University of Stavanger

THE NATIONAL IOR CENTRE OF NORWAY

Final report
2013-2021

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Contents

Foreword by Head of Host Institution

As a young University but with more than three decades of petroleum high-level competence, the University of Stavanger (UiS) is proud to have been the host institution of The National IOR Centre of Norway over the last 8 years.

In 2013, the Centre was awarded by the Research Council of Norway after a national competition and UiS was given the opportunity to show leadership within improved oil recovery (IOR) research and competence building. A basis for being able to establish such a strong team was the joint forces created by the key research partners UiS, NORCE, and IFE, and the industry partners. The Centre has delivered top educated young scientists and leading-edge research results now published in high quality and recognized journals.

As the Dean of the Faculty of Science and Technology and member of the centre board I was always impressed about the excellent quality discussions and feedback between the research and user partners, and how the cooperation led the way for the achievements that are summarized in this report. The methods, understanding and practices developed in the centre will certainly contribute to an increased value-creation of the Norwegian Continental Shelf.

The learnings of the Centre will impact the technology development within improved oil recovery (IOR) for decades to come, even more when energy security, effectivization, reduction of environmental impact and achieving the climate goals are imperative. On this regard, the National IOR Centre of Norway has inspired the University of Stavanger to endeavour into a new Petrosenter, the National Centre for Sustainable Utilization of the Norwegian Continental Shelf – NCS2030. This new centre, granted by the Research Council of Norway and announced personally by the Minister of Higher Education and Research, Ola Borten Moe in December 2021, is the next natural stepstone where we as a host institution, together with the research and user partners, aim to contribute over the next 8 years to the research knowledge and technology development necessary to develop the NCS into a sustainable energy system, contribute to reach the climate goals and continue value creation.

The National IOR Centre of Norway and now the NCS2030 centre show the leading capacity of the University of Stavanger within education and research in the energy sector, and its ability to quickly adapt to the energy transition.

Øystein Lund Bø,
Dean of Faculty of Science and Technology

Photo: Elisabeth Tønnessen/UiS

Foreword

The eight years of The National IOR Centre of Norway has come to an end. We started off in 2013 with ambitious goals and ended with better knowledge and tools than ever from the Centre. Looking back, we can be proud of our last achievements in improved knowledge and tools, and we have now a stronger and international leading IOR research team and building blocks making us and our industrial partners smarter in day-to-day work with better efficiency and more confidence.

Our PhD and postdoc candidates are our best knowledge dissemination ambassadors in oil and gas companies, academic institutions and research groups. In addition, our recommended practices, scientific publications and research reports as the collective memory will form important stepstones for our future research, education and training of the new generation of researchers and engineers. I am sure that we all share the gratefulness and privilege in being part of this memorable journey through working with inspiring colleagues and having friends in a large IOR network.

Even more encouraging is our new research centre, the National Centre for Sustainable Subsurface Utilization of the Norwegian Continental Shelf – NCS2030. We truly believe that we are well prepared for this continued endeavor to bring the Norwegian Continental Shelf (NCS) to the world-leading sustainable energy producer jointly with new offshore industries. We are looking forward to continuing our contribution for more value creation from NCS and at the same time fulfil the Greenhouse Gas emission reduction goals set out by our industrial partners in line with the national and international commitments.

Finally, great thanks to all for being part of The National IOR Centre of Norway, and I wish you all a successful future in your organization.

Ying Guo, Centre Director

The National IOR Centre of Norway has now come to an end after 8 intensive years of competence building, student education, academic and industry collaboration, and deliveries towards a better understanding and management of the reservoirs. I want to express my thanks to everyone involved in this exciting and productive journey! The Centre has established recommended practices in assessing Enhanced Oil Recovery (EOR) strategies with attention to all the steps in the process, including core material handling, assessments of the microscopic mechanisms through experimental procedures and development of improved pore, core and field scale models.

In addition, the Centre has developed new data acquisition methods and workflows to better resolve the remaining potential in the fields. Examples of this are the developments made in interwell partitioning tracers and the improvements in ensemble modelling integrating more data types while improving open source softwares to enable a stronger understanding of the remaining uncertainty and opportunity space. The collaboration between the Centre and the industry has been continuously strengthened along the lifetime. The delivery roadmap initially set-up in partnership provided a good strategic framework for setting up and connecting specific tasks. The delivery forums have then allowed more engagement of company experts in the various tasks and ensured both knowledge transfer to the industry as well as feedback and guidance for further research. Finally, the clear definition of deliverables by the technical committee allowed a focused effort towards finished work products directly usable by the partner companies.

The Centre is ending but has planned its successor, the National Centre for Sustainable Subsurface Utilization of the Norwegian Continental Shelf. The new Centre will build on the recognized competence and the learnings acquired to date, and expand the scope related to energy efficient recovery but also investigate alternative business models for a more sustainable subsurface value chain.

Thierry Laupretre, Chairman of the Board

Summary

The National IOR Centre of Norway strived for developing methods and tools to support cost efficient and environmentally friendly solutions for improved oil recovery on the Norwegian Continental Shelf. Academic excellence and close cooperation with the industry have been key factors for the success of the Centre.

The Centre (2013-2021), hosted by the University of Stavanger, included two research partners, the national research organizations IFE and NORCE. The Centre's consortium comprised seven companies from the oil and gas sector and two service companies. The latter contributed to the Centre with both in-kind funding and research. The research team has published almost 200 journal papers and has given more than 700 presentations as conference contribution or scholarly presentations. Several researchers in the team have received awards related to their contributions in the oil and gas industry during the Centre lifetime; examples are the NPD IOR Award (Svein M. Skjæveland, 2018; Geir Evensen, 2020) and the SR Bank's Innovation Award (Arild Lohne and Oddbjørn Nødland, 2017).

A large part of the activities involved education of a large number of PhDs (15 completed by 2021) and postdocs. They have been contributing to delivering and disseminating research results in research community and broader audience. International cooperation has been a key component of the Centre with mobility of students and researchers in Europe, North America and Asia.

The Centre conducted research on oil recovery at multiple length scales and conveyed competencies from several scientific fields (among others, geology, reservoir chemistry, material science, computational engineering and methods, advanced mathematics and physics). The activities included both experimental and modelling work which complemented each other. Being able to connect (oil) recovery mechanisms at length scales spanning from core to pore and field scale require both in depth understanding of mechanisms and effect of parameters at each scale and a more holistic view of the problem at hand. The industry views exchanged during regular technical and board meetings, targeted workshops, annual conference and delivery forums contributed to keeping high level of relevance of the Centre activities towards applications and operational settings.

The knowledge generated in the Centre has been organised in an online archive at the University website easily accessible to partners and interested parties. Furthermore, the Centre gave rise to several initiatives within education, research and innovation. The Petrosenter NCS2030 was granted funding by the Research Council of Norway in December 2021 and, with a similar collaboration between academia and industry as in the IOR Centre, will expand the research focus on the topics within sustainable subsurface utilization. The Subsurface Academy is an initiative by the University of Stavanger within the education aspect and focus on preserving subsurface competence and extending it to cope with future energy challenges. A newly granted project funded by the Norwegian Directorate for Higher Education and Skills started in January 2022 with 5 industry partner and will investigate how the university can best support the challenges of the future in the energy sector. The development of software and simulation tools in the Centre has also seen the spin off of an innovation project with industry partners that will investigate commercialization options.

Summary (Norwegian)

Det nasjonale IOR-senteret har utviklet nye metoder og verktøy for kostnadseffektiv og miljøvennlig oljeutvinning på norsk kontinentalsokkel. Faglig dyktighet og nært samarbeid med industrien har vært nøkkelfaktorer for senterets suksess.

Universitetet i Stavanger har vært vertskap for senteret (2013-2021). Forskningspartnere var IFE og NORCE. Senterets konsortium besto av syv selskaper fra olje- og gassektoren og to oljeserviceselskaper. De to sistnevnte bidro med både finansiering og forskning.

Forskerteamet har publisert nesten 200 journalartikler i løpet av senterets levetid og har holdt mer enn 700 presentasjoner (konferansebidrag eller vitenskapelige presentasjoner). Flere forskere i teamet har mottatt priser knyttet til sine bidrag innen petroleumsfeltet i løpet av senterets levetid; eksempler er ODs IOR-pris (Geir Evensen, 2020) og SR-banks innovasjonspris (Arild Lohne og Oddbjørn Nødland, 2017).

En stor del av aktivitetene innebar utdanning av en rekke ph.d.-kandidater (15 har fullført ved utgangen av 2021) og postdoktorer. De har bidratt til å levere og formidle forskningsresultater i forskningsmiljøet, men også til et bredere publikum. Internasjonalt samarbeid har vært en sentral del av senteret med mobilitet av studenter og forskere i Europa, Nord-Amerika og Asia.

Senteret forsket på oljeutvinning i flere lengdeskalaer og formidlet kompetanse fra flere vitenskapelige felt (blant annet geologi, reservoarkjemi, materialvitenskap, beregningsteknikk og metoder, avansert matematikk og fysikk). Aktivitetene omfattet både eksperimentelt og modelleringsarbeid som utfylte hverandre. Å kunne koble sammen utvinningsmekanismer i lengdeskalaer som spenner fra kjerne- til pore- og feltskala krever både dyp forståelse av mekanismer og effekt av parametere på hver skala og et mer helhetlig syn på problemet.

Bransjens synspunkter som ble utvekslet under regelmessige tekniske møter og styremøter, målrettede workshops, årlige konferanser og leveringsforum bidro til å opprettholde høy relevanse av senterets aktiviteter for applikasjoner og drift.

Kunnskapen som genereres i senteret er organisert i et digitalt arkiv på universitetets nettside, lett tilgjengelig for samarbeidspartnere og andre interesserte. Videre ga senteret opphav til flere initiativ innen utdanning, forskning og innovasjon. Petrosenteret NCS2030 ble innvilget med midler av Forskningsrådet i desember 2021 og vil, med et lignende samarbeid mellom akademia og industri som i IOR-senteret, i stedet fokusere på forskningstemaer innen bærekraftig undergrunnsutnyttelse.

The Subsurface Academy er et annet initiativ fra Universitetet i Stavanger innenfor utdanning og fokuserer på å bevare undergrunnskompetansen og utvide den til å takle framtidens energiutfordringer. Et nylig bevilget prosjekt finansiert av Direktoratet for høyere utdanning og kompetanse startet i januar 2022 med fem industripartnere. Her skal vi undersøke hvordan universitetet best kan støtte framtidens utfordringer i energisektoren.

Utviklingen av programvare og simuleringsverktøy i senteret har også satt i gang et innovasjonsprosjekt med industripartnere som skal undersøke alternativer for kommersialisering.

Vision

In the Centre application, the main objective and vision of the Centre was ”to contribute to the implementation of cost efficient and environmentally friendly technologies for improving oil recovery on the Norwegian Continental Shelf.”

The world needs energy. Up to present day oil and gas have contributed to the primary energy by more than 80 %, and even in the 2-degree scenario of the United Nations more than 50 % of the total energy must come from oil and gas. On the Norwegian Continental Shelf, more than 50 % of the total discovered resources are still left in the ground. By extracting most of the discovered resources using existing infrastructure, we protect the environment while utilizing resources in the best possible way.

OVERALL AIM

In the Centre application, the main objective and vision of the centre was defined as «to contribute to the implementation of cost efficient and environmentally friendly technologies for improving oil recovery on the Norwegian Continental Shelf.»

SECONDARY OBJECTIVES

- Robust upscaling of recovery mechanism observed on pore to core to field scale.
- Optimal injection strategies based on oil recovered, economic and environmental impact.
- Education of 20 PhD students and 8 postdocs during the centre lifetime.

Overall, it is our understanding that the IOR centre has met the primary objective. The final reporting of the IOR centre is a powerful testimony of 8 years of research performed by the centre partners. The Scientific Advisory Committee sum up their impressions of the IOR centre, by stating «overall, the breadth and depth of activities combining laboratory rock sample and fluid chemistry studies, and computer model simulations, is impressive, using the latest analytical techniques and digital rocks.»

The report from the mid-term evaluation states: «The combination of work at different scales is excellent. This means that, as well as defining the benefits of different EOR treatments empirically, the underlying mechanisms can be understood: so leading to a firm theoretical basis for subsequent modelling and optimization work.» Moreover, the centre meets with the scientific ambitions and goals, by a qualitatively and quantitatively high scientific production and output.

MID-TERM EVALUATION

Following the mid-term evaluation after the first five years, some changes were employed based on the recommendations from the committee:

- The Centre adopted an objective approach to enable a systemic identification and assessment of environmental risks

across all Centre projects including the application of research outcomes in the field
- The Centre has accessed senior competence on environmental risk assessment (ERA) that can be used on all Centre activities in planning and evaluation of results. This has been done by establishing a research project led by PhD student Mehul Vora and supervisor Steinar Sanni.
- The Centre has continued to develop case studies in the project, incorporating input from industry to make them representative of the real-world.
- The Centre has improved its understanding of the needs of individual industry partners. The last years of the project we established a strategy and plan for the exploitation of research results; Delivery Forums. The purpose was to plan the last years' research including stage-gated research activities that focus on user needs, to build industry confidence and perception of value and improve likelihood of acquiring the necessary data.
- The Centre has prioritised plans for legacy funding in the final three years for continuity of activity after the end of the funding. The application for a new petrosenter was successful. NCS2030 was awarded December 2021. The new centre builds on the competence from the IOR Centre and is led by the same research partners.
- The Centre has documented the economic and technical reasoning behind the choice of IOR methods.

The open working environment and good results of the research has made it possible for the Centre to build up a wide network of collaborating institutions, and it could be said that the Centre is now a focal point for IOR internationally. This is very positive and beyond what could be expected at the start-up of the Centre.

From the mid-term evaluation report

From left: Ingela Dahllöf, Craig Smalley, Alison McKay, and Angus Best in the mid-term evaluation committee. Photo: Kjersti Riiber

Research partners

NORCE is a research institute with expertise in a wide range of fields, amongst them energy. IFE is a research institute within energy, health and industrial development.

NORCE

Researchers within the Energy Department of NORCE ran several of the major projects in the centre. The energy group at NORCE conduct research in the field of oil/gas and renewable forms of energy, with a focus on cost-efficient, safe energy production that guarantees the lowest CO_2 footprint possible during the green shift. NORCE has been involved in several major research projects.

- Task 1: The project DOUCS-Deliverable of an Unbeatable Core Scale Simulator aimed to develop a tool for improved simulation of EOR processes at the core scale. The project Core plug preparation procedures aimed to develop methods to determine whether reservoir core plugs are contaminated by mud.
- Task 3: The objective of the pore scale task was to identity mechanisms that influence fluid transport, chemical reactions, and oil recovery.
- Task 4: The IORSim project was a collaborative effort between IFE, NORCE, and UiS to develop a simulator that can bridge the gap between the research prototype simulators and industry standard reservoir simulators.
- Task 6: Improved modeling methodology and simulation capabilities for IOR are important to perform reliable pilot and full field simulations. In this project, NORCE has contributed towards the OPM simulation framework.
- Task 7: Evaluation of the economic feasibility of implementing new IOR methods on a field.

IFE

IFE is an independent foundation and one of the world's foremost research communities on energy. They have developed unique skills over 70 years of researchers and international projects in their reactors and laboratories. Offshore, IFE has developed low-emission petroleum technology and advanced digital solutions for management, security and communication. The knowledge, innovation and development at IFE has created hundreds of billion NOK in values for Norway and improved safety, environment and climate both at home and abroad. IORSim and tracer technology are the most important IFE contributions in the IOR Centre. Researchers at IFE have been involved in projects in task 4 and 5.

- Task 4: A major achievement in IORSim has been implementation of cross-flow in wells. The researchers have investigated further the coupling between IORSim and Intersect and they have also used Ekofisk water chemistry data to verify/calibrate IORSim. Finally, they have continued the work on the Snorre sector model to simulate silicate plugging.
- Task 5: The objective of this task was to improve and develop new tracer technology for in-situ determination of residual oil saturation (SOR) and for improved description of flow fields. The targeted methods are aimed to produce valuable data for evaluation of the need for infill wells, conformance control and evaluation of the most efficient EOR method for a given oil field.

Industry partners and observers

NEPTUNE ENERGY

wintershall dea

vår energi

HALLIBURTON

Schlumberger

ConocoPhillips

Lundin Norway

equinor

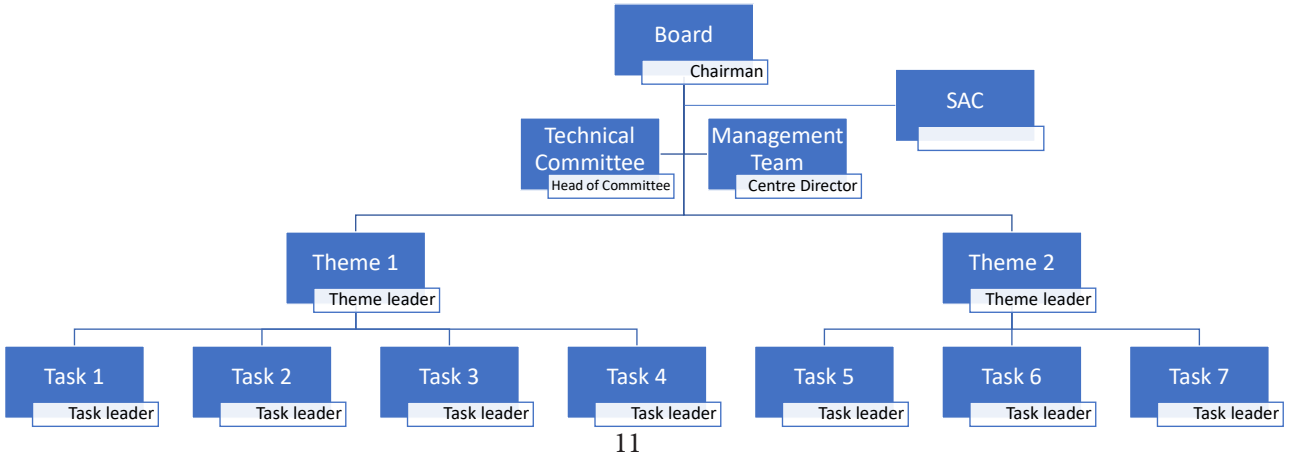
AkerBP

With funding from The Research Council of Norway

NORWEGIAN PETROLEUM DIRECTORATE

petoro

Governance system



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Research Director
Leader Theme 2

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Implementation

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Kristin Flornes (Assistant Director 2013-2016)
Geir Nævdal (Leader Theme 2 2013-2016)

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Chairman of the Board
Aker BP

Former Chairman of the Board:
Kåre Vagle (2014-2018)
ConocoPhillips Skandinavia

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Dean of Faculty of Science & Technology

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Niels Lindeloff, Maersk (2016-2018)

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The Netherlands

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Germany

Professor Yu-Shu Wu
Colorado School of Mines
USA

Task leaders

Arne Stavland
Leader Task 1
Core scale

Udo Zimmermann
Leader Task 2
Nano/submicron scale

Espen Jettestuen
Leader Task 3
Pore Scale

Aksel Hiorth
Leader Task 4
Upscaling

Tor Bjørnstad
Leader Task 5
Tracer Technology

Ove Sævareid
Leader Task 6
Reservoir simulation

Robert Klöfkorn
(2013-2019)

Geir Nævdal
Leader Task 7
Field scale evaluation

Research tasks

1: CORE SCALE

At core scale we focused on IOR mechanisms; improving macroscopic and microscopic sweep efficiency. The key research questions were how chemicals travels through a porous media, the role of mineral wettability in determining the fluid flow in porous media and how to model the chemical systems.

2: NANO/SUBMICRON SCALE

Task 2 focused on the mineralogical and geological background of tested rock material for a variety of core flooding experiments and to search for the most economic and fastest toolbox of methods to gain substantial results within this objective. Moreover, the testing and application of novel methods produced more insights into chalk and chalk reservoirs while it trained in the same time young researchers on top edge methods and applications.

3: PORE SCALE

The objective of the pore scale task was to identity mechanisms that influence fluid transport, chemical reactions, and oil recovery. The main topics in this task has been to study the behaviors of polymers and the effect of water chemistry on the strength and structure of the pore space.

4: UPSCALING

The focus area in Task 4 has been on upscaling of chemical EOR methods and to develop workflows that can quantify the environmental impact of EOR methods. It is important that proper risk assessment is done when applying EOR chemicals offshore.

5: TRACER TECHNOLOGY

The main objective of this task has been to devise methods and procedures to map volumetric distribution of residual oil saturation in a reservoir after secondary production. Such knowledge is the basis for evaluating the need for infill wells and enhanced recovery methods (EOR).

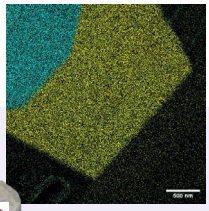
6: RESERVOIR SIMULATION

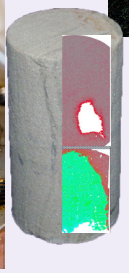
Improved modeling methodology and simulation capabilities for IOR are important to perform reliable pilot and full field simulations. In this task, we contributed towards the OPM simulation framework.

7: FIELD SCALE EVALUATION

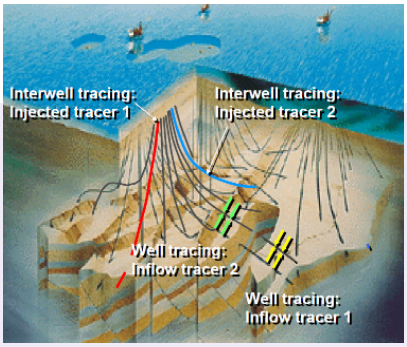
The economic feasibility of implementing new IOR methods on a field needs to be evaluated, preferably taking the uncertainty in the reservoir description into account. While optimizing future production, environmental constraints need to be considered.

Our research

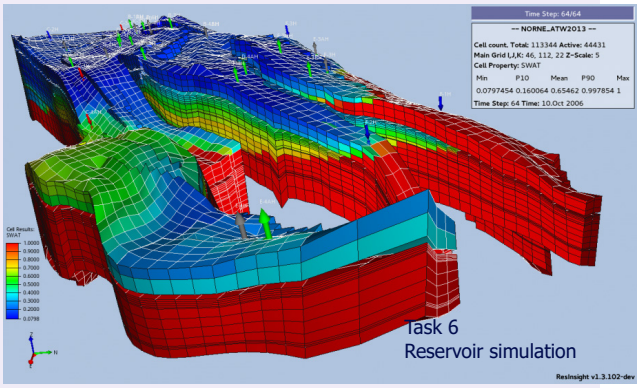




Task 2
Nano / submicron scale

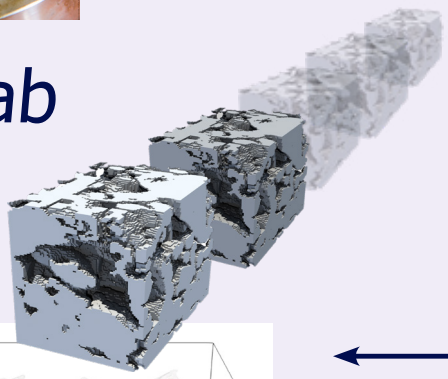


Task 5
Tracer Technology

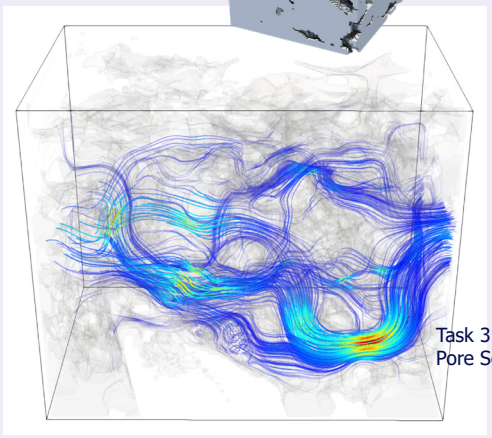


Task 6
Reservoir simulation

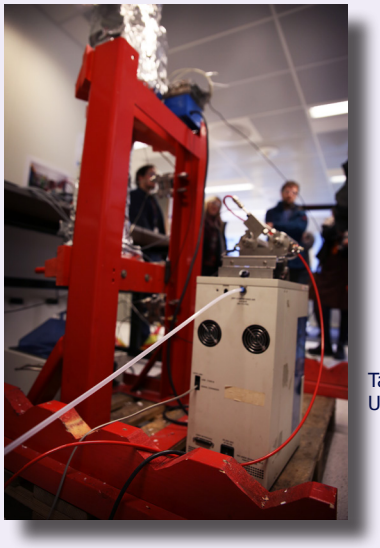
from lab



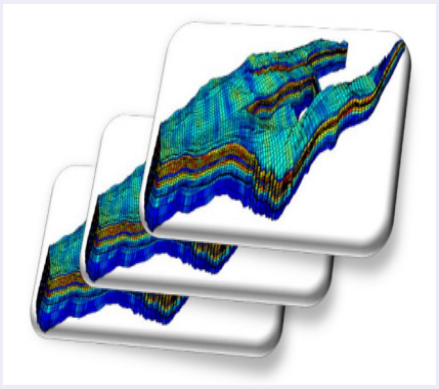
Task 1
Core scale



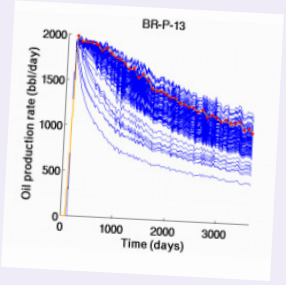
Task 3
Pore Scale

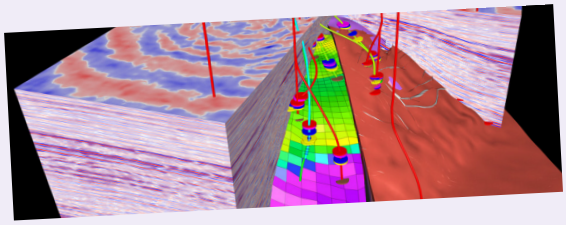


Task 4
Upscaling



to field





Task 7
Field scale evaluation

Two important arenas of networking and communication of results have been established in the IOR Centre.

1. The annual **IOR NORWAY** conference have focused on the collaboration between academia, industry and authorities. Both the Scientific Advisory Committee (SAC) and industry user partners have attended these conferences.
2. The **Delivery Forums** have been even more industry oriented. To ensure consistent and integrated workflows and high-quality deliverables from eight years of intensive work to the industry, the management have set up delivery forums for each of the research areas in the centre.

IOR NORWAY

In accordance with the commitment to the Research Council of Norway, the IOR Centre established an arena for collaboration for the national (and international) IOR research community by arranging an annual conference. IOR NORWAY has been held annually since 2014, with around 300 participants from home and abroad each year. The conference has distinguished itself internationally, and in 2017 it was arranged in collaboration with European Association of Geoscientists and Engineers (EAGE). In 2020, the conference was held together with the International Wettability Symposium, a symposium established at University of Texas, Austin. The last two years the conference was digital, due to Covid restrictions.

Entering a new phase with the establishment of the NCS2030 research centre at University of Stavanger, the conference will develop in the direction of more general energy research questions. The first edition of the **Energy Norway** conference took place at University of Stavanger 25-26 April 2022. An important part of the conference is to involve our students, from master to PhD level.

DELIVERY FORUMS

To better illustrate the Centre's main deliverables and how our projects are integrated to manage and achieve the specifications of our work plans, the centre management developed delivery forums for these areas:

- Methods & Mechanisms
- Upscaling
- Field Application
- Education & Dissemination

Within these categories, we have specified concrete deliverables from each project, tools that can contribute to environmental-friendly and cost-efficient methods for improved oil recovery. Each forum has had regular meetings with the industry user partners. The purpose of these meetings have been to ensure consistent and integrated workflows and high-quality deliverables, based on input from the industry. Each of the nine industry partners had representatives in each forum.

As the final delivery, we have set up a digital archive on our web site. Here our industry partners can find all our major deliverables; reports, dissertations, scientific papers and software. We have also published presentations from the most important industry workshops held in the Centre life-time.

Mayor Christine Sagen Helgø opened the 2019 edition.

Skandalebandet perfoming in Tjodhallen. Photos: Marius Vervik

IOR NORWAY 2019 also provided an arena for the master students.

Ying Guo summed up the conference.

Knut Åm and Kristin Færøvik together on stage. Åm was head of Phillips Petroleum Company for many years, whilst Færøvik was CEO in Lundin.

Cooperation within the Centre

Since the beginning the IOR Centre has arranged several workshops and seminars for our industry partners. The goal has been to set the direction for our research in collaboration with partners. The collaboration between the research partners and user partners were achieved through the processes established by the management groups with regular meetings, workshops, annual conferences, visits, gatherings and social events.

Amare Mebratu from Halliburton at the ERA workshop in 2018.

Erik Søndenå from Petoro at the integration of research activities workshop.

WORKSHOPS 2017-2021

2021
- Workshop with Schlumberger
- Production optimization, value of information and decision-making
- Webinar series for PhDs and post-docs
- IOR NORWAYworkshop: Symposium on Wettability
- Delivery Forum Webinars

2020
- IORSim
- Ensemble-based 4D seismic history matching
- Delivery Forum Webinars

2019
- IORSim
- Interpore
- CO2-EOR
- Core Preparation
- PhD dissemination skills seminars
- IOR NORWAY workshop: Wettability

2018
- Smart Water
- Polymer EOR
- IOR NORWAY workshop: Integrating the value-chain of IOR research in field development plans
- Integration of research activities
- Environmental Risk Assessment (ERA)

2017
- Open Porous Media Seminar
- IOR NORWAY workshop: Offshore polymer EOR; how to make polymer work in the field
- PhD dissemination skills seminars

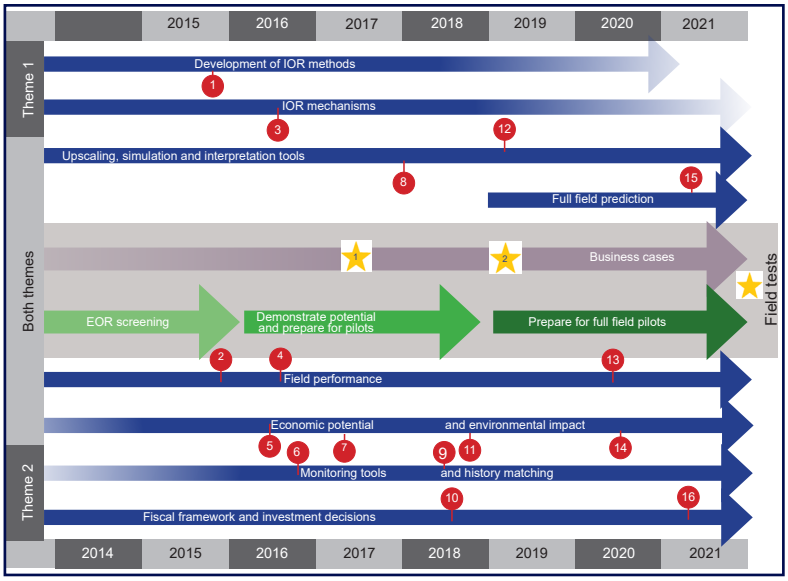
Lawrence Cathles and Mahmoud Ould-Metidji, IOR workshop 2018.

Patrizia Pisicchio and Leili Moghadasi from Eni, Polymer EOR workshop.

Core preparation workshop at University of Stavanger, 2019.

Professor Bill Rossen at the Interpore workshop at Oljemuseet, 2019.

Skule Strand at Symposium on Wettability, 2021. Photos: Kjersti Riiber



The Roadmap was established to create a framework to show the path that research at the Centre should follow. This was to ensure that everyone had the same understanding of the Centre's goals and milestones. It guided us so that we could more easily focus our research and establish good cooperation between projects.

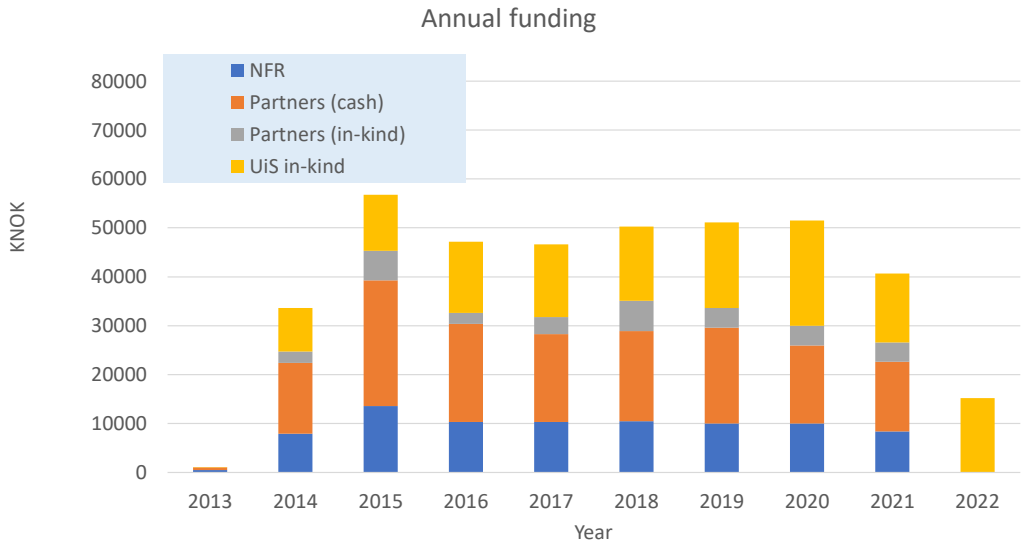
Centre financing

Distribution of funding (kNOK)

Contributor	Cash	In-kind	Total
Host (incl. in-kind)	122 921	-	122 921
Companies	149 998	32 138	182 136
Research Council of Norway	80 400	-	80 400
Sum	353 319	32 138	385 457

Distribution of resources (kNOK)

Centre activities	
Research activities (manpower and other direct costs)	
T1 – Core Scale experiments and modelling	66 275
T2 – Mineral fluid-reactions at submicron scale	20 328
T3 – Core Scale experiments and modeling	36 556
T4 – Upscaling and environmental impact	56 176
T5 – Tracer technology	31 171
T6 – Reservoir simulation tools	37 670
T7 – Field scale evaluation history matching	60 999
Centre management – manpower (UiS only, research partners' costs are included in tasks)	31 045
Common Centre activities (seminars, conferences etc.)	45 238
Total	385 457



Results – key figures

Some of the PhD candidates educated in the Centre. From top left Dimitri Shogin, Mahmoud Ould-Metidji, Mario Silva, Samuel Erzuah, Birgit Brattekås, Oddbjørn M. Nødland, Emanuela Kallesten, Shaghayegh Javadi, Anna Kvashchuk, Irene Ringen, Mona Wetrhus Minde, Remya Nair and Yiteng Zhang. Photo: Marius Vervik

	2013	2014	2015	2016	2017	2018	2019	2020	2021	Total
Scientific publications (peer reviewed)	6	1	17	23	20	39	41	27	17	191
Dissemination measures for users	13	79	94	135	121	147	119	16	12	736
Dissemination measures for the general public		2	4	4	6	16	10	2		44
PhD degrees completed*					1	3	5	4	2	15
Master's degrees			13	10	45	37	20	8		133
Number of new or improved methods/ models/prototypes										14

*+10 remaining finalising 2022

Task 1: Core scale

Long term goal: Construct models that capture the transport mechanisms observed in core scale experiments, based on the mechanisms proposed by the nano- and pore scale activities.

The focus in Task 1 has been on constructing models that capture the transport mechanisms that can contribute to improve the oil recovery. Particular focus has been on polymeric solutions.

The water viscosity increases by addition of a small amount of polymer. This will improve the mobility ratio between the displacing water and the displaced oil, improve the sweep efficiency, prolong the plateau production, and shorten the high water-cut tail production. If optimized, this will contribute to higher oil production and reduced CO_2 emission.

However, there are some hurdles when considering polymer flooding

- Many polymer systems are not, at the present, considered as green chemicals; thus, the environmental impact of polymer transport and spill has been considered and reinjection of produced water is most likely needed.
- Polymeric solutions are non-Newtonian fluids and injecting a polymeric solution into a porous medium further increases the modelling complexity. As such, we have developed a new modelling tool, IORCoreSim.

An important principle in the polymer modelling in IORCoreSim has been to include most of the important dependencies through physical models to achieve model parameters independent of varying conditions. Interpretation and extraction of model parameters from laboratory polymer experiments reproduced experimental data at various conditions with a single set of model parameters. The model handles variations in permeability, temperature, polymer concentration and salinity. Once calibrated against sufficient laboratory experiments, it can be used as a predictive tool and to investigate behaviour at larger scale.

Another IOR method that has been investigated in Task 1 is the use of Smart Water, i.e., to modify the ion composition of the injected water to improve the oil recovery. Despite the apparent simplicity of ionic optimization, the underlying mechanisms are very complex, and involve rock wettability alteration toward a more water-wet state. As such, procedures for reservoir core cleaning and restoration of wetting conditions have been developed. When it comes to selecting the optimal Smart Water composition for improved oil recovery, we recommend low salinity brine in sandstone reservoirs and modified seawater in carbonate reservoirs. The use of low salinity injection water opens new routes for chemical injection, allowing the use of low concentration polymer and surfactant and the use of alkaline flooding. Progress in upscaling the results at core scale to larger scale has been made through modelling the geochemistry.

Text: Arne Stavland, NORCE

One IOR method that has been investigated in Task 1 is the use of Smart Water, i.e., to modify the ion composition of the injected water to improve the oil recovery. Photo: Elisabeth Tønnessen

Arild Lohne (left) and Oddbjørn M. Nødland are the key researchers behind the IORCoreSim.They were awarded the Lyse Innovation Prize in 2018 for their efforts. Photo: Kjersti Riiber

Task 2: Mineral fluid reactions at nano/submicron scale

Long term goal: Full understanding of mineralogical alterations that take place during rock-fluid interaction for EOR experiments in a reservoir/rock as a fundamental parameter to evaluate porosity, permeability evolution and wettability.

Task 2 focused on the mineralogical and geological background of tested rock material for a variety of core flooding experiments through investigation of chemical and textural alterations due to rock-fluid interaction. As IOR fluids varies in composition and therefore impacts the rock in different ways, a major focus had been is the development of methods to provide a methodological 'toolbox' to investigate as quick as possible and as reliable as necessary sample material related to flooding experiments, which is achieved. This toolbox is permanently improving with the advance of state-of-the-art methods.

INTERDISCIPLINARY

We now can apply rapidly and effectively the necessary methodology to each experiment made. The 'toolbox' is already used by other tasks and projects within the IOR Centre and several methodological papers have been published to distribute the methods as well for application in other research contexts. The study of mineralogical changes is paramount for the understanding of changing rock mechanical parameter (e.g. specific surface areas, porosity, permeability, strain stress) during EOR experiments. The research group in Task 2 is also involved in projects of Task 1 and provides data to all modelling related approaches. On-shore chalk and their compositional changes during and after flooding are now better understood and well related to geomechanical processes. These areas cover a fully in-depth study of fractured chalk and the mineralogical processes during flooding experiments. We also study in depth the role of dolomite during flooding experiments, followed by flooding experiments with calcite-dolomite mixtures to mimic reservoir chalk composition.

LONG-TERM TESTS

Finally, we will compile all data available of reservoir chalk and compare with a larger study on on-shore chalk to determine similarities and differences. We could determine and quantify in extreme long-term tests (1-3 years) under reservoir conditions, the major mineralogical changes with first dissolution and subsequent precipitation of phases. The tests with simple materials (only calcite, dolomite and calcite-dolomite mixes) determined the importance of non-carbonate phases for water weakening, a topic for further research. The systematic study of on-shore chalk enabled us to compare with reservoir chalk (e.g. Ekofisk, Eldfisk) from the Norwegian Continental shelf (NCS) to substantiate that on-shore testing is a relia-

ble method for the understanding of EOR processes within reservoirs at the NCS. We implemented edge-science methodology novel for chalk and EOR research, specifically. These methods like helium microscopy coupled with secondary ion mass spectrometry or atomic force microscopy coupled with tip enhanced RAMAN spectroscopy have a high potential in the HC industry and elsewhere. The task has a well-developed international network including centers of excellence of highest level. These institutions are regularly visited by our PhD students for training and knowledge transfer (substantiated as three post-graduate students of Task 2 entered permanent staff at University of Stavanger). The fact that our researchers carried out all analytical steps personally, guaranteed that data acquisition has been 100 % controlled and well documented. The involved students are all adsorbed by hydrocarbon processing industry or academic institutions.

Text: Udo Zimmermann, University of Stavanger

Photo: Marius Vervik

Task 3: Pore scale

Long term goal: The objective of the pore scale task is to identify mechanisms that influence fluid transport, chemical reactions, and oil recovery, on the core scale.

The main objective of the pore scale task is to identify mechanisms that influence fluid transport, chemical reactions, and oil recovery. The main topics in this task have been to study the behavior of polymers and how chemical reactions can alter the mineral composition of rocks and pore geometry. In the Delivery Forums for wettability and smart water EOR it was identified a research goal for task 3 which was to use the pore scale simulator to calculate relative permeability curves for different brine compositions, wettability conditions, and pore space geometries. A focus of this work was to simulate the relative changes in the permeabilities as function of the water chemistry. A larger part of this task was to acquire actual pore scale images of the pore scale of reservoir rock. Even though some reservoir rocks can be easily visualized using micro-CT methods, some chalks have very small pores such that more intrusive methods like focused ion beams, conducted at Sandia National Laboratories, must be used.

SURFACE FORCES

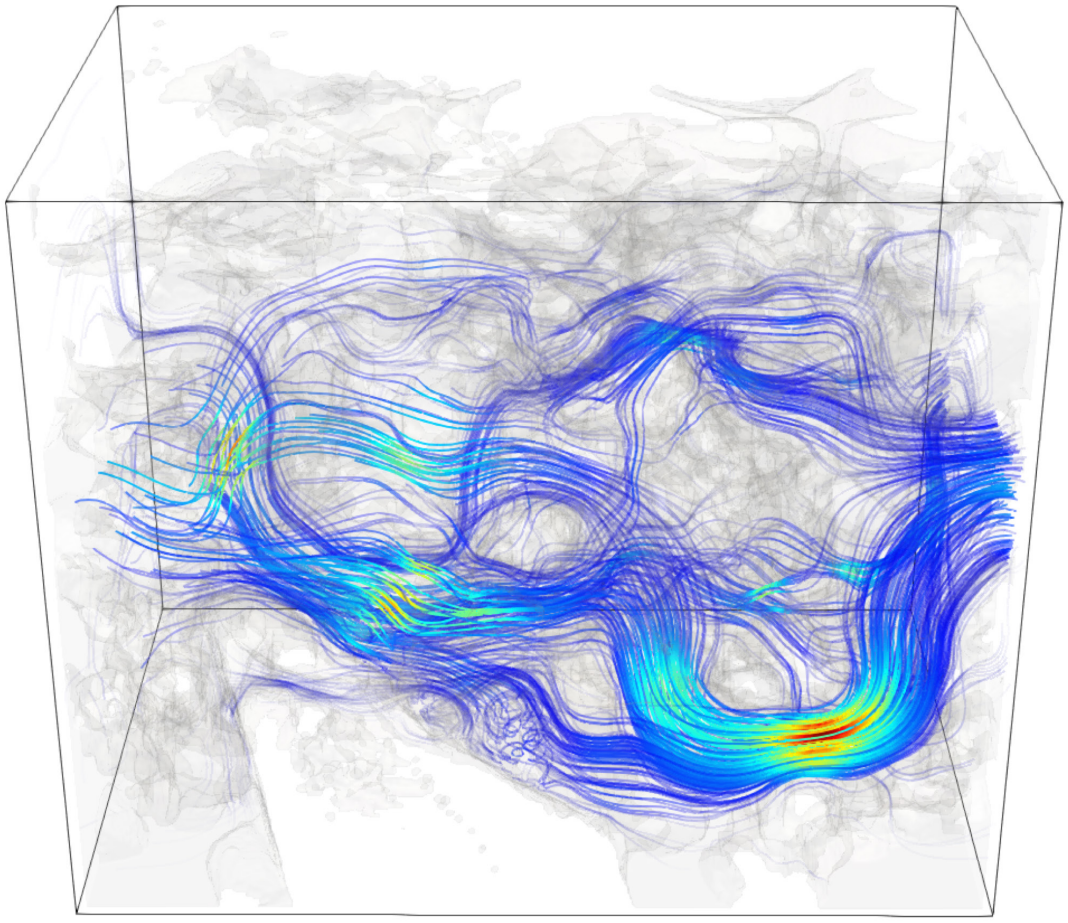
Another important aspect for IOR is how surface forces change with water chemistry. This was studied in a PhD project analyzing changes in surface behavior of chalk samples as a function of water chemistry, using atomic force microscopy and the surface force apparatus. In addition, we have developed both analytical and numerical models for polymer fluids. The analytical models have focused on describing effective rheologies, that is, a description of how fluids react to externally applied stresses and deformation, based basic molecular models. This work has been supported by a type of coarse-grained molecular dynamics simulations, called DPD models, where more complex polymer interactions can be studied to, for instance, describe how polymers behave close to pore walls. These results and insights have been used in the in the pore scale simulator, which for instance has been extended to incorporate wall polymer interaction, i.e , the so-called depletion layer effect. These models support the effective polymer models used on larger scales through direct numerical simulations.

OPEN SOURCE

The source code of the pore scale simulator is made available on GitHub, documentation and user cases are continuously improved and updated. Different packages for simulation of one phase fluid flow, polymer flooding and multiphase flows will be available. This software package has been and is used also outside of the IOR Centre. Where it has been used to study

chemical cementation in bio-cement.; the flow of cements for plug and abandonments projects; blood flow in large arteries for heart diagnostics and the air flow around wind turbine blades to assess effects of blade erosion. These methods like helium microscopy coupled with secondary ion mass spectrometry or atomic force microscopy coupled with tip enhanced RAMAN spectroscopy have a high potential in the HC industry and elsewhere. The task has a well-developed international network including centres of excellence of highest level. These institutions are regularly visited by our PhD students for training and knowledge transfer (substantiated as three post-graduate students of Task 2 entered permanent staff at UiS). The fact that our researchers carried out all analytical steps personally, guaranteed that data acquisition has been 100 % controlled and well documented. The involved students are all adsorbed by HC industry or academic institutions.

Text: Espen Jettestuen, NORCE



Task 4: Upscaling

Long term goal: Robust upscaling of recovery mechanisms observed at the pore and core scales to the field scale.

The focus area in Task 4 has been on upscaling of chemical EOR methods and to develop workflows that can quantify the environmental impact of EOR methods. It is important that proper risk assessment is done when applying EOR chemicals offshore. Among the EOR methods in the IOR Centre, polymers of various types have had a particular focus, while environmental impacts of other products and solutions have also been evaluated (e.g. tracers and smart water).

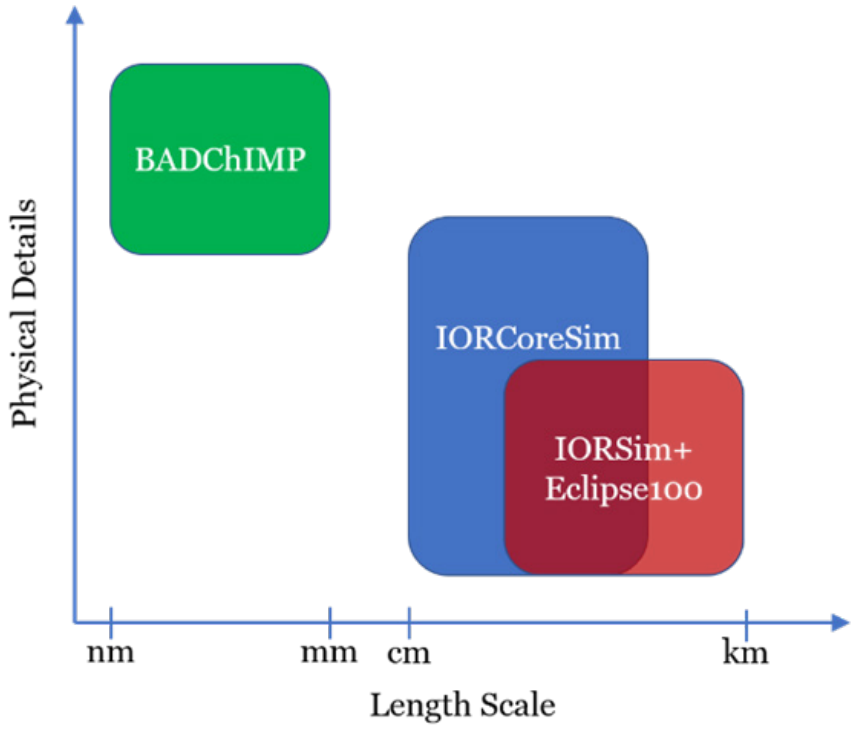
Polymers are highly effective both in improving sweep in the reservoir and as a treatment to avoid too much water production. New products (thermo thickening polymers) are being manufactured that might be trapped in the reservoir permanently. Nevertheless, it is important to evaluate potential discharge to sea in potential operations offshore. One key result from the IORCentre is simulation guidelines and experimental protocols to determine the fate and effect of polymers discharged to sea. These results are summarized in best practices documents and in two PhD theses. Apart from the environmental aspects of IOR chemicals, a major concern has been the fate and effect inside the reservoir of polymer and smart water. The IOR Centre has developed numerical tools for simulating the physicochemical effects of Smart Water flooding behavior on different length scales. The simulators developed for this purpose include BADChIMP, a lattice Boltzmann (LB) based pore scale fluid dynamics solver, and the continuum scale based IORCoreSim and IORSim. These simulation tools span from the pore scale, describing the behavior in the nm (10^{-9} m) to mm (10^{-3} m) range, all the way up to reservoir scale, describing the behavior in the m to km range (see Figure). We have developed simulation codes and workflows across scales from pore to core and field scale. To validate the simulation tools we have performed experiments at the relevant scales. A particular important experimental work in Task 4 that would not have been possible without the IOR Centre is the large scale test that was done in collaboration with Halliburton. This project was run in two phases – in the first phase we focused on the transport of polymeric liquids from the platform into the formation.

When polymeric liquids flow through pipes and valves before entering the reservoir, there was a major concern that the polymer molecules could be degraded and lose their IOR effect due to degradation in choke valves, prior to entering the formation. This test was done on a full scale. Chokes were acquired from commercial vendors and flow rates from 70 to 600 L/min were used. After the test it was concluded that polymers would degrade if care was not taken. The test also identified three possible solutions to mitigate this problem and demonstrated that it was possible to keep polymer

degradation to an acceptable level. The results from this test were also reproduced at smaller scale in the lab (Task 1), demonstrating that it is possible to investigate this phenomenon with a bench top set up, but care must be taken to correctly account for turbulence that will happen at larger scale.

On the simulation side a major undertaking in Task 4 has been the development of IORSim. The main idea behind IORSim is that most simulators used on the NCS do not have good models for simulating EOR processes. Sometimes the models are completely lacking from commercial simulators, and in other cases the numerical errors are so large that one cannot trust the simulation results. IORSim tries to bridge the gap between commercial and research codes. IORSim reads physical information (phase rates, pressures etc.) from the reservoir simulator and then use its own EOR modules to transport chemicals and estimate their effect on flow functions. The chemical effects on the flow functions are then fed back to the commercial simulator. IORSim also has the possibility for local grid refinement to suppress numerical errors. IORSim has been run with ECLIPSE on realistic field cases. The model has been tested on the silicate injection, which was done by Equinor on the Snorre field in 2013. Silicate is water soluble, and has very complex chemistry and gelation kinetics. The gelation kinetics is published, but no commercial reservoir simulator has the ability to calculate both rock fluid interactions, gelation and subsequent plugging. In the IOR Centre we have used IORsim to simulate the injection of silicate on the Snorre field using a reservoir model from Equinor. The results are in line with previous studies and field observations.

Text: Aksel Hiorth, University of Stavanger



Schematical representation presenting the levels of physical details in the numerical models and at what length scales the simulators are applied.

Task 5: Tracer technology

Long term goal: Develop new field-applicable tracer technology to measure residual oil saturation, SOR, in flooded volumes between wells (interwell) and in the near-well zone (single-well).

Task 5 focused on improving and/or developing tracers and tracer methods to characterize fluid saturation and circulation in the near- and inter-well regions (single-, and inter-well applications) of mature oilfields. Understanding hydrocarbon saturation and circulation is key for the design and evaluation of Improved Oil Recovery (IOR) projects.

The single-well chemical tracer test (SWCTT) approach: The SWCTT measures immobile oil saturation in a volume of a few meters around a well. The existing test relies on the use of a partitioning reactive tracer that is injected, partially hydrolyses (during a few days) originating a passive water tracer, and back production of both tracers. As many samples as possible are then collected and send to onshore laboratories for analysis. The tracers used typically have analytical detection limits in the mg/L range. Two main research lines were pursued to improve the SWCTT:

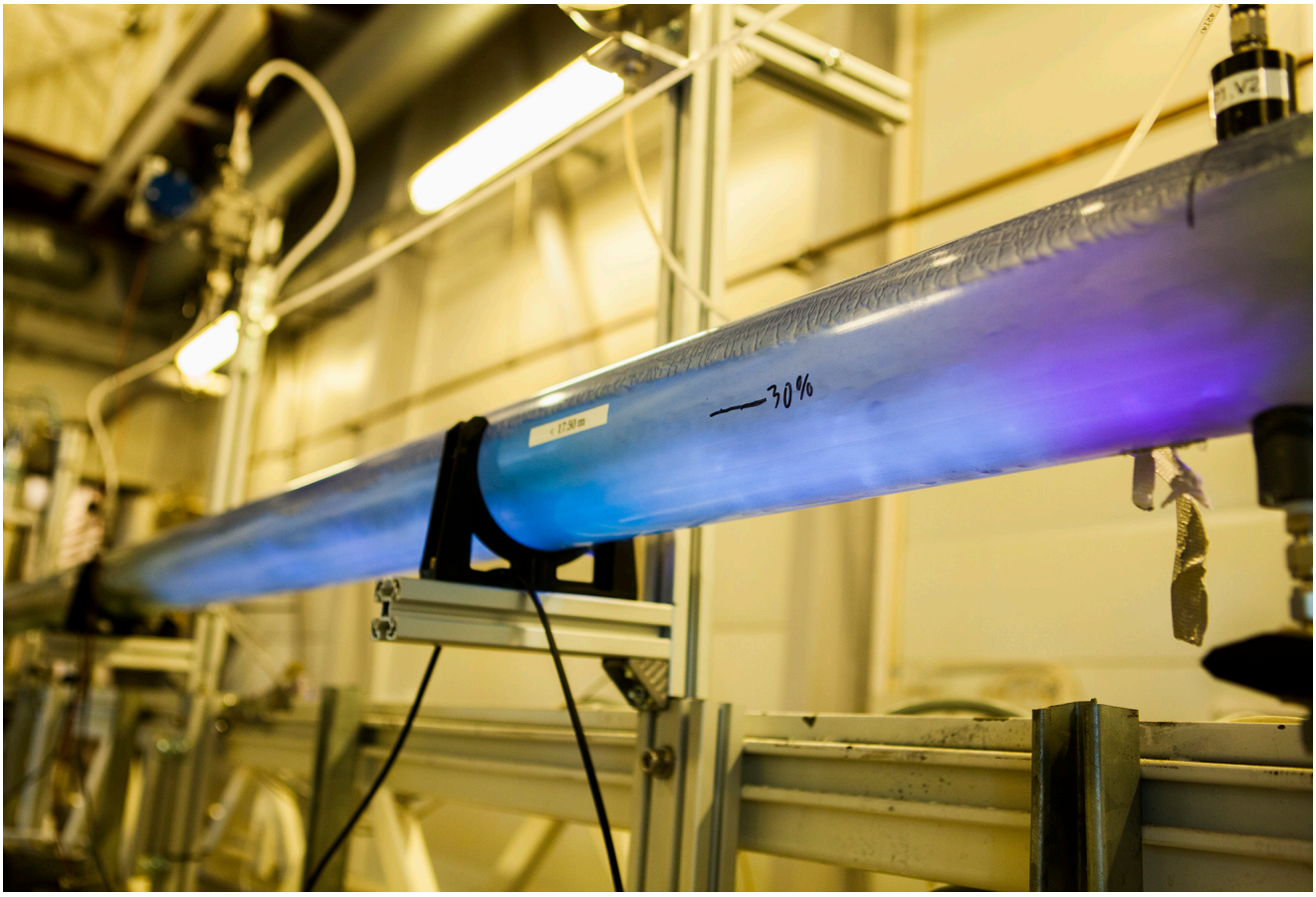
1. The reduction of the amount of tracer required by the test and on-site analysis: we synthesize partitioning lanthanide-ester complexes. Lanthanides have a unique fluorescent signal detectable in concentrations of µg/L with equipment installable onsite and probably online. These esters would reduce the amount of tracer needed by factors of 1000 and eliminate the need of sample shipment. The synthesis of different esters, lanthanide complexation, analysis by fluorescence, characterization of hydrolysis rates and evaluation of flooding properties in porous media were successfully achieved. The water/oil partitioning was not satisfactory, and thus these tracers are not ready for field deployment.
2. Reduction of the time and tracer amount required by the test: this is an ongoing PhD project expected to be completed during the spring of 2022. This approach consists of the development of nanocarriers for instant deployment of tracers in the formation in the SWCTT. Instead of reactive tracers, the carriers will deliver existing passive and partitioning tracers quantifiable in ng/L concentrations, which will be released by the injection of an appropriate trigger (i.e. pulse of salinity, temperature, or pH). If successful, this «reformulation» of the SWCTT will reduce the amount of chemicals necessary to a few hundred grams and the time from days to hours.

The approach to inter-well tracer tests:
Our work focused on the development of new oil/water partitioning tracers for the partitioning inter-well tracer test (PITT) and on carbon quantum dots (C-dots) for fracture description. The PITT measures immobile oil saturation in the swept volumes in the interwell region. It consists of

the injection of one or more passive and partitioning tracers (molecules) which are then monitored in the target producers. C-dots, like other nanoparticles, are known to travel preferentially through fractures and detectable by fluorescence. The main developments were as follows:

1. C-dots: different processes for synthesis, purification, obtaining a stable colloidal suspension (no aggregation) long term thermal and chemical stability, dynamic flooding behavior, and enhancement of fluorescence detectability by the incorporation of lanthanides were investigated. The incorporation of lanthanides was unsuccessful, and the colloidal suspension tends to be unstable under conditions relevant for use in the oilfield. Further development is necessary, as this promising technology collects unique dynamic data about fractures.
2. New PITT tracers: we presented and applied a systematic methodology to qualify new partitioning tracers for the inter-well region. The thermal stability, chemical stability, interactions with reservoir rocks, analyzability, partition behavior, and dynamic flooding properties were evaluated and presented as a PhD thesis. 7 new partitioning tracers were completely qualified in laboratory and are ready for a field pilot.

Text: Sissel Opsahl Viig and Mario Silva, IFE



Task 6: Reservoir simulation

Long term goal: Open source tools for Reservoir Simulation.

The overall aim for task 6 has been to provide modelling methodology and simulation capabilities for Improved Oil Recovery (IOR) processes. The activity has been shared between UiS (University of Stavanger) and NORCE (Norwegian Research Centre), where model development has taken place at UiS, while NORCE has focused on simulation technology. A combined total of five Postdocs and two PhDs have been affiliated with Task 6 at UiS and NORCE.

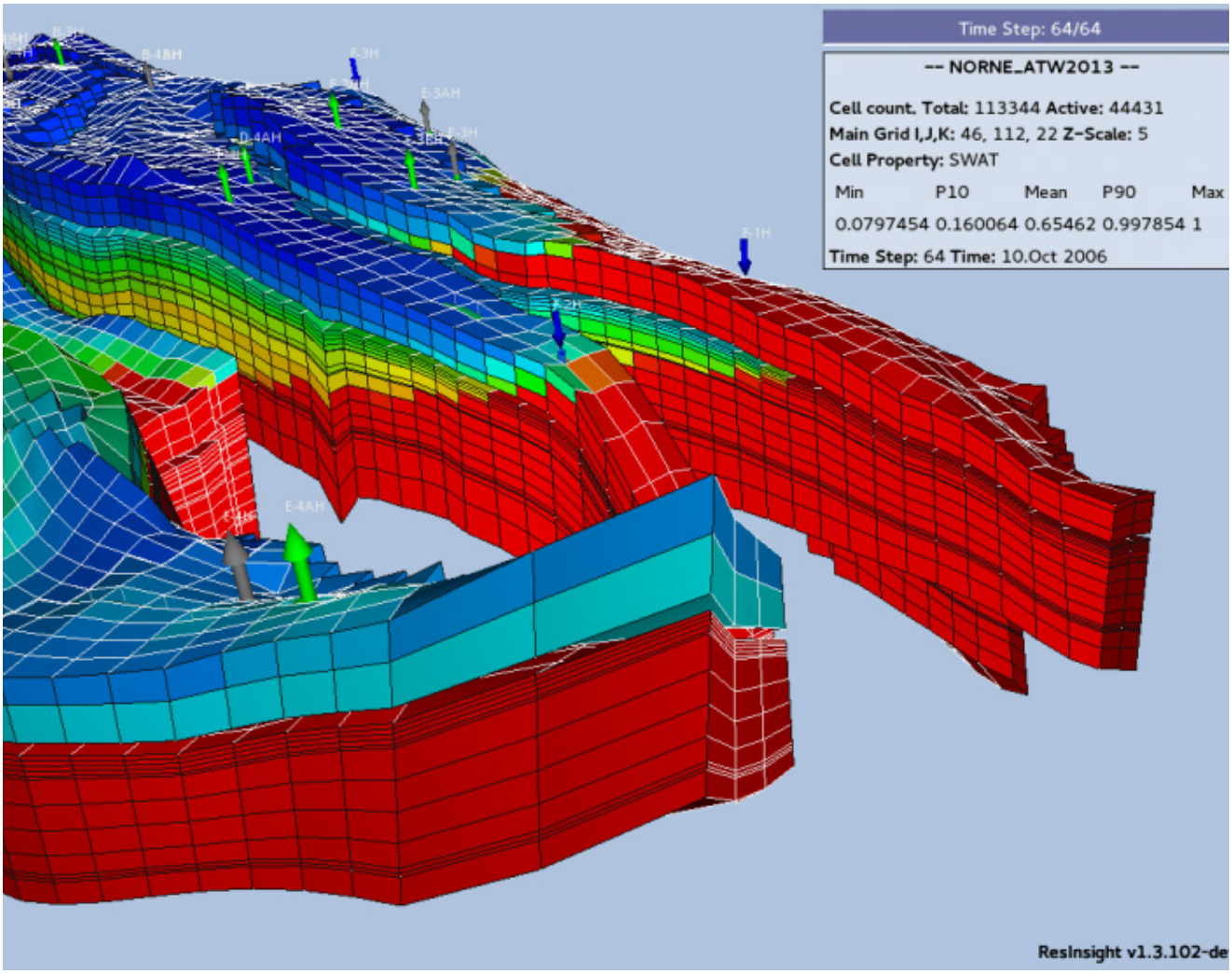
The research at UiS has been motivated by the need for new and improved mathematical models for multiphase and reactive flow in porous media, and has developed fundamental modelling concepts and tools, supporting a variety of IOR applications across different Tasks within the IOR Centre. Examples include generalized relative permeability formulations, fracture-matrix interaction ranging on scales from a single fracture to field scale modelling, and interpretation and upscaling of chemically reactive flow. In particular, the study of CO2 injection into shale reservoirs contributes modelling capabilities relevant for combining CO2 storage and methane extraction. Development of reservoir simulation tools has taken place within several of the Tasks at the IOR Centre. In Task 6, the focus has been on field-scale models, and the activity at NORCE has aligned itself with the Open Porous Media (OPM) Initiative with the goal to contribute to an open-source reservoir simulation framework. Research results presented in terms of publicly available source code have proven to be a valuable supplement to traditional scientific publications and promote reproducible computational science. Open-source development is well suited to foster collaboration across disciplines as well as institutions. Also, an open codebase lends itself to extensions both in breadth (new application areas) and depth (more advanced features and functionality), thus supporting and accelerating technological development and innovation.

During the early years of the IOR Centre, several projects within Task 6 provided hands-on support to bring the bring the full field simulation capabilities of OPM up to speed. From 2016 onwards, this aspect has been catered to by dedicated industry support outside the Centre, and the activity has since then promoted fundamental research to improve models and computational methods. Topics investigated include higher order numerical schemes, aiming at more accurate prediction of distribution and flow when polymer solutions are injected into reservoirs to improve sweep efficiency. In a related project, flow of polymer

mixtures in complex geometries (e.g., well completions) has been simulated both with classical finite difference methods as well as novel techniques based on physics informed machine learning. Being able to solve these strongly non-linear problems on complex geometries, can provide guidance for correlations or surrogate models that can be incorporated as sub-models in large scale reservoir models.

Another line of investigations has been to improve the representations of fractures in porous media flow. Conventional modelling for industry relevant models is based on dual continuum models where the fractures are given an effective representation via dual porosity / dual permeability formulations. By incorporating the fractures more explicitly into reservoir models, a more detailed and realistic understanding of the reservoir behavior can potentially be obtained. Investigations within Task 6 also include simulation studies related to CO2 injection for EOR (Enhanced Oil Recovery) purposes, as well as modelling of compaction and fracturing of porous media.

Text: Ove Sævareid, NORCE



Task 7: Field scale evaluation

Long term goal: Develop new and improved methodology that support decision making for improved volumetric sweep.

Research within "Field scale evaluation and history matching" has been an important activity within the centre through its full life time. Part of the plan for this activity was based on the success of utilizing ensemble-based methods for history matching of production data, with a natural aim to extend this to also history match 4D seismic data. To exploit an ensemble of history matched reservoir models in decision making on can do production optimization. Providing an optimal production strategy, optimized over an ensemble of reservoir models, obviously adds complexity to the problem. For optimizing waterflooding processes, it was demonstrated that this problem could be solved with ensemble-based methods, but optimization of EOR cases was scarce. Ensemble-based methods within reservoir characterization and improved recovery was in a report from Rystad evaluating research supported by Research Council of Norway highlighted as research giving large return on its investment in 2020. This research was further recognized by the award of the Norwegian Petroleum Directorate's IOR-prize to the NORCE researcher Geir Evensen the same year.

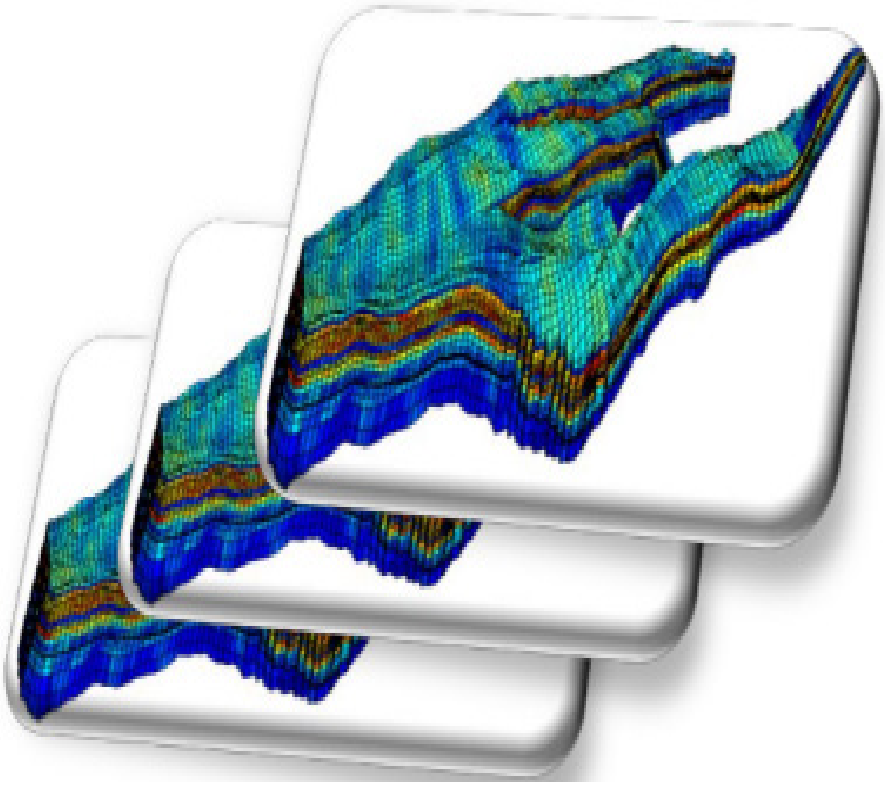
The research on ensemble-based 4D seismic history matching within the IOR centre resulted in a large number of publications. In 2021 a review paper was published with title "4D seismic history matching", reviewing all the components of the workflow of this challenging task. In the earlier phases of the Centre's lifetime more focus was on developing the required methodology. One aspect that needed to be addressed was the challenges of handling the large amount of data coming from 4D seismic surveys in an ensemble-based methodology. In the last few years, the developed methodology was put together and tested successfully on real data provided from the industrial partners of the centre. A main achievement was reported in the paper with title "Simultaneous assimilation of production and seismic data: application to the Norne field" by Lorentzen et al.

Focusing on real field data in developing new methods and techniques for the benefit of the whole Norwegian petroleum industry was a motivating part of the Centre. Schlumberger's research resulted in a case study integrating seismic attribute analysis with image log interpretation for natural fault and fracture characterization for the southern Ekofisk field. Besides utilizing data from the Norne and Ekofisk field, data from the Edvard Grieg field was provided and used by PostDocs and PhD students. Also for ensemble-based production optimization the initial work was on developing improved methodology.

Researchers from TU Delft and TNO were cooperation partners both in this work and part of the work described above. In the final years this was exploited to handle the case of production optimization of EOR processes utilizing polymer flooding, injection of smart water and CO2. This aligned well with the work done on better understanding of the processes behind these EOR methods as well as their environmental consequences.

The educational aspect has been important, and will provide a long term influence of the work done, both for the individual students getting their education, and through their contribution to the society at whole. The first IOR Centre student completing a PhD was Aojie Hong. He defended his thesis "Managing geological uncertainty analysis with decision analysis in reservoir management" in December 2017. After that he had three years as a PostDoc before starting in a position as an associate professor at University of Stavanger in 2021. The educational part will continue after the official end of the centre as a number of PhD students will still be funded to complete their degrees. Dissemination of the results of the research, as well as presenting relevant questions to address from the industry has been an important part. Six more topical workshops has been arranged to achieve this. Due to travel restrictions in 2020-21 the last workshops had to be virtual events. Still the most popular workshop by number of participants was the workshop on *production optimization, value of information and decision-making*, attracting more than 80 participants in September 2021. Besides the workshops several additional meetings was held with the industry.

Text: Geir Nævdal, NORCE



Awards

During the lifetime of the IOR Centre several of our researchers have received recognition for their important work improving the methods in the petroleum industry.

NORWEGIAN PETROLEUM DIRECTORATE'S (NPD) IOR AWARD

The NPD IOR Award has been awarded annually from 1998 to 2010 – from 2010 the prize has been given every other year. Professor Emeritus Svein M. Skjæveland at the University of Stavanger was one of three nominees to the 2018 prize. Skjæveland has been nominated for his efforts to build the petroleum engineering program at UiS. The nomination of Skjæveland states: «He has for many years contributed in education, research, management and organization. For several years he directed petroleum activities at both the District College and Rogaland Research (now NORCE). He developed the first master's program in petroleum technology in Stavanger. And later, he contributed to the University College of Stavanger's PhD program in petroleum technology.»

The winner of the IOR Award 2020 was researcher Geir Evensen from NORCE. The jury found that Evensen has made significant contributions over a number of years toward the development of modeling methods based on the ensemble approach. The research group in task 7 at The National IOR Centre of Norway works with field scale evaluation and history matching. They have played an important part in the development of modelling methods based on the ensemble approach.

SR BANK'S INNOVATION AWARD

The prize was given to Arild Lohne, NORCE and PhD student Oddbjørn Nødland, UiS. Both were researchers at The National IOR Centre of Norway. The winners of 2017's innovation award have developed a new simulation tool, IORCoreSim, with potentially great positive implications for the oil industry. Senior scientist Arild Lohne has been the main developer. During the Centre lifetime Lohne has added functionality to simulate the injection of non-Newtonian fluids, such as polymers. Professor Aksel Hiorth has added functionality to simulate geochemical interactions. Lohne's and Hiorth's PhD student Oddbjørn Nødland has improved the numerical codes and tested the simulator against core scale.

THE SKJÆVELAND AWARD

In honor of Svein Magne Skjæveland's extensive contribution to the establishment of the petroleum education programmes and his work for the University of Stavanger, the first Skjæveland Award was presented at IOR NORWAY 2016. The award is given to a young researcher who shows excellence, courage and innovation in his/her research, and should motivate for further bold moves towards optimizing oil and gas production.

Eystein Opsahl won the Skjæveland Award 2019. Photo: Marius Vervik

International cooperation

Cooperation and openness have been keywords for The National IOR Centre of Norway, and we strive to maintain a good contact with our collaborators. Through an active collaboration, we aim to promote applied research of a high scientific level.

International cooperation has been a key component of the Centre with mobility of students and researchers in Europe, North America and Asia. PhD and employee mobility has been important both regarding experimenal work, but also to strenghten the collaboration between Centre researchers and international partners. The Centre has also been part of the Erasmus+ programme for student exchange traineeship on Master's level.

R&D COOPERATION

NORWAY
- University of Bergen
- University of Oslo
- NTNU / Ugelstad Lab
- SINTEF

EUROPE
- DTU / GEO / GEUS
- TNO
- TU Delft
- Université de Lyon
- Ecole Polytechnique Paris
- TU Bergakademie Freiberg
- University of Münster
- University of Stuttgart
- University Bicocca Milano
- Institute of Science & Technology, Luxembourg

NORTH AMERICA
- Cornell University
- University of Texas Austin
- National Center for Atmospheric Research
- Sandia National Laboratories
- Rice University
- University of Wyoming
- Memorial University of Newfoundland

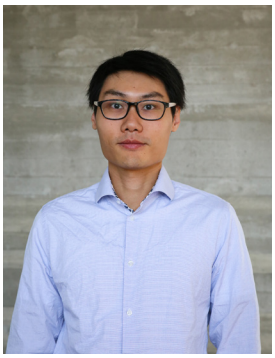
ASIA
- Institute for the Study of the Earth`s Interior, Japan
- China University of Petroleum, Beijing, China

Training of researchers

The National IOR Centre of Norway has financed 30 PhD candidates and 20 postdocs. 15 PhD candidates have defended their their doctoral theses. The remaining candidates are expected to complete their work within 2022. 19 candidates are now employed as shown in the table below.

Employment of PhD candidates (number)

Centre company	Other companies	University	Research institute	Outside Norway	Total
4	5	6	3	1	19



AOJIE HONG
Managing geological uncertainty with decision analysis in reservoir management

MONA W. MINDE
Mineral Replacements in Flooding Experiments Linked to Enhanced Oil Recovery in Chalk

KUN GUO
In-situ and ex-situ catalytic upgrading of heavy crude oil

ODDBJØRN M. NØDLAND
Core scale modelling of EOR transport mechanisms

LAURA BORROMEO
Raman Spectroscopy applied to the mineralogical analysis of flooded chalk

REMYA NAIR
Smart Water for Enhanced Oil Recovery from Seawater and Produced Water by Membranes

MOHAN SHARMA
CO_2 Mobility Control with Foam for EOR and Associated Storage. Multi-Scale Approach for Field Application

SAMUEL ERZUAH
Wettability estimation by oil adsorption

SHAGHAYEGH JAVADI
Interaction between two calcite surfaces in aqueous solutions. Study of nano-scale interfacial forces using AFM and SFA

TIJANA VOAKE
Thermal properties of reservoir rocks, role of pore fluids, minerals and diagenesis. A comparative study of two differently indurated chalks

JASPREET SINGH SACHDEVA
Impact of Wettability on Rock Mechanics and Oil Recovery

DHRUVIT BERAWALA
Numerical Modeling of Gas Production and CO_2 Injection in Tight Shale Reservoirs for Enhanced Gas Recovery

EMANUELA KALLESTEN
Permeability evolution in chalk linked to stress and thermochemical aspects of North Sea reservoir conditions

MARIO SILVA
Development of new oil/water partitioning tracers for the determination of residual oil saturation in the inter-well region of water-flooded reservoirs

SIV MARIE ÅSEN
Synthetic polymers for Enhanced Oil Recovery; Mechanical degradation, and alleviation thereof

Media contributions

IOR-prisvinner Geir Evensen mottar gaver fra Ingrid Sølvberg.

01.09.2020 For 16. gang delte Oljedirektoratet ut en økt utvinning. Denne gang gikk IOR-prisen til forsker Evensen ved forskningsinstituttet NORCE.

Olje- og e
Reiso fra

Rappo
fra Olje
effekte
rettet

Avanserte metoder for reservoarforståelse har gitt økt utvinning

Avanserte metoder for reservoarkarakterisering har bidratt sterkt til økt oljeproduksjon. Forskningen og utviklingen av metodene er hovedsakelig utført av forskere ved NORCE.

Sist oppdatert: 21. feb. 2020
Publisert 7. feb. 2020

Veronica Helle
Rådgiver kommunikasjon

Oljeadsorpsjon i reservoaret

DOKTORGRAD: Samuel Erzuah (34) har avlagt doktorgrad ved Universitetet i Stavanger om korleis olje bind seg til steinoverflata i oljereservoar.

Fukta i stein- og mineraloverflater i oljereservoara avhenger av såkalla adsorpsjon av polare oljekomponentar. Adsorpsjon er ein prosess som skjer når ein gass eller væske blir bunden til overflata av eit fast stoff eller væske. Erzuah har studert fuktvilkåra i reservoaret og korleis dei blir påverka av interaksjonar mellom råolje, vatn og stein.

Første fase av studiet var eksperimentelt. I neste fase vart resultata modellert. Under modelleringa vart mengde oljeadsorpsjon påvist, og òg adsorpsjonsmekanismane.

Dei eksperimentelle teknikkane som vart brukte var flotasjonstest, oljeadsorpsjon med mikrovekt (Quartz Crystal Microbalance with Dissipation, QCM-D) og kontaktvinkelmåling ge overflateeigenskapar i laboratoriet. Fukta i oljereservoara styrar både fluidfordelinga og strømmingseigenskapane. I olje- og gassindustrien kan SCM brukast til å optimalisera komposisjonen av injeksjonsvatnet som blir brukt i oljereservoara for dermed å auka oljeproduksjonen.

Forskinga vart finansiert av Forskingsrådet og Det nasjonale IOR-senteret sine ni industripartnarar.

Kandidaten

- Samuel Erzuah er 34 år og frå Kumasi i Ghana. Fagområdet hans er bore- og brønnteknikk og doktorgradsarbeidet vart utført ved Det nasjo-

Kronikk

Imagine The Potential

Nylig fikk vi informasjonen om at Equinor vurderer å øke utvinningen på Statfjord A plattformen samt øke den totale verdiskapningen fra feltet nok en gang. Statfjord produsert verdier for svimlende 1500 milliardar norske kroner siden oppstarten i

29.januar 2020 Av Håkon Skretting, direktør Norwegian Energy Partners

De planene som lå til grunn for Statfjord-utbyggingen var at feltet skulle leve i 20 år fremdeles kan vi se for oss at Statfjord A vil bidra med 4.000 til 5.000 årsverk og be er bare et eksempel på hva industrien har oppnådd på sokkelen og som er med og

Det er symptomatisk at en slik positiv informasjon ikke får mer oppmerksomhet i noen få aviser og skuldertrekning fra de fleste av de som gidder å lese den er nest vane. Som om det kommer av seg selv. Men det gjør det ikke. Oljevirksomheten b konservativ og lite innovativ. Det er absolutt feil. Da Stafjord-feltet ble bygget, var utviklet. En boret rett ned og eventuelt litt på skrå for å nå ut til de forskjellige dele

Det vakte oppsikt da en forsker i mars anbefalte full Professor Aksel Hiorth og førsteamanuensis Roald I Universitetet i Stavanger, var ikke enig. De diskuter og anbefaler:

9.

KJEMI 5 2020

Pris for beste doktorgrad i katalyse til Kun Guo

Styret i Norsk Kjemisk Selskap – Faggruppe for katalyse har tildelt faggruppens pris for beste doktorgrad i katalyse 2019 til Kun Guo. Guo tok doktorgraden ved Universitetet i Stavanger med Zhixin Yu som hovedveileder.

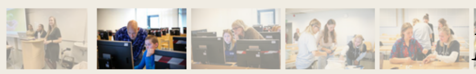
Kun's PhD project is financially supported by the National IOR Centre of Norway. This project focuses on upgrading of heavy crude oil, which accounts for ca. 70% of total world oil reserves. Heavy or extra heavy oils are highly viscous and uneasy to flow under normal reservoir conditions. Relative to water that has a viscosity of ~1 centipoise (cP) at room temperature, heavy oil's viscosity is normally larger than 100 cP. Thereby, conventional flooding methods are insufficient and in-situ heavy oil upgrading inside the reservoir is required prior to the oil recovery. Equally important is the ex-situ upgrading of recovered oil prior to the commercial usage. Such upgrading processes involve a series of hydrotreating reactions with the ultimate goal of viscosity reduction and quality enhancement.

Rational design and synthesis of high-performance catalysts are of vital importance for the in-situ and ex-situ catalytic upgrading of heavy crude oil. To this end, Kun's PhD thesis reports the synthesis and application of monodispersed nickel and cobalt nanoparticles (NPs), common carbon materials (i.e., carbon nanotube, graphene and carbon black), and carbon supported nickel as catalysts for the in situ upgrading, together with thiospinel ($NiCo_2S_4$) NPs and molybdenum disulfide (MoS_2)-based monolayers as catalysts for the ex-situ upgrading. These catalysts are evaluated using either model compounds, such as thiophene and pyridine, or heavy crude oil. In each case, remarkable catalytic performance has been demonstrated, highlighting the potential of these catalytic systems. Kun's achievements also entitled him the 2018 Chinese Government Award for Outstanding Self-Financed Students Abroad.

Kun Guo graduated with a B.Eng. in Materials Science & Engineering from Huazhong University of Science & Technology in 2011, a M.Eng. in Chemical Engineering from Shanghai Advanced Research Institute in 2014, and Ph.D. in Petroleum Engineering from University of Stavanger in 2018. He did a post doctor research at Manchester University, UK during 2018-2019 and is currently Associate Professor at School of Chemistry and Chemical Engineering in Shaoxing University, China. ●

Kun Guo. Foto: Kjersti Riiber/UiS.

Selma Thu får hjelp av Aksel Hiorth i programmeringsworkshopen. Tema: Hvor fort spres et zombie-utbrudd?



Det er Realfagsrekruttering som står bak Girls Day in Tech. Tirsdag var første gang Universitetet i Stavanger arrangerte dagen, hvor alt handlet om jenter og teknologi.

44 jenter fra Vågen og Hetland videregående skoler deltok. I løpet av dagen fikk de høre inspirasjonsforedrag, de fikk møte rollemodeller som har valgt teknologiutdanning, og de fikk prøve egne evner i tre ulike workshops.

tv vest

På TV

Rogaland Aktuelt | 19. Mars 2019

Oljeselskap deler oljedata til forskni ved UiS

Økt eller forbedret oljeutvinning står i fokus når konferansen IOR arrangeres på UiS fo gang.

18 ONSDAG 20. MARS 2019 STAVANGER AFTENBLAD

Vil jobbe på Universitetet:

Lundin deler hemmeligheter om Edvard Grieg-feltet

STAVANGER: Oljeselskapet håper å få ut ekstremt lønnsomme olje fra Nordsjøen. Datadelingen er også et nybrottsarbeid for et forskningssenter i Stavanger.

Ola Myrset

Sharing our knowledge with the public has been an important factor. During the eight years, several of our researchers has been visible in local, national and international media.

Communication during the Centre lifetime

From the opening of the IOR Centre, 2014.
Top: Centre director Merete Vadla Madland and rector Marit Boyesen.
Right: Minister Tord Lien.

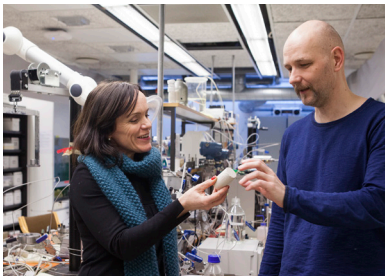
IOR Centre gathering at Hjelmeland 2015.

Ingrid Anne Munz from the Research Council of Norway.

Visit from the Norwegian Petroleum Directorate. Professor Udo Zimmermann (left) shows one of his labs to Ingrid Sølvberg and Arvid Østhus.

2013 | 2014 | 2015 | 2016 | 2017

First general assembly, 2014. From left researchers Aksel Hiorth and Geir Nævdal, chairman Kåre Vagle and assistant director Kristin Flornes.



Centre director Merete Vadla Madland and research director Aksel Hiorth.

ONS 2014. From left researcher Ola Ketil Siqveland, rector Marit Boyesen and assistant director Kristin Flornes.

SCA 2014 in Milan, Italy.

Our first PhDs in place. From left Mohan Sharma, Anna Kvashchuk, Aojie Hong, Samuel Erzuah, Mario Silva and centre director Merete Vadla Madland.
Right: Mona W. Minde.

The IOR NORWAY conference in 2017 was hosted in collaboration with EAGE. Top: Ingvill Smines Tybring-Gjedde Bottom: Aina and Aril Schøld.

Remya Nair and Elena Sikveland.

Chair of Board Thierry Laupretre.

PhD students Tine Vigdel Bredal and Irene Ringen and professor Alejandro Escalona at Open Day at UiS.

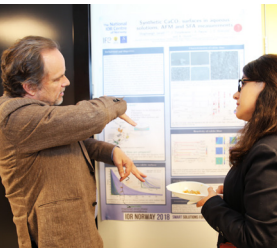
The Centre got a new management team September 2019; director Ying Guo (left) and assistant director Tina Puntervold.

Marie Herredsvela & Marie Bue Kassel.

Host Tor Øyvind Skeidseid.

IOR NORWAY 2021 went digital from Dataverkstedet at UiS. Right: Assistant director Tina Puntervold.

2018 2019 2020 2021



Professor Stephan Herminghaus from the Scientific Advisory Committee in conversation with PhD student Shaghayegh Javadi.

PhD student Siv Marie Åsen won the Skjæveland Award 2018. Here with rector Marit Boyesen.

PhD student Jaspreet Singh Sachdeva explains his work to professor Bill Rossen.

IOR Centre gathering at Sola strandhotell 2020. Middle: Mario Silva and Sindre Hassfjell. Bottom left: Randi Valestrand, Tina Puntervold and Sissel Opsahl Viig.

HIGHLIGHTS

- In the last 5 years, the Centre organised numerous workshops, both dedicated to the partners and for general public, to disseminate the research results and to exchange information.
- Field data have been made available for us.
- More than 800 conference presentations have been given in a number of conferences.
- The Centre's website www.uis.no/ior, in addition, a number of dedicated social media channels have been updated regularly and actively used to disseminate the research activities. The annual reports are published and distributed through the centre's homepage as well as in printed form.
- The annual conference IOR NORWAY has been well attended since its start in 2015 till the final conference organised by the IOR centre in 2022 which is transitioned to the Energy Conference. The Petroleum Research School of Norway (NFiP) has co-sponsored the conferences. The 2017 conference was organised in collaboration with EAGE, the 2021 edition in collaboration with the 14th International Symposium on Reservoir Wettability and its Effects on Oil Recovery.

Effects of Centre for the research partners

IOR research has been developed at the University of Stavanger (UiS) over several decades through close collaboration with the industry and research partners. Hosting The National IOR Centre of Norway has been a natural extension and strengthening of this theme at UiS.

In the start-up phase for the centre, one priority areas in the university strategy was "Petroleum- and Offshore-related subjects" which was well aligned with the IOR Centre focus. In the new strategy, valid from 2020, "Energy" and "Green transitions" are two of the main strategic focus areas. The IOR centre has certainly strengthened and widened out the energy and oil & gas research at UiS and is one reason why the energy theme is in the core also of the new strategy.

Hosting the Centre has improved the collaboration within our organisation and between the partners through joint research activities and arrangements. Thematically, the research topics have expanded significantly, covering not only the petroleum groups but also researchers from other disciplines like physics, chemistry, environment, and risk management. Since the start, the centre has aimed for an open structure, forming a platform for forming a unique joint IOR competence in Norway. Based on the collaboration in the IOR Centre, the partners have established closer relations that have also resulted in new joint initiatives within petroleum as well as themes related to energy transitions.

The IOR Centre has been an important factor in enhancing UiS' image as an attractive destination for students and researchers and has beyond doubt attracted several outstanding graduate students as well as impacted the courses given at master level within Energy and Geoscience Engineering.

UiS recognizes that the Centre has succeeded in attracting top scientists and in particular a large number of female researchers.

Øystein Lund Bø
Dean, UiS

IFE has, for more than 70 years, been at the forefront of international, applied science. Our heritage originated in nuclear science, and this was the foundation on which we built our researvoar and tracer technology. For many decades IFE has invented and re-invented tracer technology for reservoir characterization, as well as mathematical and numerical modelling tools for improved understanding and, subsequently, increased recovery. In The National IOR Centre of Norway, IFE's team of researchers have worked in close collaboration with the teams from NORCE and UiS, particularly focusing on tracer developments and improved reservoir modelling. There are, at present, no commercially available tools which permits geo-chemical modelling in full, field-scale reservoir models. Such calculations are necessary to understand the effect of different IOR-technologies and -strategies. To meet the industry's needs, the IOR Centre developed a numerical model called IORsim which functions as a plugin to the industry standard Eclipse (by Schlumberger). The solution implies that a change of reservoir modelling tool is not necessary for developing IOR-strategies. In this way, IORsim closes the gap between small scale lab-experiments and computational fluid dynamics simulations and full, field scale modelling.

IFE has greatly appreciated the collaboration with the other institutes in the IOR Centre, as well as a close collaboration with several of the industry partners. The collaboration will continue into the new petrocenter called NCS2030, where we will focus on sustainable solutions for the future.

Martin Smedstad Foss
Research director, IFE

Photo: IFE

We have performed research and development within IOR and have currently more than 70 researchers working in the field. Subsurface understanding from pore and core scale to reservoir and field scale, reservoir characterization, modelling, management and production optimization have been in our strategic research priority area for several decades. The University of Stavanger has been a close partner from the beginning, and IFE has also been a long-term cooperation partner. The IOR Centre was therefore strategic important for NORCE and a tool for further development of the fruitful cooperation with UiS and IFE. Collaboration with the industrial partners through the IOR Centre have been very important to ensure impact and relevance of our research, and have resulted in a number of new and large projects which have matched and adopted the research activities in the Centre.

NORCE researchers have been heavily involved in the IOR Centre including theme and task management and wide range of research topics.

One example is experimental research and model development on the chemical reactions leading to alteration the mineral composition of rocks and pore geometry, chemical kinetics of polymeric solutions and smart water, flow processes capture IOR mechanisms for estimating the potential for improved recovery, etc. The results have formed basis for modelling tools such as BadChIMP, IORCoreSim and IORSim software tools.

Another example is the development of modelling methodology for field application, aligned with the Open Porous Media (OPM) Initiative and implementation of ensemble-based methods for history matching of production data, also including 4D seismic data, for better decision making. This research has been recognized by Rystad Energy in their report to the Research Council of Norway evaluating value creation based on petroleum research (2020). It was further acknowledged by the award of Norwegian Petroleum Directorate's IOR-prize to the NORCE researcher Geir Evensen. In 2021 a review paper was published with title "4D seismic history matching", reviewing all the components of the workflow of this challenging task and contributing to widely implementation of the ensemble methods in oil and gas industry.

NORCE have appreciated very much the long-term collaboration in the IOR Centre with research partners, industrial partners and authority. We are looking forward to continue this collaboration for the future development, innovation and value creation in the two new petroleum research centres, namely "National Centre for Sustainable Subsur- face Utilization of the Norwegian Continental Shelf" hosted by UiS and "Center for Sustainable Subsurface Resources" hosted by NORCE.

Aina Margrethe Berg
SVP Energy, NORCE

Photo: Helge Skodvin/NORCE

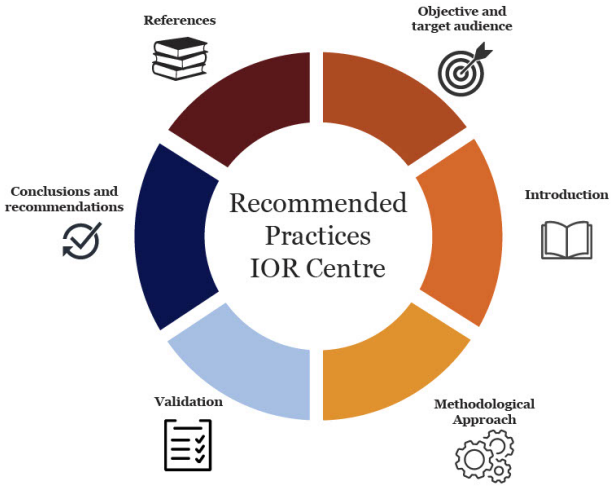
The National IOR Centre of Norway has made strong efforts to link the research to the industry partners' needs.

During the Centre lifetime, we have, through joint meetings, asked the user partners for input on what should be the main deliverables from the Centre after eight years of research. In addition to delivering fundamental research and academic excellence, our user partners have contributed with industrial perspectives ensuring focus on applied deliverables, and deployment of several of the Centre's R&D activity results.

OUR MAIN DELIVERABLES

The individual user partner's needs have been addressed through company visits and their specific feedback. Based on this mutual collaboration, we defined four main categories of deliverables: 1) Methods & Mechanisms, 2) Upscaling, 3) Field Application and 4) Education & Dissemination. Within these categories, we specified concrete deliverables from every project involved; knowledge and tools that can contribute to environmentally-friendly and cost-efficient methods for improved oil recovery. During the last years of the Centre, key researchers and industry specialists have met on a regular basis in topic-specific discussion forums, "Delivery Forums", to create added value from working across themes and tasks. Four delivery forums were formed: 1) Wettability and Smart Water EOR, 2) Polymer, 3) Field application and 4) Upscaling. These topics largely reflect the Centre's research focus for the last eight years. The mandate of the forums was to define deliverables from the Centre and to ensure that both scientific and applied deliverables were reached.

In the Centre, extensive experimental and modelling work related to several topics has been developed and performed. Thus, to capture and document these workflows, one important deliverable from the Centre was "Recommended Practices". In total, the Centre has written eleven Recommended Practices within the topics of core preparation, Smart Water EOR experiments, modelling and upscaling, polymer experiments, modelling and upscaling, adding 4D seismic data to history matching, ensemble-based optimization for EOR processes, tracers for interwell and single well Sor-monitoring, and environmental risk assessment of IOR solutions. Each of the eleven documents gives a state-of-the-art recommendation of how the user partners should apply tools and perform workflows to secure the most optimal results.



FIELD DATA

In The National IOR Centre of Norway we have focused on having a multi-scale understanding of the IOR processes to secures that the reservoir scale models we develop are consistent with the underlying physical and chemical processes taking place in the pore space. This, in turn, allows us to evaluate, in a robust way, the potential of IOR operations for realistic cases. This is done by integrating information from all types of data, from both lab scale and field scale, into our research methodologies and workflows for reservoir management. We have put emphasis on real fields demonstrations and aimed to develop methodologies that can ease the decision making for the user.

REAL FIELD CASES

The research has focused on challenges for the entire NCS while demonstrating the improved methodologies on real field cases. Several real fields have been used as test cases during the eight-year Centre, e.g., Norne, Ekofisk and Edvard Grieg. A highlight for the Centre was when Lundin Energy Norway AS awarded all the available Edvard Grieg field data to the Centre for research. Lundin is one of the first operators on the NCS who has shared all data from a field under operation. In 2020-2021 several new research projects was set up to use the data from the Lundin data set.

Large scale tests at Halliburton. Top photo from 2019, bottom from 2015. Photo: Mari Løvås

Industry relevance

In our web archive our industry partners can find recommended practices and tools developed at The National IOR Centre of Norway. The archive is a resource bank for all centre affiliates.

WEB ARCHIVE CONTENT

RECOMMENDED PRACTICES

- Core restoration
- Smart Water Flooding Part 1
- Smart Water Flooding Part 2
- Polymer Flooding - Lab scale
- Polymer Flooding - Simulation input parameters
- Polymer Flooding - Simulation Upscaling Workflow
- Workflow for adding 4D-seismic data
- Optimization EOR processes
- Partitioning inter-well tracer test (PITT)
- Single-well chemical tracer push-and-pull technique (SWCTT)
- Environmental Risk Assessment (ERA)

SOFTWARE

- OPM
- IORSim
- IORCoreSim
- BadChimp

WORKSHOPS AND PRESENTATIONS

- See list on page 38
- Also contains some conference presentations

PHD THESES

- Links to all PhD theses published in UiS Brage
- The archive will be updated as new candidates defend their theses

POSTDOC AND FINAL PROJECT REPORTS

- Postdoc reports 2013-2021
- Final project reports from NORCE and IFE

Archive is found here: https://www.uis.no/en/research/ior-centre-archive

Please contact kjersti.riiber@uis.no if you have questions regarding the archive.

Where do we go from here? We are ready to continue the work in the new centre NCS2030 – National Centre for Sustainable Utilization of Energy Resources on the Norwegian Shelf.

Together with NORCE, Institute for Energy Technology (IFE) and University of Bergen (UiB), UiS will find solutions that maximize the value creation of energy resources on the Norwegian continental shelf, while at the same time achieving the the net zero emission (NZE) goals. NCS2030 will not only benefit the oil and gas industry, but also other industries that will develop energy with a reduced carbon footprint. The centre will provide new knowledge about areas in the subsurface, both in terms of extraction of new resources and how the shelf can be utilized in the transition to renewable energy and storage of CO2 from the use of fossil energy sources.

LONG LIST OF PARTNERS

University of Stavanger is the host institution in the research centre. In addition to NORCE, IFE and UiB, NCS2030 will collaborate with two other Norwegian universities (UiT and UiO) and 13 international academic institutions, as well as the Norwegian Research School in Petroleum. The centre includes seven major operators on the Norwegian shelf, two major technology suppliers, as well as eight innovation companies that will ensure high relevance and societal benefits.

HOLISTIC APPROACH

The activities will span four research areas: energy systems, net-zero emission production, digitalization and society.
«The centre will work for a holistic approach to energy-efficient use of the subsurface on the Norwegian shelf. The goal is to create a sustainable value chain from start to finish. The subsurface contains the energy we need now, but we can also store energy for future generations,» says Professor Alejandro Escalona, who leads the new centre.

NCS2030 shall among other things:

- Build integrated near field subsurface holistic models for increasing reserve base and evaluate the potential of geological CO2 and H2 storage;
- develop new IOR solutions for improved and accelerated HC production at low environmental footprint, and;
- develop data-driven approaches to integrate subsurface characterization, uncertainty quantification and management workflows

NCS 2030 National Centre for Sustainable Subsurface Utilization of the Norwegian Continental Shelf
University of Stavanger

Conclusions

The impact from our 8 years research activities extends from young PhD's career development and researchers competence strengthening, to knowledge accumulation to the end users in the improved daily field operations and be better prepared to meet the current and future challenges.

The Centre has contributed to all partners with new knowledge and tools for IOR making Norway as leading nation for IOR. The research partners have strengthened the position as an important national partnership for the future energy research and education, in collaboration with the established international network.

The steering of such an extensive research program involving large number of researchers, teaching personals, PhD candidates and students is challenging and rewarding. It requires effective management to maximize the research output with high scientific impact at the same time relevant for the end users. Working closely with the Board, Technical Committee, and Scientific Advisory Committee is instrumental. The advice from the Research Council of Norway, Norwegian Petroleum Directorate, Petoro and managements from research partners have shown to be invaluable. Good roadmaps with specific goals and intermediate milestones, are important for integration of research from individual projects.

The Delivery Forums were effective arenas for research dissemination and getting feedback from user partners with focus on the industrial needs. Multi-disciplinary research was effective and impactful, in our case connecting disciplines from pore to core to field scales.

Contact with other similar national and international centres, through projects, mutual visits, annual IOR Norway conferences, contact meetings organised by the Research Council of Norway and student activities were important both for improving Centre performance and for stimulating better research results and create larger networks.

Industrial partners' involvement could be even more effective and constructive by separate Technical Committee's with specific topics, assign industrial partners in leading roles, giving partners opportunity to influence research for more relevant applications thereby improve impact of the research work.

The IOR Centre management team: From left Tina Puntervold, Sissel Opsahl Viig, Aksel Hiorth, Ying Guo, Svein Skjæveland and Randi Valestrand.

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Kjersti Riiber, UiS
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