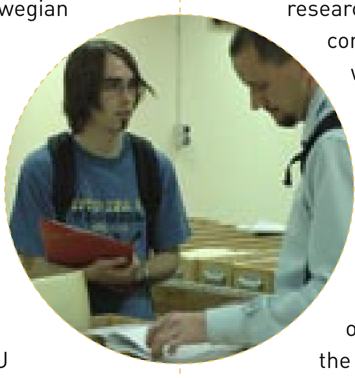
NTNU plans to organize the BRU Seminar as an annual event. This will build on our close relationship and contact with the petroleum industry.
The BRU Seminar 2006 will report on the results from the BRU Programs and discuss the focus and future direction of petroleum research at NTNU/SINTEF.



Part I

1 The BRU Project Goals

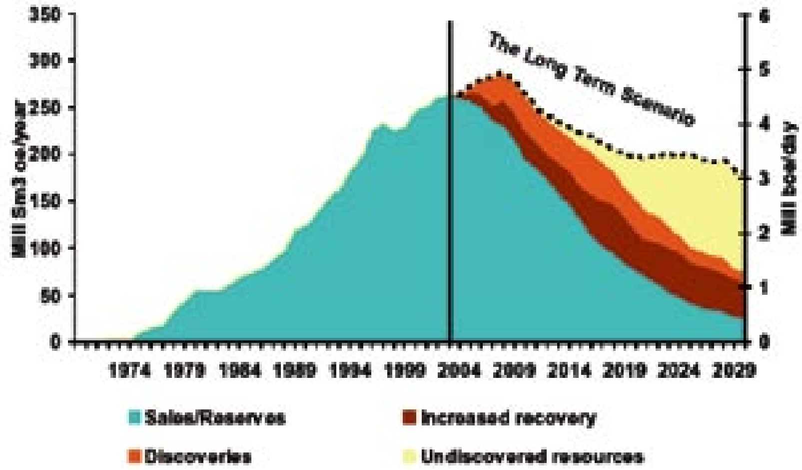
The BRU Project has the goal of determining the most important areas for Technology and Competence (T&C) for operations on the Norwegian Continental Shelf and in the Norwegian Petroleum Cluster in order to realize the long-term scenario presented by the authorities. The BRU Project will conclude with a concerted Research, Development & Competence strategy (R&D and C) for NTNU in petroleum and outline the priority areas for NTNU in the future. NTNU needs to have significant focus and decide a priority set of major areas in order to deliver this R&D and C to the petroleum industry. All departments at NTNU that have relevance for petroleum research have been taken into consideration in combination with activities at SINTEF.

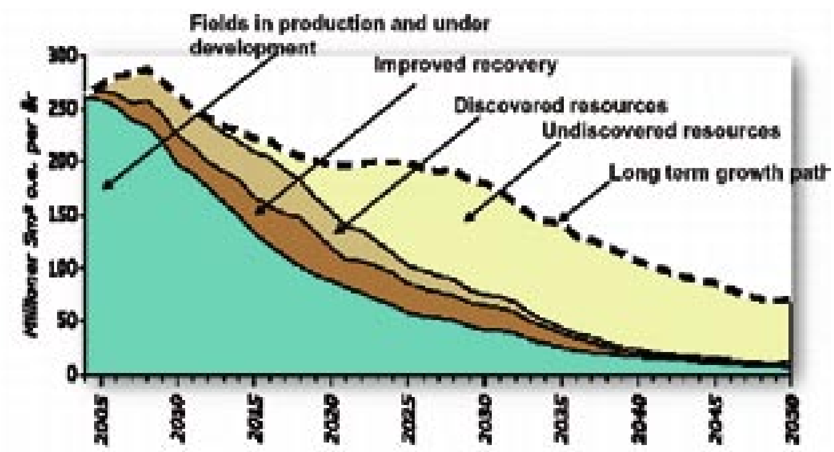


The Government's objective is to facilitate profitable production of oil and gas in a long-term perspective. The parliamentary debate on the previous Report to the Storting on the Oil and Gas Activities (White Paper no. 38: 2001-2002) gained widespread support to work for the realization of a long-term scenario for the petroleum industry.

This requires that all profitable petroleum resources on the Norwegian Continental Shelf are produced. It is an ambitious goal which will result in oil production from the Norwegian Continental Shelf for more than 50 years from now and gas production with a longer perspective (see the figures below).

In this context, NTNU has the goal of contributing to national value creation on the Norwegian Continental Shelf and this long-term scenario. NTNU will also contribute to the internationalization of the Norwegian petroleum industry. These dual objectives will be realized by focused R&D.





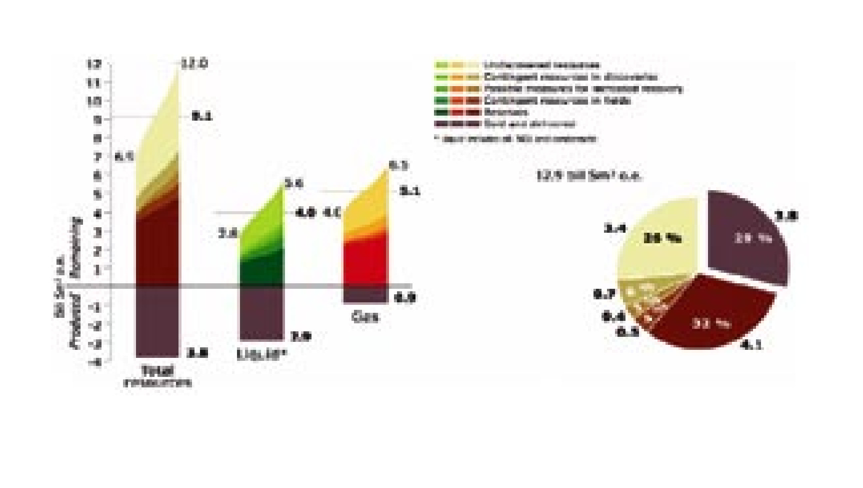
Source: Ministry of Petroleum and Energy (MPE)

2 The Norwegian Continental Shelf - Challenges for the Norwegian Petroleum Cluster

2.1 THE NORWEGIAN CONTINENTAL SHELF – OVERALL OPPORTUNITIES

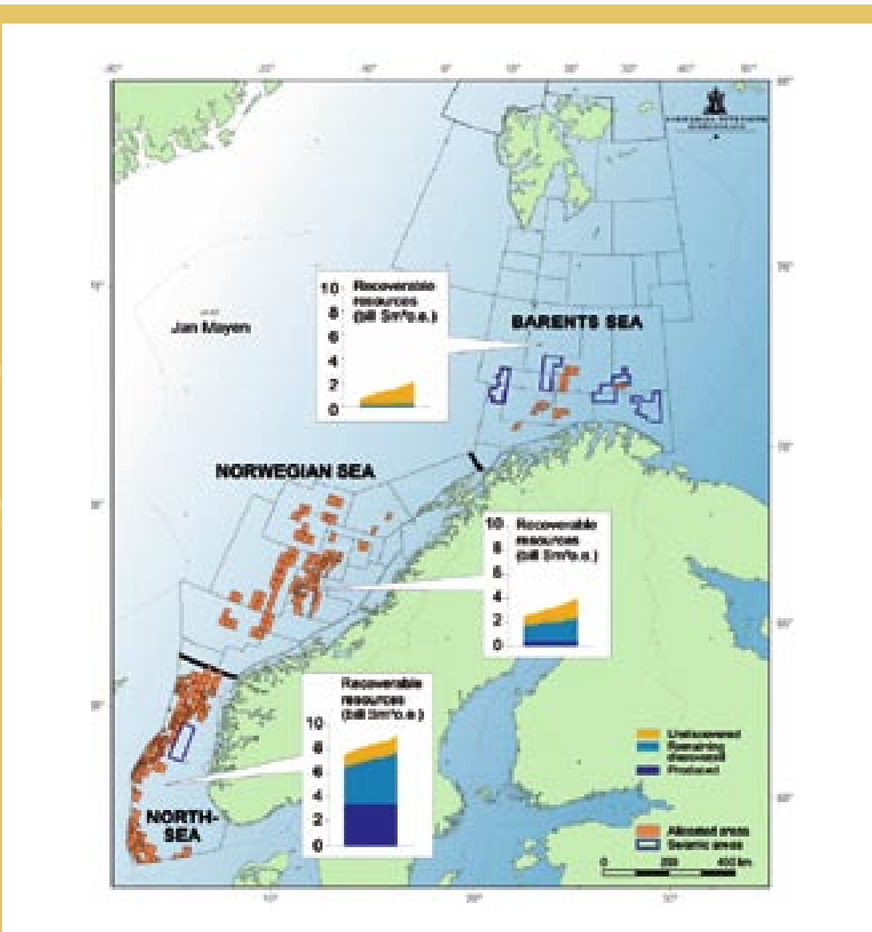
Strong industrial position and resource potential

The Norwegian oil and gas industry today has a very strong position in the Norwegian economy and is internationally competitive. It is important to make sure that this situation lasts so that the Norwegian petroleum industry will continue to be competitive and contribute to future value creation. Long-term industrial management of the Norwegian Continental Shelf and the internationalization of the entire Norwegian Petroleum Cluster are important issues in this context.



Source: Norwegian Petroleum Directorate (NPD)

After 40 years, the Norwegian Continental Shelf (NCS) is in a mature phase in most areas. There are still significant remaining resources on the Norwegian Continental Shelf and Norwegian waters experience keen interest from the international petroleum industry. There are a lot of new oil and gas companies that have arrived and several others are investigating the possibilities on the NCS. At the same time, we have a Norwegian petroleum industry which is industrially developed, robust and internationally competitive.



Source: NPD

International markets are very attractive for the Norwegian petroleum industry and service industry. A key issue to address is how to maintain future competitiveness in the twin focus areas: making sure that the entire Norwegian Petroleum Cluster contributes to value creation on the Norwegian Continental Shelf and building up long-term international business.

There is still huge resource potential on the NCS. After 35 years of production, only 1/3 of the total resources have been depleted. Improvements in the recovery rate in mature fields, new field developments as well as the future exploration potential represent significant resources.

Exploration potential

It is vital to discover new petroleum resources from the exploration activities to realize the long-term scenario.

According to NPD the undiscovered resources are still estimated to be 3.4 billion Sm^3 o.e. with an uncertainty span between 2.6 – 4.3 billion Sm^3. The expected distribution between the different areas is North Sea (35 %), Norwegian Sea (36 %) and the Barents Sea (29 %). The average field size has diminished over recent years and there has been reduced exploration activity in this period.

Mature fields and improved oil recovery (IOR)

We have the following situation in mature areas on the Norwegian Continental Shelf:

- Mature fields with falling production and high operational costs
- Significant increase in unit costs
- 50 % of the future exploration potential is in mature areas
- The infrastructure in mature areas has a limited life span
- Challenges:
  - Reduce operational costs
  - Improve resource recovery
  - Add satellite resources

The resource potential and the potential for future added value in mature fields are both significant:

- IOR potential of 900 million Sm^3 (5.5 billion barrels)
- Upside potential of 1500 million Sm^3 (9.5 billion barrels)

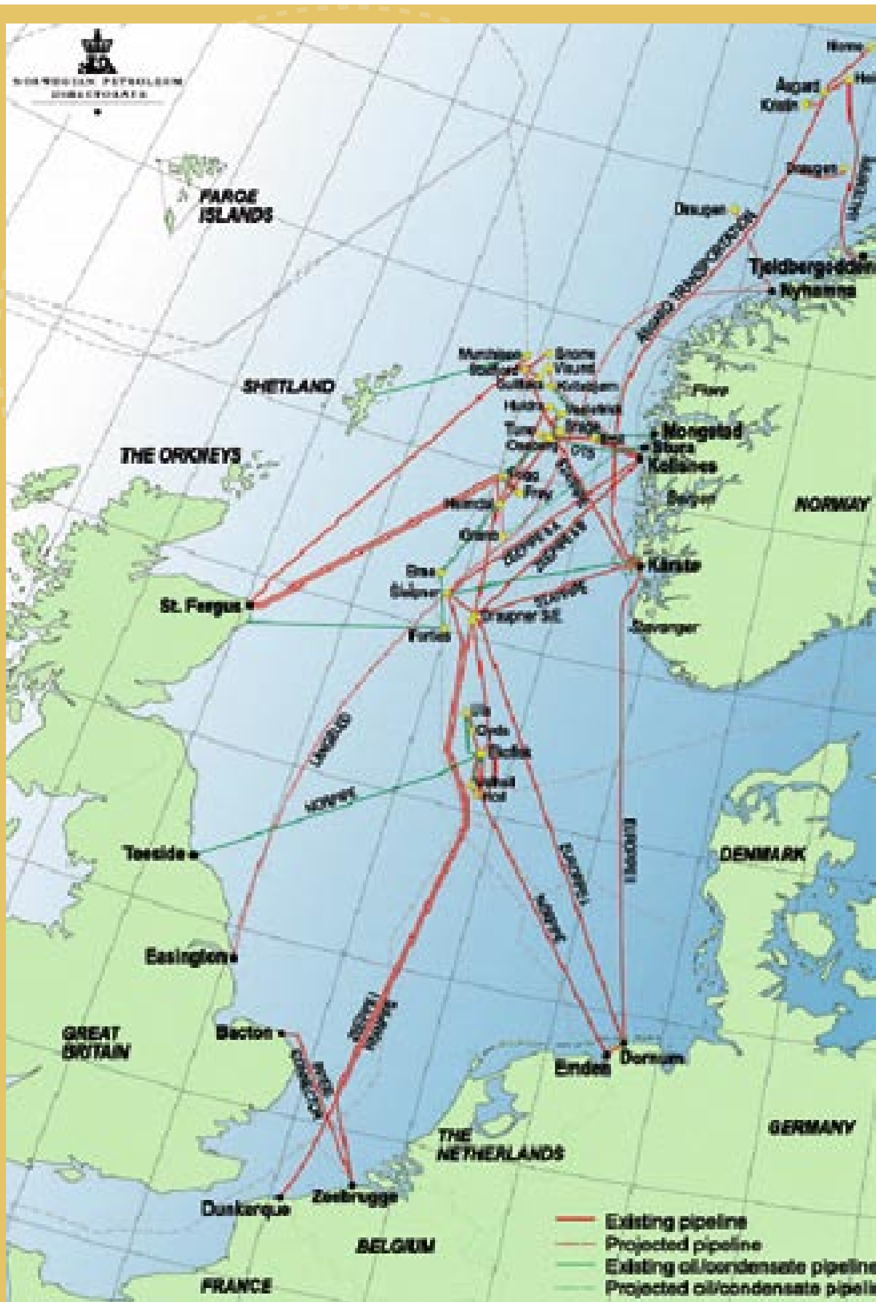
Source: Statoil

NPD has identified 100 different concrete and relevant projects for added value in producing fields. Several of these projects are marginal and need R&D. In addition, satellite fields will also add value. The objective to obtain an average recovery rate of 50 % may not be ambitious enough.

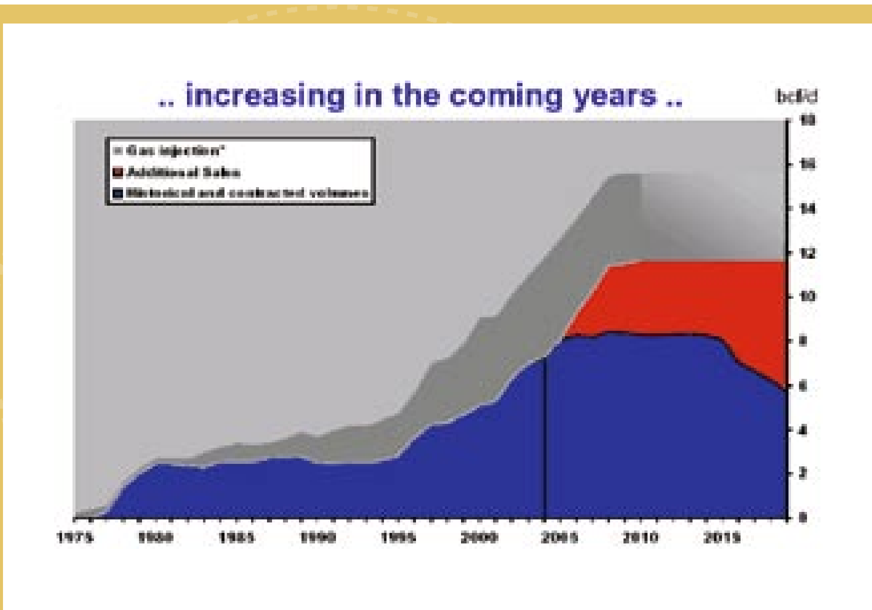
Pipeline infrastructure

The Norwegian gas pipeline system today represents one the most efficient transportation systems in the world. It has been developed over 30 years and connects the major gas fields on the NCS to the continental European market. Flexibilities in the chain are built in so that the supply security of the gas supply to the market is taken care of. There are interconnections between the different fields. These are related to gas flexibility to the market and supplying gas to the major oil fields for reinjection purposes. The entire gas pipeline transportation system has satisfactory capacity, flexibility and economic efficiency. The access principles are based on having a common carrier and well-established rules about third-party access and tariffs. The owner structure GassLed is represented by the major oil companies and the operating company Gassco – assures efficient utilization of the infrastructure. Further, third-party access to the capacity is assured by regulated prices.

However, there are still several R&D challenges in order to improve the technical and financial efficiency of pipeline transportation systems.



Source: NPD



Source: MPE

Gas production and export
Norway is one of the major gas suppliers to continental Europe and its relative importance will increase in the future. Gas exports are expected to increase from about 80 billion Sm^3 to 120 billion Sm^3 annually towards 2010.

In addition to exports, a significant volume of gas is reinjected into reservoirs (about 40 to 50 billion Sm^3 annually) in order to improve the recovery rate in oilfields. This highlights the importance of an efficient and flexible transportation network on the Norwegian Continental Shelf. The injection volumes also represent additional flexibility in the supply chain to the market.

Cross-border opportunities and the cooperation corridor between the UK and Norway
The UK – Norwegian Cooperation Corridor along the median line between the UK and Norway still represents a very promising petroleum asset. The corridor is a mature area with a lot of infrastructure in platforms and pipelines. It has been extensively explored and exploited during the last 30 years. Geologically this part of the North Sea has some of the biggest basins and the corridor has been and still is a rich area of petroleum resources. The geology is almost mirrored on both sides of the median line.

The petroleum and energy ministers in Norway and the UK signed a joint Cooperation Agreement in 2003. The objective is to assure the continuation of value creation from the activities of the petroleum industry in this part of the North Sea on both the Norwegian Continental Shelf and the UK Shelf. The underlying studies forecast about USD 100 billion in future investments, operational costs and removal costs in the Cooperation Corridor between 2002 and 2020. The current production level of oil and gas fields in the corridor is about 4.5 million barrels of oil equivalent, representing 50 % oil and 50 % gas. There are still a lot of commercial opportunities in this mature area.

The possible values in cross-border cooperation are highlighted by the two ministries in Norway and the UK. In November 2001, the two energy ministers in Norway and the UK promoted increased cooperation in the North Sea. This was followed up by a report presented at ONS in August 2002. This was further developed by a group that presented the results in London in December 2003. The joint Cooperation Agreement of October 2003 outlined the potential financial benefits from such cooperation:

- Multitude of cheaper infrastructure
- More efficient transport systems
- Operational synergies
- Revitalization of marginal resources
- Multitude of satellite fields

Time marginal resources along the median line that are close to already established infrastructure will play a crucial role.

On 4 April 2005, the Norwegian Petroleum and Energy Minister Thorhild Widvey and the UK Energy Minister Mike O'Brien signed a new agreement. This is a framework agreement covering the petroleum sector across the median line between the two countries.

There are still a lot of challenging issues to be addressed that are candidates for R&D.

Source: NPD

Barents Sea and industrial opportunities for Russia and Norway in arctic technology

It is estimated that about 25 % of remaining hydrocarbon resources in the world are located in arctic areas. Norway has had activities in the Barents Sea since the opening of the area in 1985. We have experienced different phases in the level of activity during these years and in the estimation of the resource potential. About 50 to 60 exploration wells have been drilled over 20 years. This has resulted so far in the development of the Snøhvit LNG project and the discovery of the Goliat oilfield. The Norwegian Continental Shelf is a huge part of the Barents Sea and 50 to 60 exploration wells is a small number in this context.

On the Russian side there has been a high level of exploration activity and there is international competition for developing the extensive gas resources on the Shtokmanovskoye Field. Further there are a lot of other discoveries and prospects on the Russian Continental Shelf in the Barents Sea and the Pechora Sea.

Whatever activity level and industrial solutions we choose for the Norwegian part of the Barents Sea, the oil and gas activity on the Russian part of the Barents Sea will continue. The importance of the area is also highlighted by the Russian plans to transport huge amounts of oil to a terminal and ship this by tanker along the Norwegian coast. The export volume of 3 million bbl/day has been mentioned in this context on several occasions. This will definitively add to oil activities and the environmental challenges in both the region and along the Norwegian coastline.

There are very interesting industrial opportunities to plan and develop this arctic area as cooperation between Russian and Norwegian industry. This means potential value creation for both countries and the application of environmental best industrial practice. The Norwegian Petroleum Cluster is a world leader in environmental technology and in the application of environmentally sound solutions.

Technology opportunities

Technology is the most important instrument in order to reduce costs, increase recovery and secure sound environmental solutions. R&D is an important investment in order to maintain a competitive oil and gas industry in Norway. There are still huge challenges in order to improve the technical and financial solutions throughout the whole value chain from the mapping of resources, exploring for new resources, field development and depletion, improved oil recovery, new operational approaches such as e-field and integrated operations, environmental issues and the removal of installations. The petroleum industry has strategic cooperation in the OG21 where ten Technology Programs are highlighted. This industrial cooperation is unique and directs priorities in companies, research institutions and universities. The academic institutions are also very important suppliers of R&D and long-term competence.

2.2 THE NORWEGIAN CONTINENTAL SHELF – OVERALL CHALLENGES

Mature shelf phase
Even though there are a lot of future opportunities and the petroleum industry experiences a new high price level, there are several very serious challenges for the future. These are structural and the entire Norwegian Petroleum Cluster needs a strong focus on these issues for long-term planning.

A mature shelf means that we go into a phase with a flattening out and even reduction of the addition of new resources both with respect to exploration and improved oil recovery. The addition of petroleum resources is being diminished in all resource categories. We do not find enough petroleum resources and we drill too few exploration wells to compensate for this. Improved oil recovery helps but does not compensate for this trend. During the last 5 years, we produced 250 million Sm^3 annually while the annual total addition of petroleum resources through the combined effort of exploration and improved oil recovery has been about 100 million Sm^3 (50/50 exploration and IOR). Even considering a longer timeframe - the past decade - exploration on average only produced about 50 million Sm^3 annually. This goes in combination with a future significant increase in the unit costs on all the major oilfields because they are or are about to enter the decline phase.

The structural challenge for the NCS is the combined effect of these two elements related to:

- Too little added petroleum resources by exploration and IOR
- Significant increase in unit costs

The most efficient instruments for this challenge are focused investment in:

- Technology development in the whole value chain from the reservoir to the market
- Internationalization of the entire Norwegian Petroleum Cluster to maintain a long-term Norwegian oil and gas industry

A concerted focus and effort to develop Technology and Competence (T&C) will be the best platform for realizing the long-term scenario for the NCS and having an internationally competitive Norwegian oil and gas industry. These issues invite the need to reconsider our common strategy – we need a paradigm shift in order to concertedly harvest the resources in the entire Norwegian Petroleum Cluster and have the needed focus and required effort.

The high price level that the industry experiences will produce a lot of new projects in field development and exploration. The long-term trends are however still the same in the mature province. The higher oil price level may give us more time to solve future challenges, but the same challenges have to be addressed and resolved. We have to take into account the dynamic aspects of the traditional planning horizon for the petroleum industry of about 15 years, and use the instruments we need today to face tomorrow's challenges. Results do not come overnight and we must expect a time lag of several years between applying these instruments and obtaining the end results. Given long-term stable strategies, the Norwegian Petroleum Cluster can also be an important economic locomotive for all Norwegian industry.

Lack of petroleum resources
As mentioned, each year we produce significantly more oil and gas than we reproduce through exploration and IOR. In addition, our remaining proven resources are challenging to make them commercially feasible

In 35 years we have produced about 4 billion Sm^3 o.e (77 % oil and 23 % gas) of a total of 13 billion Sm^3 o.e. We have remaining resources of 9 billion Sm^3 o.e (43 % oil and 57 % gas). There are great uncertainties in such geological estimates. We have both a downside and an upside to these numbers. There are about 4 billion Sm^3 o.e. (40 % oil and 60 % gas) reserves in fields already producing and where development is decided. Further there is about 1.5 billion Sm^3 o.e. resources in fields in the planning phase and IOR projects and about 3.4 billion Sm^3 o.e. (45 % oil and 55 % gas) is estimated for exploration.

It is still an overall challenge to commercialize the remaining discovered petroleum resources in an economically efficient manner in order to realize the long-term scenario. So far we have had a 30 - 40 year period with development and exploitation of petroleum fields with reservoirs of 100 – 500 million Sm^3. In the future we have to find efficient technologies in order to deplete fields in the order of 1 – 5 million Sm^3. This is a significant challenge to the industry, the authorities and the entire R&D sector. In addition a lot of the resources are located around producing fields and installations with a limited remaining life span. Thus we have a lot of "time marginal" resources that need to be exploited within a limited window. This goes for improved oil recovery, tail-end production, satellite fields and exploration in mature areas in the North Sea and Haltenbanken. These topics are specifically relevant in the Cooperation Corridor between Norway and the UK.

The future strategies in exploration should use the NPD figure of 3.4 billion Sm^3 as a starter for future planning. But since the annual exploration results have been about 50 million Sm^3 during the last 5 -10 years we have to revisit the strategies. We would claim that there are a lot of challenging technology issues to resolve in order to reach the NPD figure in terms of economic feasibly within a reasonable industrial time span.

These issues invite R&D and C strategies in the following areas:

- Novel exploration methods
- Advanced drilling methods
- Improved oil recovery methods
- Time critical resources (tail-end, satellite, infrastructure exploration)
- Subsea development

Significant increase in the unit costs on the Norwegian Continental Shelf

The mature phase is characterized by declining fields. Several of the major work horses on the NCS are already in the decline phase or about to enter decline. This will inevitably produce a significant increase in the unit costs in the future and the oilfields will increase water production. We will soon produce more water than oil on the Norwegian Continental Shelf.

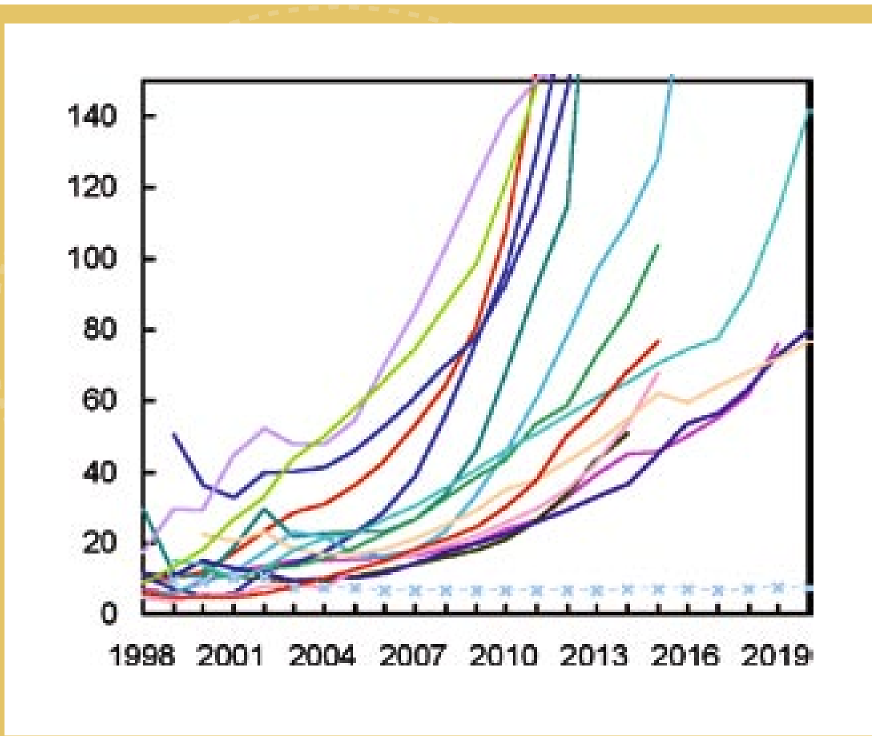
The cost level is essential for the long-term profitability of the resource base on the NCS. The high cost level influences exploration and exploitation in a negative manner. It is essential to control costs in the future.

In the mature phase of the NCS the unit cost is expected to increase significantly. We will see changes in the fashion that we operate fields. Transfer of work onshore by eField and integrated operations (IO) will both reduce costs and improve the decisions taken. Thus the reduction in work tasks and number of people offshore will be an integrated part of the new way to exploit and produce fields. We will see more flexible work off-shore and new work processes including the reduction of permanent maintenance people offshore and more campaign oriented maintenance. There will be focus on improving the utilization of the supply boats and the efficiency of the supply bases. Finally we will harvest even more by integrated area optimization.

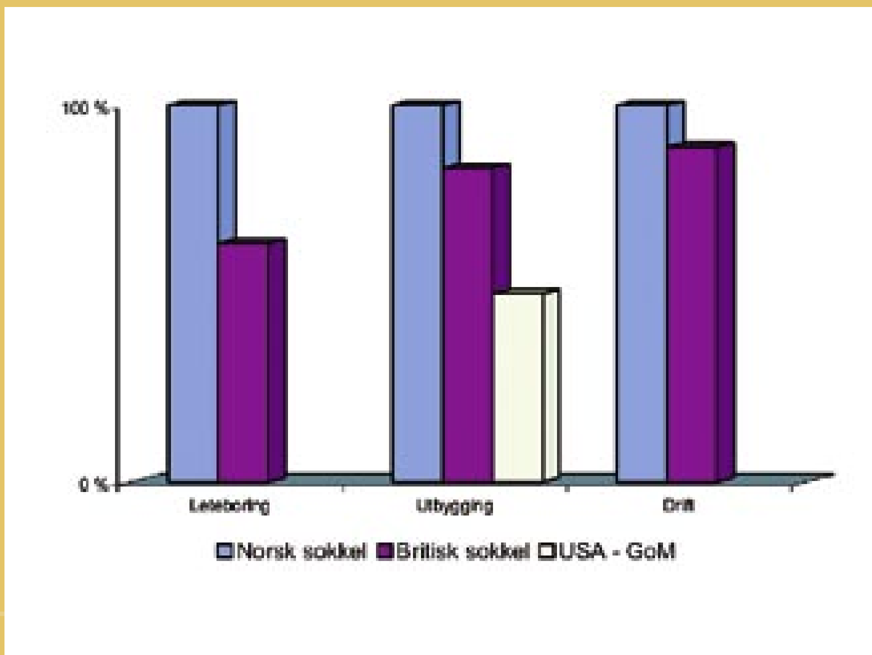
- The cost level is crucial for the profitability of the resource base on the NCS
- Significant potential for cost reductions on the NCS (KON-KRAFT & NPD)
- Cost drivers: personnel (65 % of total operation & maintenance cost), manning, HSE regulations, organization & work forms
- Drilling is a major cost element on the NCS and a key to future exploration and exploitation
- In the operational phase billions of NOK can be saved by transferring best industrial practice to all fields

Both technology and new organizational work processes are required to counteract the increased unit costs in the future. These include the following technology areas:

- eField and integrated operations
- Reduced drilling costs
- Better reservoir monitoring and reservoir management
- New development solutions including efforts to improve subsea developments
- Technologies and methods to handle the increased water production



Source: Kon-Kraft



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2.3 NTNU/SINTEF AND THE NORWEGIAN PETROLEUM CLUSTER

This BRU Project and BRU Report will conclude by showing the most important areas for Technology and Competence for the entire Norwegian Continental Shelf and Norwegian Petroleum Cluster. Then a concerted R&D and Competence (R&D and C) strategy will be outlined for NTNU in petroleum. In this context all departments at NTNU with relevance for petroleum research are considered in combination with SINTEF.

NTNU and SINTEF have about 5000 scientists together. NTNU has about 20 000 students – of which more than 50 % are technologically oriented. The Trondheim Science Campus is the fourth largest in Europe and has a tremendous opportunity to provide the required technology and competence for the Norwegian Petroleum Cluster.

Our goal is to conclude with the areas of technology that are required and direct both the R&D investments and human capital towards these focus areas. In addition to the scientific manpower on the Trondheim campus, there is significant expertise in the PhD and post-doctoral researchers on campus.

It is important to further develop technological cooperation between NTNU and the international oil companies as well as the entire service industry. The triangle between the universities and R&D institutes; the international oil companies and service companies; and thirdly the authorities and research funding represents a powerful cooperative force. However, it is a challenge to obtain the inherent added value from the organizations here.

2.4 TECHNOLOGY FOCUS IN THE NORWEGIAN PETROLEUM CLUSTER

Technology and Competence are as mentioned the most powerful and cost-efficient instruments to solve a lot of the remaining and future challenges on the NCS. Technology has been one of the vital elements in contributing to improved efficiency on the shelf up to now. This has to be maintained – but renewed effort is needed with significant focus, on extensive, comprehensive and long-term strategies in order to reach the goals.

We need a total integrated technology strategy for further research, development and testing of new solutions. A combination of significantly higher R&D budgets together with a concerted cooperation in the complete Norwegian Petroleum Cluster is needed. It is expected that such a national focus will be a very profitable investment. We will see a good return from these investments on the NCS at the same time as the Norwegian Petroleum Cluster will improve its competitiveness internationally.

Technology and Competence have been the most important instruments during the last 15 – 20 years and have more than doubled oil production compared to the basis of the PDO Plans and investment decisions. Technology is still the most significant instrument to realize the long-term scenario in the next 15 - 20 years.

Technology will thus be the major contributor in order to improve the amount of commercial resources found in the whole value chain from exploration to exploitation and tail-end production. We have 40 years of experience in building up relatively good economic efficiency in exploration and production.

But for the last 5-10 years we have been in a transitional period from the growth phase, to a phase with stabilization, and now face the decline phase. We are confronted with a completely new set of challenges where it will be significantly more demanding in relative terms to manage to maintain the production of oil and gas economically in the future.

Important examples are the following areas where we need significant improvements and where technology will be the most important contributor:

- *Novel exploration methods:* We need to investigate new methods and interdisciplinary approaches in order to improve the capability to explore a continuously more demanding environment
- *Novel and cost-efficient drilling:* We need to reduce the drilling costs significantly in order to handle the future resources in exploration as well as production. We need novel and cost-efficient drilling methods in both exploration and production. The combination of new efficient seismic mapping methods together with significantly better and less expensive drilling methods, will be an important contributor. About 50 % of annual total costs on the NCS are related to drilling.
- *Improved recovery:* There are still huge resources remaining as oil in place on the NCS in all petroleum fields. A 10 %-point increase in the recovery of oil represents an addition of 1000 million Sm^3 oil. It is also important to have special focus on the recovery from subsea fields which on average have 10 -15 %-points less recovery than similar platform connected wells.
- *eField and integrated operations:* We will see significant improvements in the economic exploitation of oil and gas fields in the near future by the next generation of petroleum field exploitation by eField, Integrated Operations and Smart Field Technologies. These challenges are in all disciplines in the value chain from the reservoir to the control and support room onshore. There are a lot of technologies that need further development and improvement within this area.

This is the next major efficiency gain for the entire global petroleum industry.

Significant results depend on a focused investment strategy and concerted cooperation in the whole Norwegian Petroleum Cluster. These elements will be an important contributor to realize the long-term scenario on the NCS and have an internationally competitive Norwegian Petroleum Cluster.

A massive focuse on improved oil recovery is one of the most important elements in the strategy to reach the long-term scenario. Important elements will be:

- Continue to develop exploitation knowledge and exploitation technology throughout the Norwegian Petroleum Cluster
- Allocate national resources to IOR projects which are a very profitable investment
- Combine basic reservoir and exploitation knowledge together with efficient methods within seismic mapping and drilling technology
- Focus on improving the recovery for subsea fields
- Full-scale pilot tests and pilot programs with focus on IOR

NTNU is positive to contributing to solve all these challenges together with the petroleum industry.

Two steps to provide a basis for drawing up the technology strategy for the Norwegian Petroleum Cluster:

Review of how the R&D sector in the Norwegian Petroleum Cluster is organized

The governance structure of any system is important for the economic efficiency of that system. The first instrument may be to look into the organization of the entire Norwegian R&D resources and the R&D sector in the Norwegian Petroleum Cluster. The R&D sector in the Norwegian Petroleum Cluster has three levels:

- Universities: NTNU, UiS, UiO, UiB
- R&D institutes: SINTEF, RF, CMR, IFE, and others
- Norwegian oil company R&D: Statoil R&D and Hydro R&D

This represents a powerful international resource. However, a more concerted integrated strategy and organizational cooperation would produce added value for all parties involved and enhance the international position of all petroleum related R&D in Norway. This includes the R&D activities in the service industry (AkerKværner, FMC Kongsberg, Schlumberger, Halliburton and other smaller and very creative Norwegian service companies).

Common use of the R&D funds allocated in the Account Agreement

A second instrument for the Norwegian Petroleum Cluster is to investigate the possibilities for common use of the R&D funds allocated in the Account Agreement. This agreement states that 1.5 % of the total annual investment and operational costs in the license shall be allocated to R&D. This represents between NOK 1.5 – 2.0 billion annually. So far, the Operators have used this money for their own R&D. It may be that the entire R&D sector will produce more efficient solutions by opening up this system to more concerted and focused R&D for the Norwegian Petroleum Cluster. If the investment of this money is done in a transparent manner where the results from the research will be available for the entire R&D sector, we will obtain added value that can be shared by all parties. In this respect we need to highlight the transfer of experience from one field to another.

2.5 INTERNATIONALIZATION OF THE NORWEGIAN PETROLEUM CLUSTER

Many areas in the world have been opened up to the international petroleum industry during the past decade. This results in more commercial competition on the NCS on the one hand but also a lot of new opportunities for the Norwegian Petroleum Cluster on the other hand.

The Norwegian Petroleum Cluster has a unique opportunity internationally based on the experience built up from the Norwegian Continental Shelf. However, the cluster needs focused technology and competence development in a long-term strategy. Such a strategy will highlight the numerous possibilities in the cooperation between universities, R&D institutes, the supply industry and the petroleum companies that can strengthen its international competitiveness.

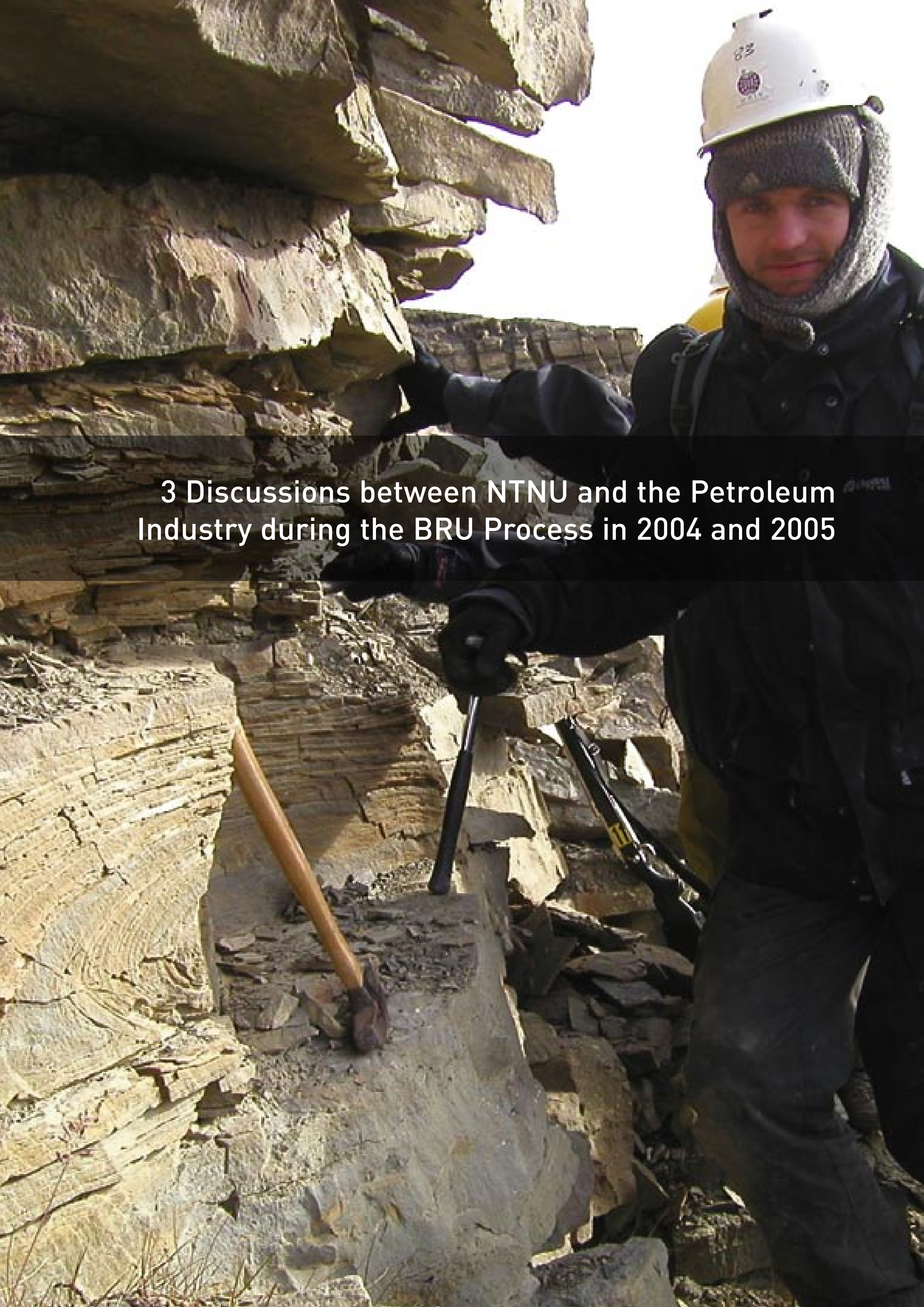
In the long run the only way for the Norwegian Petroleum Cluster to maintain its position and grow is to penetrate international markets. The next 3-5 years seems very important in order to develop the long-term platform for a transition from activities related to projects on the Norwegian Continental Shelf to projects in other geographical regions. Technology and Competence are the most efficient instruments in order to obtain successful developments here.

It is important to establish common understanding of the importance of long-term stable and concerted strategies related to competence, education, knowledge and research & development. These elements are fundamental in order to succeed on the NCS as well as internationally. NTNU has the stated goal being an important contributor in this respect.

Many of the new issues and challenges that the Norwegian oil companies and service companies meet in other geographical regions are already addressed in the curricula for scientific and engineering degrees at NTNU. This is an area where it is important to have a continuous dialog in order to capture future demands. NTNU has developed a broad contact network with the international petroleum industry and regulatory bodies during the last 10 -12 years. This platform will be used in cooperation with the Norwegian Petroleum Cluster.

There is a sound foundation for the internationalization of the Norwegian Petroleum Cluster. After 40 years of activity this group has a very good position in relation to international markets. But there is also a window for internationalization. This is while we have a reasonably high level of activity on the domestic market. An active and efficient domestic market is vital in order to succeed internationally. In this respect the Norwegian Petroleum Cluster can be a driving force for other sectors of the Norwegian economy. The scale of the Norwegian market is huge, the level of expertise is very high and there is vast potential on the international markets. The universities can be an important element to obtain sound technological contact with oil and gas producing countries and build up competence in issues that are relevant in other parts of the world. Potential countries include: Angola, Nigeria, Libya, Iran, Azerbaijan, Brazil, Venezuela, Mexico, and Russia. Issues for such cooperation that are of interest in other parts of the world include the technological challenges of arctic waters, deepwater operations, and chalk reservoirs. The Norwegian high technological expertise in all segments is relatively cost efficient compared to other countries. The Norwegian Petroleum Cluster is in a very good position to network with all major oil companies that are active on the NCS. The international oil companies have a huge share of the global market and the Norwegian Petroleum Cluster is in a unique position to network with all National Oil Companies (NOC) in the most important oil producing countries. The cluster already has a well-established international network organization with Intsok, Petrad, NORAD, and the international contacts at the universities.

NTNU will be an important part in this process of internationalization due to the established international network it has built up over the last 10 – 15 years. It is believed that the present practice whereby Norway exports knowledge, skills and competence by offering university education in petroleum to graduates and staff from oil producing countries and National Oil Companies can be very useful in the internationalization process.



3 Discussions between NTNU and the Petroleum Industry during the BRU Process in 2004 and 2005

3.1. MEETINGS WITH ABOUT 50 OIL COMPANIES, SERVICE COMPANIES, ORGANIZATIONS, AND THE AUTHORITIES

In order to establish a good technology network and listen to advice from the entire Norwegian Petroleum Cluster, the BRU team from NTNU together with the Secretariat PetroManagement, organized a fact finding and network program. During the period from November 2004 to April 2005, the team visited about 50 oil companies, service companies, organizations, and the authorities.

The program of visits has proven to be most valuable. NTNU has had very positive, constructive and creative dialogs with the petroleum cluster in Norway. NTNU has obtained a good overview of the issues that were raised during the meetings:

- Views about the future and remaining resources on the Norwegian Continental Shelf
- Technology and Competence in order to realize these resources
- Technology gaps and future technology challenges
- Review and discussions on relevant technology areas
- Advice about which topics the industry sees a role for NTNU and the R&D needs where NTNU and SINTEF can make a significant contribution
- Cooperation between the industry and NTNU
- Educational needs for the future
- Aspects related to the technology and competence needs for the internationalization of the oil and gas industry in Norway
- Future contacts

The input from all these meetings constitutes a valuable background for this report and is significant for the policy implications and conclusions for the technology priorities in the focused R&D programs described in detail in Chapter 4. The following table gives an overview of the program of visits (there are still other companies that NTNU will keep in touch with for future meetings):

1 AkerKvaerner	14 FMC Energy Systems	27 OD	40 Revus
2 Baker Hughes	15 Gassco	28 Odfjell	41 Ruhrgas
3 British Gas	16 Gaz de France	29 OED	42 RWE-DEA
4 BP	17 Halliburton	30 OG21	43 Schlumberger
5 Ceetron	18 Hydro Oslo	31 OLF	44 Seabed
6 CGG	19 Hydro Bergen	32 Paladin	45 Shell
7 ChevronTexaco	20 INTSOK	33 Pertra PGS	46 Statoil
8 ConocoPhillips	21 KON KRAFT	34 Petoro	47 Stolt Offshore
9 Demo 2000	22 Lundin	35 Petrad	48 Talisman
10 DNO	23 Marathon	36 PTIL	49 TOTAL
11 EMGS	24 NGU	37 PGS	
12 ENI	25 NFR	38 Prosafe	
13 ExxonMobil	26 NORAD	39 ResLab	

3.2. SUMMARY FROM THESE MEETINGS

NTNU is very pleased with the response from the industry. The meetings have been most valuable in two respects. First, the technology network between NTNU and the industry has been taken care of by this type of direct contact with all these companies and their representatives. Second, NTNU has got an extremely useful update of all major topics in the industry focus areas at the moment. This goes for technology challenges both on the Norwegian Continental Shelf as well as internationally. NTNU needs to get an overview of the technology gaps that have to be solved in order to capture the future remaining resources and value on the NCS. There are a multitude of issues in the different areas on the NCS and internationally. In short, these are:

- The very mature areas in the North Sea
- The semi-mature areas on Haltenbanken
- The deep water and relatively immature areas in the Norwegian Sea
- The environmentally challenging issues in the Lofoten area
- The Barents Sea and the arctic issues
- Technology challenges in different geographical areas internationally

The areas that were discussed covered a variety of technology and strategic topics:

- Geology and Geophysics
- Exploration and Seismic
- Drilling – Well Completion - Intervention
- Subsea Solutions for the Future
- Reservoir Management – Reservoir Simulation – Reservoir Geology
- Improved Oil Recovery
- Multidisciplinary Integration
- E-Operations/Smart Field and Integrated Operations
- Small fields development – Tail-end and Tie-in
- Operational Technology Issues – Exploitation - Surface Facilities
- Arctic Technology
- Environmental Technology
- Gas Technology and Shipping
- International Developments
- General Technology Policy
- NTNU Policy Actions

NTNU got a good overview of the main challenges within all the above areas. NTNU also had a meeting with OG21 and discussed their priority areas within their Technology Target Areas:

1 Environmentally sound operations
2 Exploration and reservoir characterization
3 Enhanced recovery
4 IO and real-time reservoir management
5 Cost-effective drilling and intervention
6 Subsea processing and transport
7 Deep water and subsea production technology
8 Gas technologies

The main objective of the meetings has been to get advice about selecting future focus areas (described in more detail in Chapter 4). NTNU was interested both in discussing future R&D programs as well as aspects of the long-term competence the industry will need from the higher education system. It has been a striking fact during these meetings that many of the technological specialists and decision makers in the industry have their education from NTH/NTNU. This highlights the importance factor of Trondheim as the producer of skilled, competent people for the industry for decades.

In the period 1974 -2004, NTH/NTNU have produced about 1600 M.Sc. graduates for the industry. In the period 1977 – 2004, 100 postgraduates were awarded their Dr. ing./Ph.D. degrees in petroleum-related areas. Just in 2004, NTNU produced 100 M.Sc. and 10 Ph.D. graduates in petroleum-related areas. This places NTNU among the most significant educational campuses for petroleum engineering in the world. Since 1992, NTNU has given all of its lectures in petroleum technology at M.Sc. and Ph.D. levels in English and 40 % of the students in petroleum are international, coming from a variety of countries.

NTNU made a detailed list of issues for internal use only of all the technology areas discussed during these meetings. This document has been processed internally and is the basis for the policy implications for choice of the new BRU Programs. There is only an overview here, but Chapter 4 describes the BRU Programs in detail.

NTNU has also noted policy advice from different companies highlighting the following elements:

- The technology challenges are relatively more difficult in a mature region, deeper waters and arctic areas – this is characteristic of the NCS today
- There is a need for step-changing technology and breakthroughs in several areas. The key to success in this respect is focus and scale
- A prerequisite for success is to concentrate research efforts within fewer areas ensuring adequate strength
- Integration of technologies in order to solve future technology challenges were highlighted by several companies – this means multidisciplinary research
- Demand for people that can understand multidisciplinary integration and that can work and contribute to multidisciplinary project teams – this means highlighting multidisciplinary education
- Demand for graduates that understand the international challenges of the oil industry
- Develop technology networks and technology knowledge bases at NTNU/SINTEF level

3.3. POLICY IMPLICATIONS FOR NTNU

Based on these discussions NTNU has suggested the following *10 strategic conclusions* with the overall goal to contribute through new *step-changing technologies, strategic alliances and the multidisciplinary approach:*

Strategic conclusion 1: Finding and Producing (BRU Program 1)
Based on these discussions NTNU decided to integrate the knowledge base within geophysics and geology together with reservoir description and reservoir management into "BRU Program 1" of underground topics named: "Finding and Producing" (Exploration and Production). The argument for this is the integration of the unique competence within geophysics and geophysical mapping together with the specialized areas within reservoir characterization and reservoir modeling and reservoir simulations. NTNU/SINTEF's combined expertise within these areas is world class. The multidisciplinary approach between geologists, geophysicists, and reservoir engineers is expected to contribute significantly to solve the future challenges required to access the remaining petroleum resources on the Norwegian Continental Shelf.

Strategic conclusion 2: Drilling and Subsea Technology (BRU Program 2)
The next strategic area has been to integrate the expertise at NTNU/SINTEF in drilling and well technology with interventions, subsea technologies and operational issues into "BRU Program 2". This will also capture the challenges with tail-end production, tie-in of satellite fields and small field development. This will be a surface oriented area bringing the drilling and operational topics into a second focused research area. About 50 % of the annual operational costs on the NCS are related to drilling. In new field developments, the drilling and well costs are very important contributors to the total cost. We need to reduce the drilling costs significantly in order to handle the future resources in exploration as well as in production. Low cost drilling, drilling for improved recovery and subsea technology for improved recovery are all important elements in BRU Program 2.

Strategic conclusion 3: eField and Integrated Operations (BRU Program 3)
The next strategic conclusion has been to take industry's advice and develop "BRU Program 3" on "eField and Integrated Operations". This is one of the more challenging issues in the petroleum industry and we foresee that this area will be the next major step and an efficiency breakthrough for the entire global petroleum industry. To solve the challenges in this area, NTNU/SINTEF are going to integrate the combined expertise of about 7 - 8 different departments and institutes across both organizations. In this respect NTNU/SINTEF is in a unique situation because it has the needed highly specialized expertise from different areas within its organizations and these people can be put together in project cooperation. NTNU/SINTEF will place high priority on this program and is committed to deliver valuable industrial solutions and long-term competence within this area. This is also an area with great export potential in the long run. Another important reason to further strengthen the Norwegian Petroleum Cluster in eField and Integrated Operations.

Strategic conclusion 4: Arctic Technology (BRU Program 4)
NTNU has decided to establish "BRU Program 4" in Arctic Technology. This integrates environmental technology, gas technology, flow assurance and gas transportation together into a special program with an arctic technology focus. It is estimated that about 25 % of the remaining hydrocarbon resources in the world are located in Arctic areas. The Barents Sea has received renewed interest from the entire petroleum industry. Furthermore the Russians have focused priority on their continental shelf both in the Barents Sea and in the Pechora Sea.

The Norwegian Petroleum Cluster has a golden opportunity to further develop the cooperation with the Russian oil and gas industry in this context.

Strategic conclusion 5: Step-Change Technology to Improve Recovery
The first three BRU Programs: "Finding and Producing", "Drilling and Subsea Technology"" and "eField and IO" will all use the knowledge base at NTNU/SINTEF to improve the recovery rate in oil and gas fields.

In addition, there is an interesting challenge of putting together research and development experts across the disciplines. This will bring seismic mapping, reservoir description, reservoir management, drilling and wells into close cooperation in the different BRU Programs to develop a new paradigm in resource recovery by step-changing technologies. Such an effort will definitively contribute to the long-term goal of significant increases in the recovery rate across all petroleum fields.

The average recovery rate on the Norwegian Continental Shelf is currently about 45 %. The NPD goal has been to lift the average rate to 50 %. The industry has put forward recovery goals of 55 % to 65 %. An additional challenge is that the subsea completed fields have a 10 % to15 % lower recovery rate than platform completed fields. There is still significant value in improving the recovery rates on the Norwegian Continental Shelf. This know-how also represents a valuable asset in the internationalization of the Norwegian petroleum industry.

NTNU and SINTEF will contribute to the industry by cooperation on the current targets of 55 % - 65 % recovery rates. In addition to this work the NTNU – SINTEF petroleum cluster will address the next step to contribute to developments that will lift recovery rate options from the 55 %-65 % level to the 65 %-85 % level. It is important for the academic and scientific network to address the long-term challenge – which calls for a renewed step change in our technological approach and a long-term goal of recovery rates of 80 % for all types of fields.

Strategic conclusion 6: GEMINI Center
NTNU and SINTEF have over a period of time worked with the plans to establish a GEMINI Petroleum Center. During the BRU Seminar 2005, this GEMINI Center was formally opened by the Minister of Energy and Petroleum Thorhild Widvey.

The objective of the GEMINI Petroleum Center at NTNU/SINTEF is to establish larger and scientifically stronger groups with a higher quality than the organizations can manage separately. The vision is to be world class together. The two parties will establish common strategic processes, work out strategic plans together and deliver an annual report on the cooperation and results. The GEMINI Petroleum Center will strengthen the entire petroleum capacity at NTNU and SINTEF.

Strategic conclusion 7: Arctic Exploration Center (EXTRA)
The oil industry considers the Arctic to be the ultimate new petroleum frontier. According to the US Geological Survey, this region contains a quarter of global hydrocarbon reserves. During the BRU meetings with the industry the arctic issue was raised by several companies.

In this setting the three independent organizations NTNU, SINTEF and Norges Geologiske Undersøkelser (NGU) have agreed to join forces, and will seek support for an Arctic Exploration Center.

A solid foundation for this cooperation will be the three partners' complementary history, knowledge and mission, as well as common visions for the future petroleum E&P research and technology development. All three partners have extensive experience in petroleum research in Arctic areas. The co-location in Trondheim should ensure easy integration of key personnel. Establishing common databases and research education (Ph.D.s) will be important parts of the center's philosophy.

The initiative has been named "EXTRA": "Exploration Technology Related to the Arctic".

Strategic conclusion 8: International University Cooperation
NTNU has a well-established contact network with the major universities and educational competence centers in the world. NTNU is about to sign Cooperation Agreements with some of the best competence centers in the world within each BRU Program Area with the goal to contribute to step-changing developments.

Strategic conclusion 9: R&D Focus and Scale
As a consequence of the BRU strategy, NTNU will focus its R&D funding, academic manpower and the Ph.D. candidates towards the four new BRU Programs.

Strategic conclusion 10: Organizational Issues and Networks within Energy and Petroleum
The organizational issues are very important to reach the overall goals. NTNU and SINTEF are committed to implement a management structure for cooperation across the different institutes and competence centers in order to meet their stated objectives.

It will be very important to combine conclusions 9 and 10: sufficient scale of focused R&D and the organizational structure. NTNU and SINTEF have the expertise, knowledge base and knowledge network in all the needed areas to solve all these challenges and reach the goals. However, it is very important to facilitate an overall management structure and management cooperation across the whole of NTNU and SINTEF.

NTNU will develop a *"knowledge base structure"* which will have the flavor of a virtual organization linked together in technical networks in different network groups. These types of networks have been implemented within several of the international oil companies with great success. NTNU and SINTEF have together about 5000 employees most of whom are working in science and technology. There are many experts in the different departments and institutes working directly and indirectly on areas which are invaluable for solving the challenges within the oil and gas sector. NTNU will organize a *"global R&D*

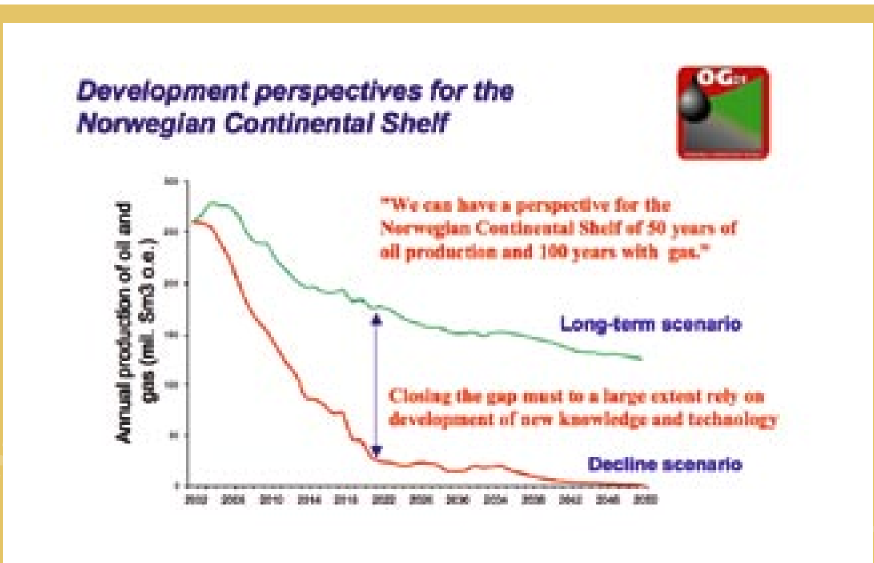
scouting program" in order to have an updated overview of all R&D activities in the focused areas performed internationally. This will give an opportunity to utilize results and developments of activities performed internationally either at universities or in the industry. It will also avoid unnecessary duplication of research.

NTNU will also set up an *"industry scouting program"* in order to have a clear understanding of the industrial needs on the short, medium and long terms. This will be a continuously organized activity. The BRU meetings during the BRU process have been an excellent reference for this activity.

4 BRU Programs
– Strategy and R&D Focus for the Future

4.1 INTRODUCTION TO THE R&D PROGRAMS

This chapter defines the areas of research and technology development that NTNU and SINTEF should focus on in the years ahead in order to contribute as much as possible to the overall objective of Better Resource Utilization of Oil and Gas (BRU). The areas are defined on the basis of the input we have collected from about 50 oil companies, organizations, government units and the Research Council that have been visited during the past year. In addition, we have studied available strategy documents from the industry, NPD, Research Council, OG21, and, of course our own deliberations at NTNU and SINTEF. The starting point of the BRU Project was in fact the well-known figure defining the long-term scenario and the decline scenario for the oil and gas production in Norway. Our basic question was this: How can NTNU (and SINTEF) use their education and research resources to make a substantial contribution to the national objective of closing the gap between the two curves?



The following policy signals (also reviewed in Chapter 3) were highlighted during several of our meetings:

- A step-changing technology breakthrough is needed in several areas. The key to success in this respect is focus and scale. It is thus a prerequisite for success to concentrate research efforts in fewer areas but with adequate strength
- Integration of technologies in order to solve future technology challenges were highlighted on by several oil companies – which means multidisciplinary research
- Demand for people who can understand multidisciplinary integration and that can work and contribute in multidisciplinary project teams – which means highlighting multidisciplinary education

Academia and research institutes should be challenged to place these issues high on their research agenda. There is little doubt that they can make a considerable contribution to reaching the common goal of higher recovery rates, given the required means. By joining forces, and defining the key short-term and long-term objectives, fruitful collaboration can be achieved.

A key strength of academia in research is the use of doctorate candidates under supervision of professors. These are enthusiastic young people that can spend 3-4 years totally focused on one research topic, document and publish the results and then move on to advanced jobs in industry or research. Then new doctorate candidates start on new topics. This is an excellent mechanism for research that should be valued even more. Virtually hundreds of new doctoral candidates could be working on topics related to the many issues of improved recovery. If only a fraction of these are successful in their research, this could represent a significant contribution to higher recovery rates.

Another potential strength of many academic institutions and perhaps particularly NTNU/SINTEF is their multidisciplinarity. Here groups doing research and development in virtually all applied technological areas coexist with basic research groups in mathematics and the natural sciences. The potential benefits of integrated research should not be under-valued. However, it is a great challenge to take the leadership in such integrated research, and great efforts are required to create motivation and effectively organize the work, with proper balancing of basic research and applied research, as well as long-term and short-term research.

Based on our discussions internally and externally, we finally arrived at defining four BRU Programs that we will focus our research on over the next few years. They are:

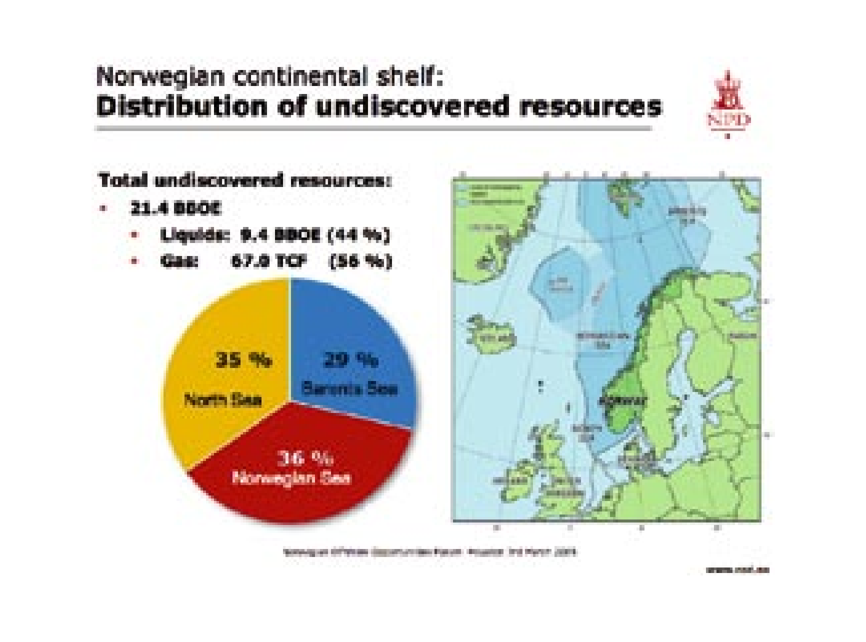
- BRU Program 1 – Finding and Producing
- BRU Program 2 – Drilling and Subsea Technology
- BRU Program 3 – eField and Integrated Operations
- BRU Program 4 – Arctic Technology

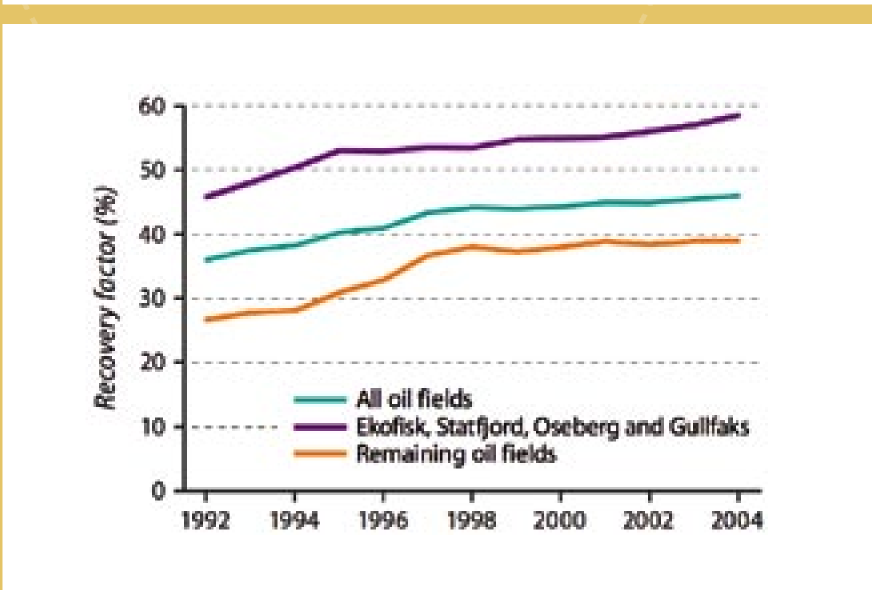
The programs are described in more detail in the rest of this chapter.

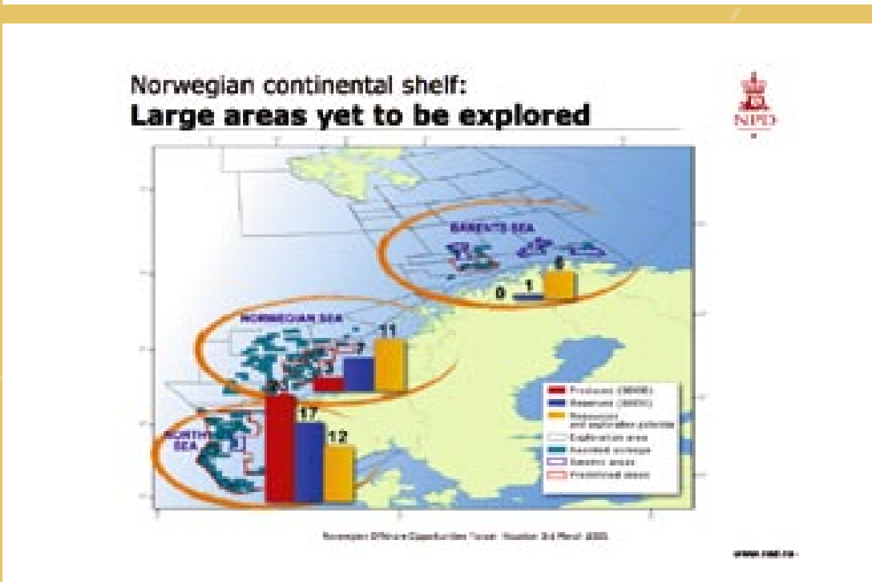
4.2 BRU PROGRAM 1: FINDING AND PRODUCING

Introduction

Finding and producing is a wide field and it may seem non-focused to define a program that may encompass the entire upstream value chain. However, in our definition we will describe some challenges and research issues that we feel are of particular importance, and where NTNU/SINTEF may contribute in their research. The key issues are, of course.







1) how to find more oil and gas, and
2) how to recover more from the reservoirs.

Below we will group our discussions into these areas:

- Geology and geological modeling
- Advanced geophysical methods
- Improved recovery from reservoirs

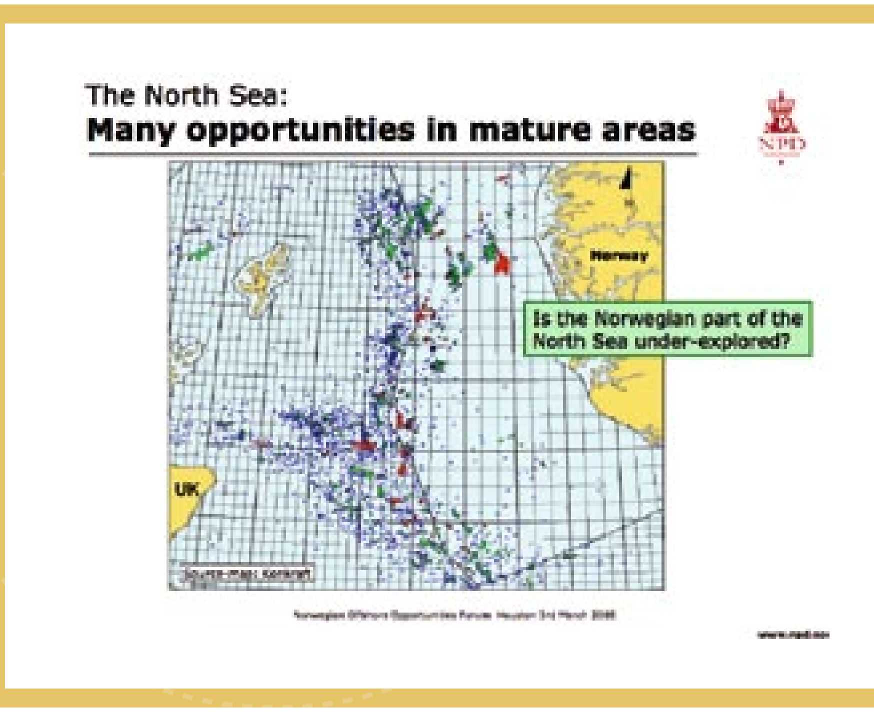
Geology and geological modeling

Exploration of the Norwegian Continental Shelf has reached different maturities (See Section 3.2), and the understanding of the geologically related challenges is accordingly at different levels. Many challenges are, however, common for the different provinces.

There is a need for better understanding, quantification and modeling of the geological, physical and chemical processes which govern basin formation, sedimentation and fluid flow on the basin scale.

- Modeling of hydrocarbon generation, expulsion, migration and entrapment is relevant in all petroleum provinces. There is a need for better pre-drill phase predictions and prediction of liquid properties (e.g. density, viscosity).
  - Consistent modeling of petroleum components and groups from generation to entrapment will be important.
  - High resolution basin modeling will be needed in mature exploration provinces (e.g. the North Sea), where smaller exploration targets are sought.
  - We believe there is a potential in more extensive and innovative use of seismic in basin modeling and vice versa (positive interactions).
  - Improved predictions of heat flow and temperature history will be important for some areas (e.g. Vøring and the Barents Sea)
- Salt-related exploration targets impose special challenges.
  - Prediction of pore pressure using seismic data and basin modeling will provide valuable information before drilling (and while drilling updates).
  - Timing of salt movement and its effect on hydrocarbon migration is important.

- Prediction the hydrocarbon potential of alternative source rock models on the Norwegian Shelf (e.g. the Cretaceous in the Norwegian Sea and the Paleozoic in the Barents Sea). This may involve both stratigraphic/organic facies modeling, geochemical data interpretation and development of conceptual source rock models.
- Prediction and quantification of permeability and rock mechanical properties for caprock units is required.
  - Laboratory measurements are valuable input for well bore stability analysis on reservoir scale to fluid flow modeling on basin scale.
  - Information on rock physics from seismic data will be important.
- Mapping and modeling of fault and fractures on reservoir and basin scale are crucial in exploration, particularly their effect on water and hydrocarbon flow. The amount of sand and clays in the fault zones greatly control the sealing properties on a geological time scale. Research topics will include interrelation between the pre-existing fracture pattern, pressure and stress changes on basin scale.
- Stratigraphic traps as exploration targets will include detailed 3D seismic interpretation and stratigraphical interpretation. Analogs from nearby areas are important.
- Developed carbonate fields on the Norwegian Continental Shelf are restricted to the chalk deposits of the southern North Sea (Ekofisk and neighboring fields). In the Barents Sea there is a major hydrocarbon potential in Upper Palaeozoic carbonates. Internationalization also calls for increased focus on carbonates. Topics will be:
  - Understanding the carbonate system: modern analogs, facies, chemistry
  - Carbonate play concepts: source – reservoir – seal interplay.
  - Carbonate settings: reef systems, shelf carbonates, chalk, etc.
  - Reservoir properties: diagenesis, dolomitization, fracturing, dual porosity etc.



Advanced geophysical methods
It is expected that more refined measurements and sophisticated data processing techniques will be needed in future exploration and production of oil and gas. A key element will be the integration of different data sets and types to be used in describing the reservoir. Seismic data will be dominant with emphasis on high-resolution imaging and inversion for reservoir parameters. This will require more data to be collected to obtain multi-azimut and long offset data coverage. It is possible that present routine seismic data processing will be replaced by a simpler, but more computer-intensive, data flow:

- Noise removal
- Multiple removal
- Depth imaging (PP and PS)
- Analysis of amplitude-versus-angle-and-azimuth (AVAZ)
- Estimation of reservoir parameters

The output will be several 3-D data volumes representing images and estimates of reservoir parameters. The input data will be 3-D surface seismic (marine streamer data), ocean bottom seismic (including permanently installed sensors) and VSP data. Repeated seismic surveys (4-D) will be used for reservoir monitoring and production planning.

Seismic modeling will be used for survey planning, to verify interpretation and to test new data processing algorithms. Modeling in anisotropic poro-elastic media can be based on

- Ray-tracing including diffractions
- Finite-difference methods
- Finite-element methods
- Frequency-wavenumber methods

Seismic multiple attenuation will be based mostly on multiple prediction using wave equation methods and adaptive subtraction. Seismic imaging will use ray theory or one-way or two-way propagators based on generalized screens or finite-difference methods in anisotropic viscoelastic media. Inversion or parameter estimation will combine asymptotic inversion formulas with stochastic methods.

More electromagnetic data (including magnetotellaric data) will be used in exploration, and, possibly, repeated measurements for reservoir monitoring. The interpretation will be based on modeling and inversion with some input from seismic data. A challenge is to develop data processing methods for shallow water and/or deep targets.

Geological challenges are:
- Areas with complex tectonics

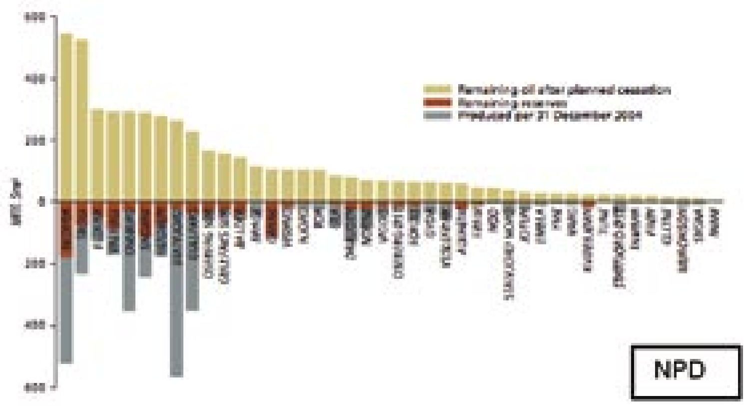
- Complex ocean bottom topography
- Targets below salt
- Targets below basalt
- Small stratigraphic traps

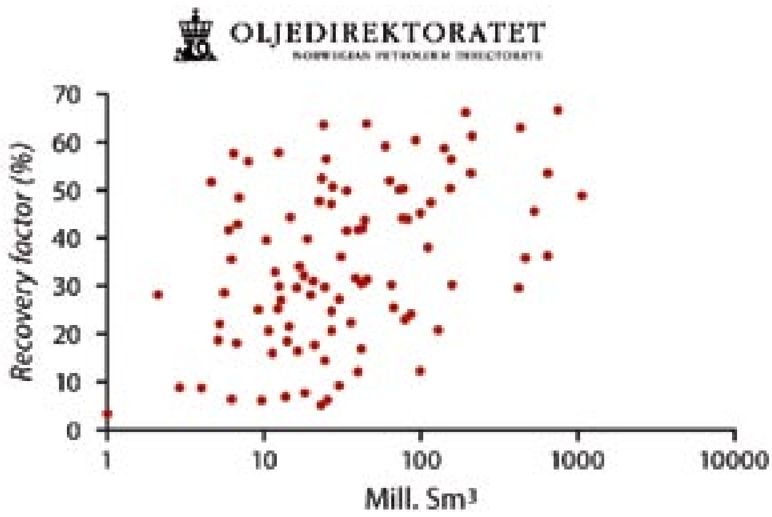
Advanced exploration methods require:
- Geological understanding and modeling
- Basin modeling
- Seismic depth imaging
- AVAZ analysis of seismic data
- Electromagnetic data used as a hydrocarbon indicator
- Gravity (for salt modeling)
- Rock physics modeling

Based on the available data, different prospects can be analyzed using a rock physics database for lithology and fluid properties. Pressure prediction using seismic data and basin modeling will be important.

In the production phase permanently installed geophones will give frequent 3D seismic data sets. These can be integrated with well log data, production data and stochastic reservoir simulation to produce improved estimates of the reservoir and production parameters.

Advanced 3D display techniques can be used for interpretation both in the exploration and production phase. Combined with repeated seismics, the 3D visualization tools will be used for production planning and well steering.





Improved recovery from reservoirs

Introduction

The recovery efficiency for Norwegian oil fields, in particular the large ones currently entering the tail production phase, should be given very careful attention in the years ahead. It is totally unacceptable for society that such large amounts of oil remain in the ground when the fields are shut in. Improving the recovery efficiency of oil reservoirs is the most important area for research and technology development in Norway. Although the Norwegian shelf already ranks high among the world's oil provinces in regard to oil recovery efficiency, there is much more to be done, and our ambition must be that Norway becomes the leading nation in this regard. Potentially enormous economic rewards for society are waiting to be harvested, and warrant a manifold increase of the efforts in research and technology development. At current oil prices, an extra percentage point of oil recovery from existing producing field amounts to a gross value in the range of NOK 200 billion. Already the government, the Research Council and the industry are focusing strongly on this issue. Over the past few years, significant increases in the estimated recovery factors have been achieved. However, much more can be done.

Improved oil recovery encompasses a multitude of activities and disciplines, and certainly not only sub-surface issues. As pointed out in Section 7.11, re-appraisal of seismic data and the geological field model, acquisition of new 3D or 4D data, in-fill drilling, converting injectors to producers, reducing hydrate and wax problems in pipelines, are examples that may yield improved oil recovery on an equal basis with conventional sub-surface improved recovery research and technology development. Many of these issues are discussed in other sections of this chapter. Below we will briefly focus on four categories of improved oil recovery research: 1) Microscopic research issues, 2) Macroscopic research issues, 3) Reservoir modeling, and 4) Integrated reservoir research.

Microscopic research issues

The two key objectives in this category are to reduce the microscopic residual oil saturation and make the displacement process of oil by water or gas more efficient on a microscopic scale by modifications of mobilities and relative permeabilities/capillary pressures. In spite of all the research conducted on displacement processes on a microscopic scale, there is still a lack of understanding of the flow processes taking place. Fundamental research on rock-fluid interaction in flow processes, fluid phase behavior in pores, wettability, residual saturations, and flow parameters in general should still get strong focus in the years ahead. This type of research is particularly suited for doctoral work. Miscible gas injection for reduction of residual saturations is potentially attractive. With high oil prices, chemical treatment of reservoirs by surfactants and polymers for reduction of residual oil saturations and improvement of displacement processes will become attractive and requires new basic and applied research. Research on new chemicals for this purpose is vital. Microbial techniques may potentially lead to great improvements in oil recovery, and will be a focus for research.

Macroscopic research issues

In this category, the two key issues for research are reduction of uncertainty in reservoir description and better volumetric sweep efficiency. The technology of seismic monitoring of reservoirs during production has improved greatly over the past years, however many improvements must still be made for this to really have a deep impact on reservoir description in reservoir models. Seismic methods and integrated research combining seismic and reservoir technology are discussed elsewhere in this chapter. Research issues related to better volumetric sweep of reservoirs are again related to the monitoring technology needed for collecting the data for proper steering of the recovery process. Monitoring during drilling of branched wells would potentially lead to great improvements in reservoir description. Development of additives for blocking zones to improve sweep efficiency is also an important area.

Reservoir modeling

The methodology of current simulation models offers a reasonable description of flow processes, but the models are much too coarse to properly represent the reservoir geometry and heterogeneity. With current computers a practical limit on the number of grid blocks is around one million. However, for one of the large fields on the NCS, it means that an average grid block has a volume of, say, 3 000 m^3. Knowing the typical heterogeneity of reservoir rock, assigning average properties such as permeability and fluid saturations to such a block is meaningless. Grid blocks are of course of variable size in models, smallest both where the heterogeneity is greatest and also in areas of special importance such as close to wells. Still, this issue is of great importance. One limitation is the speed of computers. Assuming Moore's law still will apply, it will be a long time before models can have 100 million blocks, and thus the average grid block size is reduced to 30 m^3, which still is a large volume. Parallel computing is one solution, and research on effective parallelization is important. Dynamic grid refinement that follows fluid fronts in reservoirs, combined with parallel computing is another. Automatic or semi-automatic history matching of models based not only on production data but also on frequent time-lapse seismic is an important topic for research.

Integrated reservoir research

The issue of integration is addressed by Martin Landrø in Section 5.3. The cooperation between specialists in the disciplines of seismic and reservoir technology, as well as drilling has the potential to reduce the uncertainty of reservoir data and thus improve the monitoring and management of production processes in reservoirs. In particular, close and efficient coupling of 4D seismic and reservoir simulation will be important for better updating of models. Efficient methods for updating reservoir models when new time-lapse seismic and production data become available are crucial for proper reservoir management. Today, it may take months and sometimes years from the shooting of new seismic to the final update of the reservoir model is ready. Ideally, this process should be instant. Efficient integration of geoscientsts and engineers in this process is needed. Another issue is the representation of uncertainty in reservoir models. Integrated reservoir model building including uncertainty assessments should be addressed. Seismic while drilling is another area of great potential to reduce reservoir uncertainty.

Organization of BRU Program 1

We will organize BRU Program 1 in cooperation with the oil companies, service companies and the Research Council of Norway in line with the models used in the Petromaks and Demo2000 programs. Bru Program 1 will be further developed during the fall 2005.

4.3 BRU PROGRAM 2: DRILLING AND SUBSEA TECHNOLOGY

Introduction

During the BRU meetings most of the industrial partners gave us very clear signals that cheaper drilling had high industrial priority. Drilling technology influences both recovery and the ability to improve recovery rates significantly. A major part of future field developments is related to subsea fields.

NTNU will therefore integrate its expertise in drilling and wells together with interventions, subsea technologies and operational issues into BRU Program 2: Drilling and Subsea Technology. This will also capture the challenges with tail-end production, tie-in of satellite fields and small field development.

About 50 % of the annual operational costs on the NCS are related to drilling. In new field development the drilling and well costs are very important contributors to the total costs. We need to reduce the drilling costs significantly in order to handle the future resources in exploration as well as in production. Low cost drilling, drilling for improved recovery and subsea technology for improved recovery are all important elements in BRU Program 2.

Lower Drilling Costs

Typical Time and Costs for Subsea Drilling and Completion

The cost of a typical North Sea subsea exploration well is in the order of NOK 100 million. Typical costs for subsea production wells are in the NOK 200-300 million range. Approximately 50 % of the total well costs is rig cost (time sensitive), 25 % is service/anchor/supply/planning and 25 % for consumables (exploration well). (Approximately 50 % of investments in the North Sea are related to drilling.)

The typical cost distribution for a deep-water field development in the Gulf of Mexico (GoM) is illustrated in Figure 4.1. As shown, drilling and completion costs represent 48 % of the field development costs. In terms of time, 43 % of the time is for drilling while 57 % of the time is used for completion. Time sensitive Capex for drilling and completion operations are 63 and 80 %, respectively. The day rates for the fifth-generation drilling and completion units are in the order of USD 180 000 – 250 000 and above. Spread costs approach USD 400 000 – 450 000 per day. These numbers are also expected to be representative for developments in deep waters offshore Norway.

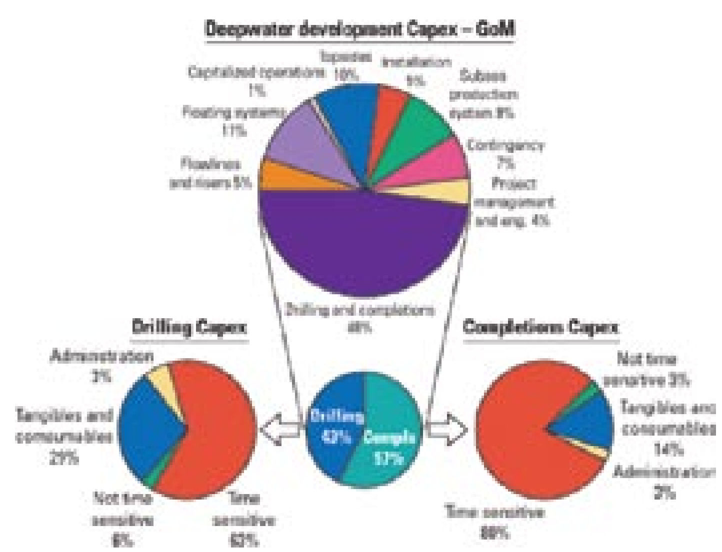


Figure 4.1 Deepwater development Capex GOM (World Oil)

Subsea Drilling Costs

In order to embank on a program to reduce drilling costs, we have to consider the different elements.

Drilling Costs = *rig day rate x rig days in operation + the costs of consumables + service, supply & auxiliaries*

Rig day rate

Due to climatic conditions, rules and regulations, work environment, etc., rig rates can only be reduced marginally in the short run on the Norwegian Continental Shelf. Introducing new drilling technology with reduced needs for lifting and storage capacity may allow lower specification rigs (3rd and 4th generation rigs) to be used in environments where higher specification rigs (5th generation rigs) are used today. A 15 – 20 % reduction in the day rate may be possible. Reduced consumption and less need for lifting and storage capacity may also allow for new and smaller design mobile offshore drilling units (MODU) which may reduce the overall cost of new builds.

Drilling time

It is expected that new drilling methods or combination of existing and new drilling methods will allow the drilling time to be reduced. Reduced time is the single most important factor for reducing well costs. Some important issues for reducing the flat spots (time for non-productive drilling) are listed below:

- Rig transit and positioning time
  - Dynamic positioning
- Time to run risers and BOPs
  - Smaller and lighter riser and BOP systems (surface BOP)
- Increase drilling speed
  - Optimal hole size, hole cleaning, mud system and pressure differential
- Reduce the number of casing points
  - We must alter the way we control and manage borehole pressure
- Reduce the casing running, testing and cementing time
- Run liners, not casing
  - Liners are shorter and do not require exact setting depth
  - Less time to cement liners
- Reduction in problem/down times
  - Manage pressures down hole
- Reduce the time to plug and abandon (P&A) the well

It can be noted that more than 50 % of all problem time can be traced back to underground pressure. Hence the way the drilling industry manages underground pressure as it relates to the formation (rock strength) is the most important factor in reducing non-productive time and improving drilling efficiency.

Costs of consumables

Consumables (casing, wellheads, mud, cement, etc.) contribute only to approximately 25 % of the well cost in an exploration well. A 30 % cost reduction of consumables will hence contribute to only 7-9 % of overall well cost reduction.

In subsea production wells the cost of completion fluids, subsea production equipment and completion equipment is substantial. Reduction in size and volumes must be balanced with the production potential. Hence there are many factors that must be evaluated in order to achieve cost reductions.

Service, supply & auxiliaries

The cost is typically 25 % of total well costs.

Drilling Trends

Figure 4.2 illustrates a standard well and a slim well completion, both using a 7" liner through the reservoir. The standard drilling program in use today is based on using an 18 3⁄4" wellhead both for exploration and production drilling. This wellhead normally allows for three casing points below the surface casing, including a 7" liner run through the reservoir section. If needed, two additional casing points may be added. However, this requires under-reaming and more time consuming drilling and completion operations.

Comparing the conventional well with the slim well, the mud volume in the riser is reduced from approximately 300 m^3 to 120 m^3, and the volume of drill cuttings is reduced from typical 500 m^3 to 130 m^3 based on using new drilling technology, i.e., expandable casing. In addition, the amounts of steel, mud and cement are reduced. Slimmer wells introduce several challenges. The radial clearances between the drillstring and the borehole are reduced which increases the pressure loss in the annulus. This may lead to reduced drilling length before a new casing has to be set, more critical tripping operations due to surge and swab effect, and more critical well control operations due to high pressure loss in annulus and kill / choke lines, etc. Drilling fluid technology / rheology and better understanding of well bore stability are also important issues. Another issue is the reduction of the drillstring size which may be required. A weaker drillstring is more frequently twisted off which leads to costly fishing operations.

Most semisubmersible drilling rigs operating in the North Sea have a standard 18 3⁄4" Blow Out Preventer (BOP) and a 21" marine drilling riser. So, far, no contractors offer slim well drilling systems. The reason is probably the risk and the lack of incentives for the drilling contractors. However, it is stated by the industry that the well cost must be reduced. A step-wise development is seen. Expandable casing and liners are introduced in order to reach the target with sufficient diameter, and Managed Pressure Drilling/Under Balanced Drilling have been used on the Gullfaks Field. Managed Pressure Drilling, is a general expression for drilling with constant/optimum bottom hole pressure above the formation pressure, which implies compensation for the dynamic annulus pressures and active control of the bottom hole pressure. When sufficient records are gained with the integration of new technology in standard drilling operations, the slim well will be introduced.

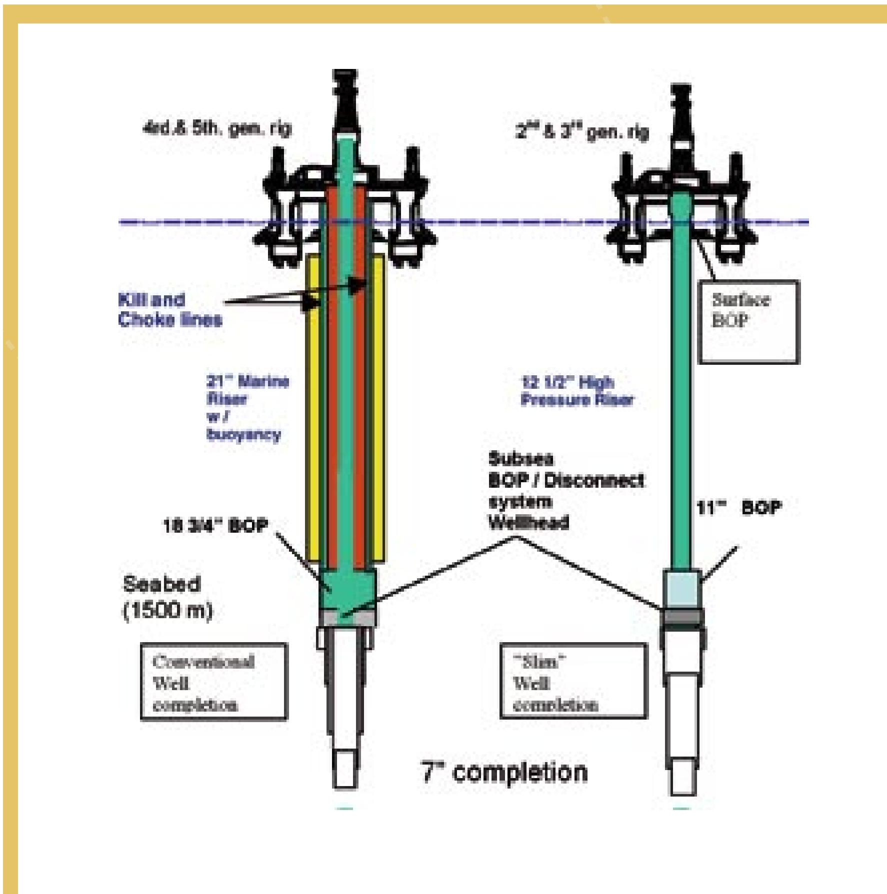


Figure 4.2 Conventional vs. potential "slim hole" drilling system

Strategy for R&D in Subsea Drilling

Based on the above considerations, the reduction in operational time is the most important factor for achieving cost reductions in drilling. Also, the day rate cost for the drilling vessel will have a significant impact on the total well costs. Both of these factors must not reduce the operational safety. The new technologies that will be needed should also contribute to improved safety in operations. Historically this has been difficult to achieve since new technologies that have made operations safer have more often than not contributed to increased construction time for the well. Hence further work should be focused on improving existing and / or developing new effective drilling technology and should contribute to the following five main strategies and include some of the underlying technologies:

1) Technology which will reduce drilling and completion time

a. Managed pressure drilling allows drilling operations to take place with less pressure fluctuation in the borehole. This allows the drilling of complex wells with a low margin between pore pressure and fracture pressure which again will allow for longer hole sections to be drilled.
b. Online communication with the drill bit (i.e., electric drillstring). This is an issue which will make a breakthrough in drilling. Online monitoring and control will allow action to be taken before serious downhole problems occur. Seismic while drilling will allow

the wellbore to be drilled optimally to maximize the recovery from the field. This may make a significant contribution to well cost reduction.
c. eField with centralized decision-making
d. New drilling technology, for example, Electropulse Boring (EPB), see box below.

2) Technology which will allow for smaller or less expensive and more effective drilling vessels
a. Smaller riser and BOP systems
   i. High pressure (HP) riser systems
   ii. Surface BOP or hybrid BOP systems
b. Expandable casing technology
   i. Monobore or monodiameter wells
c. Technologies for slim well design

3) Technology which will allow for a reduction in material consumption
a. Smaller riser and BOP systems
   i. HP riser systems
   ii. Surface BOP or hybrid BOP systems
b. Expandable casing technology
   i. Monobore or monodiameter wells
c. Technologies for slim well design

4) Technology which will improve operability and well safety (reduce risk)
a. More effective drilling units
b. Improved station keeping
c. Arctic technologies

5) Technology for reduced environmental impact
a. Technology for reduced consumption (slim and slender wells, expandable casing technology.
   i. Implies less logistics and transport
b. Technology for reduced discharge to sea (seabed mud lifting, subsea pumping).
c. Technology for reducing CO_2 emissions from operations
   i. Environmentally friendly well testing (no burning)
   ii. Managed pressure drilling as opposed to underbalanced drilling

Combination of conventional and or new drilling methods may be optimal for achieving lower well costs.

Electropulse boring: game change in the search for oil and gas?

An electric pulse is discharged between electrodes in contact with the formation and breaks it at energy consumption down to 1 KWh/m^3, smaller for the larger diameters. In a matter of nanoseconds a plasma channel occurs between the electrodes causing matrix to break and crack. Hydraulic and mechanical interaction scrapes out the cracked matrix and removes the cuttings before the next pulse. This is EPB. With pulses repeated and the electrodes suitably arranged it is a recipe for hole-making. The possible game change follows from its speed and hole-sizes, the ensuing hard rock drilling cost per meter and other inherent characteristics.

A 101/2" EPB bit will typically make a 12" borehole at penetration rates ultimately in excess of 1 m/min in difficult formations like conglomerates, chert, quartzite or equivalent, faster in less demanding formations. At 24" diameter this ROP is doubled; EPB drills inherently faster at increased diameters; zero weight on the bit (WOB) and 1000 m bit lifetime or more. The over-size borehole, another inherent EPB characteristic, opens the option for stepwise installation of a protective liner (casing) as the hole is being drilled. EPB may be used with rotary pipe power generation integrated in the BHA or coiled tubing. Feasibility studies made indicate average borehole drilling costs per meter at USD 100 - USD 500 (onshore ▶ offshore); equal time set aside for non-drilling activities. A particularly promising EPB concept* is in the form of a stand-alone wireline tool package that is compatible with existing drilling operations much in the same manner as existing wireline services. EPB thereby holds simultaneously a format allowing for it to be brought in to solve hard formation problems in existing drilling operations and the format of a new complete drilling system; by its diameter potential, speed and cost aspiring as a real step-change in drilling technology. Research at NTNU on EPB has been in progress since 1997. Field drilling trials begin 2006 with initiation of commercial operations to follow.

*allows for 1)stepwise drilling and lining of the borehole (during bailing trips); 2)minimizes the drilling assembly time on bottom thereby minimizing the ambient temp interference; 3)much reduced hydraulic circulating energy.

Strategy for R&D in Platform Drilling

The majority of wells on the NCS are platform completed wells. Continuous drilling and recompletion is an ongoing process to maximize recovery.
For fixed platforms, time is often less critical compared to a moored drilling unit (MODU). Most drilling installations on fixed platforms are operator owned. Although the drilling package has a high initial (new) cost and with an equally high day rate cost, the focus might be different once the platform has reached plateau production. As most fixed installations are fully depreciated within 6 years or less, day rates are continuously declining in years 1-6. On fully depreciated production installations, the rig day rates are substantially lower than from a MODU.

Important issues are reduction in consumables and material handling. However, approximately 95 % of the time is production drilling, thus introducing new well completion technology such as improvements in intelligent well technology, fiber optics, remote sensing & metering, well tractors, extended coiled tubing reach, downhole pumping and downhole separation, may be more important.

High angle, 10 000 m long reach wells have been drilled and completed. Improvements in drillstring materials, online communication for better control of downhole conditions may allow 12 000 to15 000 m long wells to be drilled. Well completion using expandable casing and liners may increase reach and larger diameter through the reservoir. Monodiameter wells reduce consumables and material handling on the platform.

In-fill drilling (adding more wells to an existing field) in mature water flooded reservoirs is difficult, risky and often impossible due to the complex pressure regime in the various reservoir and cap-rock layers. Managed Pressure Drilling/Under Balanced Drilling have recently been used successfully on a Gullfaks platform. A challenge is the surface space requirements which is often a limitation on integrated platforms (drilling & production). The effective separation of produced water using high density oil-based drilling fluids with polymers, means that one important issue is the development of a more compact and efficient 4-phase separator. This will open a new window of opportunities for in-fill drilling with under balanced technologies.

Through Tubing Rotary Drilling (TTRD) is another important method for in-field drilling. Long sections of 5-6" boreholes have been drilled through the existing completion to drain small reservoir accumulations (30 000 m^3). Improvements in drilling efficiency may allow a smaller volume to be drained.

Drilling for Improved Oil Recovery

Managed Pressure Drilling (MPD) and effect on IOR

The invasion of particles from the drilling fluid into the formation locally around the wellbore causes formation damage (skin). Formation damage also depends on exposure time and the type of drilling fluid used. Skin effects reduce well productivity and recovery from the reservoirs.

Due to the generally high permeability and long highly deviated completion intervals for reservoirs in the North Sea, it may be agued that a reduction in permeability or return permeability after drilling and completion would be less important. However, in tight reservoirs and in reservoirs with short completion length, the skin effect may be significant. Selection of proper fluids and pressure conditions may be an important issue for increasing productivity in some types of reservoirs. The potential for IOR using MPD will make these methods more attractive. MPD will allow extended reach, faster drilling, less problem time, easier well control and increased operability.

Underbalanced Drilling (UBD)

UBD has been used extensively in the USA and Canada and recently on the Gullfaks Field.

Drilling in underbalanced conditions allows:

- Increased drilling rate
- The drilling of complex wells with a low margin between pore pressure and fracture pressure.
- Increased recovery and production rate. Production of formation fluids takes place while drilling. UBD prevents particles from the wellbore entering the formation and reducing the fluid flow capability in the reservoir.

The MPD / UBD methods need to be further developed for offshore drilling (floating units). Challenges are related to equipment, maintaining sufficient pressure barriers, well control issues, and the separation of large amounts of formation fluids from drilling fluids.

Subsea Technology for Improved Oil Recovery

Subsea Well Intervention

Subsea well intervention is performed in order to maintain or improve the production from the field. The main differences between platform wells (dry wellhead) and subsea wells (wet wellhead) are as follows:

Features of Platform Wells

- 57 % average reservoir recovery today (Statfjord 60 %)
- Easy access (an average of 0.8 well interventions per year)
- Fast service (3 days)
- Low day rate cost for intervention and drilling operations
- Effective drain hole drilling through tubing using rotating drillstring

Features of Subsea Wells

- 42 % average reservoir recovery today (Statoil - target recovery rate 50 %)
- No easy access (an average of 0.2 well

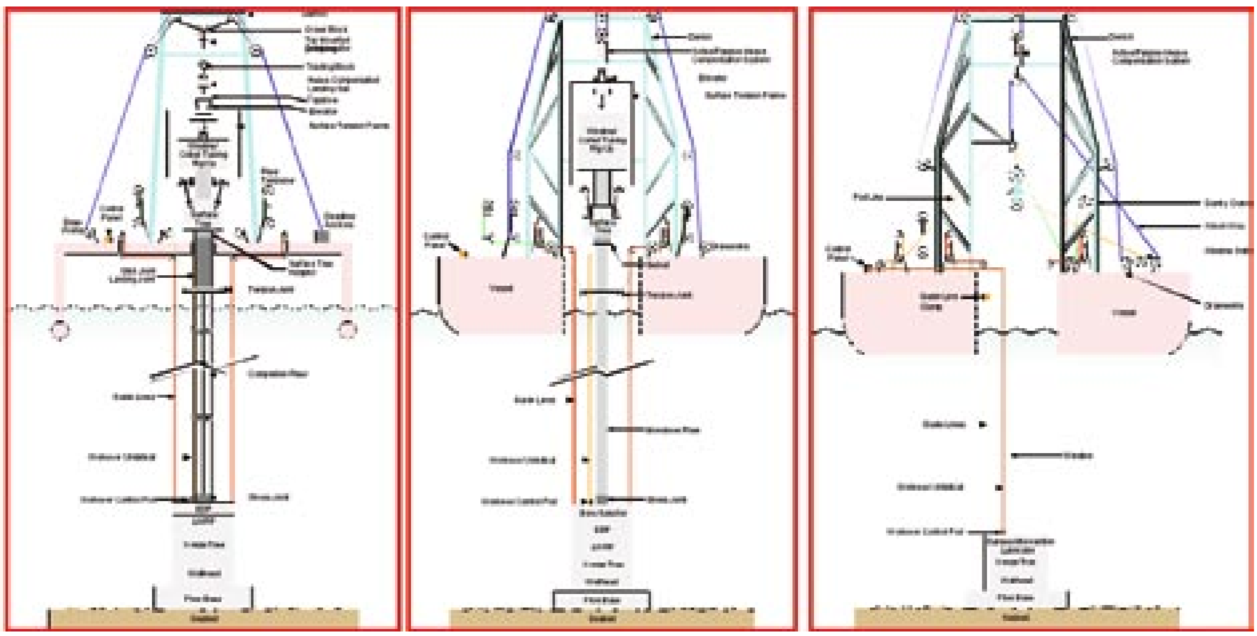


Figure 4.3 Subsea Well Intervention Methods
(a) Dual Bore Completion Riser (WL and CT services) (b) Single Bore Completion Riser (WL and CT services) (c) Riserless (WL services)

interventions per year)
- Time consuming service (12 days on average)
- Difficult intervention methods
- High intervention cost (Floating vessel needed)
- Drainhole drilling through tubing limited to Coiled Tubing (Not Effective)

Other issues are well control, contingency methods, availability of rigs and vessels, risks, personnel resource, competency and availability. The low recovery rate calls for more cost-effective subsea well intervention and drilling methods, i.e., Through Tubing Rotary Drilling (TTRD).

Subsea Well Intervention Methods

Figure 4.3 shows the typical set-up for subsea Wireline (WL) and Coiled Tubing (CT) services.

Conventional WL service operations

Existing methods for subsea well intervention are based on using completion riser (Dual or Single bore) between the surface vessel and the subsea wellhead. A control head located on top of the completion riser allows wireline and coiled tubing to be applied for downhole service under full well pressure. Recent improvements of the system for wireline and coiled tubing involve the introduction of a slip joint in the riser below the surface control head. This allows the surface equipment to be rigged up without being affected by the rig heave. After rigging up, the surface Xmas tree with tension frame is lifted and the slip joint is extended and locked for high pressure service using the heave compensator. Due to the high weight of the riser and associated equipment, the surface vessel required is normally a conventional drilling rig.

Riserless WL service operations

The control head is located subsea and the WL is run through the open sea. These types of operations are normally termed (Riserless) Light Well Intervention. Further developments and improvements may be the introduction of other types of cable, i.e., composite logging cable and coiled tubing. Modification of the system for deep waters is another issue. This system allows a lower specification rig or monohull vessel to be used.

Tubing replacement

Tubing replacement requires lifting capacities in the order of 300 - 400 tonnes. These types of operations are normally termed Heavy Well Intervention. A full size drilling vessel is required to handle the BOP, the 21" marine drilling riser and the completion string with 18 3/4" tubing hanger. (The tubing hanger size dictates the size of riser and BOP.)

Subsea Through Tubing Drilling

Drain hole drilling will become an important issue for increased recovery in subsea wells. However, there are no commercial systems available today.

Subsea Through Tubing Drilling using Coiled Tubing

The experience with Through Tubing Drilling (TTD) using Coiled Tubing (CT) is limited. Features of CT are online communication, fast running and pulling speed, but it cannot be rotated. This causes high drag force, limited reach and insufficient and uneven weight on the drill bit. Hole cleaning, heave motion and fatigue and safety issues topside are other limitations.

Subsea Through Tubing Rotary Drilling using Jointed Pipes

General

Recent demand for drilling long sections of drain hole through existing subsea completion calls for Through Tubing Rotary Drilling (TTRD). The main advantage is that the completion remains in place and no costly casing cutting and pulling for side track drilling is needed. 1200 -1500 m long, 5-6" drainholes through existing completion have successfully been drilled through platform completed wells. A 2 7/8" or 3 1/2" drill pipe is normally used through the 7" completion string. General challenges are wear on completion and subsea production equipment due to the rotating drillstring, pressure loss due to small clearance between the drillstring and the borehole/completion string.

Subsea TTRD

Subsea TTRD may take place through the conventional 21" marine drilling riser

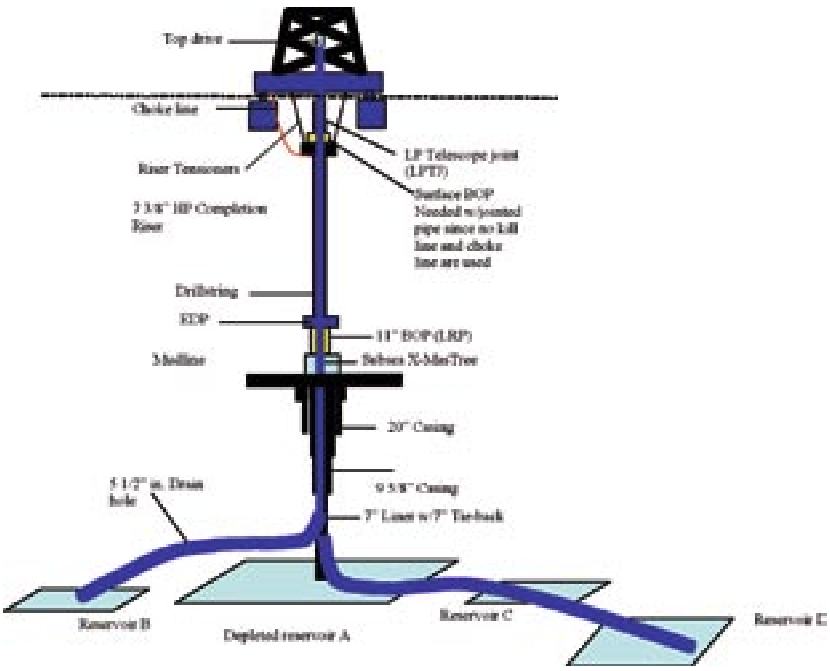


Figure 4.4 Set-up for TTRD

and the 18 3⁄4" BOP. This has been performed recently on the Njord Field using the permanently moored drilling and production semi-submersible rig. For TTRD in subsea wells, smaller, lighter riser and BOP systems can be used in combination with a lower specification rig (dynamic positioned or moored). Figure 4.4 illustrates a typical set-up. A conventional lower specification rig with a 7 3/8" completion riser is used. Additional challenges compared to fixed platform operations are surge and swab pressure effect due to rig motion, and the riser and associated equipment needed between the seabed and floating vessel.

Subsea TTRD using MPD
Drilling reservoirs with a small difference between formation pore- and fracture pressure may be possible using MPD. The dynamic pressure loss in the annulus during drilling can be eliminated, i.e., the bottom hole pressure can be maintained at constant level. Fast and safe downhole pressure regulation as a response to variable pressure regimes down hole is probably the most important.

Subsea TTRD using UBD
Drilling in underbalanced conditions allows for increased productivity and hence potential increased reservoir recovery. Production of formation fluids takes place while drilling. As mentioned, UBD prevents particles from the wellbore entering the formation and reducing the fluid flow capability in the reservoir. Challenges are to maintain sufficient pressure barriers and the separation of formation fluids from drilling fluids. The handling of the produced fluids from a MODU and environmental concerns are other issues.

Subsea Completion Systems

General

In the 1980s, field developments on the NCS were mainly based on using platform completed wells. Subsea wells were mainly used due to lack of well slots from the fixed platform, not being able to reach the target from the fixed platform, or for application in deep waters. The costs were generally high. Due to improved performance and reduced costs, subsea completions of today are often considered the main option in field developments even in water depths as shallow as 70 m.

The technology needs for the small fields are different from the technology needs for the larger fields.

Subsea tie-back to existing infrastructure and process capacity is often a prerequisite for profitable developments. Time marginal resources is an issue. Time is often a critical factor due to short remaining lifetime of the infrastructure / platform / pipelines, etc. The trend "From Sea to Beach" solution (ref. Ormen Lange and Snøhvit) with no platform and offshore support during production requires improvements of existing technology and / or new technology to be developed. Some relevant issues are now listed.

Technology Gaps - Need for Improvements:

- **Downhole or seabed separation**
  Downhole or seabed separation of oil and water has a considerable impact on prolonging the production life of offshore oilfields. The impact has many aspects; most of them are well understood and widely documented in the petroleum literature. Wider implementation of downhole or seabed separation has been inhibited by the need to introduce pumping/boosting to one or two of the separated streams. This considerably increases the complexity of the separation system and the development and operational costs. Challenges are power distribution including cables and terminations, closed loop control system, lack of reliable key components and systems for pressure boosting, sand, hydrate, scale and wax control and handling, and efficient separator designs.
  An alternative and novel approach for downhole oil-water separation utilizes the energy of the production stream to drive the separation and its product. This has been launched and currently tested through the DGRASS project. The Department is in the process of establishing a new R&D program for in-line separation, primarily installed on the seabed or near the wellhead.
- **Optimized design of seabed systems**
  In order to get full benefit of monobore completion / slim well construction, smaller tubing hangers with sufficient number of penetrations (needed for downhole communication) must be developed as illustrated in Figure 4.5. Further improvements may include all-electric control systems for long step out and / or for operation in environmentally sensitive areas, optimization of seabed systems and components for simplified installation and maintenance.
- **Optimized design of well completion**
  Reducing the time for completion is essential for cost reduction. This may include cemented well completions,

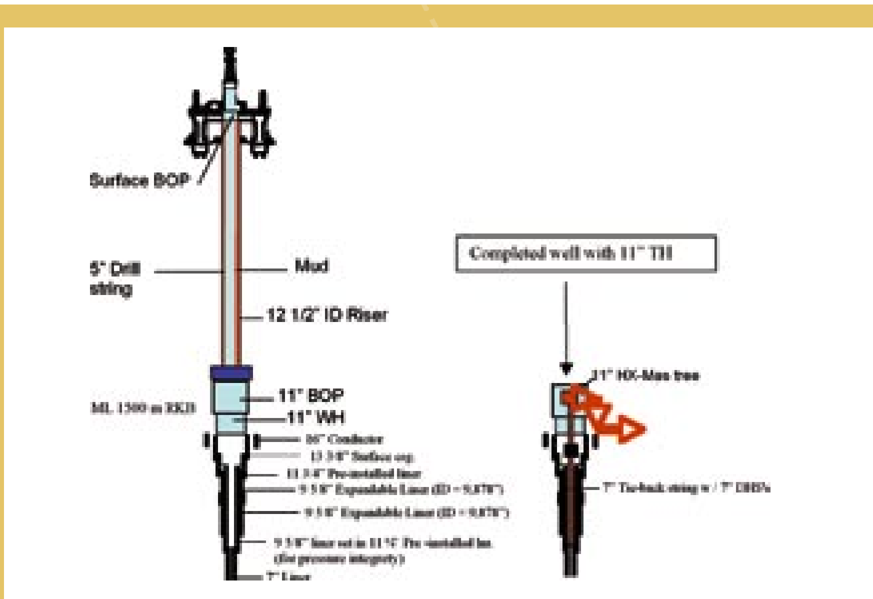
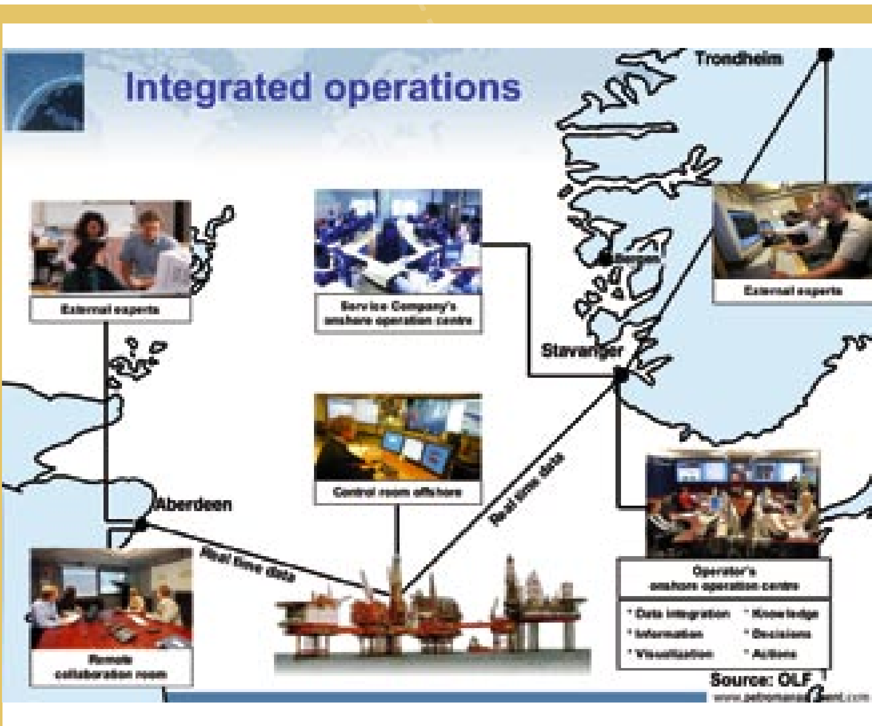


Figure 4.5 Low Cost Drilling and Completion Concept (11" wellhead)



(Source: OLF)

new isolation and plugging methods, better protection of sensitive equipment such as downhole control cables, to allow faster installation.

- **Smart wells / multilateral wells** Multilateral well completion makes wire-based systems difficult to use. Downhole wireless control and monitoring is a challenge in such wells. Instruments that can cope with high pressure/high temperature both in small and conventional production tubing are other challenges.
- **Flow assurance** including multiphase transport and cold flow, see Section 8.5.
- **Subsea fiscal measurement,** multiphase flowmeter for subsea application to improve testing of subsea wells.
- **Big bore completions** Some deepwater fields benefit from big bore completions. Big bore completions refer to those where the production tubing is 7" or larger. These completions have a larger internal diameter, thereby reducing the friction pressure when producing and allowing for higher flow rates. For example, the subsea Ormen Lange Field is using a combination of 9 5/8" and 7" production tubing and a 7" Down Hole Safety Valve (DHSV). In this case, the number of wells needed to effectively drain the reservoir was reduced from 16 to 8. However, these options are field specific and may not be readily used in oil and condensate fields or fields with complex reservoir structures.

The main challenges for big bore completions are as follows:

- Less casing points available - more difficult to reach the target
- Costly (casing, liner, more mud, larger drilling rig, increased drilling time)
- High flowrate in case of an uncontrolled blow out
- Equipment like completion riser and associated equipment, DHSV, Xmas tree valves, etc., is not qualified for big bore completions

Organization of BRU Program 2

We will organize the BRU Program 2 in cooperation with the oil companies, service companies and the Research Council of Norway in line with the models used in the Petromaks and Demo2000 programs. BRU Program 2 will be further developed during the fall 2005.

4.4 BRU PROGRAM 3: eFIELD AND INTEGRATED OPERATIONS

Introduction

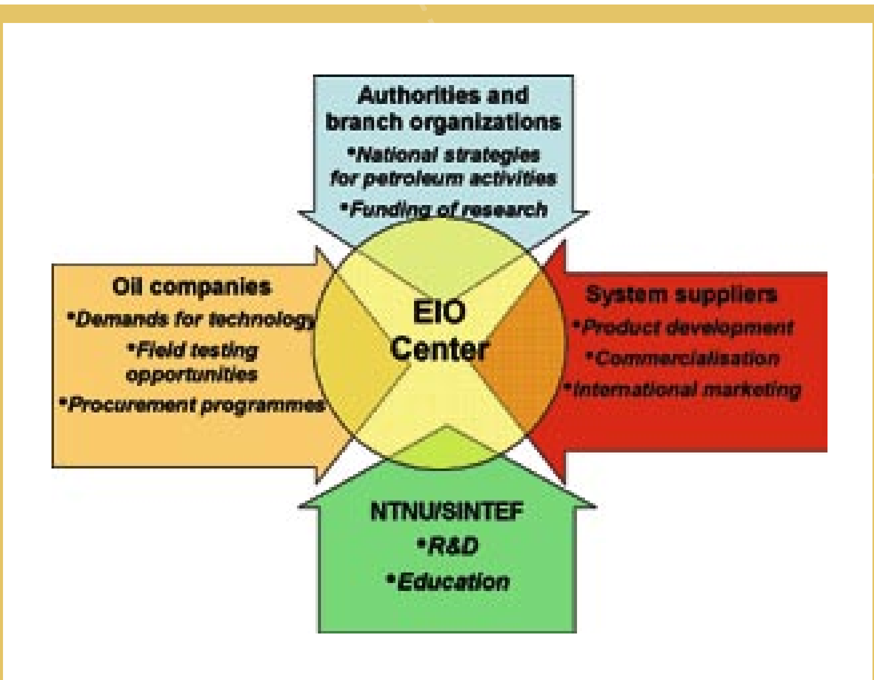
A number of oil companies operating in Norway (including BP, ConocoPhillips, Hydro, Statoil, Shell, ChevronTexaco) have started to implement eField and Integrated Operations (EIO) as a basis for new products and operation systems for the oil and gas exploration and production value chain

Norwegian system and service suppliers are world leaders for eField development, and have the potential to develop products for an international market. Several international service companies are developing technology in Norway related to eOperations.

eField and Integrated Operations are emerging technologies internationally and on the Norwegian Continental Shelf. According to the OG21 TTA-report: "eOperation and maintenance" there is a need for research, development and competence development in the interaction between petroleum technology, operations, HSE, ICT, organization and business development to exploit the potential for EIO. There is a strong interest from the government and the oil and gas industry to focus on research and development for the exploitation of EIO. This is manifested in the development of a number of "eField-work groups" within OG21, OLF and NPD.

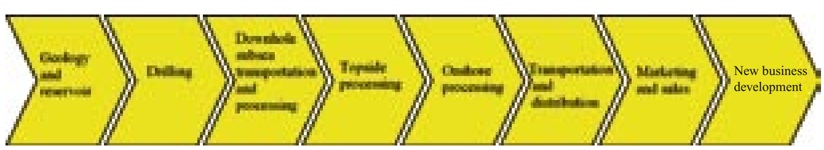
During all BRU meetings, the BRU Project received clear advice from the petroleum industry to target EIO as a prioritized research area. NTNU and SINTEF will thus address EIO as a key research topic.

NTNU and SINTEF already have a large number of projects related to EIO. Currently more than 50 projects with funding of about NOK 250 million are related to EIO. There are several departments and institutes already involved in this research. Thus NTNU/SINTEF has a unique possibility to put together multidisciplinary projects for research cooperation in this area across their organizations.



The EIO center's vision is to be a world leader for R&D, innovation, education and competence development related to eField in the petroleum sector.

The goal for the EIO center is to contribute to optimize the petroleum value chain defined in the following figure.



There will be integration of the relevant activities that are currently performed at NTNU and SINTEF in order to meet the vision and goal. The following is a description of these ongoing activities. The program itself will be worked out in more detail during the fall 2005. NTNU/SINTEF are two of the few organizations in the world that have the possibility to integrate all specialties needed to deliver industrial solutions, long-term research results and long-term competence. In order to promote step-change technologies within integrated operations, it is a challenge to handle the multidisciplinary integration and still keep a focus on the deliverables.

Cross-disciplinary teams

Performance measurement of teams

Integrated operation requires more than goal setting. There is a need to establish top level key performance parameters across the disciplines, find methods to measure them and create ways by which teams can jointly understand and commit themselves to the goals. The research to be carried out should be based on and extend the balanced scorecard concept.

Management of organizational change processes (transformation from discipline-based organization to cross-disciplinary organization)

Smarter Together (a team work model developed at SINTEF) is a process for ensuring safety and efficiency in operations. Firstly, the bottom-up design, even under conditions where the complexity of the challenges invite an expert-driven top-down approach. Secondly, the focus on the actual working team, that is across company structures and equivalent "dividing lines" (i.e. the focus is on the communities of practice). And thirdly, the explicit search for arenas and processes which encourage trust, playfulness and confidence. To fully succeed with integrated operations there are several disciplines and companies that will be accompanied by organizational change and therefore need special attention.

Visualization and conceptual understanding

To ensure and further increase safety and efficiency it is vital that there is a cross-disciplinary conceptual understanding of the actual operation, not least when it comes to possible hazards. In order to achieve this goal it is important to develop a common knowledge base between the various disciplines. *Smarter Together* is currently implementing a concept for real-time cross-disciplinary collaboration where cross-disciplinary understanding is a major focus point. This is also the prerequisite for effective concurrent planning in addition to real-time data, appropriate ICT tools and processes.

Visualization is a powerful tool to clarify and simplify operational issues. *Smarter Together* has focused on alternative solutions to present information (i.e. procedures and control documentation) and adjust these to an operational environment. Animations, work process modeling and real-time visualization of data can simplify and clarify various operational issues and contribute to safer and more efficient solutions. This is a means for facilitating/speeding up/enhancing the process of transforming information into knowledge. An informative/high quality visualization constitutes a powerful basis for cross-disciplinary collaboration. We believe that visualization tools will be increasingly important in the years to come.

Consequences for deployment of human resources

Motivation and knowledge (also about others' knowledge), are two key elements to build safe and efficient work practice. To accomplish these elements work-force participation/bottom-up processes, ownership, clarity of roles and responsibilities are crucial. *Smarter*

Together has extensive experience with similar issues and processes from other areas within the oil and gas industry.

Simulation and training for cross-disciplinary team work (e.g. handling of emergency situations)

Visualizations, like animations, have considerable pedagogical power, and are highly effective tools due to their close relation to reality. They are applicable both when it comes to self-study and in classroom presentations/process-meetings, and they can communicate generic cases/phenomenon, specific cases (historically correct), as well as possible critical situations. Efficient training demands, and is qualitatively enriched by, shared collective knowledge and experience transfer. Such processes are more easily triggered and significantly improved by such visual input than other more traditional means. Successful implementation of integrated operations demands efficient training of cross-disciplinary work-teams. *Smarter Together* has extensive experience in facilitating training processes within the offshore industry.

Education and recruitment, the need for new educational content for candidates who will enter cross-disciplinary teams

NTNU has a strong focus on student programs targeted towards eOperations and Integrated Operations. Currently the program of study "Engineering science and ICT" has students following a cross-disciplinary range of courses, and students following this program will be very good candidates for work in the new eOperation disciplines. The new Experts in Team concept at NTNU helps to prepare students for this type of work. The Department of Petroleum Technology and Applied Geophysics is currently building an operations center (ready early in 2006), which will be used as a training center for students at NTNU. This operations center is closely linked to the main visualization center at NTNU.

Real-time drilling and reservoir models (from OG21)

Real-time Drilling

Most of the major operators in Norway are using onshore drilling centers to improve drilling performance and geosteering. Real-time information from the drilling bit, allowed by high bandwidth transmission, is visualized in the operations center. Traditional operating modes where the decisions were taken by the wellsite personnel are moving towards an experienced team following operations real-time and making multidisciplinary decisions. Some key monitoring positions have been moved from offshore to onshore. Measurement while drilling is used to optimize the reservoir targets by updating geological models utilizing the real-time data. Geosteering is the most critical event when drilling the reservoir. By using real-time data transfer the necessary action can be taken to increase net pay and thereby increase production from the wells. The real-time data is loaded into geomodels in a 3D visualization environment. Real-time drilling data to PC enables engineers to follow the drilling/logging operations from their desks and thereby follow offshore operations more efficiently.

Intelligent wells

While real-time monitoring of well surface data traditionally has been handled by the surface production monitoring systems, real-time monitoring applying downhole sensors (often referred to as "Intelligent Wells") is becoming more common on the NCS. The advantage is twofold: securing key performance and diagnostics data when random events occur as well as enabling real-time monitoring and hence pro-active well and reservoir management. The cost savings associated with a reduced need for well interventions is substantial, particularly for subsea developments. Downhole pressure and temperature gauges are the most common sensors in North Sea wells, but more advanced monitoring sensors and control devices have been installed in various fields. Fiber optic technology is expanding and improving the speed and capacity of downhole data transmission. A series of "data to desktop" initiatives are being taken, and contractors, service companies and vendors are being more closely integrated with the operators support organizations for day-to-day well optimization and problem solving. Real-time supervision of well stimulations, logging operations and well interventions from shore are used to utilize the onshore expertise and thereby improve results. As with drilling, some reduction in offshore staff requirements can be seen.

Seismic

There has been and still is focus on the development of hardware solutions both for seabed seismic and downhole applications. In seabed seismic the trend is to move to cost-effective full-field installations, in progressively deeper and deeper water. The four-component seismic sensor technology is well established and tested and is today relatively mature. Ongoing developments will still improve the sensors in terms of their quality and reliability. Data transmission from seafloor to facilities or directly onshore still represents a challenge due to the vast amounts recorded in a full-field set-up. Fiber optic systems are currently prototyped and tested. Downhole geophone technology is being further developed to improve signal-to-noise ratios in flowing wells and enhance reliability for downhole permanent monitoring. The installation of permanent seabed/downhole seismic sensors opens new opportunities within reservoir management. The spatial resolution provided by the seabed measurements combined with downhole calibration of the seismic signal enables the 4D seismic data to be more integrated into the overall reservoir management process. This is important input not only to define the needs for and location of further in-fill/injection wells but also for shorter term production optimization. A special application of in-well seismic measurements is seismic while drilling. This technology is available and is being used today, in particular for geosteering complex wells.

Reservoir management

There is a need to convert reservoir simulator output to simulated seismic for calibration of simulation models with time-lapsed seismic data. This requires the development of software tools for automated and accurate analysis of multicomponent and time-lapse seismic data. Also, history matching with 4D seismic is required, including the use of spectral decomposition technology for improved reservoir description in the simulation model building process. The optimization of development planning under uncertainty using simulation is needed. This includes rapid history matching and research into fast performance predictors. Data integration (e.g. static and dynamic) is a reoccurring theme throughout most exploration and reservoir characterization elements and must be considered a key area to improve tools. There is no single software tool capable of providing a fully integrated reservoir model all the way from seismic, through the geomodel to the flow model due to problems with moving data, changing scales (upscaling) and common standards/workflows.

Real-time modeling and production optimization

Real-time optimization of assets

Real-time optimization of assets such as a petroleum field with a set of wells, a pipeline system and downstream processing equipment is a technology with a huge potential and will be a critical component in eField development and operation. This is because operational decisions involve a large amount of parameters, and decisions always are made under uncertainty. The sheer scale of the problem necessitates the use of mathematical programming techniques. Feedback control is a complementary technology to improve design and stretch operational limits. Experience is limited in petroleum production; hence research is required to draw the full benefits of this technology.

Online estimation of non-measurable parameters

Online estimation of non-measurable parameters is important, for instance to alleviate the need for downhole measurements in a production well. This technique, which again requires extended research activity, will spread due to limited accessibility of production equipment in eFields.

Safety-critical systems

Safety-critical systems are and will be even more vital for the protection of people, the environment and assets. As technology for enhanced recovery becomes more delicate, systems for control and surveillance are even more critical topside, subsea and downhole. Thus better information integration is necessary to achieve the goals.

Condition monitoring

The annual costs related to operation and maintenance on the Norwegian Continental Shelf are predicted to be steadily rising to reach about NOK 20 billion to 35 billion over the next decade. At the same time, the unit costs are predicted to increase strongly. eOperations and maintenance are believed to represent a major contribution to meet this challenge, and realize the third efficiency leap on the NCS.

Increasing the relative amount of condition-based maintenance is regarded a prime mover in order to reduce the operation and maintenance costs. This will require the development of methods and tools for decision support and diagnosis as well as conducting new work processes that will require attention from operators, contractors and suppliers.

From a technical perspective, improved fault diagnosis will be of vital importance. In an operational context this implies improved process models making early fault detection a primary tool for avoiding spurious trips or severe accidents. Early fault detection has significant impact on maintenance and logistic support performance. The success is dependent on improved methods, tools and models for describing deterioration processes.

Despite previous and existing research programs worldwide, the decision support for maintenance and operation suffers from incomplete models of the degradation processes and influential factors. Quantitative models describing deterioration processes do exist, but they are often limited to items or equipment with one or at the best a few dominating failure mechanisms. Use of maintenance records, condition-monitoring data etc. is vital to develop new quantitative degradation models requiring strict methodologies for data handling and new knowledge of degradation mechanisms and causes (affecting factors).

The evaluation of residual life is a further step in utilizing the information about the degradation and deterioration processes. Defining residual life requires knowledge about external as well as internal requirements in terms of technical safety and cost-efficient solutions, for example. Being able to predict residual lifetime will enable much more reliable maintenance and logistics support planning.

Operations and logistics

Offshore supply logistics and supply chain management

Offshore logistics supported operations have so far been mostly regarded as a transport service between onshore suppliers and depots and the offshore installations. Given the development of onshore operation centers maturing into primary "decision support" hubs of networked organizations this understanding of the offshore logistics support operations should change. Such networked organizations rely extensively on their supply chain operations. The success of such centers is therefore tightly linked to having superior system-wide situational awareness, the system including the demand and supply chains and management of the logistical resources.

Both loss mitigation and opportunity exploitation are areas where the offshore logistics support ("the onshore / offshore supply umbilical") could contribute if improved planning, control and response mechanisms were developed.

Offshore supply chain integration

Integration of actors and modes of the offshore supply chains are prerequisites for improved decision-making capability in onshore operations centers. The main driver for this is to improve the true logistics service, i.e. alignment of true demand with the needed supply so that use and availability of resources are improved. Better understanding and improvement of processes and interfaces within the demand and supply chains are essential here.

Offshore supply chain planning and control

Real-time and online planning and control with the logistical resources and the supply chains are important to take

out the effect of supply chain integration. To be successful, one should develop both technology and methodology in parallel, as the complex interplay between people and machinery is the fundamental aspect in developing decision support systems. Benefits will include: (i) finding the correct trade-off between cost effectiveness versus operational benefit and risk, long and short-term, (ii) enabling proactive and/or highly responsive disruption management (loss mitigation), (iii) focus on mission critical decision support systems for management and control of operations, (iv) providing a support function for offshore logistics supply which will primarily be judged by the quality of their situational awareness. Consequently, in addition to the direct physical systems issues – the proposed process, giving system support and necessary competence development will increase personnel motivation and work satisfaction in offshore logistics support, by helping decision makers build superior situational awareness.
It goes without saying that this will have a positive effect on continuous competence development, personnel motivation and ultimately retention.

Information technology

For a scenario where subsea installations are visualized in a three-dimensional environment, users can click on any piece of equipment in such visualization. Ontological information about this equipment is displayed, and the user may ask for more information if needed. Requests for more information may involve looking up information in the ontology and/or retrieving relevant documents. The requests may involve several pieces of equipment and other possibly non-ontological terms that specify in more detail what we want to know. In case the answer involves specific pieces of equipment, those pieces may be highlighted in the visualization.
The assumptions for such a scenario are that there exists an OWL ontology of the domain, textual documents from domain and links between data to be visualized and elements in the ontology.

A number of research issues come from the above scenario: How should documents be indexed semantically to improve the retrieval process. How can relevant information be retrieved from the ontology. How can real-time data be verified against ontologically specified rules. How can real-time data be combined with ontological descriptions to interpret and reason about a situation. How can the ontology be used to navigate in the three-dimensional space given by the visualization.

HSE in connection with remote operations

Changes that can influence safety

Computer (intra)networks are getting more integrated and external networks are linked up to existing infrastructure because of practical reasons. Are routines good enough, and is there a common understanding of the potential problems emanating from this network transparency?

Various types of technology are becoming increasingly integrated. Combining the control system SCADA and Microsoft's Windows system (which is known to have many security problems) can lead to problems. Even though update patches are regularly installed potential problems may occur. Is it possible to test for such problems? Who should pay for it? Have the systems being connected been quality assured – i.e. are the right systems prioritized?

Safety systems in network organizations

It is important to design emergency plans and the establishment of redundant equipment. Are all relevant objects identified in the network organization? Is there a focus on a safety culture? Is there a mutual understanding between the actors in the network organization?

Business development

Integrated teams will be in a good position not only to optimize running tasks, but also to develop new business through integration of field exploration, acquisition of license shares, investments in new infrastructure etc. New models for integrated team work applied to business development tasks should be created and tested. Integrated decision support tools should be developed.

Management of the EIO Center

As a result of the BRU Project, NTNU and SINTEF have decided to start a center called "eField and Integrated Operations (EIO)". The center will be set up with a board chaired by Professor Jon Kleppe, NTNU. The project and management structure will be developed during fall 2005.

We will organize the BRU Program 3 in cooperation with the oil companies, service companies and the Research Council of Norway in line with the models used in the Petromaks and Demo2000 programs. The BRU Program 3 will be further developed during the fall 2005.

The following departments at NTNU and SINTEF are participants in the program:

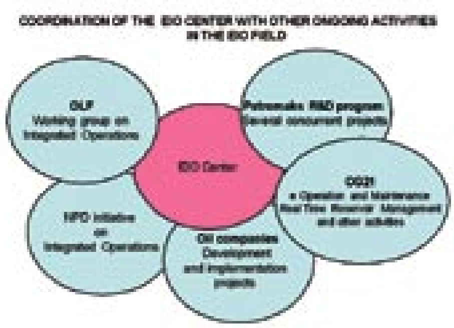
NTNU

Department of Petroleum Technology and Applied Geophysics
Department of Marine Technology
Department of Engineering Cybernetics
Department of Computer and Engineering Science
Faculty of Social Sciences and Technology Management
Industry's Innovation Fund at NTNU

SINTEF

SINTEF Petroleum and Energy
SINTEF ICT
SINTEF Marine
SINTEF Technology and Society
SINTEF Materials and Chemistry

The program will be worked out in cooperation with the industry during the fall 2005. It is important for NTNU/SINTEF to adjust the program according to the other activities and initiatives illustrated in the following figure.



Funding of research

An application will be sent to the Research Council of Norway in order to try to be selected as a Center for Research-based Innovation (CRI), an initiative supported by the Ministry of Education and Research. The program will seek financial support from the Petromaks R&D program (Research Council of Norway). Industry will be invited to join the program in either joint industry projects or as stand-alone projects.

Deliverables

Competence development
- Research education – Ph.D.
- Continuing education – design and operation of eOperation systems
- Network – knowledge communication
- R&D visits to NTNU and SINTEF from industry personnel
- M.Sc. candidates with competence in eOperations

Products and goals

Improved recovery, lower operating costs and improved safety and environmental protection, through:
- New technological solutions for eOperations
- Improved organizations and work processes
- Improved communication solutions throughout the petroleum value chain
- Better visualization and real-time surveillance of subsea processes

The EIO center will promote activities that can lead to spin-off activities and innovation, which again can lead to industrial products and commercialization.

4.5 BRU PROGRAM 4: ARCTIC TECHNOLOGY

Introduction

During the BRU meetings we discussed the challenges in Arctic regions with a lot of the industrial partners and the need for a research program in this field. The Barents Sea has gained renewed interest from the entire petroleum industry. Furthermore the Russians have a focused priority on their continental shelf both in the Barents Sea and in the Pechora Sea. The Norwegian Petroleum Cluster has a unique opportunity to further develop the cooperation with the Russian oil and gas industry in this context.

NTNU has decided to establish BRU Program 4 on Arctic Technology. NTNU will integrate exploration technology related to the Arctic, environmental technology, gas technology, flow assurance and gas transportation together into a special program on arctic technology and flow assurance. The key elements in the program are:

- Exploration Technology Related to the Arctic (EXTRA)
- Marine Operations and Systems
- Environmental Technology
- Gas Technology and Transport

Exploration Technology Related to the Arctic (EXTRA)

The oil industry considers the Arctic to be the ultimate new petroleum frontier. According to the US Geological Survey around 25 % of the remaining global hydrocarbon resources yet to be located are in the Arctic regions. During the BRU meetings with the industry the Arctic was raised by several companies.

In this setting the three independent organizations NTNU, SINTEF and Norges Geologiske Undersøkelser (NGU) have agreed to join forces and will seek support for an Arctic Exploration Center.

A solid foundation for this cooperation will be the three partners' complementary history, knowledge and mission, as well as common visions for the future petroleum E&P research and technology development. All three partners have extensive experience in petroleum research in Arctic areas. The co-location in Trondheim should ensure easy integration of key personnel. Establishing common databases and research education (Ph.D. level) will be important parts of the center's philosophy. The initiative has been named "EXTRA": "Exploration Technology Related to the Arctic".

Marine operations and systems

Operations in Arctic areas represent new challenges for structural design and operational procedures compared to the standards developed for the North Sea. Marine operations in harsh environment areas where ice is present require flexibility. The surface vessel must be able to quickly move off location in an emergency situation. Protection of seabed equipment and systems from ice is another issue.

The use of jack-up rigs for exploration drilling in moderately ice-covered waters is expected to increase in the future. Ice actions from the breaking of drifting ice as well as rubble accumulation between platform legs may represent a hazard. Resonance may occur between the time-varying ice breaking force and platform's global deformation.

The fact that Arctic areas are particularly vulnerable to pollution makes it especially important to focus on the safety and reliability of structures and operations. Developments needed to meet the zero-harmful discharge requirement include:
- Tophole drilling systems which recover the drilling fluids and drill cuttings from the borehole.
- Development of improved subsea and pipeline leak detection systems.
- Application of subsea control systems with no discharge to sea.

Closed subsea control systems with no discharge to sea introduce technical and operational limitations and cause a significant increase in cost due to long control umbilicals. All-electric subsea control systems may be developed. Additional protection of control and electric cables from the crab species *Paralithodes camchaticus* may be needed.

Environmental technology

Important issues to be investigated are wind, waves and seawater current profiles, seawater temperature profile, and the salinity profile of water. Ice actions from the breaking of drifting ice may represent a hazard. Geological conditions of seabed sediments such as "permafrost" extended from shore, hydrate pockets, shallow gas reservoirs, must be investigated. The impact of issues such as fluid disposal on the marine-biological condition is an important issue. Hazards include oil spill, discharge from drilling and production chemicals. Examples of discharge of unwanted fluids and materials to sea are listed below:

- Conventional tophole drilling causes large discharges of drilling fluids and drill particles into the sea.
- Subsea control systems (open systems) discharge a limited volume of control fluid into the sea for each valve operation.
- MEG (Monoetylenglykol) used to reduce hydrate formation in subsea systems and pipelines is discharged into sea in some cases (planned/unplanned).
- Platform and sea-line decommissioning also cause discharges.

Gas technology and transportation
Subsea production of oil/gas involves the transportation of hydrocarbons to a processing facility where the fluids are processed for export or for further refinement. One vision for the future transportation solutions is to avoid platforms and floating structures altogether and employ long distance wellstream transfer in multiphase pipelines to shore. The subsequent means of transportation to end users will probably depend on the location, but remote areas often exclude pipelines, and transportation may then be in the form of shipping liquids (oil, condensate, LNG) or possibly solids (gas hydrates).

The special challenges in arctic regions are related to the extreme and cold climate and to the fact that it is an environmentally very sensitive region. This dictates stricter requirements for transportation systems than elsewhere, and in particular:

- Extreme system reliability and safety
  Failure of the transportation system will have large consequences, as intervention is more difficult in the extreme climates.
- Zero harmful emissions
  No emissions at all, or chemical free transportation solutions is the ultimate ambition.
- Iceberg protection
  Subsea structures and pipelines must be iceberg proof, probably requiring the burial of pipelines to sufficient depths on the sea floor.

There are a number of research challenges related to the fundamental and technical aspects of hydrocarbon transportation.

Fundamentals of multiphase systems
Computer simulations are the base tools for the design of transportation systems. It is extremely important that these codes meet the accuracy and reliability required for arctic developments, which calls for a continuing effort on advancing the understanding of multiphase flows. Flow transients (unstable flows, severe slugging, shut-in and start-up, pigging) are particular flow challenges in multiphase systems.

Precipitation of solids (gas hydrates, wax, scale) can lead to wall deposits and plugging of pipelines. This can have dramatic consequences, in particular for Arctic environments, where remediation and intervention are more difficult. Better understanding of multiphase flows of complex mixtures and better confidence in prediction methods will therefore contribute strongly to increased safety in Arctic oil-gas production. The research activities will cover:
- Physics of multiphase flows: gas-oil-water-solids
- Thermodynamics of multicomponent mixtures
- Flow models and numerical methods
- Experiments in laboratories

Transportation technology
Reliable flow simulators, together with experimental work, form the basis for designing transportation systems. Key issues are:

- Flow transients
  Severe unstable flows can occur, with alternating gas and liquid flows. This can often occur when a transportation system is operated outside the design basis for stable production. Modern control systems for flow stabilization are being applied today.
- Gas hydrate management
  High costs are associated with systems to avoid gas hydrate formation in pipelines. This normally includes temperature control (insulation, heating) and the use of chemical inhibitors. New transportation solutions are envisaged, where hydrates in pipelines are allowed to form in a controlled manner, with properties such that agglomeration into plugs is avoided ("Cold Flow"). Bulk transportation of gas in the form of stabilized hydrates has also been investigated as a transportation option.
- Water management
  Water is often produced naturally, or as a consequence of water injection for enhanced recovery. As water is the source for a number of fluid related effects, subsea or downhole water separation and reinjection would be very beneficial.
- Pumping/compressing
  Long distance wellstream transportation will often require a boosting station along the way. Reliable subsea systems for multiphase pumping or compression is then required.

Organization of BRU Program 4
We will organize the BRU Program 4 in cooperation with the oil companies, service companies and the Research Council of Norway in line with the models used in the Petromaks and Demo2000 programs. BRU Program 4 will be further developed during the fall 2005.

4.6 IMPLEMENTATION AND MANAGEMENT STRATEGY FOR THESE R&D PROGRAMS

The programs described in this chapter will be further developed during the fall 2005. Each of the programs will be organized in further cooperation with the oil companies, service companies and the Research Council of Norway in line with the models used in the Petromaks and Demo2000 programs.

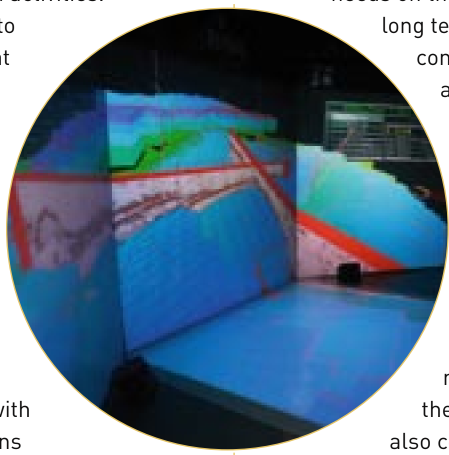
The four programs will determine the resource allocation at the Department of Petroleum Engineering and Applied Geophysics in cooperation with other departments and institutes at NTNU and SINTEF in the coming years.

There are about 50 Ph.D. candidates at any time at the Department of Petroleum Engineering and Applied Geophysics. This resource will be directed towards the four BRU Programs in the future. In addition there is a similar amount of Ph.D. candidates at other departments that also will be influenced in this direction. This means that within a reasonable time about 100 Ph.D. students will be working in these four programs. The use of doctoral candidates is an excellent mechanism for research.

Further the Department has different ongoing long-term R&D programs already with the petroleum industry. This research funding will be directed towards these four BRU Programs. This will be supplemented with renewed applications for funding both from the industry as well the Research Council of Norway.

It will be part of the strategy to focus the resources towards these four BRU Programs. In this manner NTNU/SINTEF will obtain the needed scale in order to be in a position to contribute significantly. The organizational issues are very important to obtain the overall goals. NTNU and SINTEF are committed to implement a management structure for cooperation across the different institutes and competence centers in order to reach their stated objectives. Each program will also have an organizational structure with a management committee with representatives from NTNU/SINTEF and the industry.

NTNU wants to recruit the best students to further excellent R&D in petroleum engineering and geosciences. A central emphasis will be the recruitment of women, the BRU Project aims for at least 40 % participation of women in the various research activities. This will contribute to setting priorities that take into considera-tion the viewpoints of women, who often consider other research problems as being more important than the priorities given by men. NTNU as a national university with international relations wants to engage women to continue to achieve high-quality results in an increasingly competitive world. Experience from research areas and global industry shows that a gender balanced workforce is beneficial in achieving the overall goals of institutions and enterprises.



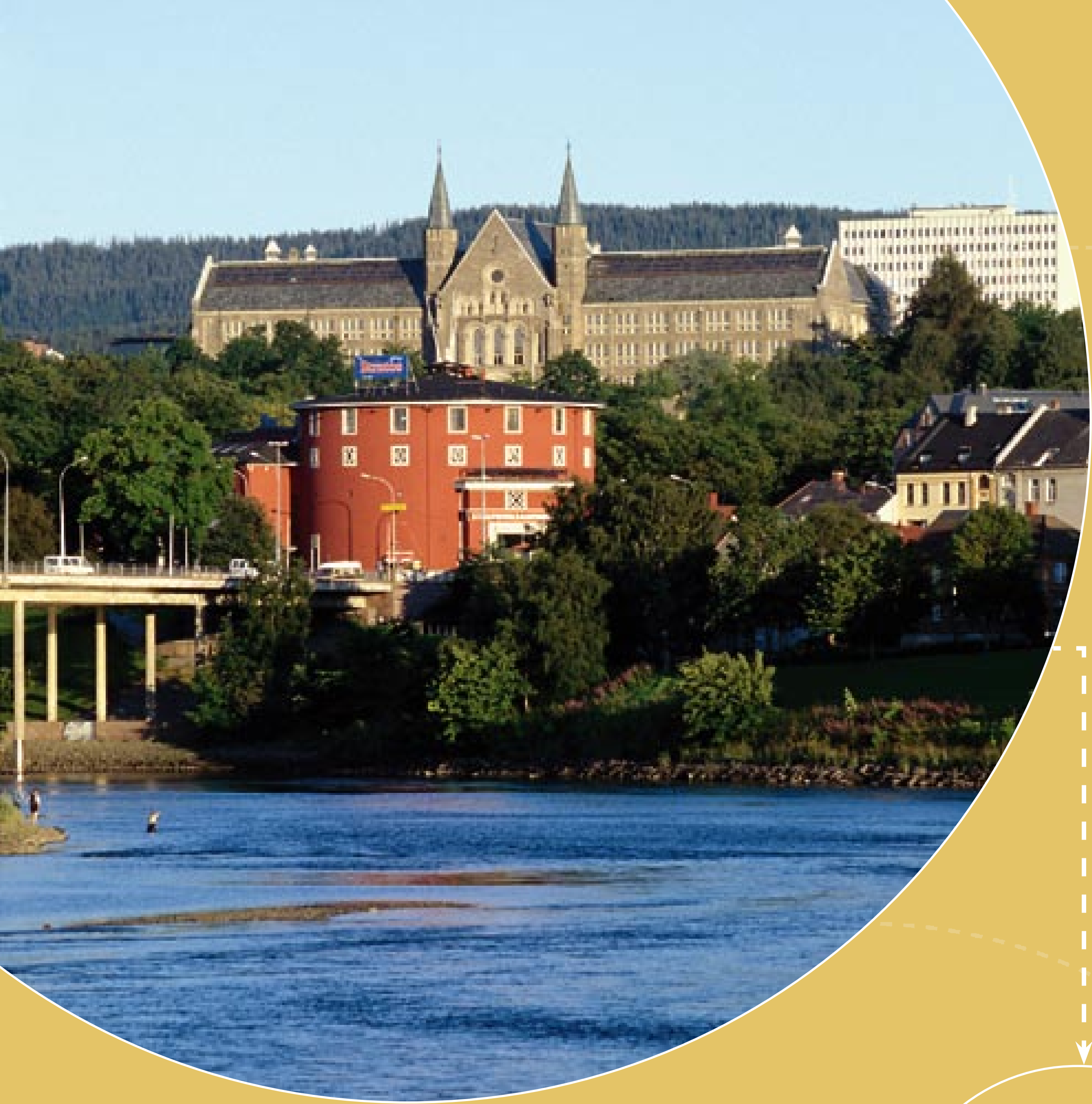
NTNU has a well-established contact network with the major universities and educational competence centers in the world. NTNU is about to sign Cooperation Agreements with some of the best competence centers in the world within each BRU Program area with the goal to contribute to step-changing developments.

NTNU will develop a "knowledge base structure" with reference to these four BRU Programs. This will have the flavor of a virtual organization linked together in technical networks in different network groups. These types of networks have been implemented within several of the international oil companies with great success.

NTNU will organize a "global R&D scouting program" in order to have an updated overview of all R&D activities in the focused BRU areas performed internationally. This will give the opportunity to utilize results and developments of activities performed internationally either at universities or in the industry. It will also avoid unnecessary duplication of research.

NTNU will also set up an "industry scouting program" in order to have a clear understanding of the industrial needs on the short, medium and long terms. This will be a continuously organized activity. The BRU meetings during the BRU process have been an excellent reference for this activity.

NTNU will find appropriate reporting routines for the deliveries and will also continue to organize network meetings to facilitate dialogue and discussions with the industry and other key partners.



Part II

5 The Petroleum Technology Platform at NTNU/ SINTEF and Long-Term Development of Competence

5.1 NTNU/SINTEF AS A SUPPLIER OF COMPETENCE AND LONG-TERM RESEARCH IN PETROLEUM

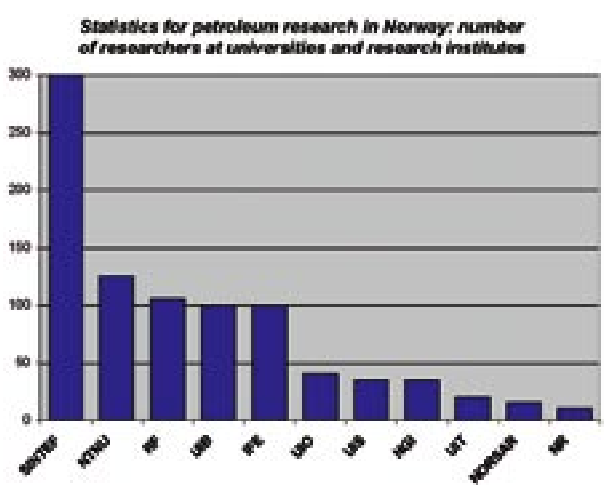
The NTNU/SINTEF campus is one of the largest in Europe in terms of education and research in technology and natural science. With more than 5000 staff and 20 000 students, these institutions are major players, not only in Norway but also on an international scale.

In Norway, SINTEF and NTNU have a dominating role in upstream petroleum research and university education. Professors Anders Elverhøi, UiO and Arne Bredesen, NTNU made a compilation of the number of man-years involved in upstream petroleum research in Norway in 2004. The figure below shows that close to one-half of the research in Norway in this area, excluding research in the industry, is conducted at SINTEF and NTNU.

On the educational side, the M.Sc. programs in Petroleum Engineering and Petroleum Geoscience at NTNU rank among the largest in the world, with 80-90 M.Sc. graduates per year. Close to 2 000 M.Sc. students have graduated since the start of the programs in 1973, and they constitute a significant portion of all the petroleum engineers and geoscientists in the Norwegian oil industry. Today these programs are taught in English, and currently 40 % of all the students are not Norwegian. Students from 40 different countries have been enrolled over the past few years, and many of these go back to senior positions in the industry in their home countries. The current trend for the Norwegian graduates is that they take more and more jobs internationally, working for Norwegian companies as well as international companies.

In addition to the key petroleum programs, many of the other M.Sc. programs at NTNU are significant suppliers of graduates to the oil industry. The oil industry is probably one of the most advanced technologically in the world, and recruits graduates in many disciplines, and significantly in computing, cybernetics, physics and mathematics, and marine technology.

The Ph.D. research programs at NTNU contribute significantly to the petroleum research statistics. Around 100 Ph.D.s have graduated in the Petroleum Engineering and Geoscience area and are employed by the oil industry and in research. At least as many have graduated with Ph.D.s in physics, mathematics, marine technology, computing, cybernetics, and other disciplines, and have found employment as experts in the oil and gas business. Often Ph.D. graduates from NTNU find employment in SINTEF for a period, working together with senior researchers, before seeking employment off the campus. This mechanism for the development of competence and expertise is of vital importance for recruitment of the experts to the industry and the public sector which is crucial for getting the most out of the petroleum reserves on the NCS. NTNU and SINTEF plan to remain the main supplier of competence and expertise to the industry in the future.



5.2 THE NTNU/SINTEF GEMINI PETROLEUM CENTER

In order to strengthen the research collaboration between SINTEF and NTNU, the concept of Gemini centers was created in 2003. The basis for the centers is illustrated in the figure to the left. NTNU and SINTEF collaborate on petroleum research in several areas, in particular in rock-physics, seismics and experimental reservoir projects. An expansion and strengthening of the collaboration between the Department and SINTEF Petroleum Research by establishing a Gemini Center has been decided, and the formal opening of the NTNU/SINTEF Gemini Petroleum Center took place during the BRU Seminar 2005.

5.3 REVIEW OF R&D ACTIVITIES IN PETROLEUM AT NTNU/SINTEF

Introduction

In this section we will highlight some of the research activities going on at NTNU and SINTEF. We have chosen those topics with focus within OG21. We have however also supplemented the OG21 list with a few other closely related topics. For this reason we have invited guest authors within NTNU and SINTEF to contribute.

We must underline that these reviews do not cover all research activities at NTNU/SINTEF within petroleum. On the contrary, this is a short list of examples. They are all very topical for the discussions that the BRU team has had with the industry and good examples of industry focus at the moment.

All the chosen topics are expected to contribute significantly to the overall goal to support the long-term production scenario on the Norwegian Continental Shelf and in export oriented activities.

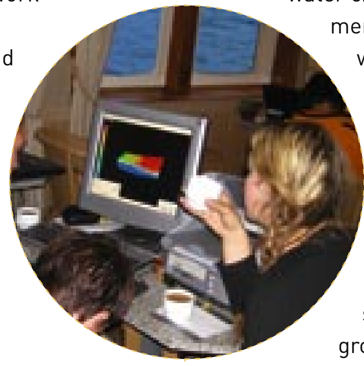
Zero emissions to sea

Halvard Ødegaard, NTNU

The Department of Hydraulic and Environmental Engineering, NTNU is currently working on a project called TOP-Water; Treatment of Produced Water, which has been funded by the Research Council of Norway under the Petromaks program. The project is being done in collaboration with The Ugelstad Laboratory (NTNU, Faculty of Natural Science and Technology), SINTEF Division of Water and Environment and the oil industry represented by several companies. The strategic objective is to develop sustainable solutions for reliable and cost-effective treatment technologies for produced water that comply with a Zero Harmful Discharge policy (OG21). The major goals of the project are;

- Develop standardized protocols for characterization of produced water that can be used for Environmental Impact Factor (EIF) evaluation and selecting treatment solutions.
- Develop methods for enhanced removal of dispersed oil and fines; target 5 ppm oil in treated water.
- Develop methods for the removal of selected dissolved/soluble components in produced water (i.e. BTEX (Benzene, Toluene, Ethyl-Benzene, Xylene), C0-C3 phenols) based on biological treatment.

Two Ph.D. candidates have been appointed by the Department and will complete their doctoral work investigating treatment options for particulate and oil emulsions and the dissolved constituents respectively.



Laboratories: the Department has several laboratories and research facilities. The water chemistry laboratory (200 m²) is well equipped with instruments for physical/chemical/microbial water quality analysis (including gas chromatograph, spectrophotometers, fluorimeters, total organic carbon analyzer, flow injection system, microscopes, and bacterial cultivation). The laboratory is particularly well equipped with regard to particle analysis (including 2 particle analyzers, for low and high particle size ranges) since particle separation is an area of priority in water treatment research. The water and wastewater treatment experimental facilities are divided in three locations: *Research hall – wastewater* - a research hall dedicated to pilot plant studies for wastewater treatment (~100 m² with a height of ~6 m). Wastewater is pumped into the facility from a nearby public sewer pipe and distributed to the respective pilot plants from a holding tank. *Research hall - drinking water:* a research hall for larger clean water pilot plant studies (~ 150 m² with a height of ~ 6 m). *Experimental laboratory:* a laboratory designed for bench-scale and small pilot plant studies where "simple" analytical work can be done (~75 m² with a height of ~5 m). The facility is equipped with a climate control room and a cooling room enabling studies at set temperatures. The room has a laboratory infrastructure including an ozone generator, ovens, furnace and some analytical equipment.

Scientific staff in the Department are divided into three groups; Hydraulic Engineering, Water and Wastewater Engineering, and Solid Waste Engineering. The Water and Wastewater Engineering Group work with planning, design and operation of water supply and wastewater systems, storm water, pipe technology and management, water chemistry and environmental hygiene, drinking water treatment and wastewater treatment. This group has very close cooperation with SINTEF Water and Environment. The research activity is divided in two thematic sub-groups (research groups) – systems and treatment. The group has three full professors, two associate professors, one adjunct professor with tenure. In addition there are post.docs and Ph.D. candidates. Three professors are involved in petroleum-related activities (treatment of produced water).

The water treatment research group is involved in projects targeting the development of new treatment processes as well as optimization of treatment processes for drinking water, industrial process water (for instance in aquaculture), municipal and industrial wastewater and sludge treatment. The strong areas of research are removal of humic substances in drinking water and removal of nutrients in wastewater (phosphate by chemical precipitation and nitrogen by nitrification/denitrification in biofilm processes). In terms of unit processes, the group has strong expertise in all the particle separation processes (coagulation, flocculation, flotation, granular media filtration and membrane filtration). Currently the focused activity is membrane filtration, a unit process that probably will revolutionize the water and wastewater treatment sector during the next decades. On the applied research side, the group has put a lot of emphasis on biofilm processes and has developed "the moving bed biofilm process" that is now commercialized and has become very popular all over the world.

Reduction of emissions to air
Mai-Britt Hägg, NTNU

Reduction of emissions to air is in all aspects a focus point at the Department of Chemical Engineering, NTNU and a main issue in many of the subjects in the education. This is mainly by optimizing the process so that emissions are reduced, or using "tail-end" purification of gases.

The main research activity at the Department today related to reduced emissions to air, is CO_2 capture; either by absorption processes or by using gas separation membranes. Also reduction of volatile organic compounds (VOC) to air is focused on. Both professors Hägg and Svendsen are active contributors to the NTNU/SINTEF Gas Technology Center.

The pilot for absorption of CO_2 in lab.

Within the research group of Professor Hägg, there is considerable activity on the development of membranes for gas separation; membrane which can be used for the purification of gases to atmosphere or for removal of unwanted components within gas process streams. A major activity is on materials suitable for CO_2 removal; tailormade polymeric materials or carbon molecular sieve membranes are developed for this purpose. The group has a large international network.

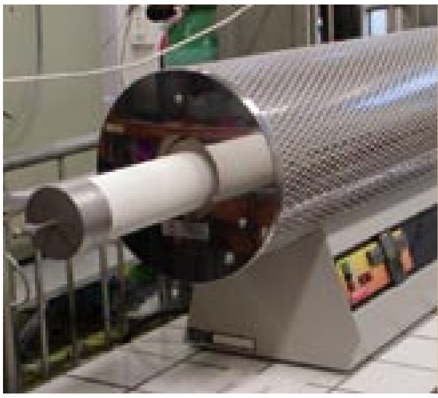
Professor Hallvard Svendsen has a major activity within CO_2 capture using different absorbents, and the focus of research within his group is development of new absorbents, modeling and pilot testing. His group is participating in two large EU-projects on this topic; CASTOR and ULCOS. Within ULCOS (=Ultra-Low-CO_2-in-the-Steel Industry) the effect of CO is also being looked into. Among national projects, the cooperation with Statoil and Aker/Kværner should be mentioned, where a large pilot at Kårstø has been set up. Professor Svendsen has cooperated with Aker-Kværner over many years on the development of membrane contactors for removal of CO_2 both for natural gas and flue gas. At the Gas Technology Center, Professor Svendsen is participating in the large national project BIGCO2 with SINTEF.

Stimulated and improved recovery
Ole Torsæter, NTNU

Concerns about the global future oil supply are leading to a renewed interest in enhanced oil recovery (EOR), defined as injection of something other than plain water or brine into the reservoir. In the literature more than 20 different EOR techniques are mentioned. The EOR-methods that are either most important or are most promising are listed in Figure 5.1. The density of the oil is an important screening parameter in EOR method selection and the optimal density range for the various techniques are indicated.

The three main mechanisms for displacing additional oil with an injected fluid are (1) solvent extraction to achieve miscibility, (2) interfacial tension (IFT) reduction and/or change of wettability and (3) viscosity change of either the oil or water. The number of projects worldwide utilizing these mechanisms is growing. Thermal projects have been successful in the United States, Canada, Indonesia, Venezuela and elsewhere. Chemical and polymer floods are being implemented in China. Microbial improved oil recovery (MIOR) is presently in progress in Norway. All EOR projects require mechanistic research of the recovery process and careful planning to design the project specific to the properties of the oil, the reservoir conditions, and the availability of the injected fluids. A schematic drawing of the IFT related mechanisms is shown in Figure 5.2.

The target average oil and gas recovery rates for Norwegian reservoirs according to Norwegian Petroleum Directorate (NPD) is 50 % oil recovery of initial oil in place and 75 % gas recovery. With a total resource estimate of 8.9 billion Sm^3 oil equivalents (o.e.) and 4.0 billion Sm^3 o.e. produced per January 2005, NPD



Oven for making carbon membranes

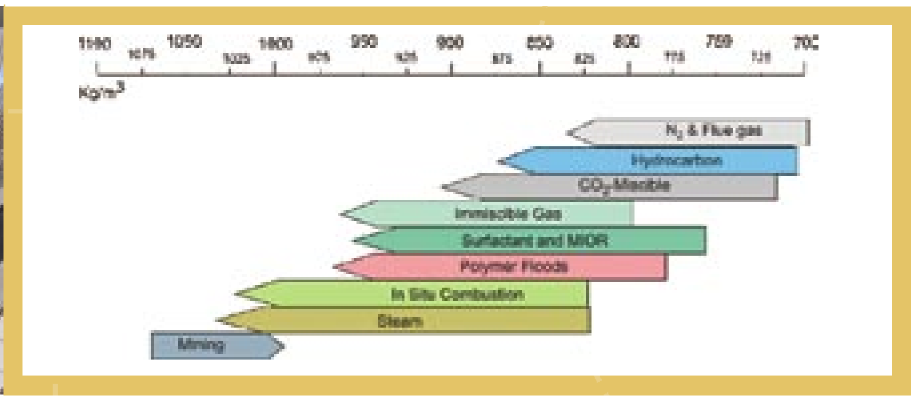


Figure 5.1 Most effective oil density range for various EOR methods.

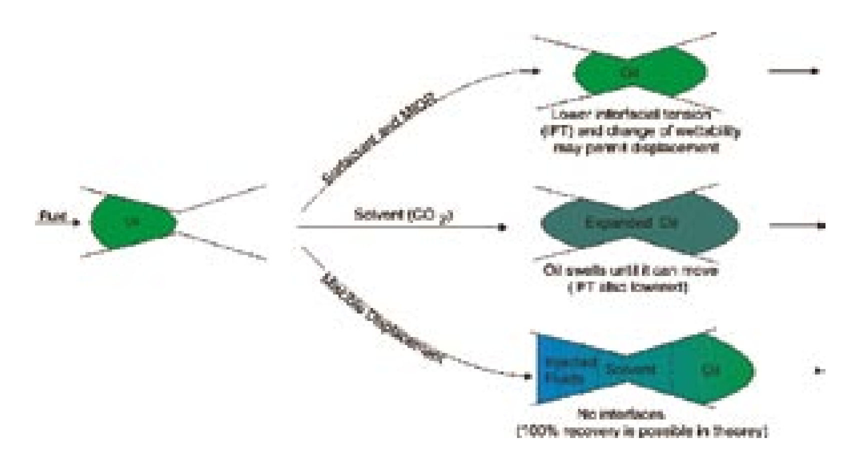


Figure 5.2 Simplified mechanistic view of some EOR methods.

estimates that Norway has an enhanced recovery potential of about 800 million Sm^3 o.e. Figure 5.3 shows the distribution of total resources. With a future oil price of 50 USD/bbl the sale revenues will be in the range of USD 250 billion. These revenues may create the basis for profitable activities within the oil companies and the service industries and thus contribute to a prolonged utilization of the total Norwegian petroleum infrastructure.

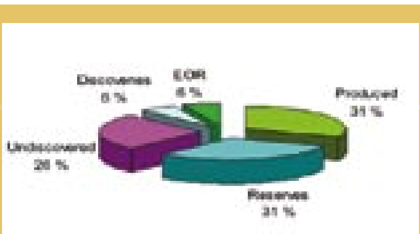


Figure 5.3 Distribution of recoverable reserves (from NPD, January 2005).

Projects:
Some of the major Norwegian oil fields are now close to or in a phase of declining production and effective EOR techniques must be implemented in the coming 5-10 years The EOR potential and the optimal time window are the main reasons for increased capital input in reservoir engineering R&D from the Norwegian government and industry. The Department of Petroleum Engineering and Applied Geophysics, NTNU and SINTEF Petroleum Research are major contributors to this research (Table 5.1).

The following is a brief review of some ongoing projects within improved oil recovery:

Table 5.1 Current IOR projects at NTNU/SINTEF.

Project Title	Client	Duration
EOR by CO_2 injection and deposition in aquifers	NFR*, Industry	2002-2006
Mobility control by foam	NFR*, Industry	2003-2005
MIOR light scattering analysis	Industry	2004-2005
Joint Chalk Research(III): Further reduction of residual oil recovery by CO_2 / CO_2 enriched water	Industry	2005
EOR screening	Industry	2004-2007
Experimental investigation of microbial improved oil recovery (MIOR)	VISTA**	2004-2007
Oil recovery by water and surfactant injection in fractured carbonate rock	Industry	2002-2005

*NFR: Research Council of Norway
**VISTA: The Norwegian Academy of Science and Letters and Statoil

EOR by CO_2 injection and deposition in aquifers: The miscible CO_2 displacement mechanism is considered an ideal process for EOR because it enables the possibility to recover in principle all the recoverable oil in reservoir zones swept by CO_2.

If the injected CO_2 is captured from an industrial source or extracted from export gas and stored permanently in oil reservoir after the field is abandoned, the process will contribute to reduced emission of greenhouse gas. NPD has recently submitted a feasibility study on CO_2 for increased recovery to the Ministry of Petroleum and Energy showing that CO_2-based EOR is a possible emerging option for many of the Norwegian oil fields.

The objective of the present research project is to advance the competence and knowledge on relevant aspects related to CO_2-based enhanced oil recovery and underground storage of CO_2 in aquifers. Descriptions, analyses and modeling of processes and phenomena related to CO_2-based EOR and aquifer deposition of CO_2 will be delivered.

Mobility control by foam: This is a project related to the poor sweep efficiency often encountered in gas injection. Foam can be used to control the flow behavior of gas by retarding and diverting it, and can be applied in injectors or producers.

Inside rock pores, foam consists of liquid films that make the gas phase discontinuous. The unique structure enables foam to selectively reduce gas mobility by orders of magnitude. The objective of the present foam project is to improve the foam modeling by validation and extension of existing foam models and develop design rules for foam systems that can be used to tailor foams that are suited for gas mobility control in oil reservoirs.

Injection of CO_2/CO_2-enriched water in chalk reservoirs: The research on CO_2/ CO_2- enriched water injection is related to the chalk reservoirs in the Ekofisk area. These reservoirs have been evaluated with respect to many EOR processes beyond standard water injection but none of them have been implemented in the fields. In the Ekofisk Field alone 1 % increase in recovery represents about 10 million Sm^3 of oil and the estimated oil recovery factor is in the range of 40-45 % so it is well worth investigating EOR processes. The objective of the present project is to evaluate the technical feasibility of CO_2 injection and to assess the potential for EOR and identify the main uncertainties associated with CO_2 injection into mature water-flooded North Sea chalk reservoirs.

Figure 5.4: Preparation for a surfactant flooding experiment in the reservoir engineering laboratory, NTNU.

Experimental investigation of MIOR: In February 2001 Statoil started a microbial improved oil recovery (MIOR) project on the Norne Field. Sodium phosphate and sodium nitrate are added to water containing oxygen to stimulate growth of aerobic oil degrading bacteria. These bacteria need both a carbon source and nutrients from the water phase. To access the carbon source, it is likely to assume that the bacteria will reduce the interfacial tension to break the interface, and this small change in surface properties could lead to changed wettability. However, it is very difficult to test the results of such a project on a field scale, especially in the case of MIOR where the claimed effects are not understood or experimentally documented even on laboratory scale. The deliverables from the present project will be a considerable amount of data from carefully performed microbial flooding experiments. Based on data analysis, interpretation and numerical simulation improved understanding of the mechanisms involved in the MIOR process should be obtained.

Oil recovery by water and surfactant injection in fractured carbonate rocks: For the giant fractured carbonate reservoirs in the Middle East the potential for increased oil recovery is considered to be high. The reservoirs in the Asmari limestone in Iran in particular are now studied with the objective of evaluating possible EOR methods. The goal of the present project is to evaluate both brine injection and surfactant solution injection in fractured carbonate rocks of the Asmari limestone type. The experiments are run on long cores representative of matrix block dimensions and an important subtask is to evaluate the initial wettability and possible wettability alteration during surfactant solution injection (Figure 5.4). The project deliverables are oil recovery data from the various processes studied and models for flow mechanisms in fractured carbonate reservoirs undergoing water injection and surfactant solution injection. This will give an improved data basis for evaluation of water-based recovery processes in specific fractured carbonate reservoirs.

Future perspective
The EOR project portfolio at SINTEF and NTNU is presently growing due to the increased interest of these processes in the North Sea and increased research activity and applications worldwide. The integration of disciplines in this type of research is important and this can easily be realized at NTNU/SINTEF. So in the near future we expect that improved seismic methods, more advanced well technology and more efficient simulation methods together with the results from the EOR research will improve the process efficiency and cost-effectiveness of EOR methods.

Cost-effective drilling in exploration and production
Sigbjørn Sangesland and Michael Golan, NTNU

Introduction
Limited changes in drilling have taken place over the last two decades. Conventional drilling technology has been extended for drilling and completion of 10 000 m long-reach high angle wells. A step change came when rotary steering systems were made available. This significantly improved the steering ability of the drill string and increased the drilling reach. Mechanization and automation of pipe handling and drilling instrumentation including new downhole tools have also been introduced. But the way we drill and complete the well is the still the same. Ongoing activities will be highlighted here.

Trends in Drilling Technology and New Drilling Methods
In the 1980s, subsea wells were drilled in 100 - 350 m of water using 2nd and 3rd generation drilling rigs. When moving into deeper waters, drilling rigs were simply beefed up, and today, the large and costly 5th generation rigs are used to drill in 2500 – 3000 m of water. The trend is illustrated in Figure 5.5. To allow a low cost rig to operate in deep water, the handling weight and storage capacity must be reduced. The main elements are the standard 21" marine drilling riser and the 18 ¾" Blow Out Preventer (BOP). Drilling and well completion technology based on a slimmer drilling riser, i.e., 12 ½" in diameter and a 11" BOP, would allow a riser mud volume reduction of 60 %, and significant reduction in handling weight. New methods in drilling and completion have enabled such an approach; Application of Expandable Tubular (liner and casing) allows one diameter to be used from top to bottom. Managed pressure drilling (MPD) is a method which allows the borehole to be completed using less casing strings, and thus allows for a slimmer riser. The rig cost is approximately 50 % of the total well cost for an exploration well. So, a reduction in the well cost will be very much affected by the efficiency of the drilling method selected. Some of the above-mentioned drilling methods may be more time-consuming than others.

In-fill drilling (adding more wells to existing field) in mature oil flooded reservoirs is difficult, risky and often impossible due to the complex pressure regime in the various reservoir and cap-rock layers. A typical example of such complexity is the Gullfaks Field where alternating depleted and highly pressurized layers make it impossible to be drill conventionally. In certain cases, layers that need to be penetrated in one wellbore or even in one drilling section have pressure alternating between 1.0 and 1.8 equivalent circulation densities (ECD). Underbalance drilling technology (UBD) and managed pressure drilling (MPD) introduced last year in Norway for such fields proved to be very successful operationally, yet, very expensive due to a range of technical issues that need to be resolved and novel measures that need to be developed. Most of these issues are related to the special nature of UBD/MPD in Norway which is conducted on integrated offshore platforms simultaneously with production and other well operations, and with platforms that have very little tolerance of the new space demanded by UBD/PMD surface facilities.

Encouraged by Statoil, the Department has initiated an R&D program that should lead to cheaper and easier UBD/PMD implementation on integrated platforms (drilling-production) in Norway. The primary objective in the investigation is to develop a more compact and efficient 4-phase separator to separate the gas, reservoir fluids, drilling mud and the solid cuttings from the reservoir that might be evacuated from the wellbore in considerable quantities during UBD. The Department has initiated an R&D program for compact 4-phase separation (gas, reservoir fluid, clean drilling mud, and drilling solids). Compact 4-phase separation is a new technology that requires a synthesis of new fundamental research with the large body of know-how that exists on liquid gas, liquid solids and gas-solids separation.

It is expected that the research results should yield a much more compact surface process facilities for the UBD such that it could be easily accommodated in the space currently available on platform decks for conventional drilling operations. This will open a new window of opportunities for in-fill drilling.

MPD applied on floating vessels seems to have a large potential. On a longer term, underbalanced drilling (UBD) may be introduced. It has been shown that UBD reduces formation damage and improves productivity and recovery, and increases drilling speed. In principle, it is not more risky to drill underbalanced with known pressure compared to drill overbalanced with unknown pressure. The method is particularly interesting in reservoirs with low permeability, short production interval and in cases where the reservoir is sensitive to drilling fluids.

High angle, 10 000 m long reach wells have been drilled and completed. Improvements in drillstring materials, online communication for better control of downhole conditions may allow 12 000-15 000 m long wells to be drilled. ElectroPulsDrilling (EPB), is a new method which has an anticipated large potential. It has been documented that a drilling volume of 50 -100 cm^3 / pulse is generated. For example, a frequency of 20 Hz and a hole diameter of 30 cm corresponds to a drilling rate (in granite) of 50-100 m/hr which is more than 10 times the existing drilling rate. The EPB method produces a larger diameter than the drill bit and makes it possible to line the well as the drilling progresses.

Operational problems cause downtime during drilling and reduce the efficiency. Such problems are related to items like wellbore stability, pressure control, drilling fluid and cement slurry hydraulics, and drilling equipment. Operational problems can be predicted, planned for or solved if the problem is properly understood and its root cause is known. Continuous research is necessary to reach the ultimate goal; zero downtime. One promising approach is called Experience Transfer During Drilling, through which new knowledge is accumulated and integrated with existing knowledge in all the above-mentioned areas.

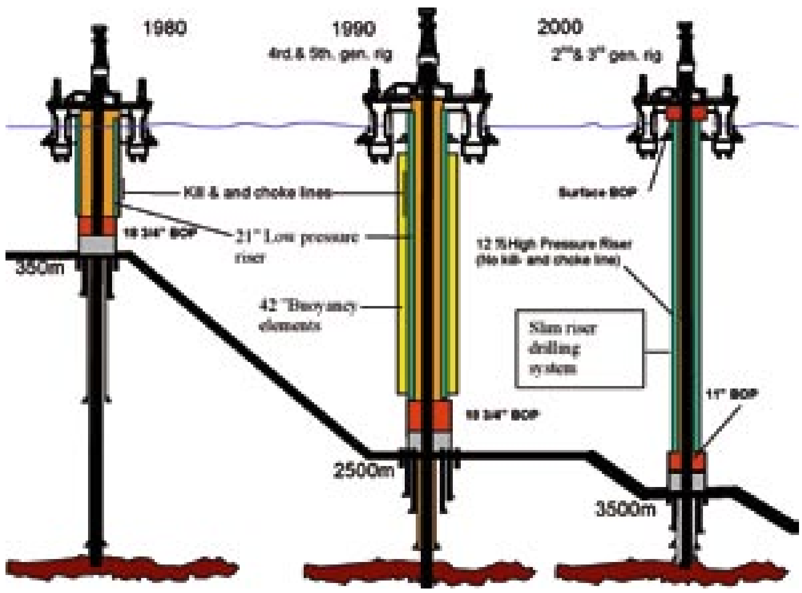


Figure 5.5 Trends in deepwater drilling technology

eField and integrated operations
Egil Tjåland, NTNU

According to the Norwegian White Paper no. 38 (2002): "eField or Integrated Operations include the use of information technology to change work processes to achieve better decisions, remotely control equipment and processes, and move functions and personnel onshore".

E-operations are often characterized by operational concepts where new information and communication technologies are used in real time to optimize offshore oil and gas exploration and production. This means that large amounts of data can be measured, sent to users by high bandwidth computer links, shared between users and processed so that the data can be used to form decisions. To employ this new technology there is a need to reorganize operations, look to new types of work processes and demand the willingness to share information. To achieve this there is a need for research, education and technological development.

According to a study by Cambridge Energy Research Associates in 2003, increased use of new and emerging digital technologies could potentially boost world oil reserves by 125 million barrels over the next five to ten years. Petoro AS has estimated the added value on the Norwegian Continental Shelf by employing the eField and IO extensively to be NOK150 billion.

Five key digital technologies will substantially improve the oil industry's ability to see reserves more clearly, plan optimal drilling and production strategies, and manage operations more efficiently. NTNU and SINTEF have ongoing activities within all these areas:

Remote Sensing
Significant remote sensing tools include time-lapse seismic, gravity surveying, electromagnetic monitoring, permanent surface geophone grids and fiber optic downhole geophones. Time-lapse seismic alone—which enables E&P companies to identify bypassed oil, map flow paths and barriers, and monitor sweep efficiency—could increase incremental recovery by as much as 3 to 7 percent.

Visualization
Three-dimensional and/or large-format rendering of complex E&P data sets helps field development planning teams optimize well placement and well paths, identify bypassed reserves, minimizes time-to-depth errors, accelerates recovery rates and reduces costs.

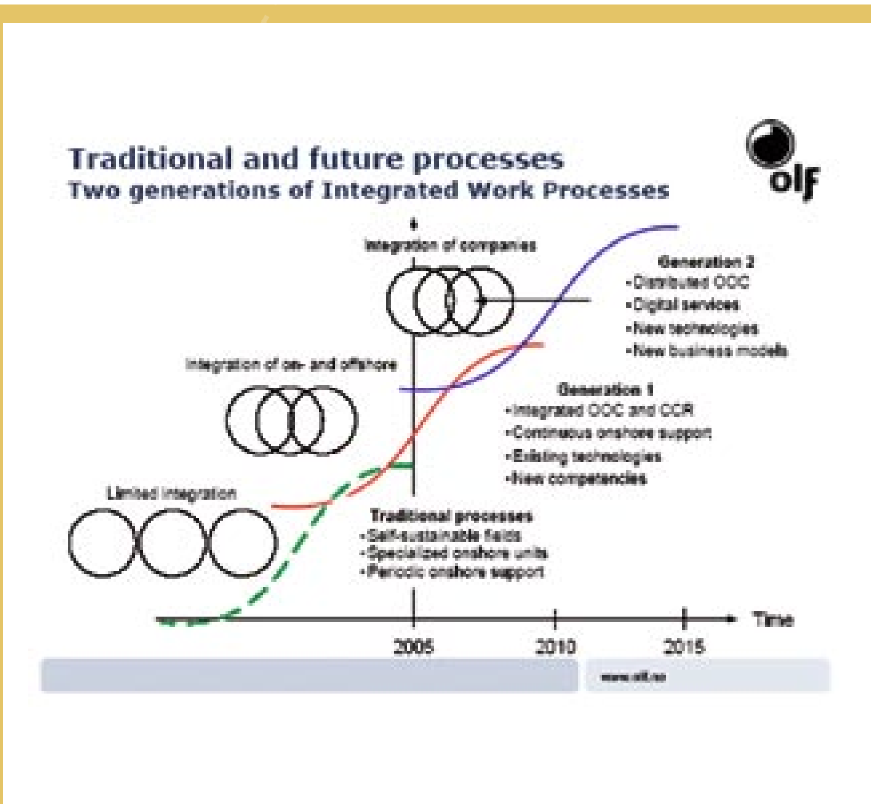
Intelligent Drilling and Completions
Real-time subsurface data acquired during drilling operations helps engineers avoid drilling problems and maximize reservoir penetration through better geosteering of the well path. Downhole temperature, pressure, multiphase flow sensors and other valves installed during completion help operators optimize well productivity, identify early water breakthrough zones and injection inefficiencies, and control flow.

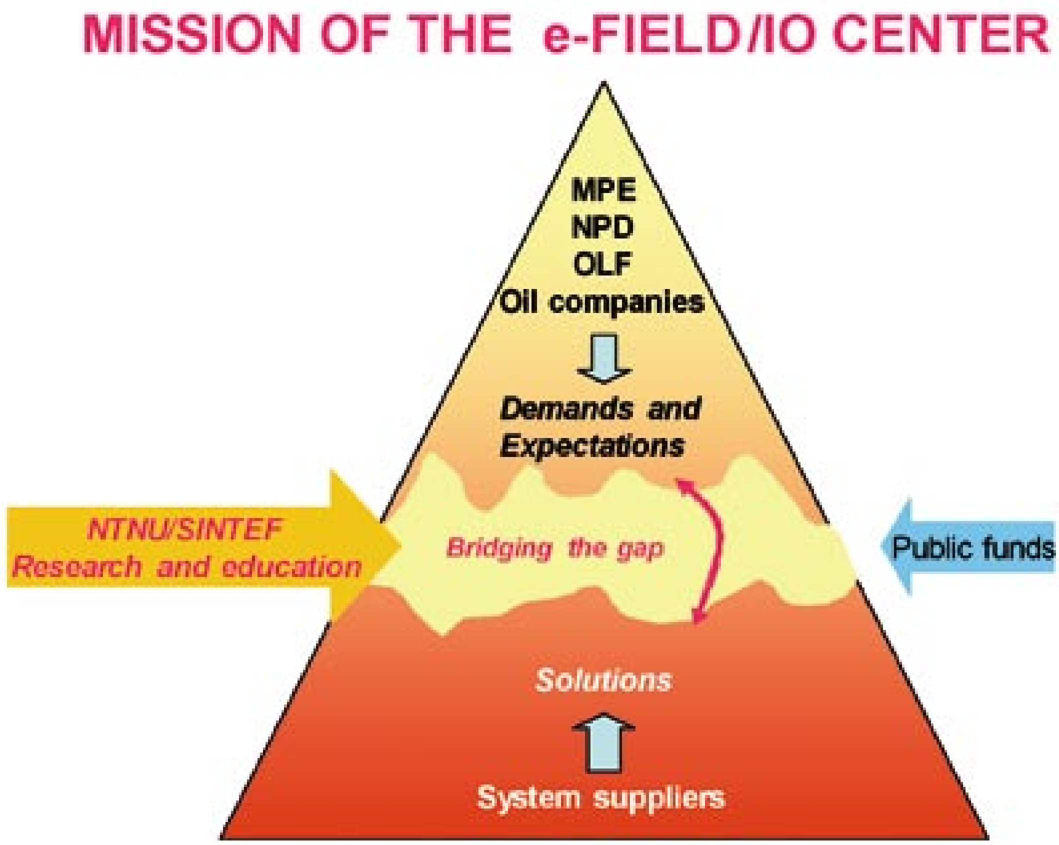
Automation
Remote monitoring and control technologies – many already in use – enable automated data gathering, automatic alarming and reduced numbers of field operations personnel. Prediction and production optimization technologies enhance performance and help prevent catastrophic failures. Autonomous operation systems allow field EOR programs and production platforms to operate like a single piece of equipment.

Data Integration
Integrating the collection and management of data about reservoirs, downhole conditions and systems will enable E&P organizations to get the information to the right people at the right time. This will yield better situation analyses and operating strategies, employing best practices to achieve more efficient, cost-effective decisions.

A number of Norwegian companies have started to develop eField solutions, particularly for drilling operations, and it seems likely that most oil- and service companies operating in Norway will employ such solutions in the future.

In a recent study (2005), the Norwegian Oil Industry Association, OLF, has predicted the future for Integrated Work Processes as shown in the figure below.





The future generations of work processes (in 5-10 years) involve development of new business models, digital services and new technologies. According to OLF this will lead to:

- 20-30 percent reduction of cost
- 5-10 percent increase of production (acceleration of production)
- 4-8 percent increased recovery
- Cost-efficient tie-in of satellite fields
- Improved safety and regularity.

From the point of view of NTNU and SINTEF we think there is a gap between the expectations from the oil companies and the technical solutions coming from the supplier industry to implement eField and integrated operations.

Together with the Norwegian oil and gas industry, NTNU and SINTEF have world class expertise to develop and employ eField and integrated operations of the future. The unique knowledge chain from NTNU and SINTEF and Norwegian industry can be used to create innovation and thus help to close the gap between the "users" and the "suppliers".

NTNU and SINTEF have a vision to develop a world class center for R&D, innovation, education and competence development related to eField and integrated operations in the petroleum sector.

Research and development on eField and Integrated Operations (EIO) by NTNU and SINTEF have been organized as a BRU Program 3 (see Section 4.4).

Deepwater platform and subsea technology

Sigbjørn Sangesland, NTNU

Introduction

In the past, offshore field developments were mainly based on using platform wells (< 250 m water depth). Due to improved performance and reduced costs, subsea well completions are more frequently used and also considered in water depths as low as 70 m. The costs have been reduced, mainly due to the experience gained, increased degree of standardization and simplification, and increased control and monitoring capabilities. Historically, the reservoir recovery rate using subsea wells is typically 10 -15 % lower compared to platform completed wells. This is mainly because of fewer drainage points due to costly drilling, and less frequent well interventions due to limited access and the high costs of the intervention vessels. Exploration wells have been drilled in 3000 m of waters and subsea wells are now producing in water depths of 2000 m. In the future, subsea wells may be used in water depths in the order of 4000 m. The following highlights ongoing activities and areas for further focus.

Trends in subsea technology and improvement of subsea technology

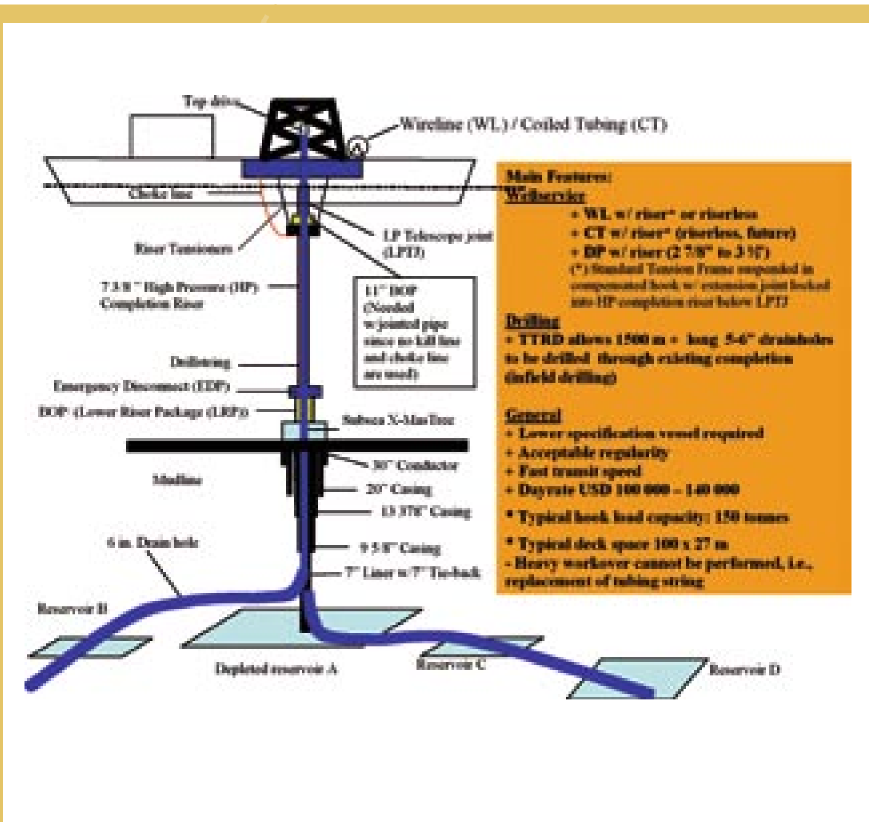
Riserless subsea well intervention using Wireline (WL) is in progress. Improvements are better wireline cable design, i.e., composite cable, increased depth by using other types of control systems, and deployment and surface systems which allow increased operability. Also progress is made in concepts based on Riserless Coiled Tubing (CT) deployed from a surface vessel, and subsea CT deployed from the seabed.

Through Tubing Rotary Drilling has been successfully used on fixed platforms for intervention and drainhole drilling, but no commercial system exists for floating units. Jointed pipes can be rotated, and it is also stronger than CT. A rotating drill string with higher circulation capacity allows well service operations such as sand washing, scale removal to be performed more effectively. Drilling and completion of drain holes /side tracks in depleted and new reservoirs add more drainage points contributing to Improved Oil Recovery (IOR).

Online communication (i.e., electric drillstring) will allow more effective operations to be performed. Action can be taken before serious downhole problems occur. Seismic while drilling will allow the well bore to be drilled optimally for maximizing recovery. This will make a significant contribution to IOR. The figure below illustrates a set-up based on using a 7 3/8" completion riser suited for drainhole drilling. Adding an extension joint from the top of the riser to the conventional heave compensated tension frame in the derrick also allows WL and CT operations using the same arrangement.

Slim riser / slim wellhead will come as a result of progress in drilling and will reduce costs in the well completion including the tubing hanger. Improved or new design of suspension systems for the tubing string allowing more penetrations for downhole control and monitoring are required. Long step-out or operating in environmental sensitive area may force all-electric subsea control systems to be introduced. Also high power electrical systems will be required to run subsea pumps and compressors. Issues for improvements in subsea and downhole separation and pumping systems include: High voltage connectors design, effective sand control, more effective separation methods, and effective methods for replacement of downhole pumps.

Platforms will still be used in field developments, particularly in shallow waters and in fields where many wells are needed. Bottom supported steel platforms, which can easily be removed and re-used may be attractive candidates for such applications. Also moored floating units with dry Xmas trees will be applied for deep waters, i.e., Tension Leg Platforms and Spar Platforms. However, the trend today is that subsea completions will be used more and more in offshore field developments, and solutions based on "Sea to beach" will be seen more frequently (Ref. Ormen Lange and Snøhvit fields).



Set-up for Effective Well Intervention and Drain Hole Drilling using Through Tubing Rotary Drilling (TTRD)

Transportation of multiphase flow over long distances

Ole Jørgen Nydal, NTNU

Background

Norwegian research institutes (SINTEF and IFE) have contributed significantly to the increased confidence in multiphase transportation of oil-water-gas mixtures in pipes. This is largely a result of a pipeline design tool, which was developed at IFE, based on extensive experimental work at the large scale SINTEF Multiphase Flow Laboratory.

With the construction of a new multiphase flow laboratory, NTNU now participates stronger in multiphase pipeline research, with focus on fundamental aspects multiphase flows.

About 15 researchers (Ph.D.s, Post. Docs, visitors) and 40 project students (M.Sc., visitors) have taken part in the multiphase flow group during the last three years.

Laboratory

Multiphase flows of oil, water and air can be studied in two inclinable test sections (16 m long, 7 m high, 30, 50 and 60 mm I.D.). The pressure and liquid fractions (impedance probes) can be measured along the pipes.

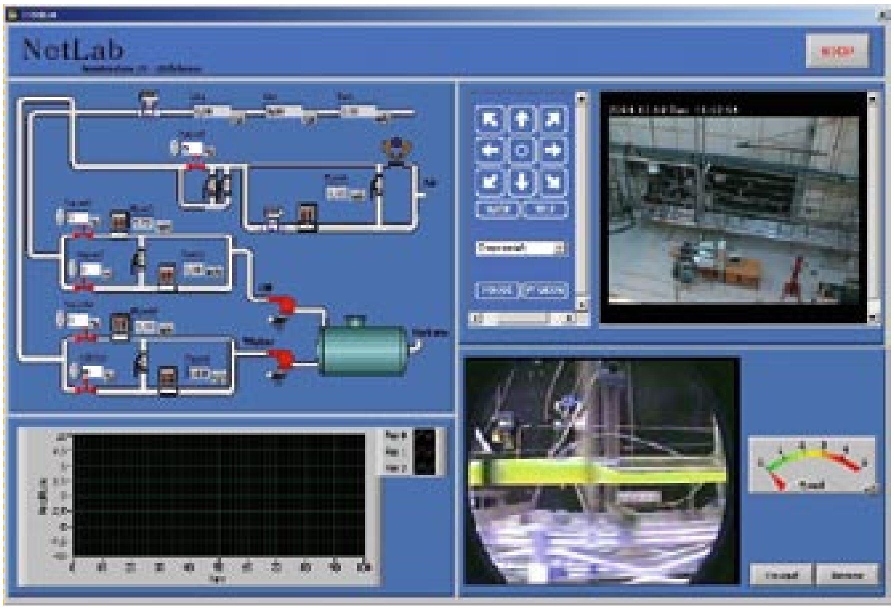


Figure 5.7 NetLab: remote operation from a web site

The loop can be remotely operated from a web site (NetLab).

A small scale, portable mini-loop has also been constructed, mainly for demonstration purposes (lecturing).

The multiphase flow laboratory at NTNU is registered as an "EU Marie Curie Training Site", enabling EU support for visiting researchers/Ph.Ds.

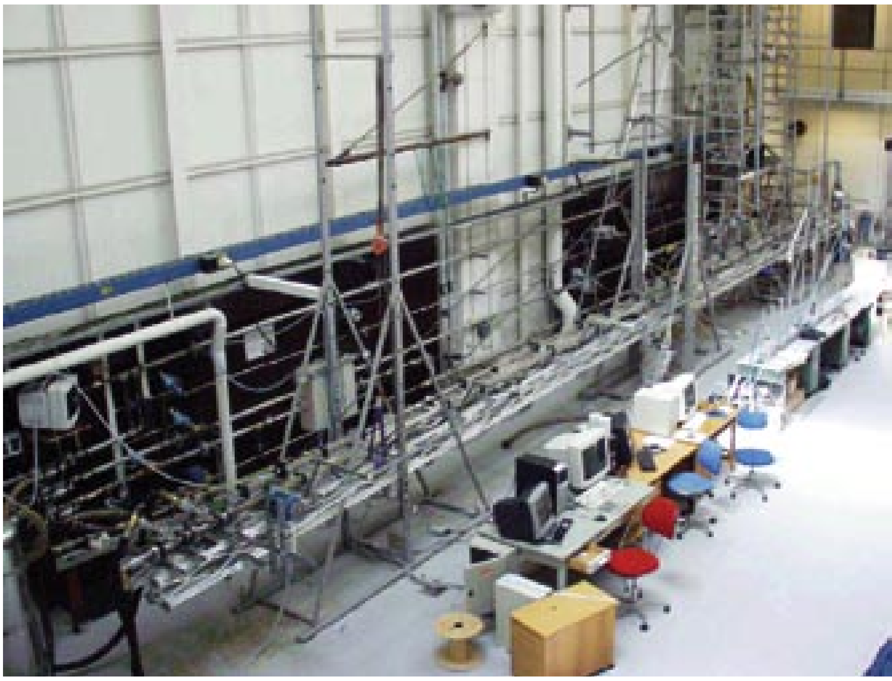


Figure 5.6 Multiphase flow laboratory

Experiments

Experimental work is made in order to explore multiphase flows in pipes, and to generate data as a basis for flow modeling. We have largely focused on transient flow phenomena, where atmospheric flow loops can also be useful.

The following is a list of some experimental activities at the laboratory:

- Unstable multiphase flow in S-shaped risers. Gas bypass for stabilization
- Pigging at start-up and flowing conditions. Plug release experiments
- Slug flow and stratified-slug transitional studies
- Three phase flow at low liquid loading
- Unstable oil-water flow in undulating pipes
- Unstable flow in gas lift wells and long risers
- Transient stop-start experiments in V-shaped geometry

Figure 5.8 Oil-water-gas flow

Flow modeling

On the modeling side we have focused on 1D transient flow, including model formulation, numerical methods and implementation aspects. A slug tracking scheme has been tested in an object oriented implementation. The use of two

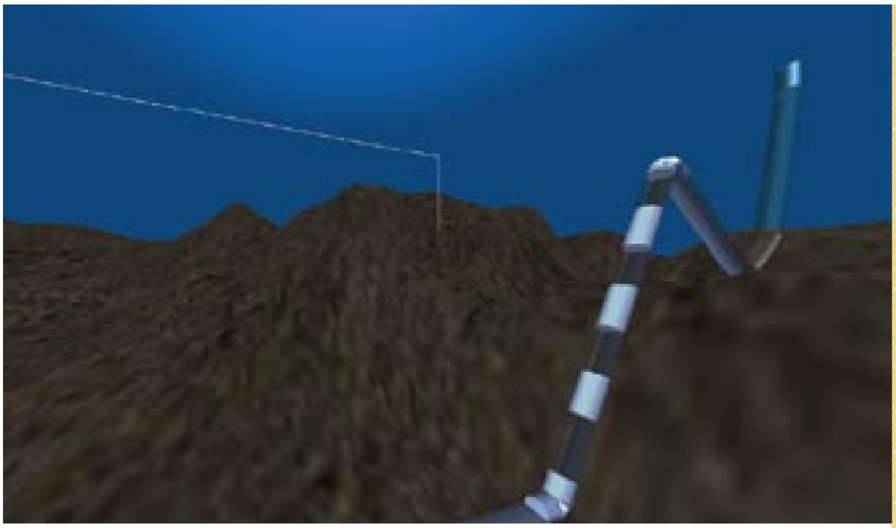


Figure 5.9 3D visualization of slug tracking simulations

fluid model for capturing all transients down to the scale of slugs and waves is being investigated.

Some particular activities have been:
- Comparison between available design tools and experimental data
- Development of slug tracking model
- Slug capturing with general two fluid model
- Transient incompressible models and numerics
- Matlab-based models (slug flow, stratified flow, flow regime transitions)
- Pigging/Hydrate plug modeling in slug tracking scheme

Figure 5.10 gives examples of a comparison between slug tracking simulations and experimental data on unstable flow in S-shaped risers.

Ph.D. program on Multiphase Transport
A group of Ph.D. candidates are working on challenges related to multiphase transport, both numerically and experimentally, where the high quality laboratories at SINTEF and IFE are also made available.

The participating companies in the program contribute with the amount equivalent to the financing of one Ph.D. candidate. Participants can then introduce candidates to the problem areas of particular interest for each company. All the other activities in the NTNU group are also reported to the program.

Acknowlegements
The work in the last three-year period has been financed by the following parties:

Project	Participant
Multiphase Transport	NFR, Statoil, Total, Shell
Visiting Ph.D. candidates	Statoil, Total, SINTEF, EU
Slug tracking methodology	Statoil, Total, Hydro
NetLab	NTNU and Gas Technology Center
Post Doc	EU (Marie Curie Fellowship)
Petronics	NFR (Norsk Hydro, ABB)
CSN fellow	Total
PLR program	NFR, Statoil, TotalFinaElf, BP, Gaz de France, Enagas
Adjunct professor, gas hydrates	Total
Adjunct professor, multiphase flow	Statoil

Some examples of projects at NTNU/SINTEF, which aim at improving transportation technology for oil and gas, are given below.

Petronics (Ref. Professor Bjarne Foss)
A group of Ph.D. candidates working on control systems for multiphase transport was assembled from three different departments: Petroleum (Professor M.Golan), Chemical Process (Professor

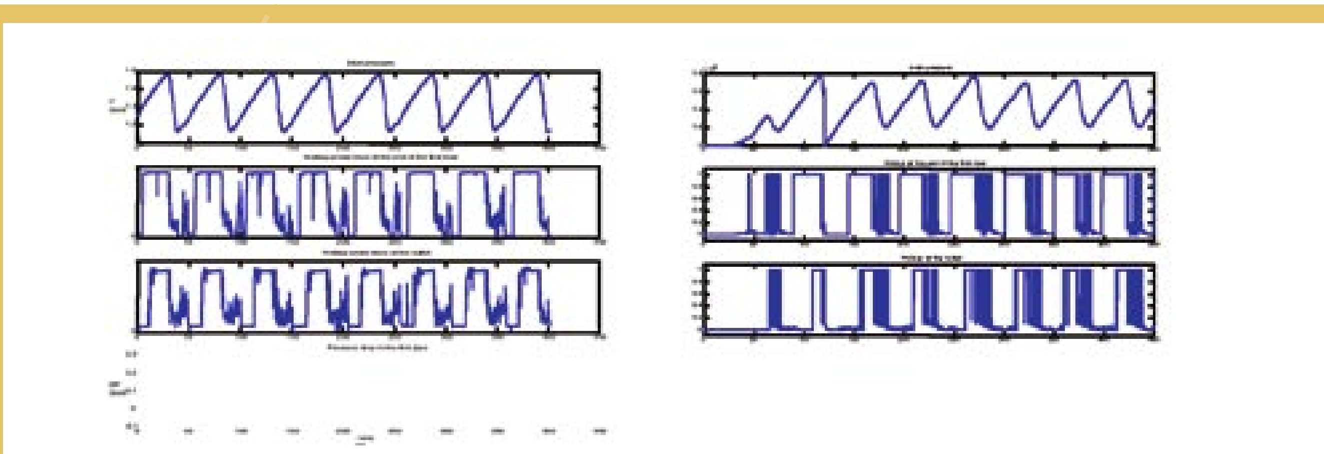
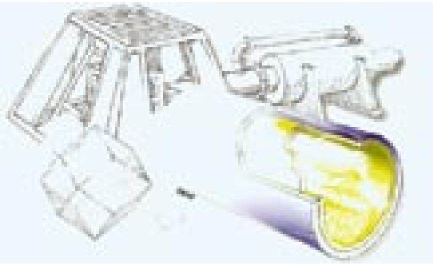


Figure 5.10 Unstable flow in S-shaped riser. Left: measured inlet pressure and holdup at two positions. Right: Computations

S. Skogestad), Cybernetics (Professor B. Foss), Flow (Professor T. Ytrehus, Professor O. J. Nydal). ABB (project coordinator) and Hydro participated in this project which was financed by the Research Council.

Flow simulators (Ref. Kjell Arne Jacobsen, SINTEF)
A new flow simulator is being developed at SINTEF in a major industry project (LEDA). The tasks include experiments at the large-scale SINTEF Multiphase Flow Laboratory, development of flow models (both 1D and 3D) and programming a computer code.



Cold Flow (Ref. Professor Roar Larsen)
SINTEF has established a large industrial project on testing a "Cold Flow" method, in which water is converted to gas hydrates with non-plugging properties. The pipeline can then be operated inside the hydrate region, with a flowing mixture of gas, oil/condensate and gas hydrates. The work is undertaken at SINTEF Multiphase Flow Laboratory.

Gas hydrates for transport (Ref. Professor Jon Steinar Gudmundsson)
An alternative gas transportation method has been explored in the Natural Gas Hydrate Laboratory at NTNU. Gas hydrates has been formed such that they are stable at ambient conditions, allowing bulk transportation by tankers.

Multiphase pumping and compression (ref. Professor Lars Erik Bakken)
Pumps, compressors and associated components have been tested for flowing gas-liquid mixtures in the laboratories at NTNU and at the Statoil Research Centre.

This research activity on transportation technology is to fully utilize our high quality laboratories and research groups in work to find safe, reliable and cost-efficient transport solutions for the Arctic environment.

Sea bottom and downhole processing
Michael Golan, NTNU

Downhole or seabed separation of oil and water has a considerable impact on prolonging the production life of offshore oilfields. The impact has many aspects; most of them are well understood and widely documented in the petroleum literature. The wide implementation of downhole or seabed separation has been inhibited by the need to introduce pumping/boosting to one or two of the separated streams. This considerably increases the complexity of the separation system and the development and operational costs.

An alternative and novel approach for downhole oil-water separation utilizes the energy of the production stream to drive the separation and its product. This has been launched and is currently tested through the DGRASS project which is part of the NFR DEMO 2000 program. The project is managed by Vetco with Statoil and Shell as co sponsors and collaborators, and the Department is a research partner. The concept is applicable primarily to mature fields, with strong water injection where production decline and well abandonment are related to water flooding of the payzones and not to pressure decline. Studies conducted by NTNU concluded that with proper selection several years of production can be added to wells that are candidates for abandonment.

The Department has been assigned with the task of performing a full scale water-oil separation research program to validate the concept and establish the bases for modeling and design of such separators. The program supported the development of an in-line separation laboratory at the Department, primarily to test the DEGRASS concept, but with the flexibility to test and research variety of in-line separation concepts with and without energy added. Phase one of the program consolidated the know-how on in-line O/W separation, its modeling and testing, and developed trained personnel in relevant R&D disciplines. It also resulted in a body of novel ideas about how to improve in-line separation, how to determine its performance and how to select candidates for the best results. Based on these activities, we are in the process of establishing a new R&D program for *in-line separation,* primarily installed on the seabed or near the wellhead. We are also searching for partners and sponsors to kickoff and realize the program

This laboratory is open for visitors subject to advance coordination. The test lab is illustrated in Figure 5.11. The technologies involved in the DGRASS phase one project are illustrated in Figure 5.12.

Figure 5.11 In-line separation laboratory at the Department

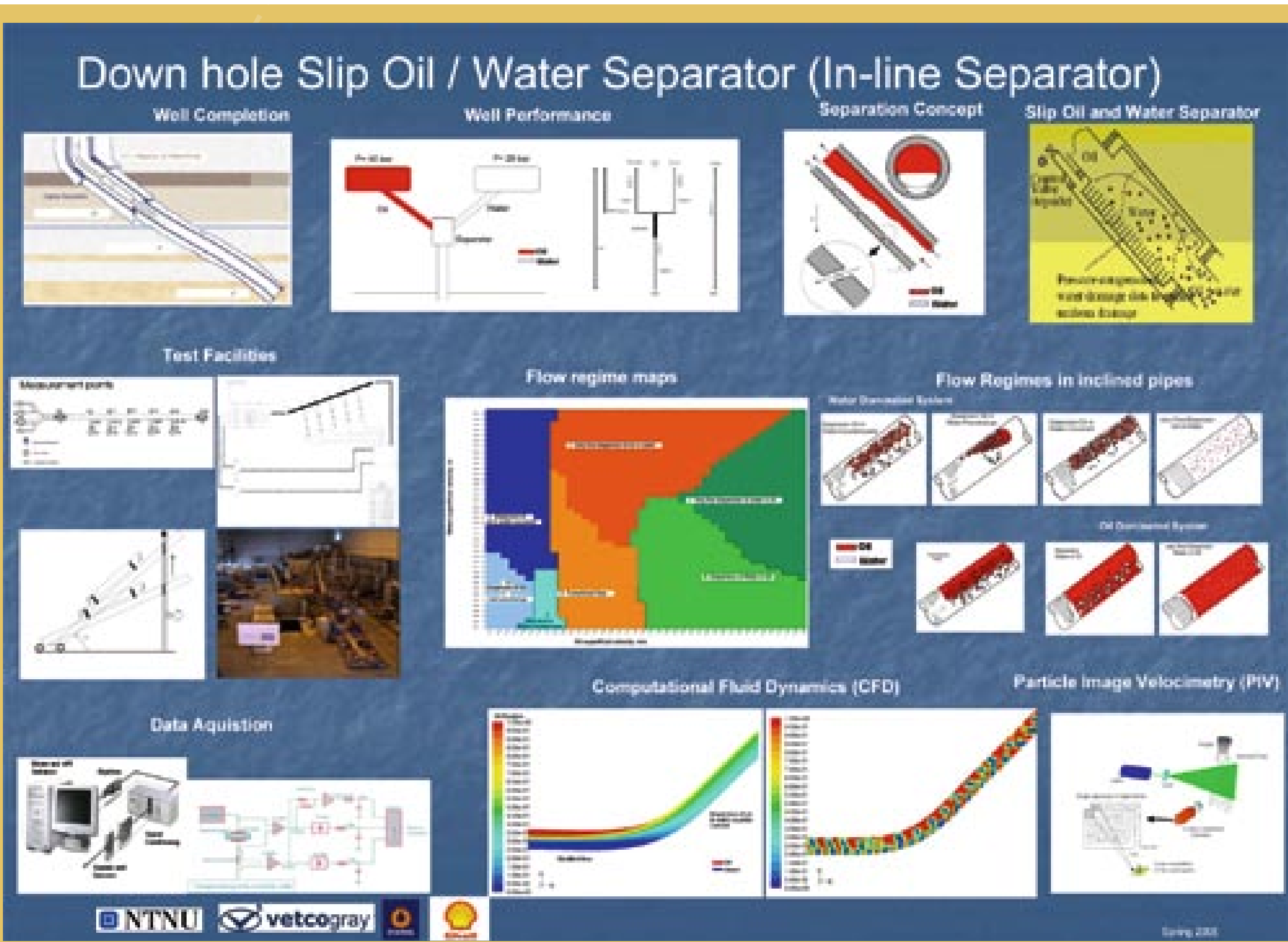


Figure 5.12 DEGRASS phase one acitivities

Competitve gas

Jon Steinar Gudmundson, NTNU

Norway exports about 75 billion cubic meters of natural gas annually by pipeline. This volume represents two-thirds of the natural gas produced offshore Norway, the rest is injected to maintain reservoir pressure and eliminate flaring. Less than 1 billion cubic meters of natural gas is actually used in Norway today. While the production of oil offshore Norway is on the decline, the production of natural gas is on the increase. And the increased production stems from resources further and further north, currently from the Norwegian Sea and soon the Barents Sea. The increased distances make it necessary to use non-pipeline technologies to transport new natural gas to markets in Europe and the USA. This means that different technologies are suitable for various annual transport volumes and distances.

The term gas chain is often used to describe the flow of natural gas from the reservoir to utilization (from pore to burner). The natural gas can be associated gas or non-associated gas, meaning produced primarily together with oil or produced primarily alone. Multiphase flow occurs in both situations with widely different gas/oil ratios, from oil-dominated to gas-dominated, respectively. Natural gas engineering concerns classical petroleum engineering (drilling, reservoir, production and logging) with extra emphasis on field processing and transport from field to market. It basically concerns the whole gas chain except the actual utilization, which can be power generation, domestic and commercial heating, transport fuel and industrial processes.

A distinction needs to be made between production distances and transport distances. Production distance is the distance from offshore wells to platform facilities and/or receiving terminal on land. Flow assurance is the main concern in production distance pipelines while flow capacity (pressure drop) is the main concern in transport distance pipelines. The presence of water in oil-dominated and gas-dominated (natural gas with condensate) production pipelines is the major problem. Water is not a problem in transport pipelines because natural gas is dewatered in offshore and/or land-based processing facilities. Water management is the key to successful production of oil and gas, including environmental caretaking.

The appetite for natural gas world-wide is insatiable and closely tied to efforts to reduce greenhouse gas emissions. The main driver for increased use of natural gas world-wide, though, is the growth in energy use in the emerging market economies in Asia. The natural gas route is the only viable way to bring such emissions under control. A multitude of activities is needed spatially and temporally, meaning national, continental and international levels now and in the near and distant future. Nationally, Norway needs to reduce its NOx emissions by replacing diesel fuel by natural gas in ships and ferries. In general, Norway needs to encourage the use of natural gas in the transportation sector. Norway must continue to deliver large volumes of natural gas to markets in Europe that are dependent on oil and coal-fired power generation. Internationally, Norway can contribute R&D results for CO_2 capture and storage in underground formations, from natural gas and coal-fired facilities.

Integrated processes between seismic, drilling and reservoir
Martin Landrø, NTNU

The cooperation between the three disciplines seismic, drilling and reservoir technology has increased significantly during the last two decades. There are several causes for this increased level of cross-disciplinary activity. First of all, there has been a management driven process aiming at closer cooperation. Second, there has been a gradual technological improvement within all the three disciplines. The growth and success of time lapse seismic and the rapid development in more advanced drilling technologies are two such examples. Although these activities have to increased hydrocarbon recovery rates, there are several key topics that should be addressed in future research and development. In my view there are three topics that I consider are crucial in future research:

- tight and efficient coupling between 4D seismic and reservoir simulation
- seismic while drilling and pore pressure prediction methods
- integrated reservoir model building including uncertainty assessments

All these topics require a joint research effort between academia, contractors and the oil companies. One attempt to improve the link between 4D seismic and reservoir simulation is shown in Figures 5.13 and 5.14, where a nonlinear inversion technique has been developed to estimate pressure and saturation changes within each grid cell in a 2D simulation model. 4D seismic differences are obtained based on reservoir flow simulation followed by seismic simulation, and the inversion parameters are saturation and pressure values within each reservoir cell. The next step in this project is to combine 4D seismic data with production data, and invert directly for reservoir parameters like permeability and porosity. Seismic while drilling has so far mainly focused on looking ahead of the drillbit, and especially the prediction of anomalous pressures. In my view, this technique is limited by two factors: technology for obtaining a good seismic signal (especially at typical reservoir depths), and improved understanding of rock physics. Presently, our knowledge is limited about how various rocks respond to stress changes, for instance. This is especially true for shales

The most important and demanding task is maybe to improve our ability to rapidly change our reservoir model, based on all relevant data that are gathered for a given field. Upscaling and downscaling issues related to well logs as well as the simulation grid, seismic interpretation and production data will be combined in more advanced ways for future fields. In order to identify real bottlenecks in this process, I think that uncertainty assessment will be a crucial part. If we are able to assess uncertainty in seismic interpretation, well logs, permeability values, well paths, fault properties, saturation and pressure values and so on, more realistic reservoir models will emerge. Future reservoir management will rely on multiple possible reservoir models as well as multipath well trajectories.

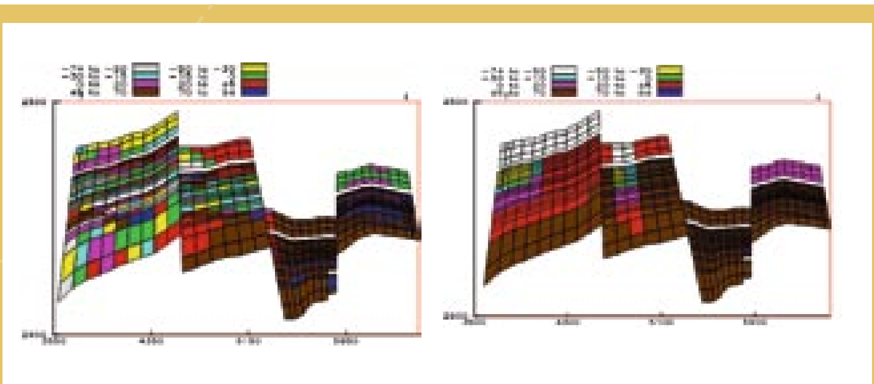


Figure 5.13: Estimated (left) and real (right) pore pressure changes for a synthetic example based on a North Sea field reservoir model (from Mohsen Dadahspor's Ph.D. work).

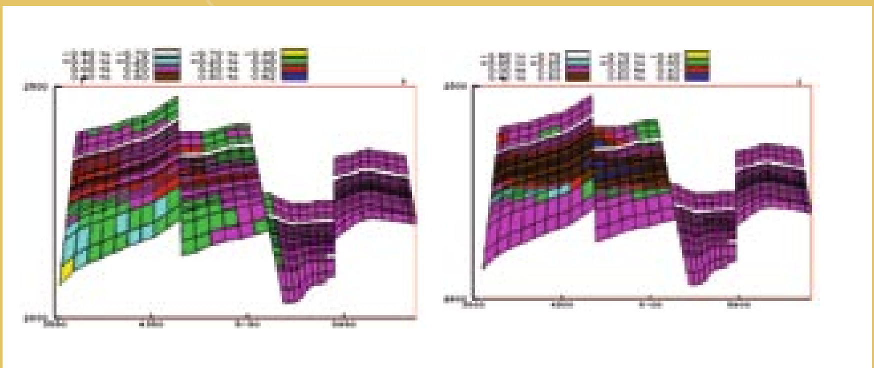


Figure 5.14: Estimated (left) and real (right) water saturation changes for a synthetic example based on a North Sea field reservoir model (from Mohsen Dadahspor's Ph.D. work).

Arctic technology

Sveinung Løset and Jørgen Amdahl, NTNU

The rapid increase of hydrocarbon exploration, exploitation and transport in arctic regions represents new challenges for structural design and operational procedures compared to those standards developed for the North Sea. Examples are: Low temperatures, periods of darkness, remote areas and, above all, the presence of sea ice. The fact that arctic areas are particularly vulnerable to pollution makes it especially important to focus on the safety and reliability of structures and operations.

At NTNU, professors Sveinung Løset at Dept. of Civil and Transport Engineering and Jørgen Amdahl at Dept. of Marine Technology have been actively contributing to the development of technology for Arctic areas.

Professor Sveinung Løset is the key person at NTNU within Arctic technology. He has taken part in several scientific expeditions to the Barents Sea and Svalbard area to investigate sea ice conditions and sea ice drift and has been instrumental in developing courses in Arctic Offshore Engineering at the University Centre in Svalbard where he holds an adjunct professor position. He is panel leader on *Ice Engineering* in the code development for ISO 19906 - Arctic Offshore Structures. He has a rich contact net with research and industrial organizations related to Arctic technology in Russia, northern Europe and North America.

Test of ice floe - steel pipe interaction

He leads a group of several doctoral students. The work comprises tests with artificial ice-floe structure interaction carried out in sea ice at Svea on Svalbard. The purpose of these tests is to verify theoretical methods for ice action prediction. At the same site ice ridge scour tests have been performed. Scouring occurs when iceberg or ice ridges strand in shallow water and penetrate the sea floor. Reliable prediction of penetration depth is essential for safe design of burial depth of subsea pipelines.

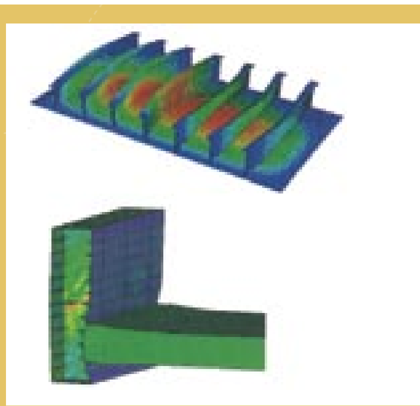
Baltic Sea lighthouse

Ice-structure interaction sometimes causes strong resonant vibrations. The causes of the vibrations are poorly understood and research is in progress to describe the governing mechanisms based on measurements made at a Baltic Sea lighthouse.

Professor Løset has also participated in several theoretical and experimental studies on novel Arctic offshore loading and transportation concepts for ice-infested waters.

Ice breaker tanker

The increased demand for oil transportation in cold regions is witnessed by the fact that one third of all DnV-classed oil tankers currently on order are specified with ice strengthening. Furthermore, new oil tankers that can cope with thick ice cover without the assistance of ice breakers are being developed. These vessels move most effectively through the ice cover stern first. A major issue is the resistance to ice action on the hull girder and stern mounted propellers. Unified requirements for polar ships are being developed under the auspices of the International Association of Classification Societies. In collaboration with DnV, Professor Jørgen Amdahl has supervised several master's students investigating the adequacy of the proposed ice strengthening requirements by conducting nonlinear finite element analysis plating and stiffeners subjected to extreme ice loads.



Simulation of stiffened plate response and ice floe-tanker side interaction

Another issue is design for very rare actions, "10 000-year actions" as opposed to "conventional 100-year " actions. In the North Sea such actions are designed for in the limit state of accidental action (ALS). This has significantly increased a structure's robustness for unforeseen or unintended loads. It is believed that adoption of the same design principles for Arctic regions will be essential to achieve the safety goals. Professor Amdahl has already used ALS principles to assess the risk of bergy-bit ice impact with shuttle tankers offshore Newfoundland. The design checks focus on the global integrity such that significant damage of say an outer hull is accepted, but the puncturing of cargo tanks or the breaking of the hull girder are not allowed. In this context ice-structure interaction constitutive modeling of ice represents a major challenge which needs increased focus.

The use of jack-up rigs for exploration drilling in moderately ice-covered waters is expected to increase in the future. Ice actions from the breaking of drifting ice as well as rubble accumulation between platform legs may represent a hazard-Resonance may occur between the time varying ice breaking force and platform global deformation. Nonlinear dynamic simulation of this process has been performed with the computer software USFOS, especially developed for ALS assessment of platforms.

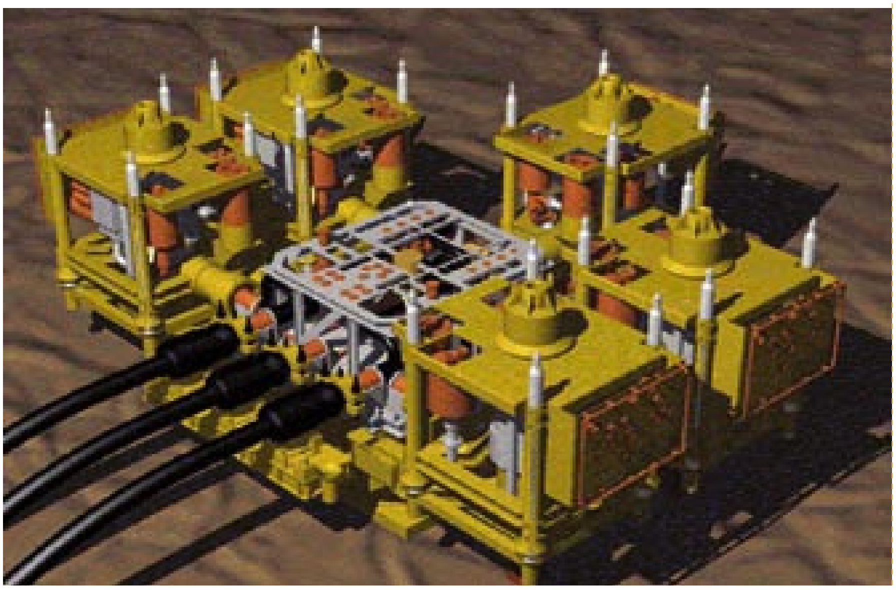
Efficient production of oil and gas from deepwater wells, using electricity for control and energy supply of subsea production satellites
Erling Ilstad, NTNU

The objective of this strategic university program is to develop new knowledge to facilitate greater use of electric power for more efficient production of oil and gas from deepwater wells. The ultimate objective of future technology is the development of subsea satellites with separation modules and various types of pumping equipment, systems for power distribution including cables, terminations and pipelines (see figure). These units may be connected to existing platforms, production ships or installations ashore for control, power supply and further processing of hydrocarbons.

This is to be achieved by means of fundamental research at doctoral level which focuses on building a scientific knowledge base regarding: Selection of appropriate materials and components for submerged electric motors, power electronics, high voltage units and distribution systems for energy supply and control.

Subordinate objectives are:
i) Develop scientific knowledge-based design criteria and new test methods for power electronics, motors and high voltage units for deepwater /downhole installations subjected to high hydrostatic pressure and temperature.
ii) Develop simulation methods and models to explore system issues such as reliability, environmental aspects, risk management and decision support.

Future technical solutions:
- High voltage power distribution system, including direct current systems for the longest distances. Linking efficient HVDC "highways" or ring networks directly to the mainland. System aspects and challenges regarding the development of reliable terminations, plug-in connectors and circuit breakers are addressed in particular.
- Downhole processing, for separation of gas, water and oil, places considerable demands on the mechanical and electric robustness of equipment operating with a reservoir pressure up to 500 bar and a temperature approaching 185°C.
- Power electronic frequency converters, for the operation of valve actuators and MW pumps, in pressure equalized oil filled chambers. The project will focus on this challenge as well as developing and testing new ideas relating to encapsulation techniques for semiconductors in power modules and other passive components



The research project is conducted in the electric power framework within NTNU and SINTEF Energy Research in cooperation with other relevant research activities at NTNU. The project duration is 2005-2009. Professor Ildstad is the project manager.

Petroleum geophysics
Bjørn Ursin, NTNU

Geophysical research at the Department of Petroleum Engineering and Applied Geophysics, NTNU is performed in close cooperation with the petroleum industry (oil companies and contractors), mostly in the form of projects involving Ph.D. candidates and post-doc scholars. There is also extensive cooperation with universities in France, Germany, Holland, Italy, Russia, Brazil and the USA. The main research effort is in seismic methods, but there have also been projects in gravimetric methods, electromagnetic methods and formation evaluation. Recently, a new research activity has been started - marine electromagnetics.

At present, there are 25 Ph.D. candidates, two post-docs and one visiting professor in addition to the permanent staff of 5 professors and 4 adjunct professors working in petroleum geophysics at the Department There is also cooperation with researchers at SINTEF Petroleum Research on joint projects involving two Ph.D.s and one post-doc.
The main research areas are:

Seismics:
- Modeling
- Noise removal
- Multiple removal
- Vector processing of OBS data
- Imaging of PP and PS data
- Tomography
- Stochastic inversion for reservoir parameters
- Time-lapse processing
- Estimation of pressure effects
- Multiparameter Radon transform

Marine electromagnetic methods:
- Modeling
- Removal of surface effects
- Migration/inversion
- Joint inversion of seismic and production data
- Visualization of geophysical data

Rock physics and geomechanics research is performed in close cooperation with SINTEF Petroleum Research. The research group at NTNU and SINTEF consists of 20-25 scientists and Ph.D. candidates and was recently selected by Shell as their primary partner in Europe in this area. The main focus of the research is on wave velocities in reservoir and overburden rocks. Particular focus is placed on how they depend on stress alterations, such as those caused by reservoir depletion. This is a key issue in the interpretation of time-lapse (4D) seismic data. Experimental studies permit determination of ultrasonic P- and S-wave velocity anisotropy under controlled conditions of stresses, pore pressure and temperature. In addition, the P-wave modulus at seismic frequencies can be measured in a separate set-up. Numerical work is performed using a discrete element model, simulating poromechanical behavior and wave propagation based on particle scale interactions. This approach is also used together with analytical and other numerical models to establish stress evolution within and outside a depleting reservoir.

The main on-going research projects are:

- **Improved overburden and reservoir characterization combining seismics and rock physics.**

  Project responsibility: Professor Rune M. Holt, Professor Martin Landrø, Professor Bjørn Ursin.

  Strategic university program financed by NFR. Advisory group consisting of representatives from NPD, BP, Conoco-Phillips, Exxon-Mobil, Hydro, Shell, Statoil and Total.

Objectives:
The presence of overburden geological bodies like channels, fans, concretions, gas hydrates and low velocity lenses causes artifacts for seismic imaging and analysis. By focusing on improved characterization of overburden sands and shales we will develop methods to correct for such effects, leading to high-resolution seismic images and improved accuracy in fluid and lithology predictions at the reservoir level. Finally, overburden-dependent tools for improved time-lapse seismic monitoring of hydrocarbon fields will be studied.

Duraction: 2004-2008, with 4 Ph.D. candidates, 3 post-docs and several visiting professors.

- **Processing and inversion of marine electromagnetic data**

  Project responsibility: Adjunct Professor Lasse Amundsen, Professor Bjørn Ursin

  Project financed by NFR, EMGS, Hydro, Statoil

Objectives:
Electromagnetic seabed logging (SBL) is a new, marine electromagnetic survey method that has been developed at Statoil's Research Centre in Trondheim. The method is now commercialized and further developed by the EMGS AS. The method is based on the use of low-frequency electromagnetic waves that are generated and received by dipole antennas close to, or on the seabed. By varying the frequency and the offset between the source and receiver antennas, one can detect and map the presence of thin layers of high electric resistivity below and the overburden of much smaller resistivity. Combining the information obtained by this method with that of seismic surveys from the same region, one can obtain a more reliable interpretation of the nature of deep subterranean reservoirs. In fact, data provided by the present method may serve as a direct hydrocarbon indicator. Good agreement between experimental data and numerical simulations has been obtained both for the initial laboratory experiments and later field surveys

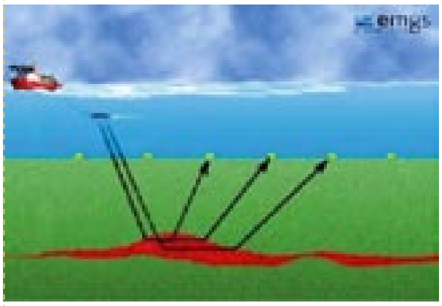


Figure 5.15 Typical survey layout in SBL. Electromagnetic waves from a towed dipole source are detected by seafloor receivers.

Electromagnetic and seismic survey methods are complementary in the sense that they are sensitive to different material properties and the seismic methods have much better spatial resolution than the electromagnetic methods. Therefore, a main challenge is to integrate electromagnetic and seismic survey methods in such a way that the maximum information about the physical properties of the sub-surface layers can be extracted by using seismic data to construct realistic geometrical models for use in the electromagnetic modeling.

Duration: 2004-2008, with 2 Ph.D. candidates and one post-doc.

- **Uncertainty in reservoir evaluation**

  Project manager: Professor Henning More, Department of Mathematical Sciences, NTNU

  This is the third project in on-going research cooperation involving several professors in both the Department and the Department of Mathematical Sciences

  Project financed by NFR, BP, Hydro, Statoil, Schlumberger.

Objectives:
To provide creative mathematically based solutions to recognized challenges in reservoir evaluation. This means to identify, develop and evaluate, and distribute information and provide training in using these models through education, publications and seminars. The activity in this project is inspired by the problem areas:

A Near-well initial reservoir characterization integrating all available information.

B Dynamic reservoir characterization based on repeated seismic monitoring and production history.

Duration: 2004-2007, with 4 Ph.D. candidates.

- **Automatic vector processing of OBS data. Strategic institute program (SIP) at SINTEF Petroleum Research financed by NFR**

Objectives:
The program will combine expertise from several disciplines, working on the development of processing and analysis methods for seismic data acquired at the sea bottom by nodes or cable technology. Such data permit the recording of vector wavefields, and the full exploitation of these should provide better images of the subsurface. Therefore the description of the reservoirs should be more accurate and the production control should be more effective. This will also have and important impact on future petroleum exploration, aiming at direct hydrocarbon detection without drilling. Work on autonomous methods also prepares for solutions that can be integrated in an eField ("smart-field") environment by application to time-lapse OBS and passive seismic monitoring.

The major objective of the proposed program is to obtain as much relevant information as possible about the subsurface from sea bottom data in the most efficient way.

This will be achieved by the following technical objectives

- Development of a vector fidelity method
- Development of a multiple removing method
- Development of a velocity estimation method
- Development of a depth migration method
- Development of a quantitative inversion method

Duration: 2004-2007, with one Ph.D. candidate.

In addition to these larger projects, there are several smaller on-going projects.

-Seismic angle migration and tomography

Seismic angle migration and tomography are on-going research topics at the Department which have received international attention. Since 1996, Professor Bjørn Ursin, NTNU and Professor Martijn V. de Hoop at Center for Wave Phenomena, Colorado School of Mines have had research cooperation involving four Ph.D. candidates. Two have graduated from NTNU, one from Colorado School of Mines and one is engaged in the SINTEF SIP mentioned above. This research has resulted in numerous conference presentations, several research papers in international journals, and it is summarized in two articles in the June 2005 issue of *The Leading Edge.*

As an example of seismic technology, we can show three seismic images from the Valhall Field. They have been provided by Dr. Sverre Brandsberg-Dahl, BP Exploration and Production Technology, Houston and are taken from one of the articles in *The Leading Edge*.

The seismic data quality on the Valhall Field is severely affected by the shallow gas accumulation, or gas-cloud, above the reservoir. The P-wave velocity is very low, so traditional P-wave imaging is very difficult, as seen in Figure 5.16.

Figure 5.17 shows an application of angle migration to sea bottom cable data from the Valhall Field. The imaging algorithm used in this example is 2D, so we extracted data from a single cable in the permanent four-component seismic array installed at the field.

The receiver spacing along the cable is 50 m and we used a maximum offset of 5 km, with split–spread geometry. The simple preprocessing scheme consisted of PZ-summation, random noise suppression, and deconvolution.

In the angle migration result (Figure 5.17), it is possible to make out the

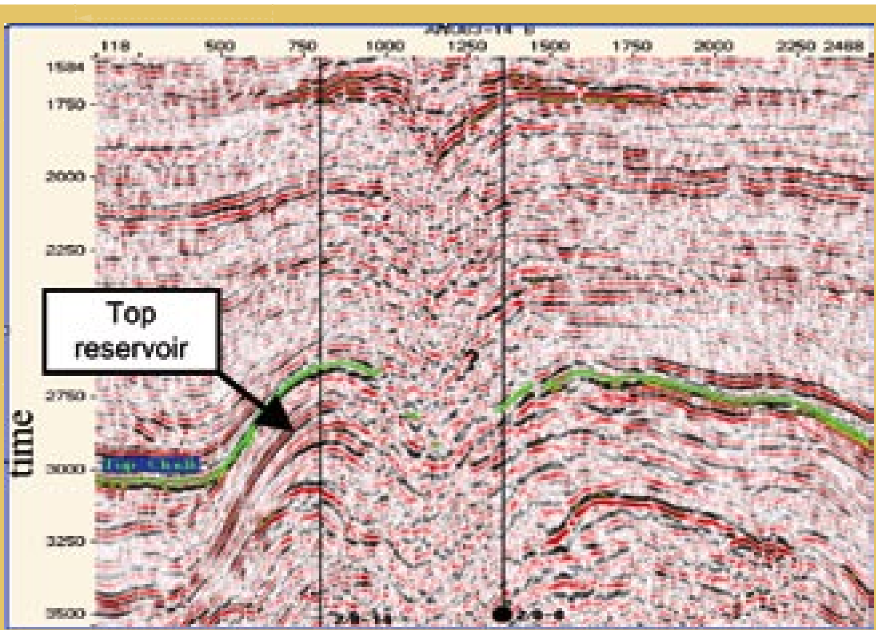


Figure 5.16 An illustartion of the "gas-cloud" problem at the Valhall Field

crestal structure of the reservoir even through the gas-cloud area. For comparison, Figure 5.18 shows the same line extracted from a 3D wavefield migration of the Valhall data. The angle migration, though only 2D, shows the same features as the wavefield results, but one can argue that Figure 5.17 illustrates the results of a technique that has better resolution through the central part of the line. This example clearly shows that angle migration is a viable alternative to wavefield imaging.

Acknowledgement: We thank the Vallhall licensees (BP, Total, Shell, and Amerada Hess) for permission to present the data.

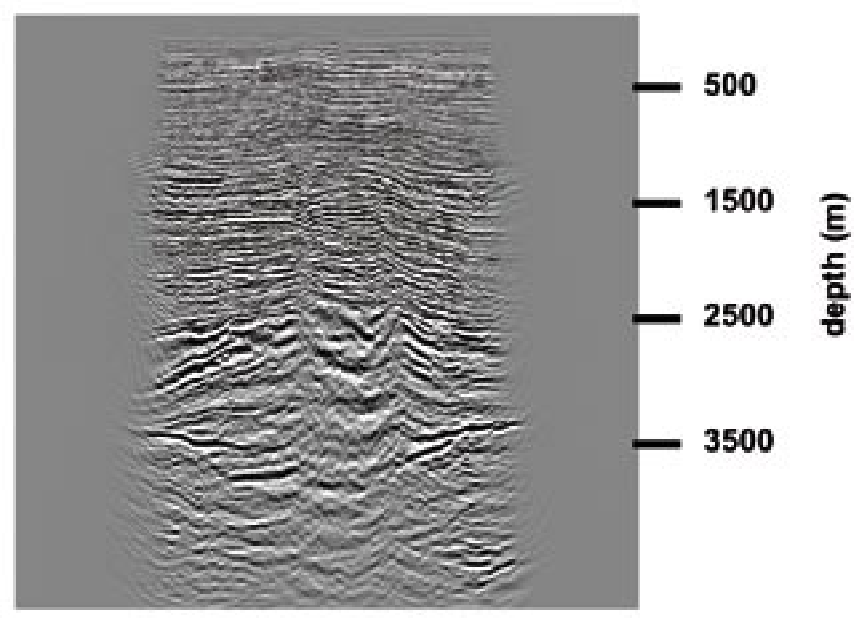


Figure 5.17 P-wave angle migration result through the gas cloud at the Valhall Field.

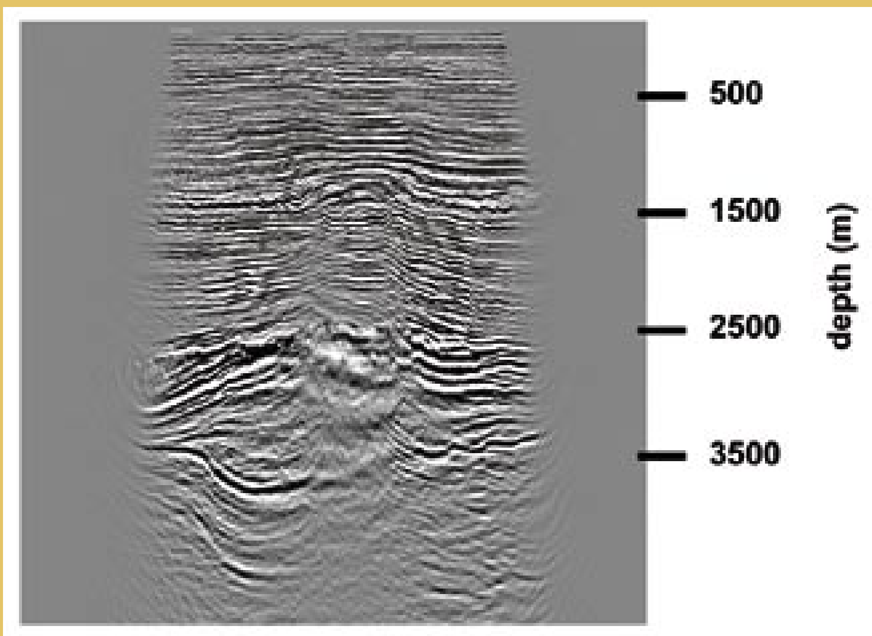
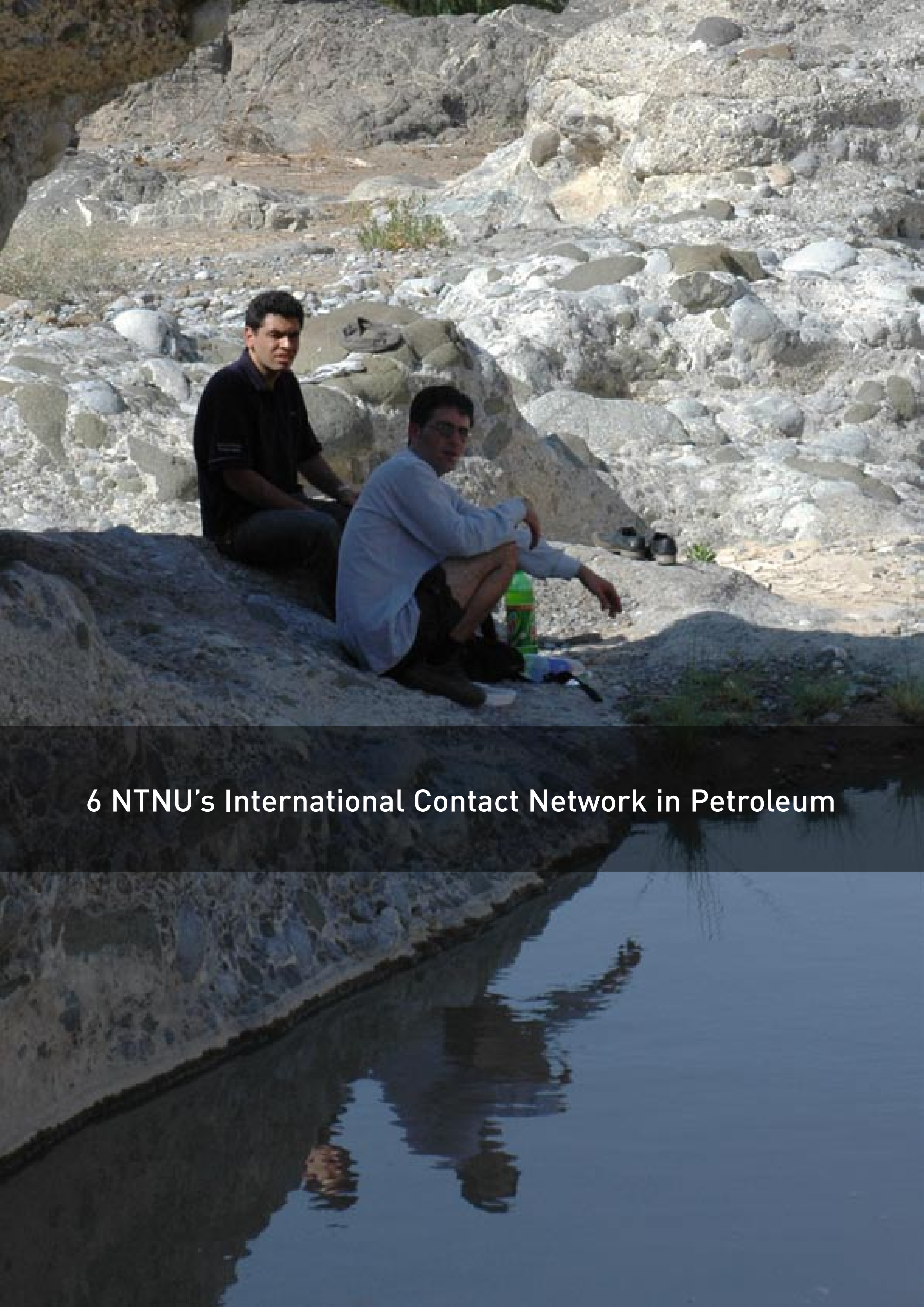


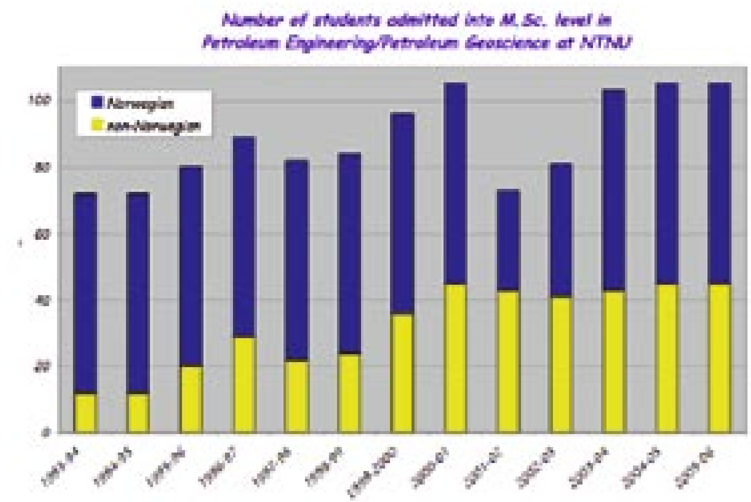
Figure 5.18 The same line as in Fig. 5.17, but extracted from a 3D wavefield (common receiver) migration.

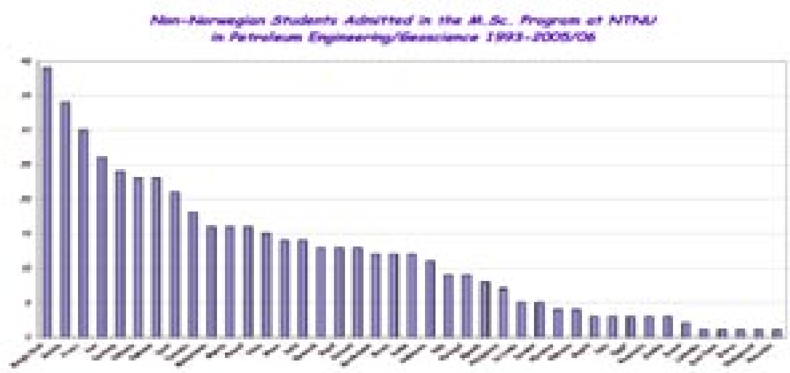


6 NTNU's International Contact Network in Petroleum

6.1 INTERNATIONAL PROFILE AT THE DEPARTMENT OF PETROLEUM TECHNOLOGY AND APPLIED GEOPHYSICS

Since the establishment of the upstream petroleum activities in 1973, NTH/NTNU have put emphasis on keeping an international profile through research collaboration. On the educational side, a one-year program in Exploration and Production for students from the developing countries was established in 1980 with the support of NORAD. About 250 students graduated from this program over a period of 14 years. However, in 1993 it was changed when the language of regular lectures at M.Sc. level became English and the internationalization of activities really gained speed. In the beginning, an agreement with NORAD reserved a number of places for students from the poorest countries. Later, in addition to NORAD, students were supported through the Quota program, and through agreements between NTNU and national oil companies. Since 1993, around 500 non-Norwegian students have attended M.Sc.-level courses in Petroleum Engineering and Geosciences. Today, around 40 % of all students at M.Sc. level in these areas are non-Norwegian. At Ph.D. level around 50 % of the candidates are not Norwegian, and the current trend indicates that in a few years a vast majority will be non-Norwegian. This is a development that our sister departments in the US and elsewhere in Europe have experienced for many years. The development is illustrated in the two figures below, showing the numbers of Norwegian and non-Norwegian students admitted per year, as well as student numbers from more that 40 nations that have been represented.





6.2 INTERNATIONAL UNIVERSITIES IN THE CONTACT NETWORK

Collaboration with international universities is important for student exchanges and for the quality of research. Each year a large number of the Norwegian M.Sc. students spend one or two semesters at a university abroad as exchange students, taking relevant courses that can be approved as part of the degree requirements at NTNU. NTNU feels that this is an important aspect of their education, and at the same time a calibration tool for NTNU's own curricula. Formal student exchange agreements have been established with many universities in the US, Brazil, Australia and Europe. An equal number of non-Norwegian exchange students, primarily from European universities financed through EU programs, attend courses or complete their M.Sc. theses at the Department. Most of these students come from Austria, France, Spain, Germany, Poland and Holland.

There are numerous projects that include research collaboration between teachers and researchers at NTNU with colleagues abroad. Every year some professors at the Department spend a sabbatical year abroad, and a number of post doc's, researchers and visiting professors participate in research in at NTNU. Currently, the international universities that the Department has most contacts with are:

- Ecole de Mines, Paris
- École Centrale, Paris
- Freie Universität Berlin
- Universität Karlsruhe
- Universidad Rey Juan Carlos, Madrid
- Technical University of Leoben, Austria
- Technical University of Delft, Netherlands
- Ukrainian State Geological Prospecting Institute, Kiev
- Czech Academy of Sciences, Prague
- Russian Academy of Sciences, Novosibirsk, Russia
- Pomor University, Arkhangelsk, Russia
- State University of Campinas, Brazil
- Federal University of Bahia, Salvador, Brazil
- University of Texas, Austin
- University of Oklahoma, Norman

- Colorado School of Mines, Golden, Colorado
- University of California, Santa Cruz
- Stanford University, California

6.3 INTERNATIONAL OIL COMPANIES IN THE CONTACT NETWORK

There is a close interaction between NTNU's petroleum activities and most oil companies with activities on the NCS. Many of these companies are global actors and this has led to NTNU's engagement in research, education and technology development abroad. The oil companies that NTNU has long-term collaboration agreements within petroleum are:

- BP
- Norsk Hydro
- Shell
- Statoil
- TOTAL

The agreements typically define the scope and direction of collaboration for a 5-year period, and are primarily focused on Ph.D. research, geological field courses and educational development. In addition, NTNU has single-project agreements with most of the other oil companies that have offices in Norway.

6.4 MOUs WITH NATIONAL OIL COMPANIES (NOC)

Over the past 5 years, NTNU has made agreements with national oil companies in Iran, Venezuela and Azerbaijan through which a substantial number of students have been supported and admitted to NTNU's M.Sc. programs in Petroleum Engineering and Geoscience. Around 50 M.Sc. students have graduated under the scope of these agreements. It is a strategic objective of NTNU to increase the educational activities directed towards students from oil producing countries, supported by national oil companies. Currently, NTNU has discussed or has entered into new MOUs with companies in Libya, Algeria, Saudi Arabia, Russia, Mexico, Iraq, Angola, Kasakhstan, Nigeria, Oman and Uzbekistan.

NTNU became a member of Intsok in 2005, and considers this to be a key partner in the development of international educational and research activities in petroleum at NTNU.

6.5 GLOBALIZATION AND INTERNATIONALIZATION OF THE PETROLEUM INDUSTRY

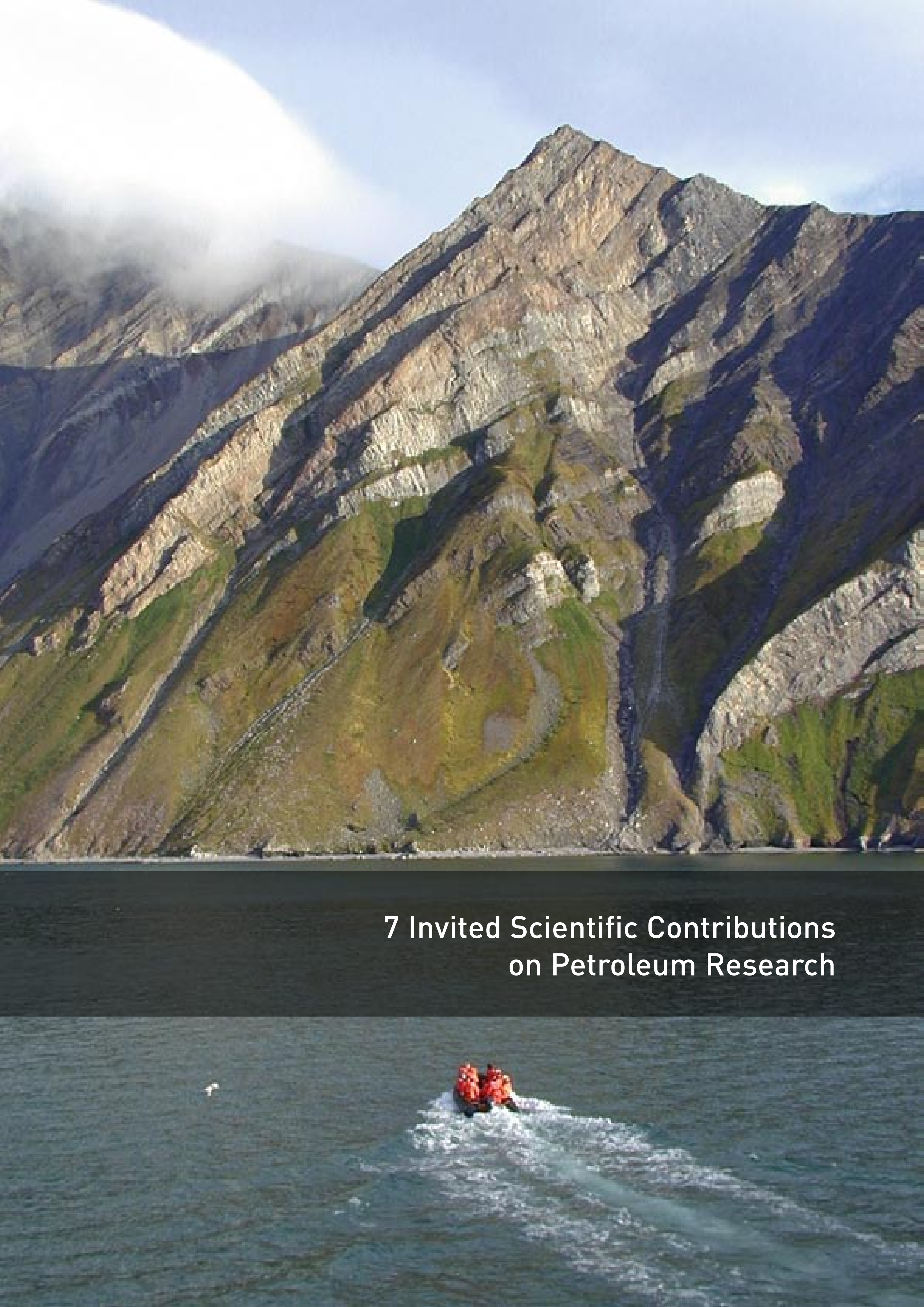
Chapter 2 has already highlighted the unique opportunity for the internationalization of the entire Norwegian Petroleum Cluster by operating on international markets.

Many of the new issues and challenges that the Norwegian oil companies and service companies meet in other geographical regions are already addressed in the curricula for scientific and engineering degrees at NTNU.

This is an area where it is nevertheless important to have a continuous dialog with the industry in order to capture future demands.

NTNU has developed a very significant contact network with the international petroleum industry including National Oil Companies and regulatory bodies in many countries. It is believed that the present practice whereby Norway exports knowledge, skills and competence by offering university education in petroleum and related to graduates and staff from oil producing countries and National Oil Companies can be very important in the internationalization process.

NTNU's international network and platform will be used in cooperation with the Norwegian Petroleum Cluster in the process of internationalization.



7 Invited Scientific Contributions on Petroleum Research

7.1 INTEGRATION OF SEISMIC AND SEA BED LOGGING

Ståle Johansen, EMGS

Seismic imaging techniques can readily detect potential hydrocarbon (HC) traps but discriminating between the presence of water or hydrocarbons in such traps has remained a challenge. Direct detection of subsurface hydrocarbons by an active source electromagnetic (EM) sounding application, termed seabed logging (SBL), has recently shown very promising results. This opens a new frontier in hydrocarbon exploration.

Remote sensing techniques record variations in petrophysical parameters such as acoustic- or electric properties. Seismic sounding is by far the most common of such tools and typically uses acoustic waves to map boundaries between layers with contrasting acoustic properties. Seismic data can provide detailed information about layering but is not very well suited for direct detection of pore fluid composition. Given the detection of a structural geometry that may have allowed accumulation of HC within porous sedimentary rocks, the main remaining uncertainty is therefore whether the pore space is filled with saline water or HC. For this reason only 10 – 30 % of exploration wells penetrate commercial oil- or gas reserves in many areas.

In controlled source EM sounding (CSEM) a horizontal electrical dipole is towed close to the seabed emitting an ultra low frequency EM signal which is recorded by stationary seabed receivers. This is also the case for SBL which is a special application of CSEM.

Seabed receivers record the EM responses as a combination of energy pathways including signal transmission directly through seawater, reflection and refraction via the seawater-air interface, refraction and reflection along the seabed and reflection and refraction via possible high resistivity subsurface layers. The refracted energy from high resistivity subsurface layers will dominate over directly transmitted energy when the source-receiver distance is comparable to or greater than the depth to this layer. The detection of this guided and refracted energy is the basis of SBL.

Resistivity variations in rocks are generally controlled by the interplay between highly resistive minerals (10^{11} - 10^{14} Ωm) and pore fluids including low resistive saline water (0.04 - 0.19 Ωm) and/or infinitely resistive hydrocarbons. Sedimentary rocks can exhibit a wide range of resistivities (0.2 - 1000 Ωm) mainly controlled by variations in porosity, permeability and pore connectivity geometries in addition to pore fluid properties and temperature.

The high resistivity of hydrocarbon filled reservoir rocks (30-500 Ωm) compared to reservoirs filled with saline formation water (0.5-2 Ωm) makes EM sounding a potential tool for detection of subsurface HC. Although EM techniques have been used for many years, EM sounding has until recently not been applied in offshore HC exploration.

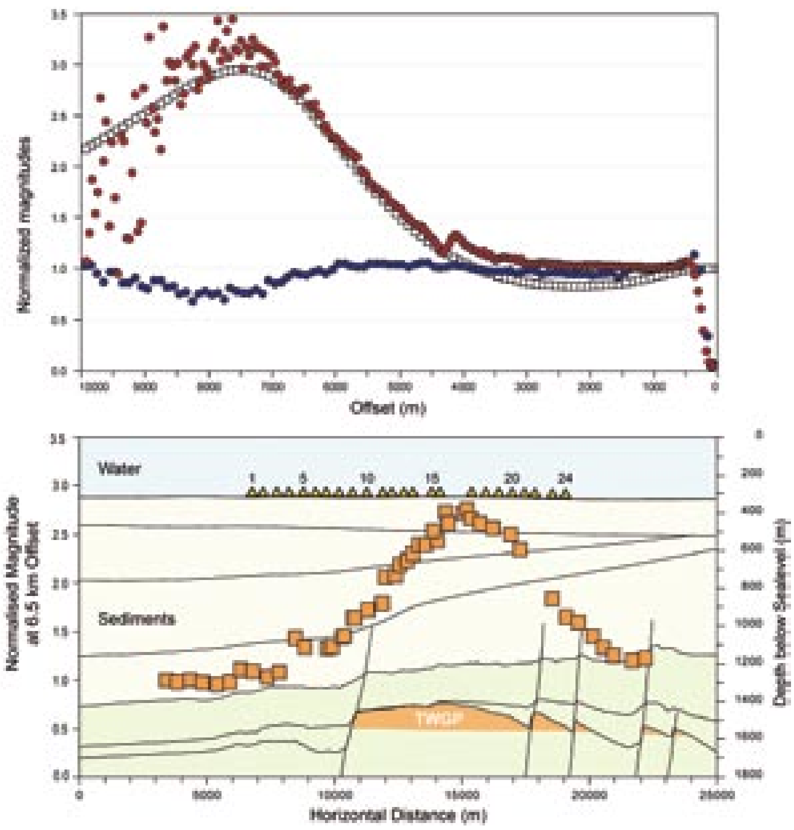


Figure 7.1: (Top) Modeled and measured SBL receiver data across Troll Western Gas Province. The red curve represents a typical response from a receiver measurement ON the reservoir divided by a (normalized) reference receiver OFF the reservoir. The source was towed SW-NE and the shown responses are on the SW in-towing side of both receivers. The blue curve is the reference receiver normalized by the modeled plane layer response representing the OFF reservoir situation. The white curve is the modelled ON reservoir response normalized by the modeled OFF reservoir response.

(Bottom) Median normalized magnitudes at 6.5 ± 0.5 km source-receiver distances along the survey line across TWGP. Normalized magnitudes are posted at common midpoints 3.25 km from receivers. For better visualization median magnitudes are overlain the simplified geological model along the survey line. The correlation between the location of the SBL anomaly and TWGP is excellent.

A full-scale EM sounding test offshore Angola showed that the new application of EM sounding, SBL, had a very clear and promising potential. Later SBL data across the Troll West Gas Province offshore Norway provided direct evidence in the detection of a deeply buried hydrocarbon accumulation by subsea EM sounding.

When interpreting SBL data it is closely integrated with seismic data. The seismic data map in the prospect will be later measured by SBL. Today this integration is simple and straightforward. There is a huge potential for improvements in this field. Research on this subject is important for further developments in combined exploration using SBL and seismic. To improve the integration between seismic and SBL forward modeling is also a critical step in the work flow. Modeling is important when comparing the EM response over the HC accumulation with the EM response in a reference area immediately outside the accumulation. It is also critical to understand SBL responses from high resistivity bodies other than the HC reservoir itself which can potentially generate significant responses. In addition to addressing these questions forward SBL modeling can also answer critical questions related to practical survey planning required for carrying out an optimal SBL survey.

In summary the research within integration of SBL and seismic should be concentrated on the co-visualization of the two data sets and forward modeling.

7.2 OCEAN BED SEISMIC

Jan Kommedal, BP

The use of multi-component ocean bed seismic (OBS) for commercial oil exploration and exploitation is still a relatively new technology. The first attempts to acquire such data in Norway took place in 1989 - an example was the deployment of seabed sensors to monitor a gas leakage in Bock 2/4 (southern North Sea), by Saga Petroleum.

The first successful case of using OBS to map the reservoir under a 'gas cloud' in the overburden, was done by Statoil in 1994 at the Tommeliten Field. In this case only 2D lines of data were acquired. One of the first 3D OBS surveys on the Norwegian Continental Shelf was done at the Valhall Field by Amoco in 1997-98. The survey covered the entire field and allowed the generation of maps of the reservoir obscured by gas in shallower sediments. Since then this type of technology has been used by a number of companies both in Norway and worldwide.

Initially the OBS cables used two sensors at each receiver station, a hydrophone and a geophone. Combining the data from the two sensors it is possible to reduce the amount of seismic energy trapped in the water layer generally considered as noise and must be removed from the data in order to produce high quality images. However, by using three geophones in addition to the hydrophone it is possible to record the full elastic wavefield. This method captures not only pressure (p-) waves, as with conventional streamer seismic, but also converted shear (s-) waves which do not propagate in fluid. While p-waves are severely affected by gas dispersed in the sediments, s-waves basically travel through the matrix of the rocks, and thus are not affected by the gas. While 'gas clouds' distort the p-wave seismic images, s-waves can be used to map reservoirs below the gas. The s-waves can also be used to gain additional information about the properties of the subsurface sediments, as well as lithology and fracturing.

The technological development of the equipment used to acquire OBS data has changed dramatically during the last ten years. The most important changes have been the improved quality of the seismic sensors as well as the number of sensors available for deployment during data collection. Norwegian companies have played an important role in this development and are continuing to work to make data acquisition more efficient, cost effective and safe.

As a world first an OBS array was permanently installed at the Valhall Field in 2003. This array covers 45 sq. km, around 70 % of the field, and has almost 10 000 channels. The purpose of this array is to use OBS data to monitor the reservoir depletion in connection with a water injection program. By collecting data at intervals of four to six months, it is possible to monitor the changes due to reservoir depletion and water injection.

In terms of data processing and analysis, the fact that the full elastic wavefield is being recorded presents both possibilities and challenges. Even if there are many instances where OBS data has added significant value, the processing of the data still needs further development in order to take full advantage of the information contained in OBS recordings.

It is to be expected that the positive development of OBS technology will continue and make this an even more important seismic tool in future exploration and production of hydrocarbon.

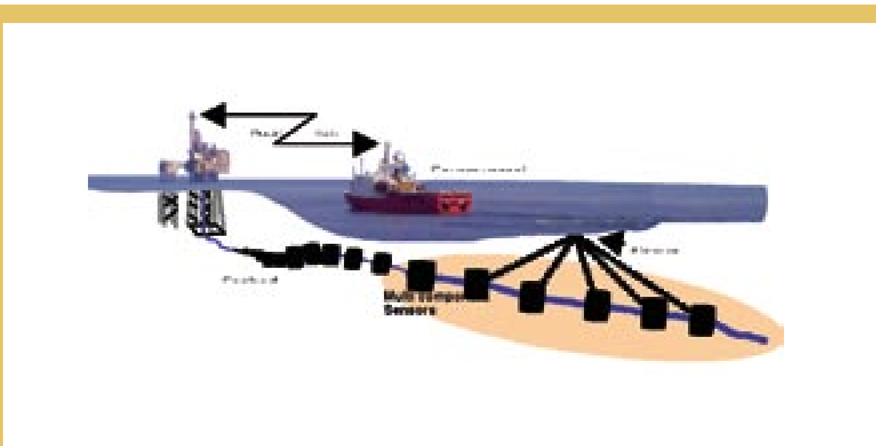


Figure 7.2 Ocean Bed Seismic data acquisition with a permanently installed cable.

7.3 4D MONITORING AND IMPROVED RESERVOIR SIMULATION

Rodney Calvert, Shell

International exploration and production essentially model variables such as vertical and horizontal permeability and fault sealing. Away from wells, these can only be estimated and cannot be directly or remotely measured. Effective permeability may vary by orders of magnitude in a reservoir, with the variability caused by fine scale features such as thin shale drapes or open fractures not resolvable by seismic and not sampled by wells. It is often the location and values of these unknown extremes that control the production performance of a reservoir. This means that at the start of production, simulation models and their predictions will have great uncertainty.

As production proceeds the fluid and pressure distributions within a reservoir will become more and more complicated. Monitoring the effects of production in producing reservoirs is essential to track changes and constrain models to reflect reality. Simulation models that can reflect the physical effects of production and reproduce measurable monitoring changes as seen on 4D seismic surveys are a great step forward. Better constrained simulation models can better predict the outcome of proposed reservoir management proposals including new well placements and Smart Well interval control valve (ICV) injection and production. Better simulation models enable production optimization approaches to be used

The conditioning of simulation models on monitoring data is a fruitful area of research. Can we combine the expert input of experienced reservoir engineers, reservoir geologists, geomechanical experts etc. with algorithmic inversion matching of the model and measurements in a multidisciplinary environment? We can easily show that 4D results from fluid front monitoring can be used to enhance simulation models, but these models will still not be unique until the fronts have been seen to sweep the reservoir. However by recognizing the uncertainty associated with this non-uniqueness and predicting a span of outcomes we should be able to rationally determine how often we need 4D surveys and still properly manage a field.

By monitoring the effects of pressure and compaction we may get an earlier constraint on the gross compartmentalization of a field since pressure travels much faster than fluid in a reservoir. The pressure effects are much less well understood and are more difficult to observe for depletion. The sensitive measurement of stress arching effects over depleting compartments, by methods such as subsidence measurements, time stretching, tiltmeters, and micro-seismic listening combined with downhole pressure sensing can be used to constrain simulation pressure predictions. A reliable capability would enable early determination of compartmentalization, better positioning of phased development wells and better risk management of fields that are currently considered marginal.

We should research the construction of a simulation model constrained by early pressure effects and show that this can give a valuable first approximation that is good enough to resolve key uncertainties. These can be refined by subsequent 4D monitoring of fluid changes. A lot of valuable work has already been started by Don Vasco and Akil Datta-Gupta.

Vasco, D.W., S.Yoon, and A.Datta-Gupta, 1999, Integrating dynamic data into high-resolution reservoir models using streamline-based analytic sensitivity coefficients, SPE Journal (1999), 4, 389-399.

Vasco, D.W., H. Keers, and K.Karasaki, 2000, Estimation of reservoir properties using transient pressure data: An asymptotic approach. Water Resources Research, 36, No. 12, 3447-3465.

Vasco, D.W., and A.Datta-Gupta, 2001, Asymptotics, streamlines, and reservoir modelling: a pathway to production tomography, The Leading Edge, 20, 1164-1171.

Vasco, D.W., 2004, Seismic imaging of reservoir flow properties: Time-lapse pressure changes, Geophysics 69, 511.

7.4 COST-EFFICIENT DRILLING METHODS

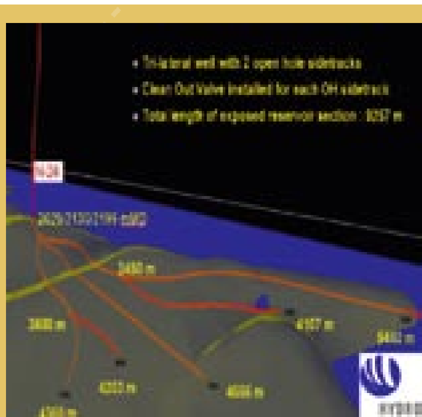
Bjarne Syrstad, Norsk Hydro ASA

Multi Lateral Drilling (MLT).

This technology has proven its value on the Troll Field. There have been approx. 30 junctions installed on Troll. This technology aims at increasing oil and gas production from wells more efficiently facilitating dramatically increased reservoir exposure.

Hydro has developed this technology for new wells and is now planning to use this technology in old wells, maintaining the production from the original horizontal section.

The cost of a two-branched well is approx. 1.3 times that of a single branched well. The lower cost of a branched well compared with several wells, combined with better reservoir exposure yields a high net present value from branched wells. This is a significant contribution to the good results from the Troll Field. Hydro is currently working on developing this technology even further.



Example of a MLT well: Well 31/2-N-24 on the Troll Field.

Monodiameter technology

Description: Casings with constant diameter along the entire wellpath.

Solid expandable technology is commercially available today. Monodiameter technology takes a step further. A joint Industry Project on Monodiameter between Hydro and Enventure GT, was established in the summer 2004.

Illustration of step-change in technology by implementing Monodiameter technology. (ex. 9 5/8" expanded to 11.4")

Goal: Complete a Monodiameter well in 2006.
Advantages:

- Unlimited number of casing strings
- One hole size from top to bottom
- Optimal production size.
- Intervention possibility
- Low risk – frequent formation support.
- Low cost (30 % – 50 % reduction)
- Smaller equipment
- Fewer consumables (steel, mud, etc)
- Smaller rigs
- Greater standardization

7.5 HOW TO INTEGRATE THE SEISMIC PORE PRESSURE PREDICTION INTO THE DRILLING PROCESS

Nader Dutta, Schlumberger.

Pore pressure prediction prior to drilling and frequent updates while drilling are important for safe drilling due to several reasons. These include supporting the well planning process by providing proper casing and mud program design; and preventing blowouts, lost circulation and stuck pipes.

A pre-drill estimate of pore pressure can be obtained from seismic velocities using either an empirical approach that relates velocity to pore pressure transform directly or a rock model that relates velocity to porosity, lithology, temperature and effective stress. The key in the later approach is to relate velocity to effective stress (defined as the difference between overburden and pore pressure) for a given temperature and lithology. Account must also be taken of the cause of overpressure in a given basin: under-compaction, diagenesis of shales, and buoyancy and charging of fluids in dipping permeable bed.

As far as velocities are concerned, one must use fit-for-purpose velocity data, for example, *conditioned* stacking velocities that reflect rock velocity and velocities from reflection tomography that contain improved spatial resolution. *Unconditioned* stacking velocities and the so-called migration velocities are unfit for pressure prediction. An example of a pressure cube in 3D is shown in Figure 7.3 (left). For drilling applications (requiring more depth resolution), one must use velocities from inversion of seismic amplitudes in conjunction with a reliable low-frequency trend, such as the velocities from post-stack inversion and inversion of pre-stack full waveforms in the offset domain (see Figure 7.3, right). In real-time, updates of seismic-based models are made using Measurement While Drilling/Logging While Drilling logs and Seismic While Drilling.

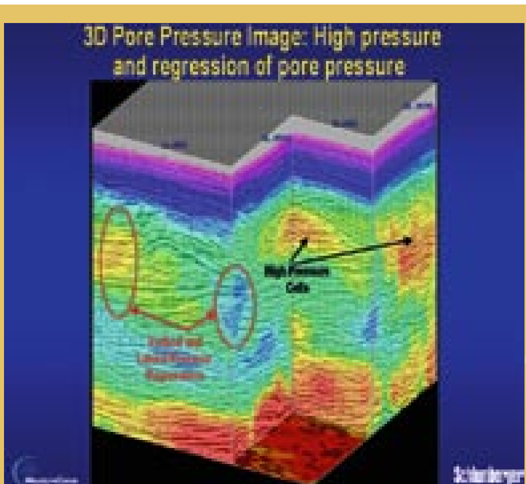
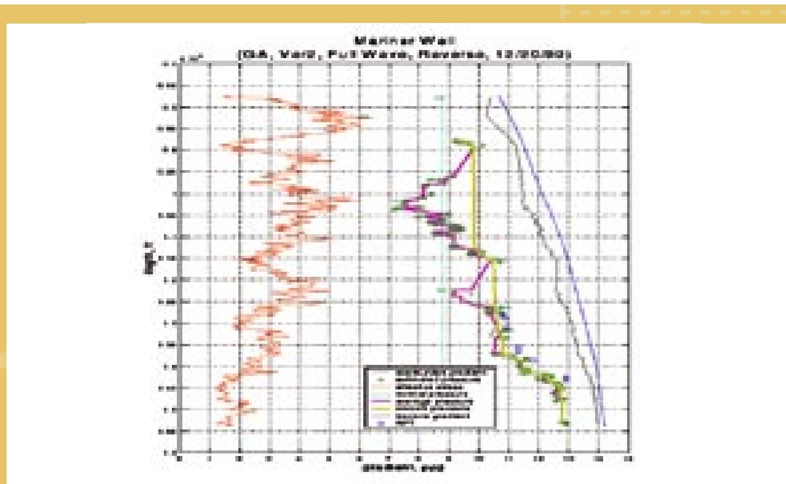


Figure 7.3 Pore pressure prediction



Effective stress (red) and pore pressure (magenta) from inversion

7.6 SEISMIC WHILE DRILLING

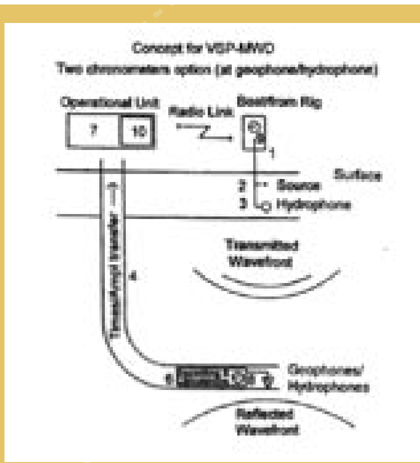
Steen A. Petersen, Norsk Hydro

Introduction

The introduction of Measurement While Drilling/Logging While Drilling (MWD/LWD) in the early 1980s had a considerable impact on almost all aspects of well planning, drilling operations and post-drill well evaluation. Basically, LWD data opened the possibility to steer and adjust the well trajectory into more beneficial positions than planned originally. The replacement of the former wireline technologies by LWD is nevertheless not completed yet. The signal transmission rate up-hole while drilling is still very restricted (6 bits/sec) and full waveform seismic data (vertical seismic profile, Sonic) have for a long period only been available after drilling.

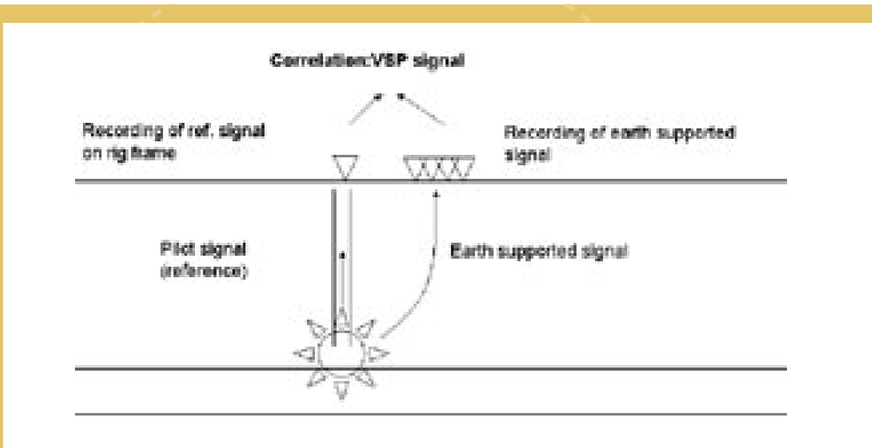
Vertical Seismic Profile (VSP) While Drilling

The search for and implementation of methods to put 'the bit on seismic' during drilling was initiated late in the 1980s using the emitted energy from the rotating bit as a seismic source. Recordings are performed on the earth's surface or sea floor. Contracting companies such as (former) Western Geophysical and Schlumberger plus a few research institutes (e.g. OGS) have succeeded in commercializing the technology for the market. The biggest limitations are related to the bit type, hole deviation, source signal measurement and sensor deployment at sea. The technique is mostly used in vertical well situations drilling with roller cone bits and poor surface seismic data.



From Norsk Hydro's patent on 'Normal' VSP While Drilling

In the mid-1990s Norsk Hydro suggested a VSP While Drilling acquisition technique in which the limitations of the drill bit source (reverse-) VSP are avoided. This implementation of (normal-) VSP While Drilling requires standard seismic sources situated near the surface and receivers in the bottom hole assembly (BHA) together with an accurate clock synchronous with the source clock. Recording takes place during drillstring connection or disconnection while the noise level down-hole is at a minimum. Because of the low transmission capacity, signals are stored and analyzed in the BHA. Only a few key numbers, such as the recorded travel-time from the surface, are transferred to the surface when drilling is resumed. The remaining information is retrieved after tripping out. The (normal-) VSP While Drilling technique has been commercialized by Schlumberger (2003) and used especially for complicated exploration drilling operations.



Principle of 'Reverse' VSP While Drilling

VSP While Drilling products

In addition to putting the bit on seismic both methods are now considered in a pre-stack depth migration context in which travel-times while drilling are used to update the velocity field for migration of the surface seismic data, also while drilling. The new seismic depth images can be utilized directly by geologists and drillers. Possibly, this 'seismic in depth' product will be provided as a standard service within a few years.

VSP While Drilling also provides an excellent opportunity to get a closer look at the subsurface to be penetrated. Features of the subsurface such as steeply dipping faults or body flanks that are normally not clearly visible in surface seismic sections will appear as distinct events in the processed VSP data. The depth of penetration is in the range of 300–600 m, which will give sufficient time for reaction if obstacles are approached. It is possible to obtain VSP-based images for any well trajectory.

High telemetry rate

The promising capability of looking ahead of the bit from VSP While Drilling data has been known to the industry for 5-10 years. The method was identified as the only one with long-range penetration. Simultaneously it was realized that reliable waveforms could not be transmitted to the surface at a sufficient rate. In 2001, SPE pinpointed the telemetry issue as the most critical technology to be developed, not only for the proper utilization of waveform data, but in general to optimize the drilling process as such.

Several MWD/LWD contractors as well as independent enterprises and research institutes have investigated techniques for a long time to get higher telemetry rates than those provided by the mud pulsing system. Recently Novatek introduced a digital wire-based transmission system using an induction coupling across the drillstring joints. Transmission rates of up to 2Mbit/secs are estimated in both directions.

The impact on the use of VSP While Drilling for near well-bore imaging is expected to be significant. Both of the acquisition methods seem to benefit from a high telemetry rate. The lack of reliable source signature in the reverse VSP case will probably be solved if the source signal is recorded directly near the bit and transmitted immediately to the surface. For the normal VSP situation the full waveforms become instantaneously available for processing and imaging.

Reflection sonic
While the VSP configuration may solve the problem of looking ahead in a 100 meter scale it is well known that sonic waveforms contain reflections scattered at a distance of 1 to 10 meters from the well bore. Reflection processing of sonic data is very demanding and not easy to perform in a blind mode downhole. Getting access to the waveform data on the rig while drilling is now becoming a realistic option. Probably waveform derived images of 10-25 cm resolution around the well bore will become a standard product in the chain of other LWD products used in geosteering.

Work processes
The availability of well seismic information while drilling will have a significant, but at present unclear, impact on the workflows associated with the planning, execution and evaluation of the drilling operation. It may take a while before the industry is able to exploit the full potential. Hopefully all parties involved with the industry, the contractors, operators and research institutes, will clearly see the potential and guide their R&D efforts in this prosperous direction.

7.7 SUBSEA TO BEACH - SUBSEA PRODUCTION FACILITIES – POTENTIAL FOR RESEARCH AND DEVELOPMENT

R.W. Dee, Shell

The progressive commercial application of subsea production facilities has matured over the last thirty years to the point where such facilities are in widespread use on a global basis.

In general, such subsea facilities provide an alternative to wells drilled from bottom-supported or floating combined production and drilling platforms. The functional capacity of subsea facilities generally covers the manifolding of subsea completed wells; their tieback to host facilities (typically 5 to 20 km distant); remote control from the host; and serviced by diver or remote tooling. Exceptions exist with single satellite well tiebacks and longer distances.

There is a noticeable trend towards:

Increasing tieback distances:
- Mensa/Gulf of Mexico, 1997, gas produced in 1640 m water depth with a 100 km tieback to a platform in shallow water
- Penguins/North Sea, 2003, oil, 65 km tieback in the North Sea

More complex production functionality:
- Draugen/Norwegian Sea 1993, multiphase pumping
- Troll/Norwegian Sea, 2002, water separation

These examples highlight the industry's growing interest in developing and applying technology for longer tieback distances for subsea facilities and more complex processing functionality and the required associated technologies. For gasfield developments this will be confirmed when the Ormen Lange and Snøhvit fields come on stream in the next few years. Operators are particularly interested in the type of subsea to beach technology, described above in order to:

- Facilitate oil and gas tiebacks for distances greater than 100 km and 200 km respectively
- Provide enhanced production performance thereby accelerating production and/or increasing recovery
- Open up deepwater prospects

Considerable challenges face the R&D community to enable the successful promotion of advanced functionality subsea production facilities, namely:

- Optimizing subsea systems with respect to: production availability, cost, performance and operability
- Further development to improve processing capability and adapting processing systems to subsea applications including the range of compact processing facilities which have recently been developed for platform or land-based facilities
- Development of cable-based power transmission, floating power generation and other novel power generation concepts
- Development and implementation of control and communication systems to allow more advanced local control (e.g. adaptive, optimal control), sensing devices and high integrity high bandwidth data transfer
- Development of cost-effective installation and intervention concepts for deepwater and applications in harsh environments

7.8 ADVANCED INTERVENTION TECHNOLOGY FOR SUBSEA APPLICATIONS

Rolf H. Utseth, Statoil

Background

Operational experience from fields based on fixed platforms imply that a high frequency of "low cost" well intervention operations are of fundamental importance for improved oil recovery (IOR). In subsea wells the associated intervention costs limit the frequency of these operations. Historically subsea well interventions have been performed based on heavy tools and vessels/rigs. Reference is made to Categories B and C in the figure to the right.

Ambition

The main objective with respect to advanced intervention technology for subsea application is to develop less expensive means to intervene in subsea wells. The ambitions are:

- Perform intervention in subsea wells at less than NOK 1 million/day.
- Perform production logging of subsea wells at less than NOK 5 million.

Production well interventions performed from a drilling rig are typically conveyed into the well through a high pressure riser with a surface flowhead and lubricator system typically run inside the riser and blowout preventer. In this configuration tools are either conveyed on coiled tubing or on wireline, some times even on pipe. The addressed services/tools include: production logging, tools for scale removal, perforation guns, packers, inflatable plugs, wipstocks and window mills.

Tools run from a category A (light) vessel have to be conveyed on wireline, run in open sea through a subsea installed lubricator system installed on top of the subsea production tree. The current lubricator system has a weight of 10–20 tons. To meet the above ambition, technology in terms of lightweight downsized subsea lubricator systems, more or less comparable to the equipment meant for the drilling rig, has to be developed for the light vessel without the use of heavy crane operations. As the equipment is installed subsea, full electric and hydraulic remote control is required without compromising safety issues under high wellhead pressure and temperature conditions.

Tools and services have to be reconfigured to retain the functionalities when run on wireline as opposed to coiled tubing or pipe. Tools that are typically activated by weight and/or rotation have to be activated hydraulically. Long tools have to be broken up into modules and shorter sections, and configured to be run in combination with an electric/hydraulic tractor for accessing horizontal well sections. Further advancements are technology enabling pumping services in terms of coiled tubing operations from a light vessel in open sea.

The table below presents these ambitions.

TODAY

Operation	Category A	Category B	Category C
Sand washing		X (VXT)	X (HXT)
Reperforation		X (VXT)	X (HXT)
Sidetrack			X
Milling of scale		X (VXT)	X (HXT)
Pull/set plugs		X (VXT)	X (HXT)
Data gathering		X (VXT)	X (HXT)
WL insert DHSV installation		X (VXT)	X (HXT)
Change ICV position (SMART well)		X (VXT)	X (HXT)
Zonal isolation		X (VXT)	X (HXT)

TOMORROW

Operation	Category A	Category B	Category C
Sand washing	X		
Reperforation	X		
Sidetrack	Very short (CT)	X (< 2000m)	X (LONG)
Milling of scale	X		
Pull/set plugs	X		
Data gathering	X		
DHSV WL insert installation	X		
Change ICV position (SMART well)	X		
Zonal isolation	X		

7. 9 ZERO WHAT? WATER MANAGEMENT IN THE NORWEGIAN OFFSHORE INDUSTRY

Marit Røsok, FMC Kongsberg

Water Management for oil companies is mainly about produced water strategies for maximum production profit, restricted by environmental rules. (Typical strategies: Re-injection into reservoir for pressure support or deposit only; removal of oil residue to max 30 mg/l before dumping to sea; reservoir water stoppers.)

Water Management from the point of view of the authorities must be holistic with respect to all "wet" pollution, which in this article is limited to offshore petroleum activities (drilling, production and transportation). This again is connected to pollution to air.

Politicians have the formal responsibility to ensure the national financial profit and protect our environment by determining the rules. This conflict of interests is as trustworthy as foxes babysitting chickens.

The latter statement is based on reflections during my 20 years as a process engineer in the oil industry. The political priorities are clearly pushing towards increased financial profit at the sacrifice of the environment. This applies both to accepting new drilling/development plans, and giving permission for extraordinary dumping of pollutants. The arguments in these complex issues are neatly phrased to fit the profit motive. This progress is going to be particularly interesting as we have just entered the political so-called zero-discharge age. We are not overwhelmed by the piles of environmental promises from politicians, SFT (the pollution control authority) and the oil companies. And do not to forget the international environmental conventions where water management is central, such as the OS-PAR Convention for the Protection of the Marine Environment of the North-East Atlantic.

Zero discharge to sea is promising reading, but what does it mean in practice? Of course one cannot produce oil without some degree of pollution, but we can improve, and aim for better solutions (better treatment and more re-injection). That is semi-good news for a process engineer with a bad conscience. But how much will the politicians spend on improvements from our huge oil-fortune? What is our basis of existence really worth? And how much is SFT going to intensify their monitoring beyond the annual report from oil companies and odd revision of their routines? Is, for example, SFT going to employ reservoir- and process expertise in order to make better judgments? Is it going to carry out practical monitoring of the oil companies on a regular basis?

Let us look at some "zero" interpretations: According to SFT zero means *zero discharge of potential harmful substances into the sea.* This means precaution, and not necessarily documented harm.

Drilling and production chemicals are tested in laboratories by their respective vendors and categorized thereafter for harmfulness in assumed concentrations: Green, Yellow, Red and Black. Black is worst. Green is regarded to pose little or no risk to the environment according to OSPAR and hence listed on the PLONOR-list. Between these we have yellow chemicals that are not listed on the PLONOR-list and must therefore be regarded potentially risky to dump. Although produced water is cleansed to max 30 mg/l residual oil, its composition when dumped is far different from seawater and contains phenols (hormone teasers), BETEX and radioactive materials, although there is disagreement among researchers about harmful effects.

But surely the produced water in vast amounts puts a persistent burden on marine life and the consequences of accumulation in organisms in the long run are of course not known. In addition, produced water contains dissolved yellow production chemicals when dumped.

But the politicians continue to accept dumping vast amounts of produced water into the North Sea. Also the amount will increase in years to come as oil production declines.

New installations are instructed to arrange for re-injection "if there are no technical reasons that justify otherwise". Does that mean that produced water is potentially harmful from new installations and not from existing ones? Or is it too expensive or "technically infeasible" to upgrade existing installations to fit the zero-philosophy?

What about slowing down production rates on existing platforms? That is likely to reduce the water-cut since the pressure drop around the well-formation decreases as well as the backsweep into the water-layer. Reduction will also increase topside residence time and hence reduce the amount of chemicals needed for effective separation. Plus this gives the environment and ourselves some time to catch our breath and adjust.

The "net present value" advocates will probably call me mentally disturbed suggesting, as their religion claims: *"Get it up fast as he... and burn it off fast as he..."*

Would it be so bad to leave just a little to our descendants? The best we offer them by our past and present strategy is the remains of our greediness, old fun on every step from the industrial chain. Anyway money in the bank is only valuable as long as the planet is reasonably fit and offers things to buy. Money does not taste good or keep you warm, not for long anyway – it is just a trading system... .

Back to business: What about water-based drilling mud, still characterized as green which we are allowed to dump, despite being proven harmful to marine life in relevant concentrations, (ref. PROOF annual meeting, autumn 1994).

Why is such a chemical still green and it is allowed to be dumped into the sea? The PROOF test-mud was barite-based. Is it not reasonable to suspect that other water-based muds, like ilmenite, may cause negative effects too, even if the concentration of heavy metals is less than the test-mud?

If not, has that got anything to do with the ongoing drilling activities in the Barents Sea?

Speaking of which, for the northern territories the rules are clearer and stricter – that is a relief! Zero discharges 95 % of the time, full stop. Well, well. Already, dumping applications for water-based drilling mud, yellow chemicals and some red are accepted by SFT. Zero, you said?

What happens on the day when 95 % of the promised environmental regularity in the north is reduced to 70 %, 50 %, 30 % or less. (This could be due to problems with re-injecting the produced water.) This is likely to occur, and politicians must have some generic emergency plan as a common ground. How much are they willing to invest in fixing a problem? What does it take to shut down a NOK 20 billion installation? Give us some examples!

How does dumping ballast water from remote seas with different biological composition to the Barents Sea influence the vulnerable spawning activities in the Barents Sea?

Finally to transportation: the oil tankers, regarded by many as ticking bombs along our coast. Why is there no international demand for spare engines? Oil installations are always equipped with one or more spare generators, but that is beneficial for profit of course (minimizes shutdown-time).

We have enough near accidents that justify the need for both spare engines and spare fuel systems and intensified state of readiness. We cannot count on luck and nice weather for much longer, particularly when the Russians will increase transport along our coast many times over in the years to come. The Maritime Directorate planned to propose spare engines on tankers as a functional requirement for the International Maritime Organization last December. Was the response positive, and is OSPAR involved in any way?

Yes, there will always be an economic trade-off at the sacrifice of the environment – more or less. But we can afford lots of precautions and not settle for less.

Politicians! Please set the rules according to your "zero" promises and stop swinging like a weathercock with the dollar-wind. Yes, we do produce and use oil and gas, but make us all behave at least half decently. Then, maybe we can look our grandchildren in the eyes 20 years from now.

7.10 E-OPERATIONS – THE INTEGRATED APPROACH

Per Ivar Karstad, Statoil

of realizing e-operations has been the establishment of onshore centers to support operations offshore. Existing and planned onshore centers within the industry are supporting drilling and operational activities worldwide. Although the centers differ in design and use, the basic concept is to apply new technology and new work processes within well planning and execution of drilling operations to increase efficiency.

Operation centers are the first step towards a more virtual organization of the oil business that is about to culminate into global collaboration patterns. Integrated Operations will also

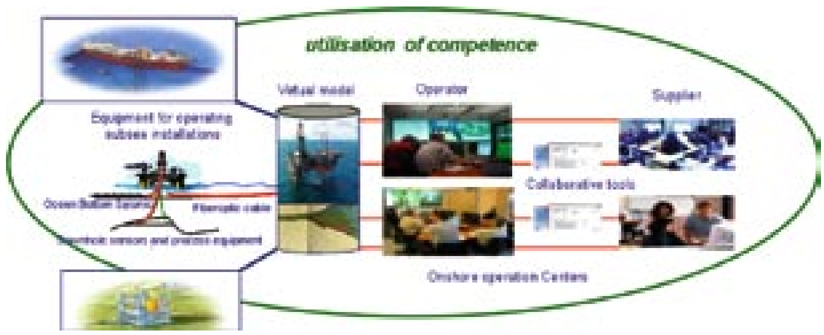


Figure 7.4: Integrated Operations, sketch of how it integrates its various elements

Integrated Operations (IO)
The predicted ICT revolution in the oil and gas industry has been given increasing attention by the industry during the last few years. Different terms describe this new way of doing business; e-operations, e-field, i-fields, Digital oilfield, Field of the future, and Integrated Operations. The common element behind all of them is oil exploitation and operation enabled by ICT. In Statoil Integrated Operations (IO) is defined as:

"an instrumented and automated field that utilizes people and technology to remotely monitor, model and control processes in a collaborative, safe and environmental friendly way in order to maximize field life value".

Integrated Operations is about optimizing three interwoven elements; people, tools/ technology and work processes. For operators and service companies in the industry, one step along the way

include permanent well, facilities and seismic reservoir monitoring providing "continuous on-line" data. Optimization of wells and facilities production control will be improved using onshore experts and advanced modeling tools to model reservoir, wells and facilities performance.

Technological drivers for Integrated Operations
There are three technological drivers that stand out as the main forces for e-operations. First, the continuous development and increase of *transfer networks*. Until recently low bandwidth satellite was the only possible onshore-offshore communication. Fiber-optic networks now make it possible to transfer large amounts of real-time data (video, audio, data control and steering, monitoring data and 3D pictures/models) over long distances. This information infrastructure makes it possible to transmit large amounts of data from

smart sensors in the wells/reservoir and from instrumented equipment.

The evolution of the Internet has provided new opportunities for information sharing and collaboration for teams across technical, organizational and geographical borders. Individuals in different locations, working for different companies can access and/or manipulate the same data at the same time making virtual organization and collaboration more the standard than the exception. A growing number of global vendors (Schlumberger, Halliburton, Baker and others) are increasingly collaborating with Statoil and have their key personnel located in centers and offices in the US, India or elsewhere in the world. At the same time Statoil is running much of its international drilling operations using expert staff in Norway. The design of new Statoil wells in Venezuela is done by virtual collaboration between Venezuela, New Orleans and Stavanger.

The second facilitator of e-operations is *standardization*. One of the most important existing standards in the O&G industry is the Well site Information Transfer Standard (WITSML) for transfer of drilling and logging data. Even if initiatives like WITSML are gaining momentum, extensive work within standardization remains. The various operators and vendors often have different vendor proprietary hardware and software solutions and data are often stored in proprietary databases.

The third main contributor is *the convergence between computing and telecommunications, and the development of collaboration tools/ software.* Video-conferencing, Net-meetings, smart boards, Instant Messaging, and 3D visualization are examples of tools available in most of the operation centers and also made available to the virtual organization that will work on behalf of Statoil. The possibilities these tools provide can be utilized for reducing the need for personnel to be physically present (e.g. in meetings or offshore), and make collaboration between global locations easier.

Research areas

Figure 7.5 illustrates how the Integrated Operations initiatives evolve around four research areas:

Automatic monitoring. This includes condition monitoring of facilities, down-hole sensors in the wells and permanent ocean bottom seismic for geophysical reservoir monitoring. This includes a high degree of instrumentation and use of sensors enabling control of the entire asset (reservoir, well, process and support systems topside/subsea) from a distant location. Developments here can lead to a dramatic reduction in manual monitoring and reporting, and increased transparency and availability of correct information as a basis for better and faster decisions.

Safe and reliable data communications and infrastructure. This means that automatically collected data from reservoir and topside facilities will flow in a safe and reliable manner to all key resources (in-house personnel, onshore control centers, external service/ technology providers) in a network with sufficient capacity and high quality of service.

Real-time processing and analysis. This area includes right-time updates of geo- and reservoir models, integrated production and process optimization tools, tools for well planning and drilling optimization, and condition-based maintenance applications. Improved methodology, workflows and software tools are needed to handle the information flow from the instrumented oil field and integrate measurements and associated knowledge in order to derive the full benefit from the data.

Work processes and decision support. This area involves new work processes for onshore operations and control centers, cross-disciplinary decision making and utilization of advanced visualization technologies. The latter will be the key enabler in incorporating the other three areas. For example, data from automatic monitoring provide important field information for increased oil recovery, but have little value without a safe and reliable data communications infrastructure. The value of the data is realized through the ability to perform the necessary processing and analysis of the data at the right time for decision making.

These four focused areas are seen as vital in order to realize the business value of Integrated Operations and maximize field life value in a collaborative, safe and environmentally friendly way.

Figure 7.5: The four research areas of Integrated Operations

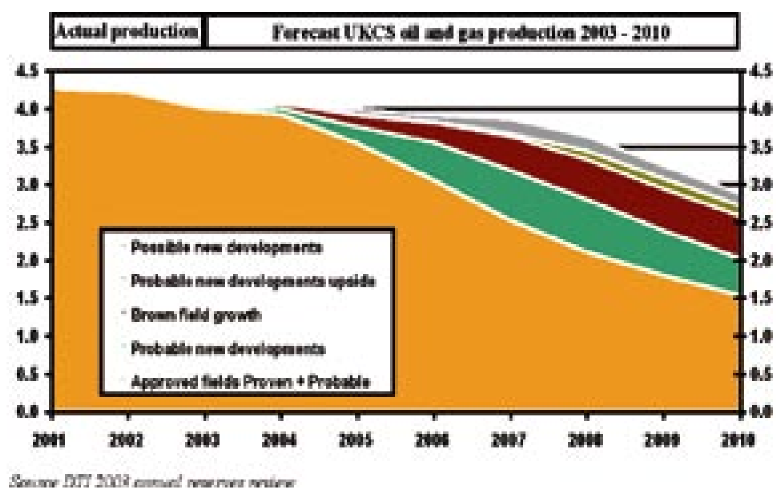
7.11 FUNDAMENTAL METHODS FOR IOR

Andrew Cable & Odd Hjelmeland
Reservoir Laboratories AS

Introduction

Without doubt, oil and gas are probably the most important natural resources to be discovered in the last century. In more recent history, mankind's demand for this finite source of energy and chemicals seems insatiable, which has recently pushed oil prices above USD 60 a barrel.

High oil prices, which are anticipated by some to remain moderately high for the next 5-10 years or more, are probably enough to raise awareness about Improved Oil Recovery (IOR). But there are other political factors that raise the stakes and interest in IOR. For example 'CO_2 Sequestration' which recently made headline news as a means of reducing greenhouse gas emissions (no mention of improved oil recovery here). Also making news in the last 12 months is the marked decline in North Sea gas production, certainly on the UK Continental Shelf (UKCS) which has resulted in the UK being a net importer of gas. However, IOR is not new... it has been around almost as long as the oil industry itself.



UKCS production forecast

Improved Oil Recovery

IOR is interpreted by the oil and gas industry very broadly and is not constrained to subsurface issues. IOR can include any initiative that leads to improved exploration, appraisal, development or recovery of oil and gas. For example re-appraisal of seismic data and the geological field model, or acquisition of new 3D (or 4D) seismic data, since there have been many technological advancements in recent years. Less than five years ago many prospects may have been uneconomic (oil at USD10/barrel), whereas today in-fill drilling, converting injectors to producers to improve recovery may well be very profitable. Dealing with gas hydrates and wax formation in subsea pipelines is another less obvious example of IOR.

Enhanced Oil Recovery (EOR) is a sub-group of IOR processes that deals with subsurface flooding mechanisms. Examples of EOR processes are secondary and tertiary oil recovery processes using immiscible (and miscible) hydrocarbon and non-hydrocarbon gas injection, chemical flooding such as polymer, surfactant and caustic flooding and thermal methods (steam, in situ combustion). There are also more obscure methods such as microbial techniques, mechanical vibration methods and acoustics. There is a requirement to be positive and innovative in maximizing recovery, so this list of processes is by no means exhaustive.

Enhanced Oil Recovery in the North Sea

Oil and gas fields around the Norwegian and UK continental shelves require bold constructive initiatives undertaken in a difficult and hazardous environment. Exploitation involves government, industry, institutions and universities actively communicating and collectively working on a myriad of issues.

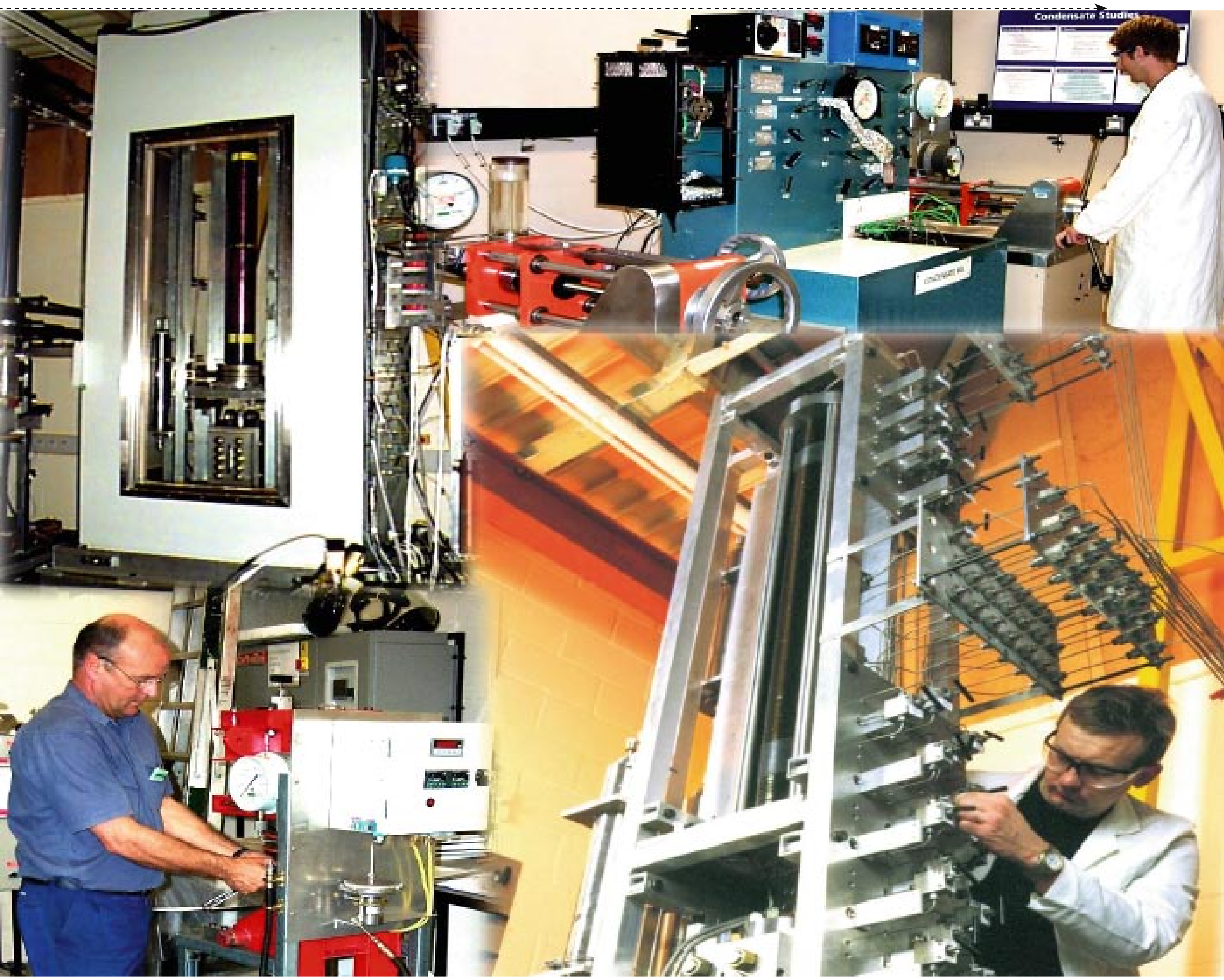
North Sea recovery is generally around 45 % to 50 %. The remaining oil in place may have been by-passed and/or trapped (e.g. reservoir heterogeneity, attic oil, compartmentalization). The North Sea is mature, so many of the remaining prospects might be fields that are much deeper, and therefore exist at much higher temperatures and pressure (e.g. gas condensate fields in excess of 200 °C at 15 000 psi).

Heavy oil prospects might be undeveloped because oil viscosities are very high (20-20 000 cP). Most heavy oil developments in the North Sea currently exist at around 200 cP. There is very little experience even globally of producing heavy oil in an offshore environment. The potential prize here alone is estimated to be more than 4 billion barrels (undeveloped) and another 2-3 billion barrels still to be discovered (source UK DTI). Work on processing this potential resource is already being developed (e.g. heavy oil residue-water emulsion as a power station feedstock).

Tight gas fields, where rock permeability is very low (<0.01 mD) and recoveries from chalk also present future development opportunities.

Understanding EOR Processes

ResLab has two laboratories that specialize in advance reservoir studies (Trondheim and Winfrith, UK). Much of the work undertaken for clients around the world is focused on EOR methods



ResLab Advanced Reservoir Studies

investigating reservoir displacement processes at given temperatures and pressure.

Miscible Gas Injection: Miscible gas injection schemes are potentially attractive methods for improving oil recovery because they can result in lower residual oil saturations than water flooding alone. Gas injection (secondary or tertiary) may also access regions of attic oil bypassed by water flooding. Where there is no route to market associated gas, and environmental considerations prevent flaring, gas injection may also provide a means of managing excess gas early in field life. To achieve a horizontal displacement with gas injection, water may be injected in alternating slugs (WAG) to help control the high mobility of the gas. Currently the use of CO_2 for offshore injection is of particular relevance.

Depressurization Studies: Studies might be investigating 'solution gas drive' where gas is liberated from the reservoir oil below its saturation pressure. Gas evolution will potentially block the larger pores (as the non-wetting phase) enabling additional production of oil. Mobilization of a trapped gas by depressurization is also investigated.

Relative Permeability Modification: Traditionally chemical surfactants and polymers have been (and continue to be) investigated. Displacement characteristics are modified using surfactants by reducing the interfacial tension (IFT) between injected brine and reservoir oil. Polymers are generally used to viscosify the injected brine to improve sweep efficiency. Polymers may also be used to shut off high permeability zones. Microbial techniques would work on similar principles, where 'starved'; microbes (which can access small pores) are fed, and the growth and excretion causes polymerization and shut-off in the target area. Wettability modification in the near well region also has the potential for improving gas productivity for gas condensate reservoirs.

8 Review of Activities and Infrastructure at NTNU/SINTEF in Petroleum Research

8.1 COOPERATION IN PETROLEUM RESEARCH AT NTNU/SINTEF

The key units for upstream petroleum research at NTNU and SINTEF are the Department of Petroleum Engineering and Applied Geophysics and the Department of Geology and Mineral Resources Engineering at NTNU, and SINTEF Petroleum Research. The majority of education and research in petroleum engineering and petroleum geoscience take place in these units. In addition, the Department of Marine Technology at NTNU and SINTEF's MARINTEK are key players in research and technology development related to surface systems and operations. However, virtually all departments of NTNU and SINTEF have research projects in their portfolios that are related to oil and gas activities.

It is a strategic objective of the BRU Project to contribute to more collaboration across departments and disciplines at NTNU and SINTEF in order to reach the overall goal of BRU – better resource utilization of oil and gas. Excellent disciplinary research combined with the added value of cross-disciplinary collaboration may generate shifts in methods and technology to be applied in the industry.

In the following, some of the Departments and Centers at NTNU have described their petroleum-related research activities, infrastructure and expertise. Some of these include their associated SINTEF-activities. However, it should be pointed out that there are many petroleum-related research activities that have not been included in this report, particularly at SINTEF. The reader is invited to go to SINTEF's home page for information on current research projects: http://www.sintef.no/, and to NTNU's home page for research: http://www.ntnu.no/research/index.php

8.2 STRATEGIC RESEARCH AREA AT NTNU: ENERGY AND PETROLEUM – RESOURCES AND ENVIRONMENT

A main objective of NTNU is to be useful to society by utilizing multidisciplinary skills to solve complicated problems of major concern.

NTNU has established six strategic research areas to realize this objective where we will develop activities that have the potential to be visible and be recognized internationally. These are Information and Communication Technology (ICT), Marine and Maritime Technology, Materials Technology, Globalization, Medical Technology, and Energy and Petroleum - Resources and Environment.

The last strategic area was created in 2004, by merging the former Strategic Area Energy and Environment with the substantial activities in petroleum at the university. This means that NTNU can now manage the whole chain of energy challenges from source to end user in a comprehensive way.

We have close cooperation with our research partner SINTEF. More than 750 people at NTNU-SINTEF are involved in our activities, including 240 doctoral candidates and post-docs. They work in six goal-oriented multidisciplinary teams; Smart Energy Efficient Buildings, Center for Renewable Energy, Gas Technology Center, Better Resource Utilization (Petroleum), Energy System Analysis, and Energy and Society.

The Research Council of Norway is the main source of funding through their large research programs "Renergi" and "Petromaks". In addition to providing solutions to complicated central problems, NTNU educates more than 250 graduates to the energy sector each year.

Our vision is *"Technology for a sustainable future"*. The overall goal of our research and education is to contribute to the global innovation processes and bring forward new knowledge, technology and economic solutions that will be useful to society. This will make it possible to meet future energy demands in a sustainable way.

This objective will be accomplished by the following overall strategies:

- Increase the efficiency of end-user consumption of energy
- Contribute to improved resource utilization on the Norwegian Continental Shelf in the whole technology chain from source to end user
- Support technological development towards "clean" electricity and hydrogen as the dominant energy carriers of the future
- Develop systems and technologies to improve the availability and efficiency of these energy carriers
- Support technological development to utilize natural gas (with its high hydrogen content) as an energy source to produce electricity and hydrogen until sufficient renewable energy sources are available (natural gas as a "path" to a renewable society)
- Develop systems and technology to promote and integrate renewable energy sources
- Integrate energy, technology and societal topics in our education, research and innovation
- Be flexible and robust in relation to possible future developments

8.3 PETROLEUM ENGINEERING AND APPLIED GEOPHYSICS

Task no. 1 is a maximum contribution to obtain the highest possible recovery of Norwegian oil and gas resources

The professors in the Department of Petroleum Engineering and Applied Geophysics, NTNU are grouped into drilling, production, reservoir, and applied geophysics. In cooperation with the Department of Geology and Mineral Resources Engineering, NTNU, the Department covers education and research in upstream petroleum. The Department has a total of 23 professors including associate professors, assistant professors and adjunct professors. In addition to the professors, more than 50 Ph.D. candidates, post docs and researchers are currently engaged in research in exploration and production.

Current research projects include phase behavior investigations, reservoir laboratory experiments, well test analysis, reservoir simulation, drilling methods, subsea production systems, rock-physics experiments, hydrates and natural gas experiments, production system analysis, visualization and Virtual Reality applications, petrophysics, 4D seismic analysis, geomechanics-seismics analysis, 4D-reservoir simulation analysis, seismic data analysis and processing, seismic modeling and seismic interpretation.

Drilling	Production	Reservoir	Geophysics
R. Holt	H. Asheim	T. van Golf-Racht[1]	L. Amundsen[2]
A. Rødland	M. Golan	O. S. Hustad[2]	T. Eidesmo[2]
S. Sangesland	J.Gudmundsson	T. Aa. Jelmert	S. Johansen[2]
P. Skalle	H. Herfjord	J. Kleppe	H. Langeland
		O. Torsæter	M. Landrø
		C. H. Whitson	O. B. Lile
			J. R. Skilbrei[2]
			E. Tjåland
			T. Torsvik[2]
			B. Ursin

1) emeritus
2) adjunct (20%)

NTNU and SINTEF collaborate on petroleum research in several areas, in particular in rock-physics, seismics and experimental reservoir projects. Formalization of the cooperation between the Department and SINTEF Petroleum Research is achieved by establishing the Gemini Petroleum Center.

Close collaboration with industry is emphasized by the Department. Long-term cooperation agreements are maintained with the major operators in Norway, and individual research projects are supported by virtually all oil companies and service companies. Around 75 % av all Ph.D. candidates in the petroleum area are financed by industry.

Geological field courses are important elements in the M.Sc. programs. In addition to the regular field courses that are included in basic geology courses, NTNU and industry have developed field courses that place more emphasis on seismics, drilling and wells, and fluid flow. Statoil, Hydro, BP and Shell collaborate with NTNU on field courses at Svalbard, in the Pyrenees, in the UK and in Oman.

The M.Sc. programs in Petroleum Engineering and Petroleum Geoscience at NTNU rank among the largest in the world, with 80-90 M.Sc. graduates per year. The programs are English-language, and currently 40 % of all the students are non-Norwegian. Students from 40 different countries have been enrolled over the past few years.

Key laboratories at the Department include the Virtual Reality Laboratory, the HP Computing Laboratory, the Rock-Physics Laboratory, the Reservoir Fluid Flow Laboratory, the Calorimetric Laboratory, the Reservoir X-Ray Laboratory, and the Multiphase Flow Laboratory.

8.4 GAS TECHNOLOGY CENTER NTNU/SINTEF

The Gas Technology Center at NTNU/SINTEF combines the efforts of NTNU and SINTEF in gas technology. The Gas Technology Center will seek to exploit the synergism of multidisciplinary research to provide knowledge, candidates and tools for applications in the natural gas value chain. The Center has more than 200 researchers and is the largest research center in this sector in Norway. This signifies the national and global importance of natural gas. One of NTNU's six strategic research areas: "Energy and Petroleum – Resources and Environment" is integrated with the Center. Some of the leading edge research work is briefly presented below:

Chemical Conversion
– Research is directed towards new reactor configurations and new catalysts which can selectively convert natural gas (methane) via synthesis gas to useful products, such as methanol, olefins, diesel and NGL components (ethane, propane, butanes) to the corresponding olefins or to fuel additives.

LNG and CNG Technologies
– Research focuses on Base Load processes, heat exchanger design, mini LNG plants, and transportation and distribution systems.

Enabling Production of Remote Gas
– Research will emphasize floating production and the processing of natural gas in remote areas.

Power Generation from Natural Gas
– Research focuses on efficient power cycles with CO_2 capture capability. This includes pre-combustion as well as post-combustion capture, transportation and storage technologies.

Gas to Market
– Optimization of gas transport and gas value into markets. Natural gas is becoming more and more of a becoming a global commodity by loosening the tie between the producer and the consumer. Technology for liquefying natural gas into LNG is the main reason for this. Thereby natural gas can be transported via ships instead of pipelines. There is a wide span of research in this field including more efficient cryogenic cycles, production facilities for stranded gas in particular offshore processes, and mini-LNG systems. The LNG technology used on the Snøhvit Field is strongly dependent on research already performed at NTNU and SINTEF.

The reservoir fluid from a gas reservoir will typically include a mix-in of other phases like condensate and water. Further, water production typically increases in mature wells. The ability to transport mixed well-streams containing gas, condensate and water over long distances is an important factor that will reduce capital expenditure on the Norwegian Continental Shelf. Examples of this are the current Ormen Lange and Snøhvit Field developments. NTNU and SINTEF have been major players in developing technology for multiphase transport.

Natural gas is the fastest growing energy source in Europe. The deregulation of the energy markets and environmental awareness are driving forces in this process. This research focuses on how to optimize the benefits from natural gas, both for individual companies and for society as a whole. The projects range from strategic problems concerning investments and infrastructure solutions to operational coordination of production, transportation, and contract management. The research is based on understanding the physical and financial commodity markets, economic theory, and optimization methods; combined with insights of the technological issues of the natural gas value chain.
A future hydrogen society based on renewable energy sources will include a long transition phase where hydrogen is produced from natural gas. Research activities span production and handling hydrogen as a gas, and includes the end use.

The Gas Technology Center cooperates closely with the BRU Project in selected areas. Concrete examples are found within the areas of Integrated Operations/eField/Smartfield, CO_2 capture and sequestration, and multiphase flow. More information on the Gas Technology Center can be obtained from www.ntnu.no/gass.

8.5 GEOLOGY AND MINERAL RESOURCES ENGINEERING

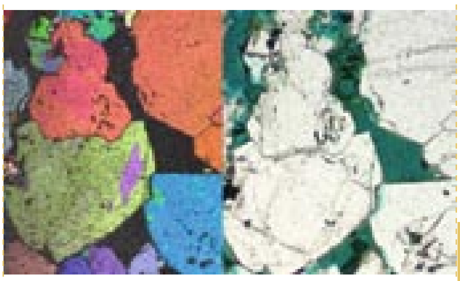
Teaching and research directed towards sustainable management of the Earth`s geological resources.

The scientific personnel are grouped into geology/resource geology, engineering/ rock mechanics and mineral production/ HMS and include 18 of the total permanent staff of 34 in the Department. Four professors and one adjunct professor are involved in petroleum geology activities. In addition, 31 doctoral or post-doc fellows were registered in 2005.

The petroleum geology program includes courses in petroleum geology, sedimentology, stratigraphy, structural geology, basin analysis, diagenesis-reservoir quality, resource evaluation and mathematical geology. Field courses focus on sedimentology and applied courses combining geology and geophysics or reservoir engineering in collaboration with the Department of Petroleum Engineering and Applied Geophysics (IPT). Master's and Ph.D. teaching is focused both on reservoir and exploration problems and benefits from collaboration with IPT, SINTEF and oil companies, in particular Statoil. Nearly 300 have graduated with siv.ing./master's degrees in petroleum geology since the start in 1974, and 16 doctoral theses have been completed since 1987.

Laboratories: microanalysis for reservoir studies are facilitated by state-of-the-art SEM equipment (collaboration with Department of Materials Science and Engineering): high/low-vacuum SEM, cathodoluminescence, EBSD, microprobe, TEM). Other labs: chemical/ XRD, engineering geology/drillability, rock mechanics, mineral dressing, particle, optical microscopy, safety, health/environmental, thin section preparation. Core store: several kilometers of stratigraphic cores are used in teaching at different levels.

Microanalysis/diagenesis studies aim at understanding reservoir properties and is integrated with sedimentology, basin history, as well as aspects of applied reservoir engineering problems. New laboratory techniques promote detailed research on mechanisms of compaction and diagenesis.

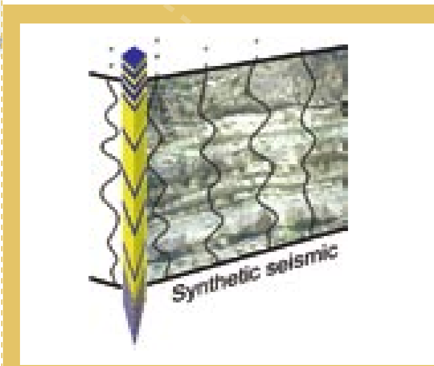


SEM EBSD techniques (left) can be used to map mineral orientation (right: optical micrograph).

Sedimentology:
Modeling of sedimentary architecture is crucial in reservoir and exploration geology. Interpretation of sedimentological and stratigraphic data is the fundament of such modeling. Most of the master's and Ph.D. theses in petroleum geology have been utilizing well- and seismic data from all productive stratigraphic levels on the NCS in order to learn more about how these sediments are distributed. Sedimentology that includes field training is emphasized at NTNU.

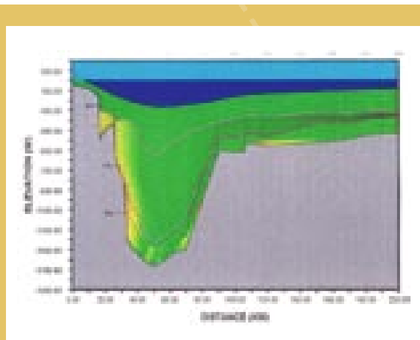
Students logging Jurassic sediments. This annual field course in England has 20-30 participants.

Resource geology/mathematical geology:
The quantification of geological processes is more and more in demand and the Department offers courses in mathematical geology and its application in evaluation of discovered and undiscovered resources, exploration strategies, quantitative basin analysis, play analysis and prospect evaluation. PhD project collaboration includes development and testing of methods for quantification and upscaling of reservoir parameters (SBED tool).



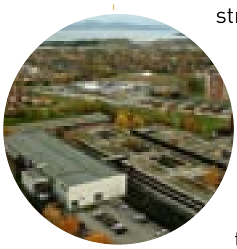
The SOP project – comprises multidisciplinary collaboration between geology and seismics on resolving reservoir heterogeneity by modeling seismic signals from real geological data, through upscaling petrophysical properties using SBED.

Structural geology/basin analysis:
Structural restoration and palaeobathymetry are important tools in predicting source rock and reservoir facies in space and time as well as understanding the timing of hydrocarbon generation, migration and entrapment. Master's and PhD theses have been conducted from Norwegian offshore areas, as well as Bangladesh, Nepal, Tanzania and Angola.



Late Cretaceous reconstruction, northern North Sea. Sand (yellow), shale (green) and water depth (dark blue).

8.6 MARINE TECHNOLOGY



The Department of Marine Technology is a part of the Marine Technology Centre at Tyholt in Trondheim. The Centre comprises the Department, MARINTEK, a research company within the SINTEF Group, and the Centre of Excellence for Ships and Ocean Structures (CeSOS).The Centre has excellent laboratory facilities and is recognized as one of the leading institutes for research and education within marine technology in the world. The scientific staff at the Department are closely involved in activities at MARINTEK and CeSOS, and have a strong network with the national and international offshore industry. Each year, the Department awards 75-100 M.Sc. and 5-10 Ph.D. degrees, including international master's students.

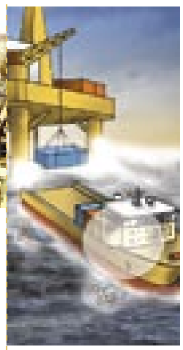
Marine Hydrodynamics is a core activity at the Department and includes analytical, numerical and experimental methods. The extensive range of activity covers classical ship hydrodynamics, propulsion and sea loads on ships and ocean structures.

Marine Structures covers static and dynamic responses, capacity of structures in terms of fatigue and collapse, design of ships and ocean structures, and structural reliability. An important activity on hydroelasticity has been initiated in cooperation with the hydrodynamic group. Phenomena such as vortex induced vibrations and slamming response on ships are considered.

Rig for prototype testing of flexible risers and umbilicals in the Marine Structures Laboratory.

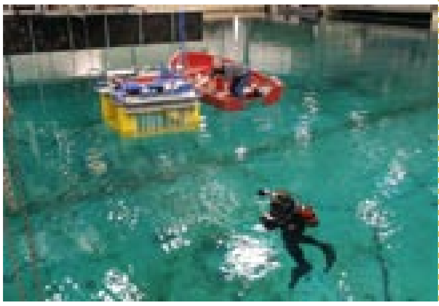
Marine Cybernetics is a new activity that combines marine technology, control theory and industrial information technology. Examples of applications include classical dynamic positioning, crane operations and control of the dynamic behavior of slender structures like marine risers.

Subsea technology plays a key role in today's petroleum production in deep water.



Marine Operations is linked to marine cybernetics and subsea technology. Dynamic simulation of complex operations like pipelaying, deepwater module installation, towing and offshore loading are examples of applications.

Marine Systems includes ship design, marine engineering, fishing technology and aquaculture, but also topics related to the offshore industry like technical operation, life cycle analysis and maintenance technology

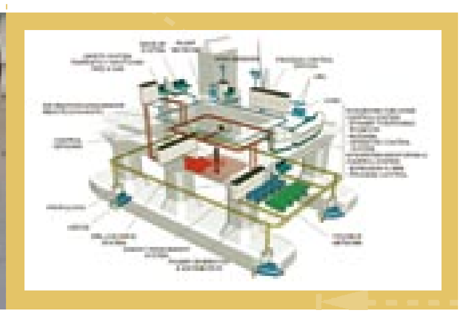


Testing of a floating production platform model including risers and anchor system in the Ocean Basin Laboratory.

Extreme loads on a floating platform is one among many topics for research.

Control of module launching through the wave zone in the Marine Cybernetics Laboratory.

Subsea Technology deals with risers and pipeline systems, and subsea operations like intervention and operation of remotely controlled vehicles.



Shipbuilding and Marine Construction includes most aspects related to the building of ships and offshore platforms, from product modeling and design to welding technology and project management.

Uprighting a trusswork section for a steel jacket platform.

8.7 ELECTRICAL POWER ENGINEERING

The Department of Electrical Power Engineering has 13 permanent scientific staff members and 28 Ph.D. fellows. The research activity is organized in three scientific groups, responsible for the following research areas:

Power Systems (KS)
Operation and development planning, supply reliability and quality, monitoring and protection of power networks, new alternative sources of power production, power markets.

Energy Conversion (ENO)
Power electronics, power control electronics, electrical machines and power generators, electrical equipment, electric heating, field calculations.

Electrical Power Technology (ELA)
Insulation technology, cable technology, power supply to offshore and subsea installations, simulations of current and voltage loads and transients, maintenance and condition monitoring of components, electrical installations in buildings, electrical plants for industrial and maritime applications, EMC, lighting technology.

In addition, the Department's staff includes *technical personnel and administration.* These cover the mechanical workshop, electrical instrument services, computer systems and the administration of the Department.

New Programs of Study
In order to meet the changes in society and business, the Department has established the new Energy and Environment Program in cooperation with the Department of Energy and Process Engineering. An international master's program in Electrical Power Engineering will be established from 2006.

Research strategies
The Department provides an attractive educational environment, and is an interesting partner for industrial cooperation. High priority is given to laboratories as this is a key factor in maintaining top scientific standards and the required profile in electrical engineering.

1 Research staff at the Department are active in international dissemination and regularly publish contributions to the international academic community in the following areas:

Methods for planning and operating energy supply systems
- Energy markets: trading arrangements, financial issues and the environment
- Supply reliability in non-regulated power systems
- Optimal means of carrying out maintenance and renewal
- End-users: quality and reliable power supply

Transport of electricity with specific focus on
- Materials and components for HVDC
- Condition monitoring and maintenance
- Power supply to subsea oil installations
- Load calculations and insulation coordination

Generation, transforming and use of electrical energy
- Renewable sources of energy and new efficient energy systems
- Maritime systems: shipping, offshore, subsea
- Installation systems and energy consumption in buildings
- Power electronics and electric engines

Most of the doctoral work at the Department is to be concentrated on the above areas.

2 Develop cooperation with SINTEF to ensure that scientific staff at the Department are in close contact with industry and the rest of the business community. Work jointly to acquire scientific equipment and use the laboratory facilities in an efficient way.

3 Develop long-term cooperation with research institutes and industrial companies nationally and internationally. This cooperation is to include project and thesis work for students and research for doctoral candidates.

Infrastucture
The Department is well equipped and has several modern laboratories for work with high voltage, high current and electrical heating, power electronics and electrical machines. There are also materials and lighting laboratories. It has its own mechanical workshop and a service/electronics workshop which has operational responsibility for the laboratories and instruments. In addition there is a modern, well equipped computer lab and appropriate software for simulations.

Contributions to Petroleum Research
For production purposes and increased recovery rates it will often be necessary to use large pumps with motors in the MW class. Such installations are already in use, both on the seabed and downhole (ESP – Electrical Submersible Pump). In addition, the fields often become more profitable if the water is separated from the wellstream close to the reservoir. This can save a significant amount of energy as large masses of water in the wellstream do not have to be transported all the way up to the surface.

Future subsea production systems will be based on the installation of modules for the separation of water from the oil and gas on the seabed. The separated water can also be utilized and pumped directly back in the wells by water injection pumps in order to increase reservoir pressure and improve recovery rates.

Such solutions, possibly combined with heating for pipes to avoid the formation of wax in the long risers reaching up to the surface, necessitate an extensive supply of electric power. The power required may be from 5 to 20 MW, depending on the field. The electric power today is usually produced in gaspower plants on board the production ships, but can also be supplied from the mainland. At present, each seabed unit is supplied with power through separate cables extended from the vessels on the surface. The technology of tomorrow will be based on a high voltage cable supplying a subsea module that will take care of energy distribution. This module is equipped with high voltage cables, connectors, frequency converters and distribution cables extending to the separate units.

At present the scientific staff at the Department of Electrical Power Engineering are working on:

- Electrical heating of pipelines to avoid the wax formation.
- Electrocoalescence for efficient separation of water from oil.
- Enabling technology for subsea production of oil and gas using electricity for control and energy supply of subsea production satellites
- Maritime systems for ships and offshore platforms.

Contact: Professor Erling Ildstad

8.8 ENGINEERING CYBERNETICS

There have been close links between the Department of Engineering Cybernetics and the petroleum industry for many years. Cybernetics, or control engineering, is contributing to the industry in four distinct ways.

Feedback control lies at the heart of cybernetics and is a technology to improve design and stretch operational limits. One example is its use to optimize production from gas-lifted wells that exhibit severe oscillating flow conditions. Such oscillations reduce average production, and may pose problems for downstream equipment. With careful design feedback control may eliminate the oscillating flow behavior and allow increased production, typically in the range of 10-20 %. This may be understood by the fact that feedback control actually makes it possible to operate a system at an unstable equilibrium much like stabilizing a nuclear reactor.

Online estimation of non-measurable parameters is important in the petroleum industry, for instance to alleviate the need for downhole measurements in a production well, or as a backup mechanism in the event of sensor or communication failure of downhole instrumentation. As an example, research shows that simple dynamic models can be combined with wellhead measurements to obtain online estimates of downhole properties like wellbore pressure. This implies that a simple dynamic model, typically involving less than five differential equations, may be used instead of highly complex multiphase models that are usually encountered in multiphase flow simulators. Moreover, a simplified model may lend itself to formal analysis such as convergence properties of an online estimator. Even though analyses may be performed under restrictive conditions experience shows that formal analyses provide insight which add to the understanding gained by a simulation exercise and field tests.

Real-time optimization of assets such as a petroleum field with a set of wells, a pipeline gathering system and downstream processing equipment is a technology with a huge potential. This is because operational decisions involve a large amount of parameters and that decisions always are made under uncertainty. The shear scale of the problem necessitates the use of optimization, or mathematical programming techniques. Here, computation time must be limited in a real-time application. Research tasks include efficient problem formulations amenable to nonlinear well and pipeline models as well as typical operational constraints. Further, the development of efficient optimization algorithms is always on the agenda. Model Predictive Control (MPC) is a technology to address uncertainty. This technology is widely applied in the process industries including refineries and petrochemical plants. The basic idea is that optimization is performed on a prediction horizon, of say 30 days, and re-optimized once a day using a receding horizon of 30 days.

Safety-critical systems are and will be even more vital for the protection of people, the environment and assets. As technology for improved oil recovery becomes more delicate, systems for control and surveillance are even more critical topside, subsea and downhole, and better information integration is necessary to achieve the goals. This complexity and functionality puts even more stringent requirements on the safety functions to supply the adequate protection without negative effects on production and flexibility. Requirements from PTIL, IEC 61508 and OLF-070 have to be adapted to the new areas.

Currently projects both in the petroleum industry and academia are pushing the use of control-related methods. This activity fits nicely into the larger concept eField/SmartField and Integrated Operations in which the petroleum industry foresees a significant reduction in operating expenses.

8.9 COMPUTER AND INFORMATION SCIENCE

The Department of Computer and Information Science (IDI) works with a large number of methods and theories which are relevant for oil exploration and the oil industry. Among our activities we can mention: information systems, software engineering and development, safety, security and reliability of information systems, computer assisted cooperative work, information management, databases and database systems, image processing and analysis, scientific computing, computer graphics and visualization, algorithms and analysis of algorithms, performance evaluation of computer systems, data mining, artificial intelligence and reasoning systems, knowledge modeling- and representation, ontology and knowledge systems, computer and computer systems architecture, special purpose hardware and embedded systems.

IDI is a large department and employs for the time being about 170 people. 75 are Ph.D. candidates, and about 40 % of them are from outside Norway. We find our computer courses in most educational programs at NTNU. We have a long tradition of participation in the technology programs. Information technology is now making its way into nearly all areas. Especially we see many and varied applications in medicine, health care and life sciences in general. IDI is an attractive research partner in a number of projects and we must balance our efforts between taking part in many application projects and developing our core skills to maintain our attractiveness for the future.

Three research activities are directly related to the petroleum industry: IDI takes part in the *Integrated*

Information Platform for Reservoir and Subsea Production Systems (IIP) project with one Ph.D. candidate and one researcher. IIP is a collaboration project between the Norwegian oil industry and NTNU. It is supported by the Research Council of Norway and involves both the Department of Computer and Information Science and the Department of Petroleum Engineering and Applied Geophysics. IIP's goal is to increase petroleum production from subsea production systems by making high quality real-time information accessible for the decision support systems in operation centers offshore and onshore. A central issue in this work is the use of technologies from Information Retrieval and Semantic Web to standardize terminologies and process information at the semantic level.

Another project aims at shaping geological horizons using 3D visualization together with equipment possessing haptic feedback. A robotic arm that can be used with six degrees of freedom for position and orientation and with tactile response connected to the positioning is applied to a voxel model of the geological structure. Surfaces are created using a dynamic parametric surface model. A conventional method for surface modeling is to employ parametric surfaces. The dynamic aspect is introduced by defining mass points distributed over the surface and adding spring forces between the mass points. Changes in the model are restricted due to the physical laws governing the behavior of a mass spring system. Measured geological scalar values associated with the voxels are used for defining the mass distribution and the forces to reflect the likelihood of a change to be detected locally.

A third project is on methods for projection on cylindrical and spherical surfaces. The purpose is to utilize a so-called conCAVE for general stereographic projection to make it a simple and relatively inexpensive substitute for a full-size CAVE.

8.10 ENERGY AND PROCESS ENGINEERING

The research activities within the Department of Energy and Process Engineering are organized in four specialist groups:

- Thermal Energy
- Industrial Process Engineering
- Energy and Indoor Environment
- Fluid Engineering

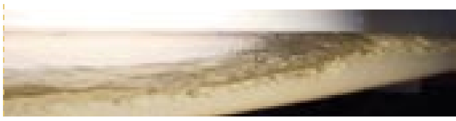
The following activities are related to petroleum production.

MULTIPHASE TRANSPORT

There are a number of challenges related to oil-gas transport in subsea pipelines, often termed "flow assurance".
Our focus is on the flow of multiphase mixtures, the special problem of gas hydrates and pumping / compression of gas-liquid mixtures.

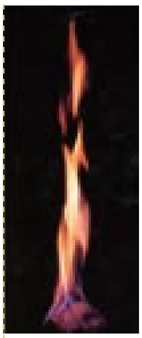
Multiphase flows

Design engineers need flow models to determine the capacity of pipelines (pressure drop and liquid content). The widespread use of the OLGA model (IFE) is largely due to the fact that the models have been verified against high quality, large-scale experimental data from the SINTEF Multiphase Flow Laboratory. The work at the small scale air-water-oil NTNU laboratory has focused on the special problem of unstable flow, with alternating gas and liquid flows at the pipe outlet. We have activities on numerical methods for transient multiphase flows, and simulations have been compared with a number of transient flow experiments in the laboratory.



Gas hydrates

An adjunct professor at the Department has courses on gas hydrates, with focus on the flow assurance aspects of particle flows. Gas hydrates are hydrocarbon-water crystal structures which are stable at temperatures above the freezing point of water (burning ice). The uncontrolled formation of hydrate particles in pipelines is to be avoided due to the risk of pipe blockages and production shutdown. Cold flow (SINTEF and others) is a new approach to the hydrate problem. Here, hydrate particles are allowed to form and flow with the mixture, but in a controlled manner to avoid agglomeration into plugs.



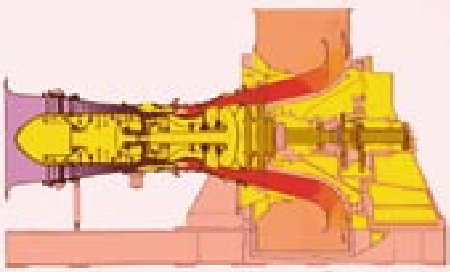
Multiphase pumps and wet gas compressors

Long-distance multiphase transport of oil and gas will eventually involve pumping or compression. New equipment, to be installed subsea, must be developed and there is in particular need for wet gas compressors (e.g. Ormen Lange Field and the Snøhvit Field). The development of the design basis and some testing of equipment is carried out in our laboratories.

ENVIRONMENTAL EMISSIONS TO AIR

Reduction of NO_x-emissions

According to the Gothenburg protocol, Norway is under an obligation to cut emissions of nitrous oxides (NO_x) by 30 %. Gas turbines used in the petroleum industry emit a significant fraction of the total emissions in Norway. The Department is working on several issues related to NO_x. Examples are measurement methods, modeling and simulation of NO_x formation using CFD tools with full chemistry, reduction of emissions by using a novel water injection method, experimental work on burners, and optimization of gas turbine operation.

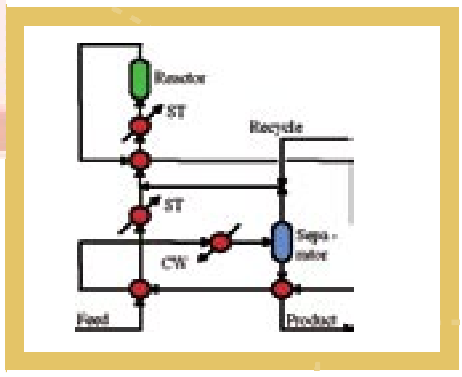


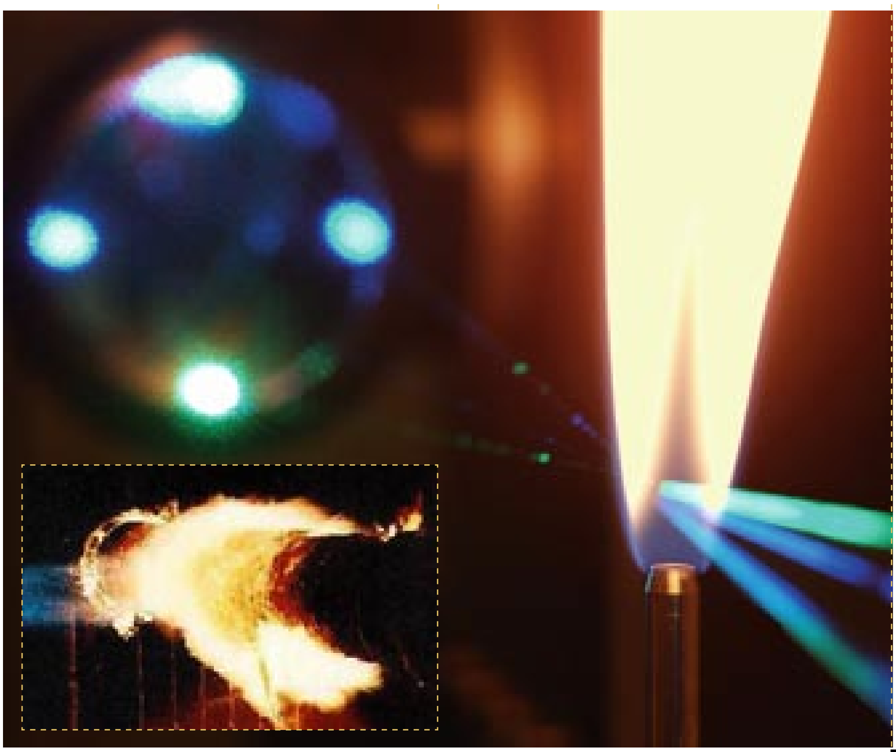
PROCESS

LNG

Our process activities related to petroleum recovery have largely been on LNG processes and general system analysis on process integration.

Further challenges include floating LNG production units, and the development of compact heat exchangers.





Process integration

Pinch analysis is central in the research activities on process integration, and extensions from heat and power applications include hydrogen and water pinch. The integration of thermal power cycles with other types of processes is important. The processes include natural gas processing plants, oil refineries, methanol production plants and LNG plants.

LABORATORIES

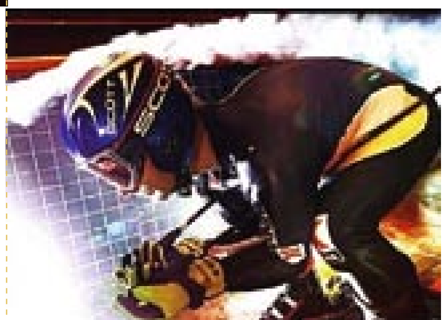
Maintaining the high quality of our laboratories is a main priority in the research strategies at the Department. We have 10 laboratories, with a total of approx. 6000 m^2. Petroleum production related work is in particular carried out in

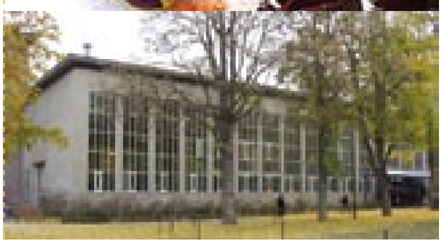
- *Multiphase flow lab*
- *Refrigeration engineering lab*
- *Combustion and laser diagnostics lab*
- *Fuel characterization and gas diagnostic lab*
- *Energy process engineering lab*
- *Wind tunnel lab*

Reduction of CO_2 emissions, and capture of CO_2

There is an increased focus on CO_2 emissions, and it is now starting to be regarded as a limiting factor for further development of oil and gas exploration in Norway. Activities in the Department comprise power cycle design, modeling and simulation of dynamic behavior and control system philosophies for novel cycles, general thermodynamics of CO_2 mixtures and purification methods for diluted CO_2. We also work on optimization of gas turbine operation in order to improve efficiency and thereby reduce CO_2 emissions.

The long-term research collaboration on LNG heat exchangers at our department, SINTEF and Statoil, has resulted in a new spiral wound heat exchanger now being put into production (Statoil-Linde alliance). The heat exchanger at Snøhvit is the first case and the MFC LNG process will be licensed worldwide. Other major research tasks have been insulation technology for LNG tankers, mini-LNG processes and development of simulation tools for optimization of LNG plants.





8.11 CHEMICAL ENGINEERING

The Department of Chemical Engineering has 20 full-time professors and associate professors and about 60 Ph.D. candidates. The petroleum sector is important in terms of research, and also as the sector that employs the majority of our graduating master's students. Historically, about 70 students graduate with a master's degree each year, but at present, this figure is significantly lower. The Department has six specializations/research groups, five of which have close connections to the petroleum sector – the exception being the pulp and paper group. The Department has extensive laboratory facilities.

CO_2 removal

Separation technology

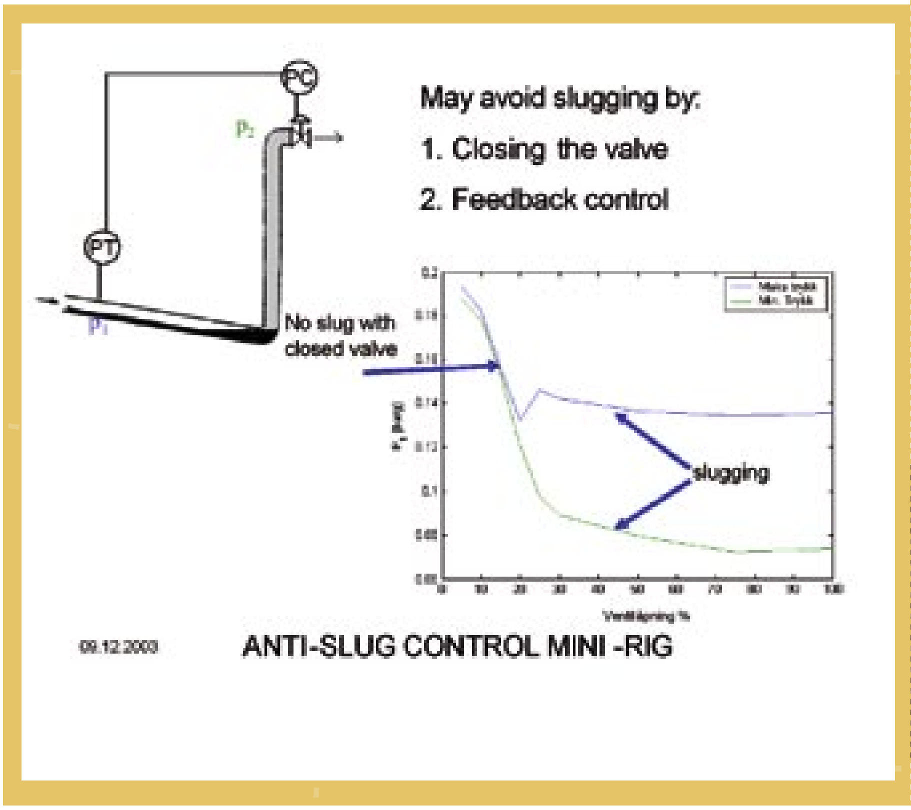
Catalysis and petrochemistry
Together with SINTEF, Professor Anders Holmen heads a large activity in the area of heterogeneous gas phase catalysis. One important objective is to develop improved and new processes for converting natural gas to liquid products. The work is very experimental, but recently the group has entered the area of microkinetics and nanotechnology, with the goal of understanding fundamental surface phenomena.

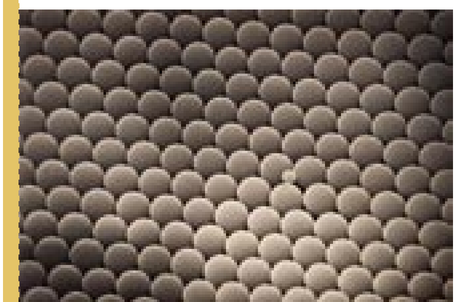
Polymer and colloid chemistry (Ugelstad laboratory)
Professor Johan Sjøblom heads a large group working on issues related to production of heavy crude oils. Topics include crude oil characterization, separation of oil and water, emulsion problems related to crude oil quality and produced water, gas hydrates and transport, characterization of surface active components in crude oils, and chemistry of naphtenic acids and their precipitation.

Process systems engineering
The group works extensively on modeling, simulation optimization and control of large-scale processes, including offshore processing of oil and gas, and refining. Professor Sigurd Skogestad and his group study anti-slug control, both theortically and in a mini-rig. One aim is achieve anti-slug control that is only based on topside measurements.

Reactor technology and fluid flow.
Together with SINTEF, Professor Hallvard Svendsen's group is involved in several large European Commission-funded projects on CO_2 removal. In the Hipgas projects, headed by Professor Hugo Jakobsen, work is aimed at finding the basis for improved and reliable design of high-pressure gas/liquid separation equipment for offshore operations.

Separation technology
New membranes for CO_2 removal are being developed in Professor May-Britt Hagg's group. The potential is enormous if a selective and robust membrane can be developed.





Ugelstad particles

8.12 INDUSTRIAL ECONOMICS AND TECHNOLOGY MANAGEMENT AND SINTEF TECHNOLOGY AND SOCIETY, ECONOMICS AND LOGISTICS

The Department of Industrial Economics and Technology Management has research groups within Managerial Economics and Operations Research, Accounting and Finance, Industrial Management, Organizational Change and ICT, Industrial Psychology and Law, Health, Safety and the Environment. Five professors and three doctoral/post-doc fellows are involved in petroleum-related research.

The engineering master's program in industrial economics and technology management includes courses in various fields within business administration and technology. 140 students graduate with such a master's degree every year and 25 specialize on energy and petroleum-related topics. The Department educates engineers with a combined background from a technical specialization and business administration. We aim to:

- confer proficiency at an international level with regard to technology, economics, management, and the workplace/safety/environment, as well as the interplay among all of these areas,
- place technology in a societal and environmental context/perspective,
- provide expertise for cutting edge work in commerce, industry and public administration

SINTEF Technology and Society, Economics and Logistics
The Department cooperates closely with SINTEF Technology and Society in research projects. A brief presentation of Economics and Logistics research group follows as well as some of our joint projects with them. This part of SINTEF is has 30 researchers (8 of whom hold a doctorate). Most of the contract work focuses on economic analysis and modeling for development, planning and operating enterprises and activities. The projects they are involved in frequently require economic and technical expertise. The objectives are either to maximize profit/minimize the use of resources or analyze and put together the right portfolio of products and investment possibilities in a world characterized by uncertainty.

Customers within the petroleum sector are industrial enterprises like Gassco, Hydro and STATOIL.

Joint NTNU/SINTEF projects:

Investment analysis and portfolio management for offshore oil and gas fields
During the last 25 years we have cooperated with oil companies on the Norwegian Continental Shelf and the Norwegian Petroleum Directorate on decision support tools for planning technology choices, selection of fields and pipelines to invest in and timing of investments. The tool takes a portfolio perspective on the available fields and pipelines and suggests in which order to develop them and which production profiles should be chosen in a 50 year horizon. The methodology used is mixed integer programming and large-scale optimization.

Investment in natural gas fired power plants
In a series of research projects we have analyzed the profitability of gas fired power plants in Norway. The valuation

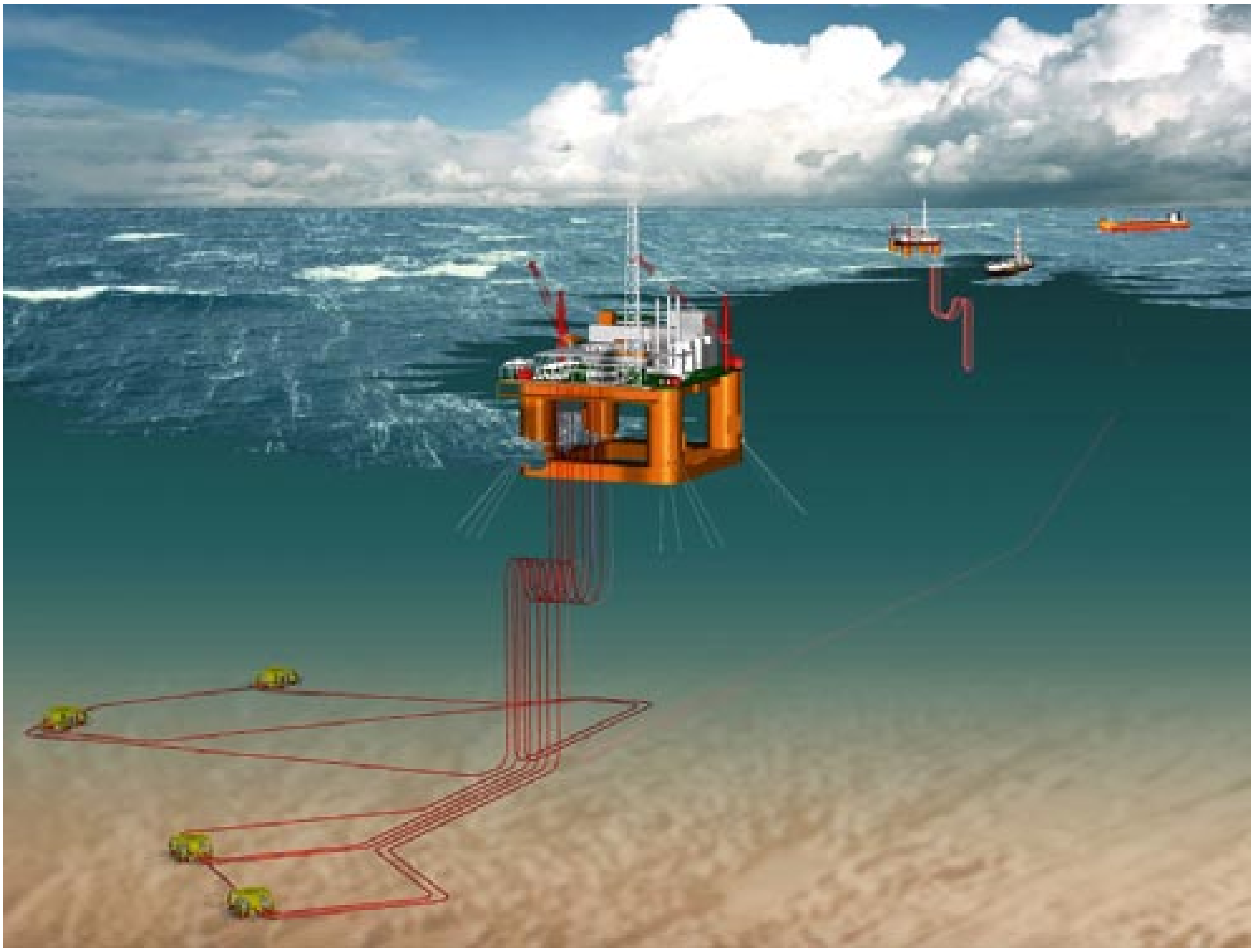
method used is real options analysis, which takes into account the uncertainty of electricity and gas prices, and decision flexibility regarding designing and operating the plant and regarding the decision to delay investment.

We also estimate the value of CO_2 removal technology, accounting for the impact of tradable CO_2 emission quotas and the possible use of CO_2 for improved oil recovery.

Managing the natural gas value chain
We have developed a decision support tool for Statoil focusing on the coordination of production, transportation and contract management in the natural gas value chain. This tool is motivated by the deregulation of the European gas markets and the introduction of markets for transportation capacity on the Norwegian Continental Shelf. The tool includes a scenario generator for describing the uncertainty in natural gas markets and a stochastic optimization engine suggesting allocations to forward sales, spot sales as well as meeting contract obligations and booking transportation capacity.

Transportation optimization for natural gas pipeline networks
The GasOpt decision support tool models a network of pipelines in a steady state model. The flow of natural gas from production fields via processing plants to the market hubs is optimized in order to maximize flow. Flow is modeled both in terms of components of natural gas and the energy content. Pressure characteristics of long pipelines are included through linearization. GasOpt is used for making tactical decisions for capacity utilization and strategic decisions for the security of supply and capacity extensions. The optimization engine uses large-scale mixed integer programming.

Analysis of the efficiency of the tariff structure of pipeline networks
In a Ph.D. project the insight from the GasOpt methodology described above is used to analyze the efficiency of tariff regimes for a network of gas pipelines.



LNG-transportation and inventory planning

A challenge in the future operations of LNG-plants will be to efficiently coordinate the production of LNG with the arrival of ships and transportation of LNG to the markets. In transportation planning we use our long experience from maritime transport optimization in planning models where the transportation decisions are integrated with production and inventory planning in the LNG plant. This is done in order to utilize both the production facilities and the LNG vessels as efficiently as possible.

8.13 PRODUCTION AND QUALITY ENGINEERING

Reliability

The reliability, availability, maintenance, and safety group (RAMS) at the Department of Production and Quality Engineering has been engaged in reliability assessments of offshore systems and equipment since 1978. The group has specialized in the collection and analysis of field experience data from well and subsea equipment. We have been involved in the OREDA project (see http://www.oreda.com) and also in forming the basis for the consulting company ExproSoft (see http://www.exprosoft.com). The RAMS group has further worked with procedures for the qualification of new technology (ref. DNV-RP 203A) and BP's procedures for reliability management of subsea projects. We are also heavily involved in assessment of safety barriers and design and qualification related to the standards IEC 61508/11 and the OLF guideline 70.

- Dr. ing. Leif Sunde from FMC Kongsberg Subsea is an adjunct professor in our group. His main job is responsibility for reliability and qualification in FMC Eastern Hemisphere.
- The international state-of-the-art textbook in system reliability analysis is written by the RAMS group – see http://www.ntnu.no/ross/srt

Risk Analysis

The RAMS group has developed procedures, methods and tools for quantitative risk analysis, with a special focus on risk indicators. Where measurable indicators are used to monitor the risk level during the operating phase of an offshore installation. We have also been active in developing risk acceptance criteria and the assessment and interpretation of risk measures/indicators.

Maintenance Planning and Optimization

The RAMS group has developed methods and tools for reliability centered maintenance (RCM) and procedures for how to implement RCM in an efficient way. We have developed models and methods for cost and safety optimization of maintenance intervals that can be time- or condition based. Focus has been placed on the implementation of data-based maintenance management systems and indicators for maintenance efficiency such as overall equipment efficiency. More information on: http://www.ntnu.no/ross/rams

Manufacturing systems

The manufacturing systems group has its research field on machines and equipment for industrial manufacturing. The activity is mainly directed towards the onshore industry, but in certain areas this expertise is of vital importance for offshore industry as well. This is primarily the case for robotics and manipulator technology, quality assurance and mechanical metrology. In addition, the Department's machine tool laboratory is to a large extent used for the production of equipment for research in the offshore sector.

- Robot/manipulator technology

Remotely operated manipulators are important in subsea operations, and robots/manipulator technology is essential for automation of the operations on the drill floor. The Department has specialized in force-controlled robots as a technology for enhancement of the quality and precision in manipulator tasks, and as a method of automation or provision of automatic support functions in subsea intervention. These are particularly useful methods to provide efficient operations for intervention tasks where unforeseen problems appear. The methods from onshore industrial robot technology will also be used for the building of more standardized intervention systems that will be easier and less costly to deploy and use for different subsea tasks. Several master's theses and two Ph.D. theses have been written in this field at the Department.

- Quality assurance and metrology

The Department has a metrology laboratory equipped for mechanical metrology of shape and dimension in the micrometer accuracy range. Recently the laboratory has been upgraded with the most precise Computerized Measuring Machine (CMM) found in Scandinavia. This machine has accuracy in the class of 0.6 micrometers.

The Department's staff has leading expertise in quality assurance for mechanical products with tight tolerances, and can provide good support for the development of methods and procedures for quality assurance in the offshore sector.

Production management

The production management group works on subjects related to logistics, which includes the global supply chain, production planning and e-business. The group conducts also research on productivity, performance measurements and quality.

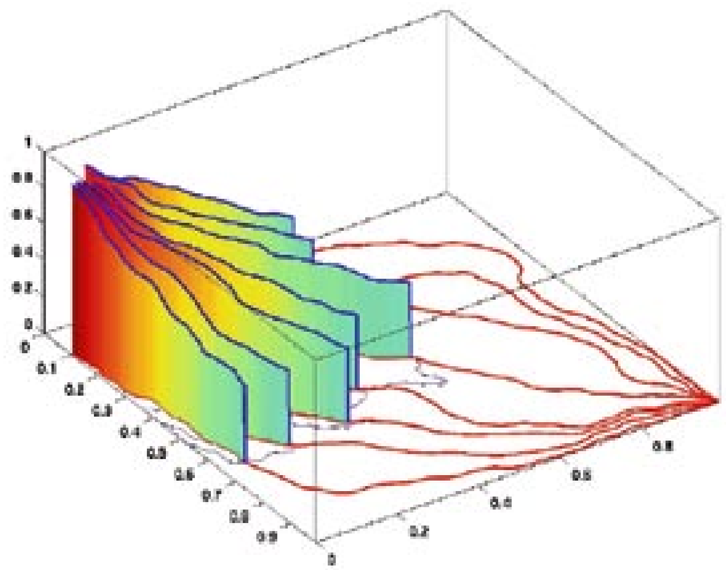
Project management

The project management group is involved in a number of research projects and activities that are conducted closely with Norwegian industry, SINTEF and other academic institutions in Norway and abroad. This cooperation is organized through the Norwegian centre for project management. Research projects are carried out within the following fields; knowledge management, risk management, stakeholders management, virtual project organizations

8.14 MATHEMATICAL SCIENCES

- Mathematics in Petroleum Research
Mathematical modeling provides powerful tools in analysis and evaluation of complex physical systems like hydrocarbon recovery. Researchers at the Department of Mathematical Sciences at NTNU have been involved in petroleum-related research for more than two decades. Examples of current research activities are:

Uncertainty in Reservoir Evaluation
URE is a research consortium initiated in 1994. Presently, focus is on integration of time-lapse seismic data and production history in reservoir characterization; and near-well modeling. The aim is to provide new, creative mathematically based solutions to recognized challenges in reservoir evaluation. Professors at Department of Mathematical Sciences and Petroleum Engineering and Applied Geophysics are involved in URE and funding is provided by four petroleum-related companies, the Research Council of Norway and NTNU.
Reference: www.math.ntnu.no/ure



Department of Mathematical Sciences facts www.math.ntnu.no

Research areas
Algebra - Analysis - Numerical Analysis
Topology/Geometry - Statistics

Size

Professors	44	total
Ph.D. candidates	35	total
M.Sc. students	130	total

M.Sc. programs (degree candidates)

Mathematics and Statistics	10	per year
Industrial Mathematics	35	per year
Biomathematics[1]	10	per year
Mathematics Teaching	5	per year

Ph.D. program (degree candidates)

Mathematics	5-9	per year

[1] BSc only.

Fluid Flow Front Tracker
The flow of hydrocarbons is described by nonlinear partial differential equations. In the front tracking approach the interface between various phases is treated separately for better accuracy. New and improved numerical techniques are developed in order to improve calculation efficiency and accuracy. Professors at the Department of Mathematical Sciences have been active in this field for over twenty years.
Reference: www.math.ntnu.no/~holden/fronttrack/

Environmental Process Modeling
Sea waves and wind induce loads on offshore petroleum installations. It is important to map the resulting responses in order to optimize the construction of the installations. Part of this work is carried out within the Centre for Ships and Ocean Structures at NTNU. This is a Centre of Excellence established by the Research Council of Norway in 2003, and the Department is an associated member of this centre.
Reference: www.cesos.ntnu.no

Opportunities
The Department has both expertise and extensive experience in computational methods for evolutionary problems. Focus is on accuracy and reliability, efficiency and good long-term behavior.

8.15 PHYSICS

The Department of Physics offers a curriculum within a broad spectrum of physics courses. The Department has 31 professors, 9 associate professors, 17 post-docs and about 50 Ph.D. candidates. Research activities are connected to various subdivisions covering Applied Physics, Biophysics and Medical Technology, Complex Materials, Condensed Matter Physics, and Theoretical Physics. An overview can be found on our homepage (http://www.phys.ntnu.no/prosjekter)

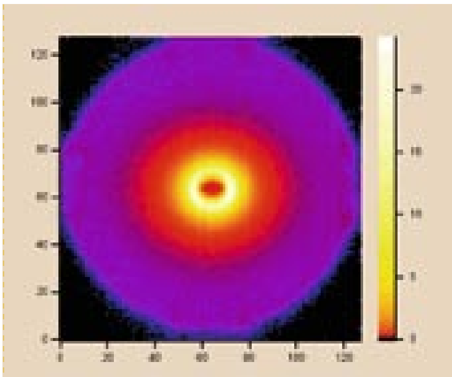
The research activities in the Department focus on several petroleum-related areas such as porous media. A brief description is given here. Most of the activities below are concentrated in the "Complex Group" with professors Alex Hansen, Jon Otto Fossum, Kenneth Knudsen and others as active members at the Department. To a large extent, this work is done in collaboration with the University of Oslo and the Institute for Energy Technology (IFE).

1 *Fracture network statistics.* This project is funded by VISTA and is focused on studies of real facture networks in the light of modern network theory.

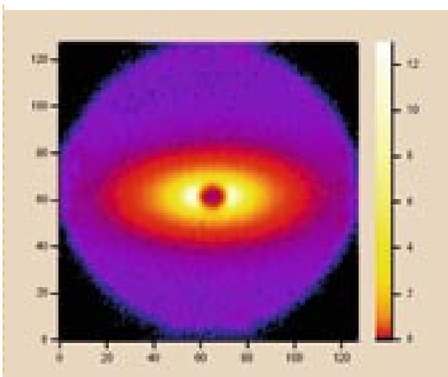
2 *Hydro fracturing.* This is a project funded by the Petromax program at the Research Council of Norway (part of the total grant of about NOK 12 million to the Complex Group collaboration). This fracture process is studied in generalized "beam"models. In addition, buckling is studied and how buckling affects the fracture processes in plate structures.

3 *Two-phase flow in porous media.* Numerical studies of two-phase flow displacement processes by implementing the two or three dimensional porous medium on a three or four dimensional torus. In this way the fluids affect each other so that steady-state can be achieved – corresponding to the conditions deep inside a reservoir. This way of approaching the problem is new. We have contacts with Statoil though NTNU's Technological Transfer organization since the software developed can easily be exploited and used as a practical tool to calculate relative permeability curves – especially in connection with Statoil's work on the reconstruction of pore geometries.

4 *Pore structure and dynamics of water uptake in silicate layers (clays).* The study of the inner structure of clay-water systems is important for knowledge about the organization at different length scales, the ultimate goal being to achieve a description of structure and macroscopic behavior. Dehydrated clay is porous and has oriented pores at nanoscale. The form and size distribution of these pores is important for material qualities like mass, stiffness, permeability for fluids. The use of small angle neutron scatterings (SANS) is important in studies of such materials. In the collaboration, the neutron beams, for example, from the JEEP-II reactor at IFE can be employed to achieve 2-D "neutron photos" of inner structures of systems.



Symmetric pores perpendicular to layers



Asymmetric pores parallel to layers

The images above show how the distribution of asymmetric pores produces an anisotropic scattering picture when using the SANS technique. A detailed analysis of the images reveals information about both average pore size and the surface area in different directions

5 *Electromagnetic seabed logging, SBL.* This is an application of marine-controlled source electromagnetic sounding that can improve the accuracy in detecting and characterizing hydrocarbon reservoirs in deepwater areas. The basis of SBL is the use of mobile horizontal dipole radiation source and an array of seafloor electric field receivers. High resistive layers in hydrocarbon filled reservoirs do not attenuate the electromagnetic waves to a great extent (in contrast to water structures) and propagation is relatively efficient. The reflections of the electromagnetic pulses emitted are recorded and contain useful information about the layer structure. The NTNU activity (together with a company, EMGS) in seabed logging development is centered around theoretical models and down-scaled experiments.

8.16 MATERIALS SCIENCE AND ENGINEERING

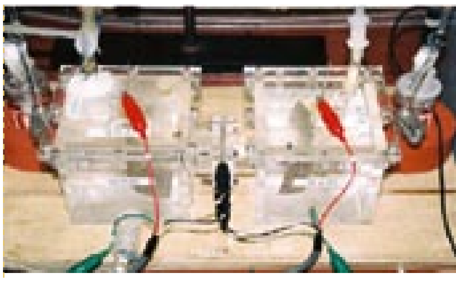
The Department of Materials Science and Engineering has been engaged in offshore-related research since 1980 within failure analysis, welding, fatigue, corrosion and scaling.

Areas of specialization
Materials Production, Electrolysis and Extractive Metallurgy, Process-Microstructure-Properties Relationship, Metal Forming, Material and Process Modeling, Casting and Solidification, Advanced Light Alloys, Fatigue and Fracture, Phase Transformations, Welding Metallurgy, Metal Refinement, Materials Science of Ceramic Materials and Functional Oxides, Carbon Technology, Scale Prediction, Corrosion and Surface Science, Electrochemical Energy Technology.

Mineral scaling, an advantage and a nuisance
Scale and sand production is a growing concern for the oil industry as more water is produced. We have 20 years of experience in mineral scale prediction and handling. MultiScale is a software package developed by us in cooperation with Statoil that is used worldwide by oil and service companies. Lately we have also developed a sand stabilization technology that is based on controlled mineral scale deposition.

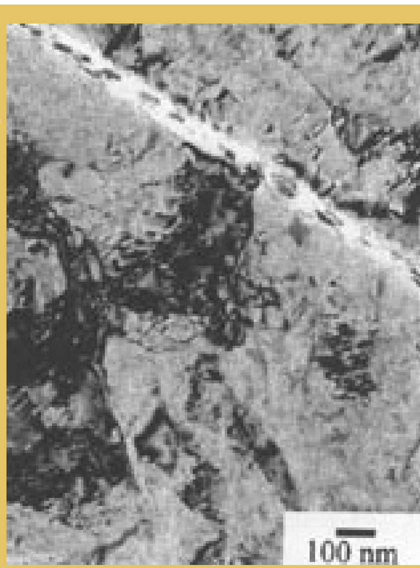
Surface science/corrosion
The work involves the modeling of corrosion protection of offshore steel structures by electrochemical means (cathodic protection - CP).

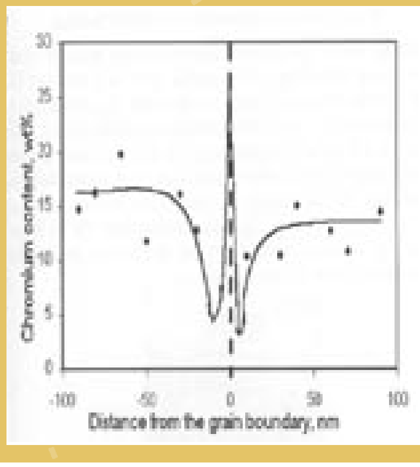
Characterization of hydrogen entrainment in steel to prevent embrittlement failures in offshore pipelines and subsea equipment



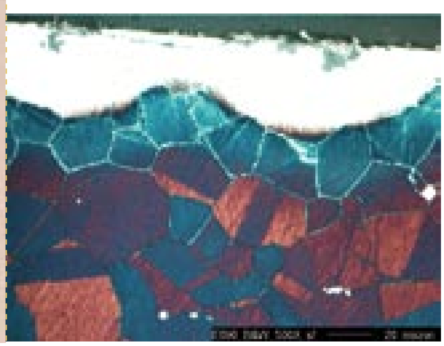
Eletrochemical cell for measurement of hydrogen entrainment and diffusion in steel.

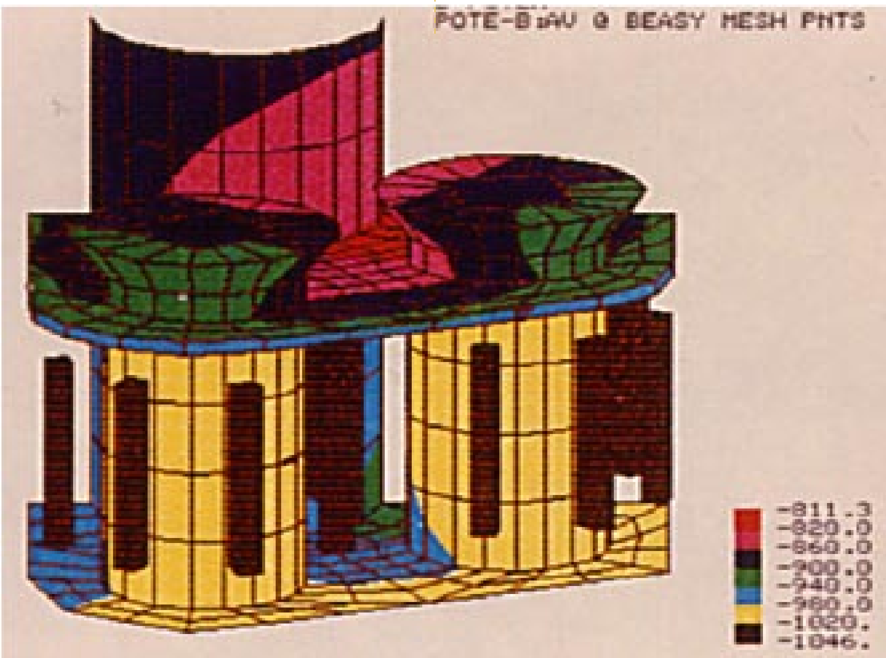
Intergranular corrosion in HAZ of supermartensitic stainless steel pipelines after welding
This corrosion phenomenon is due to growth of Cr carbides at prior austenite grain boundaries during welding (TEM image, below), causing Cr depleted zones close to the boundaries (graph, below).





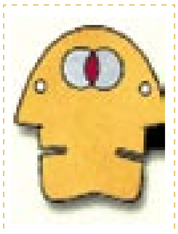
Metal dusting corrosion in Ni-based superalloys used in plants for conversion of natural gas to syngas and methanol
Carbon diffuses into alloys during long-term exposure at 400 to 800°C, causing decomposition of the metal into dust consisting of metal particles, coke etc. An example of carbon attack (white rim zone) extending into the interior of a plant-exposed superalloy along the grain boundaries is shown below.





Numerical model of CP in an offshore steel structure piling (courtesy CorrOcean a.s.).

8.17 INDUSTRY'S INNOVATION FUND AT NTNU

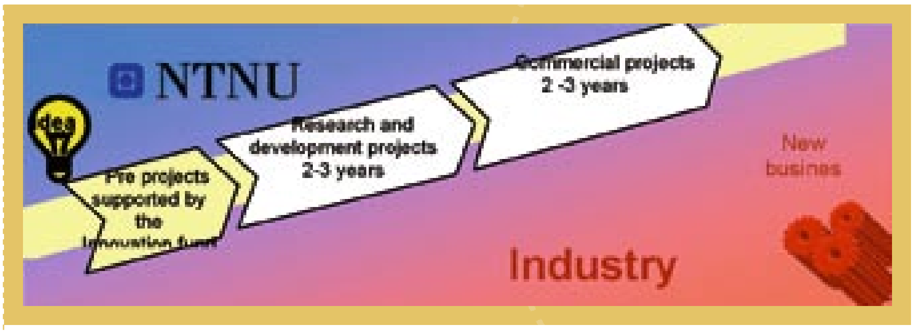


History

Industry's Innovation Fund at NTNU was established in 1998 by 16 Norwegian companies with the aim to promote cross-disciplinary and industry oriented research at NTNU in close collaboration between the university and Norwegian industry. 19 Ph.D. and post-doc candidates carried out research in the fields of Energy and the environment, Transportation and logistics, Medical technology, ICT and Organization. Industry contributed with prioritized research issues and case projects. An external evaluation in 2003 concluded that the Innovation Fund had led to important scientific results, promoted cross-disciplinary relations across NTNU and closer relations between NTNU and industry.

Current goal

Inspired by these results, the Innovation Fund has initiated a new phase from 2005, with the following goal:



Promoting a fast innovation track based on research collaboration between NTNU and Norwegian industry

The way we work

The Innovation Fund gives financial and advisory support to idea development projects and pre-projects where researchers from NTNU and business people work together in the very early stages of idea generation and technology testing. These projects initiate larger research and development projects which are the drivers of commercialization and development of new business.

Funding

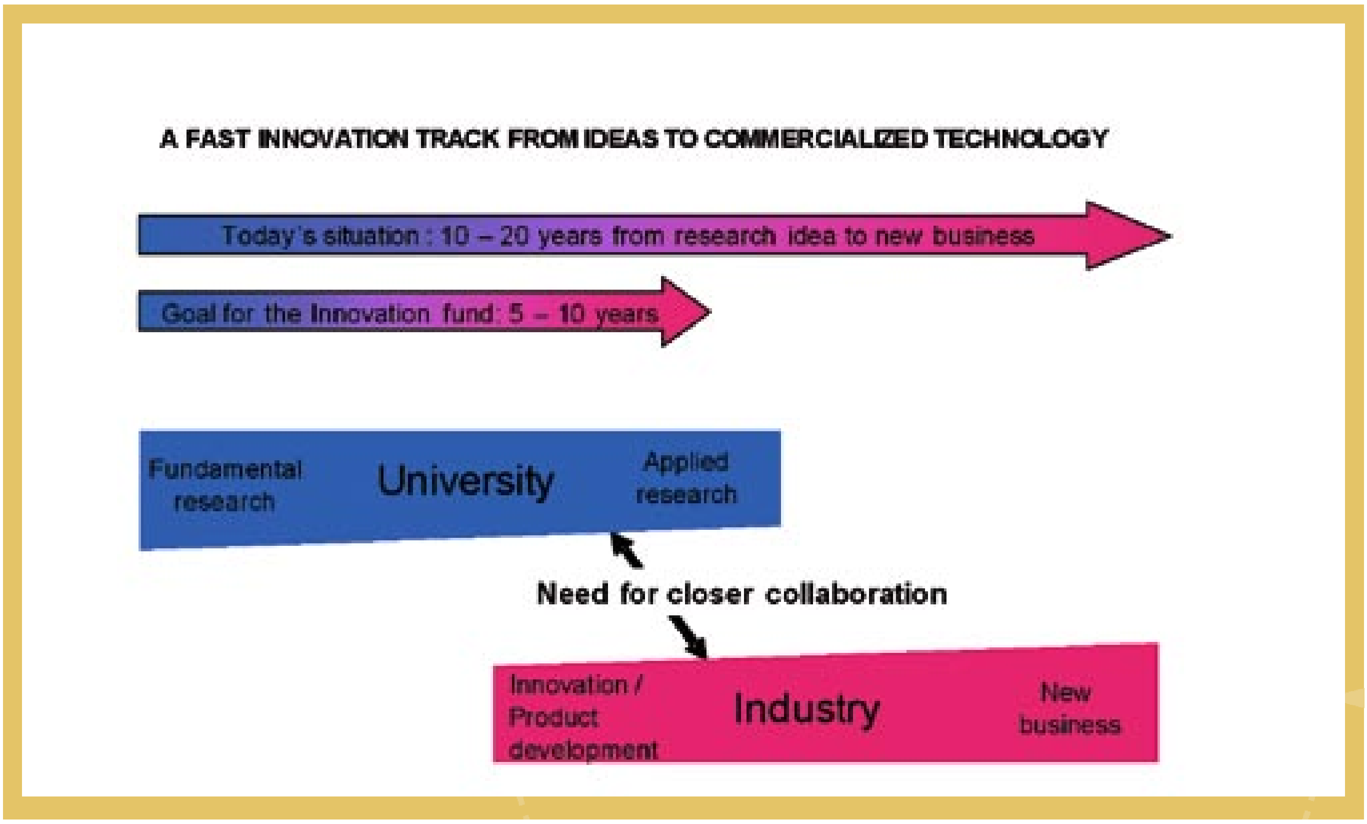
The phase II of the Innovation Fund is financed by membership from business and the Norwegian Ministry of Trade and Industry. Currently, the fund has 10 members:

Norsk Hydro, Statoil, Elkem, Aker Kvaerner, Norske Shell, ConocoPhillips, Total E&P Norway, Gassco, Gaz de France, Umoe Mandal.

Areas of activity

With the heavy participation from the oil and gas industry it is natural that a major part of the activities of the Innovation Fund belong to this area. Examples of current projects are:

- E-field; Development of a large research and development program
- Support to the BRU project
- Various projects on subsea technology



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