The National IOR Centre of Norway

WORK PLAN

JOINING FORCES TO RECOVER MORE

With funding from The Research Council of Norway

NORCE

IFE

University of Stavanger

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«(…) a focal point for IOR internationally (…)»

Awarded by the Research Council of Norway after a national competition, The National IOR Centre of Norway started December 2013. September 2017, the Centre was evaluated. An expert panel visited us, reviewed documents and interviewed both the management team and the PhD students. The conclusion was announced in an evaluation report. This report formed the basis for determining whether funding from the Research Council of Norway (RCN) should continue for three new years. The report concluded that the Centre is strong.

The evaluation also concluded that the industry-academia collaborations are excellent, and that both The National IOR Centre of Norway and sister centre ARCEX are delivering significant impact to the organisations involved and to wider society.

«Collaboration between research institutions and industry is a key to achieve solutions to the challenges for exploitation of the Norwegian petroleum resources,» sayd Fridtjof Fossum Unander, executive director of the division of Energy, Recourses and the Environment in the Research Council of Norway to the RCN website. Unander was pleased with the positive results of the evaluation. The evaluation also gave advice to the centres in order to help them to do even better in the future.

In this article it was also highlighted that The National IOR Centre of Norway «is a strong and highly performing Centre. In this first period the Centre has carried out high quality scientific research that has been externally recognised by international awards.» Given the positive evaluation report, it was no surprise that the RCN decided to continue the support of The National IOR Centre of Norway. Now we are ready to continue our work, that is to produce high quality research and innovative IOR solutions.

The report also provided advice on areas that could be even better – the environmental aspect was one of them. The Centre has now answered this by including environmental risk assessment (ERA) experts from the University of Stavanger and NORCE in the projects. One of the new projects in 2019 is a PhD project called Risk Management / ERA. This project is dedicated to develop and implement risk analysis methods and models to evaluate overall environmental impacts and risks associated with different IOR solutions resulting from the IOR Centre research activities.

Even though the evaluation of what has been done was highly positive, it is important to look forward. The new research activities in this work plan focuses on user needs, needs that has been pinpointed in both meetings with the technical committee and in the workshops we have arranged in 2018. You can read more about this process on the next pages.

We are working together with the industry experts across the two research themes which includes seven research tasks.

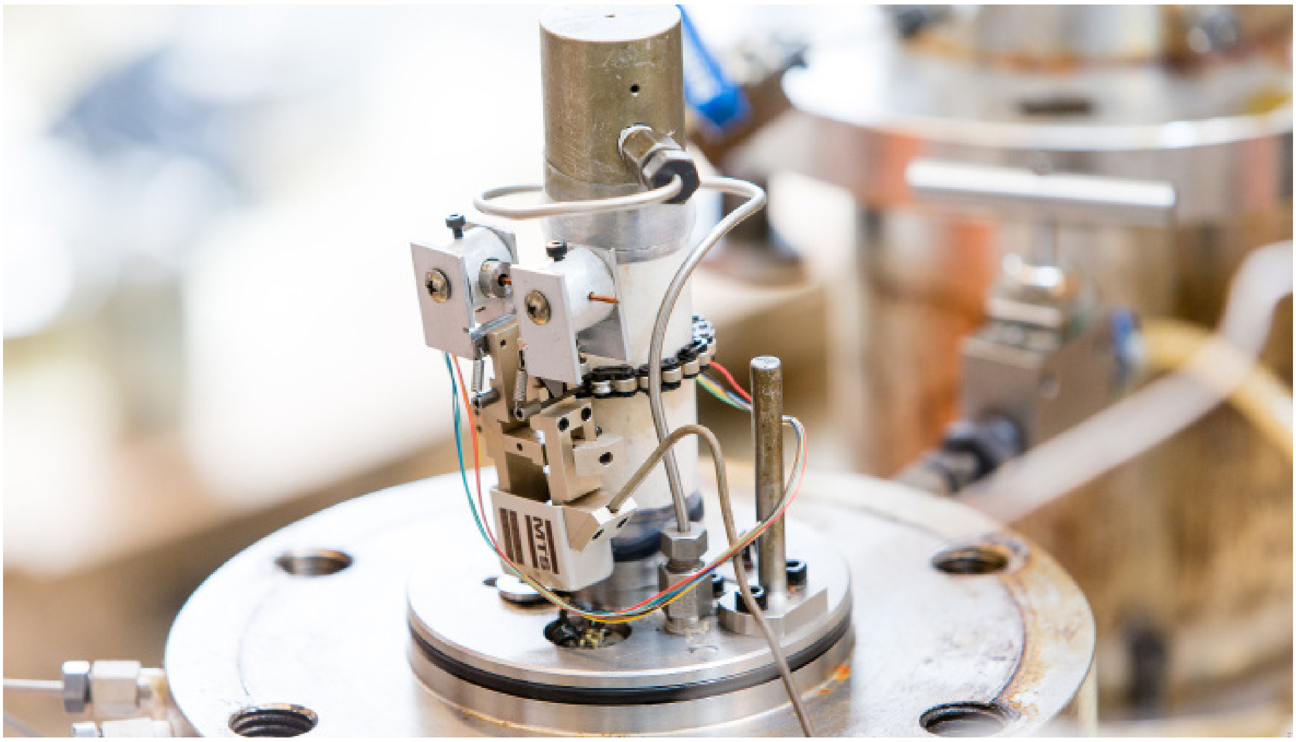
Theme 1, «Mobile and immobile oil and EOR methods» focuses on understanding, modeling and upscaling microscopic and macroscopic displacement efficiency when various EOR fluids are injected into a porous rock. We put equal emphasis on Enhanced Oil Recovery

(EOR) operations in chalk and sandstone formations. The environmental impact of the EOR methods will be assessed throughout the run of The Centre.

The primary objective of Theme 1 is to optimize the microscopic and macroscopic displacement efficiency in a porous rock from the chemical and mineral compositions of pore fluids and rock grains, considering the sustained diagenesis and translate this knowledge to industry applications.

Theme 2, «Reservoir characterisation to improve volumetric sweep» focuses on the integration of field data such as pressure, temperature, seismic data, tracer data, geophysical data, and geological data into a field scale simulation model. In Theme 2 we will focus our research on tracer technology developments, development of improved simulation tools for IOR and development of ensemble based methods for field scale evaluation and history matching. A main driver when conducting our research is to deliver new methodology that will be applied by the industry.

The primary objective of Theme 2 is to develop new and improved methodology that will support the evaluation and decision making with regards to IOR/EOR pilots at the Norwegian Continental Shelf (NCS). This addresses the potential of producing the resources in un-swept areas as well as mobilizing the trapped resources in swept areas. The research is focusing on challenges for the entire NCS while demonstrating the improved methodology on real field cases.



Mobile and immobile oil and EOR method:

Task 1: Core scale (leader: Arne Stavland/ Tina Puntervold)

Task 2: Mineral fluid reactions at nano/submicron scale (leader: Udo Zimmermann)

Task 3: Pore scale (leader: Espen Jettestuen/ Jan Ludvig Vinningland)

Task 4: Upscaling and environmental impact (leader: Aksel Hiorth)

Reservoir characterisation to improve volumetric sweep:

Task 5: Tracer technology (leader: Tor Bjørnstad)

Task 6: Reservoir simulation tools (leader: Robert Klöfkorn)

Task 7: Field scale evaluation and history matching (leader: Geir Nævdal)

The vision

Joining forces to recover more

The National IOR Centre of Norway provides solutions for improved oil recovery on the Norwegian Continental Shelf through academic excellence and close cooperation with the industry.

Objectives

The Centre aims to contribute to the implementation of environmentally friendly technologies to improve oil recovery on the Norwegian Continental Shelf.

Secondary objectives

Robust upscaling of the recovery mechanisms observed at pore and core scale to field scale.

Optimal injection strategies based on total oil recovered and economic and environmental impact.

Education of PhD students and postdocs during the Centre's lifetime.

Industry relevance

Through thematic workshops and TC meetings all partners have been active in the process of making the workplan 2019 which holds 35 projects focusing on user needs. The user partners have slightly different objectives, but several of the R&D activities include elements that all companies have interest in. We have also tried to understand the needs of each individual industry partner and all companies have been invited to give specific feedback by e-mail after TC meetings.

The process towards Work Plan 2019 started in 2017 when the Centre had to deliver updated plans for the three last years in connection with the midterm evaluation. Early in 2018 we started a more intensive work together with the industry partners to detail the plans together, and before May we had already arranged two topic-specific workshops; one on Environmental Risk Assessment hosted by Halliburton and one on Integration of Research Activities hosted by Schlumberger (see page 9 for more info). At the technical committee meeting May 2018, our industry partners were asked to give even more feedback on the process towards work plan 2019 and also suggestions on new topic-specific workshops needed. As a result, three workshops have been arranged during the second half of 2018; polymer, smart water and IORSim – simulation challenges related to IOR processes at field scale using the Centre's tools IORSim and OPM.

The result of this work has been even better than foreseen. The polymer workshop was arranged on short notice, but still 35 representatives from our partners took the time to attend – including a delegation from Wintershall's head office in Germany and several from the Eni Milan research headquarter.

The smart water workshop hosted by ENI drew a total of 50 participants, including both nationally and internationally attendees from the industry partners, and, hopefully also the IOR Simulation workshop will be of great interest for our partners (this plan was printed just before the IOR Simulation workshop was arranged).

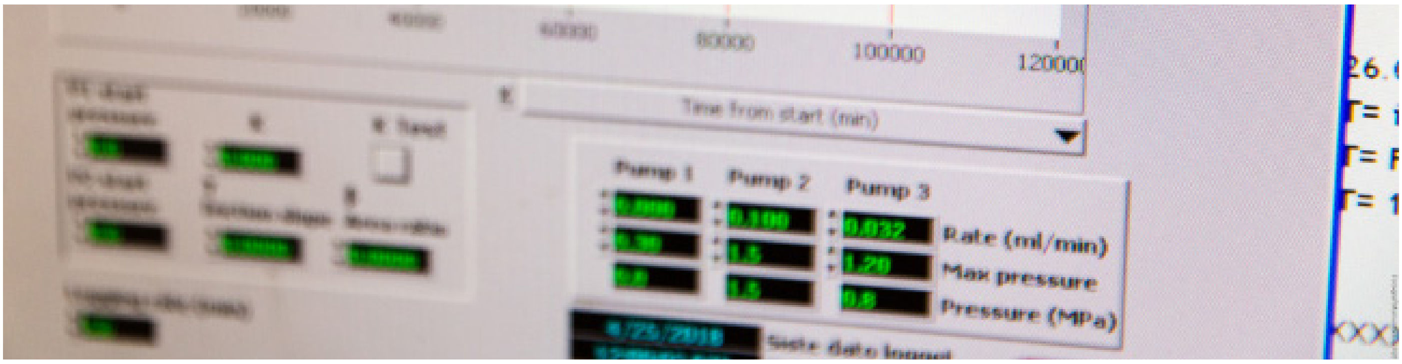
The industry partners have given plenty of feedback in the workshops, at technical committee meetings as well as by e-mail, on the topics of the workshops and also on other relevant issues. Many has been taken into consideration in this work plan. In the next few pages, there are detailed summaries of the workshops, a very broad is as follows: For the polymer research in the Centre we are on track and cover many, if not all, of the challenges related to the subsurface. The upscaling is still a major challenge, and in the Centre we will focus on both improving our simulation tools and to study the polymeric fluids at a larger scale.

Regarding the smart water challenges, there are still more questions related to the fundamentals. Although it is recognized that we understand a lot about the chemistry and rock fluid interactions, the smart water does not always work. The crucial question is why not? One of the hypothesis is that it is related to the initial wetting of the reservoir. If the reservoir is too water wet it might not be possible to improve the recovery by altering it to more water wet. Furthermore, as with the polymeric fluids there are questions related to the upscaling.

For both polymer and smart water, the following was emphasized as crucial for pilots to happen: Important modeling aspects identified in the labs need to be properly upscaled and implemented in field scale simulators. Large scale testing is a vital part in identifying the most important modeling aspects missing in field scale simulators, measuring the effect of upscaling and also prototyping a full field pilot. Data and models need to be integrated to form a robust work-flow useful for evaluation. The evaluation must include better uncertainty quantification of all uncertain aspects, such as geo-physical and geo-mechanical parameters, development of state parameters (e.g. temperature as a function of time), chemical alteration, and also uncertainty because of imperfect modeling tools and upscaling. Including all this uncertainty in a dependent manner will lead to a robust work-flow for optimization, economic evaluation and risk assessment.

On the next page are the new projects that directly address many of the issues addressed in the polymer and smart water workshops and in the TC meetings.

- Understanding the initial wettability of reservoirs
- Reservoir wettability and its effect on water based recovery processes
- Mineralogical influence on reservoir wetting and
- Smart Water EOR processes
- Upscaling of Polymer and Smart Water Processes
- Applying the analytical tool box to specific EOR related experiments to enhance oil recovery and to assist upscaling
- Development of a simulation tool for complex non-Newtonian fluid flow
- Risk Management / ERA
- Improve IOR models in IOR Sim
- Nanoparticle tracers for petroleum reservoir studies
- Lanthanide ester complexes for SWCTT
- Dynamic flooding properties of new PITT tracers
- Upscaling of chemo-mechanical compaction to field scale models
- IOR Pilot Projects – Learning by Doing
- The Value of Data and Data Analytics for IOR Operations
- Data assimilation using 4D seismic and tracer data
- Developing optimal strategies for polymer or smart water injection using synthetic models and the Open Porous Media (OPM) framework
- 4D seismic frequency-dependent AVO inversion to predict saturation-pressure changes



One step towards greener IOR

As part of answering the RCN recommendations for further work at the Centre, an environmental risk assessment (ERA) workshop was arranged at Halliburton's offices. In the 2019 workplan ERA is integrated in all Centre activities. In fact, one of our new PhD positions is dedicated to this work.

In the midterm evaluation of the Centre autumn 2017, the Research Council of Norway came up with some recommendations on our further work. In the Centre's revised plans for the last three years, we were asked to comment on the guidelines the evaluation panel gave us; how will we meet these recommendations?

A very important advice from the panel, was that «the Centre adopts an objective approach to enable a systemic identification and assessment of environmental risks across all Centre projects». The Centre has always been very concerned with developing environmentally friendly IOR solutions, and it was valuable to get advice on how we can evaluate this in a more systematic manner. The Centre has already arranged an ERA workshop. More important, ERA will be an important part of The Centre in the continuation: One of the projects (number 1.4.6, see page 34) is dedicated to this work and aims to use the concrete risk analysis results in the decision-making process regarding R&D priorities at the Centre, and more broadly to contribute to the general development of methods, models and the foundations of environmental risk assessment.

Not only is the Centre establishing ERA routines, we will also work even harder to integrate the ongoing research activities. Therefore the Centre and industry partner Schlumberger took the initiative to arrange a workshop spring 2018. Here we started planning a design of the Centre's integration test as set in our roadmap. Both the mentioned workshops were part of the Centre's follow up and aim to improve according to the recommendations of the midterm evaluation panel. The workshops have also given us input to this workplan.

From the left Kjetil Brakstad (Equinor), Jarle Haukås (Schlumberger), Ana Todosijevic (Wintershall) and Siv Marie Åsen (NORCE). Todosijevic lead the workshop.

Lars Sønneland, Schlumberger

Patrizia Pisicchio, ENI Milan

Polymer workshop

To make sure our projects are relevant to our industry partners we have arranged several topic-specific workshops. The polymer workshop was arranged with 35 participants from both industry and research institutions sharing their knowledge on polymer flooding in a successful workshop hosted by the Centre 25 June 2018.The main question to be answered was this: What should the polymer focus of The National IOR Centre of Norway be for the final three years? The participants were spilt in three groups and they were asked to come back with the top three or a prioritized list. This is the outcome of the groupwork at the workshop.

- # Optimization of the polymer work-flow which includes:
  1. Understanding of salinity impact of polymer properties and how to model and upscale
  2. Large scale testing
  3. Upscaling to field scale
- # Benchmark: Eclipse/Intersect alone vs. Eclipse + IORSim on a real field case from the companies.
- # Utilizing fall off test data / step rate test.

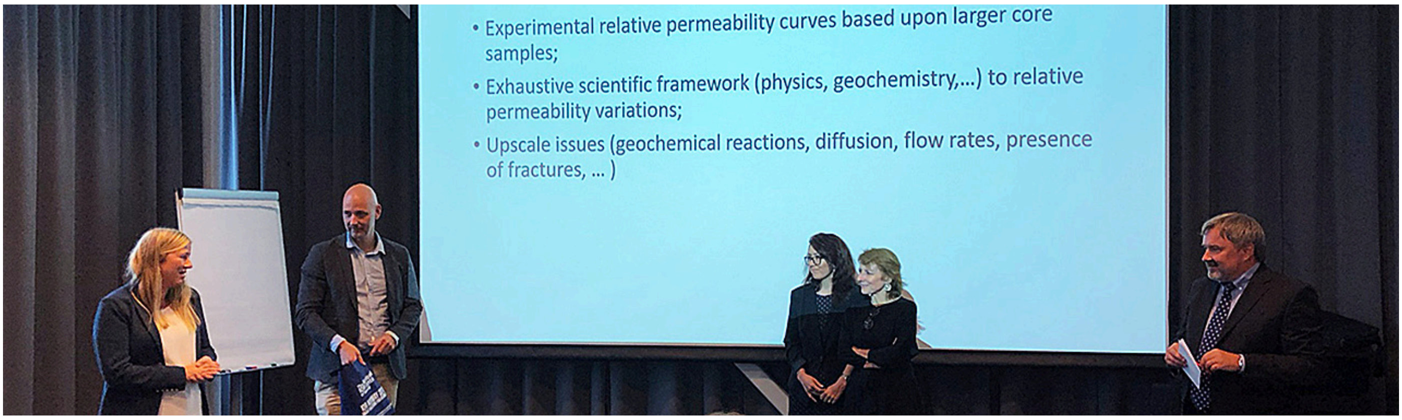
- # Integration of all relevant steps in the EOR project, identification of the critical path, including project de-risking and identification of main uncertainties from pore to full field deployment
- # Polymer EOR Simulation in the fractured rock with identification of upside and uncertainties
- # Environmental qualification of polymers: Can we change the existing regulation and test the back produced polymer on biodegradation, toxicity and bioaccumulation?

- # During the workshop, ENI presented pilot polymer application (a real case study). Due to its particularity, some interesting points were brought out. Therefore, by permission from ENI, The National IOR Centre of Norway could deeply elaborate the case study by considering different aspects related to polymer application.
- # When a polymer solution is injected into a reservoir from an injection well, the flow velocity (as it is related to shear rate), will change from wellbore to in depth. How we can have better prediction on the relationship of in situ viscosity and in situ shear rate?
- # Importance of injectivity and corresponding uncertainties and risks.


Torstein Grøstad, Equinor

Smart water workshop

The smart water workshop was very much wanted by all our industry partners and researchers, and one of our partners, ENI, was so kind to host the workshop. Actually, it had to be moved from ENI's office at Forus to Hotel Pond due to the big number of attendants. 50 participants from industry and research partners shared their experiences in the workshop 14th of September. Participating industry partners were Equinor, ConocoPhillips, ENI, AkerBp, Total, Schlumberger, DEA and Wintershall. Also, at this workshop we asked the big question: What should the smart water focus of the Centre be for the final three years? Bellow you can see the feedback from the group work.



Research Directors Randi Valestrand and Aksel Hiorth sums up the workshop and thank the delgation from ENI Milan for hosting it.

Modeling group:

Proper measurements of experimental relative permeability curves, possibly based upon alsolarger core; samples in order to provide indication of possible behavior in front of some inhomogeneity.
Exhaustive scientific framework to account of relative permeability variations.
Upscale issues (geochemical reactions, diffusion, flow rates …);
  1. Identify water composition and verify EOR potential.
  2. Sulfate and magnesium retained in field, same mechanism as seen in lab.
  3. Coupling field scale simulators to lab scale simulators.
  4. Modelling and experiments hand in hand. Input from lab experiments & geochemistry into simulators.
Presence of fractures properly taken into account.

Laboratory group:

Core pre-treatment;
  Wettability and initial wetting state are important
Crucial role of crude oil, formation water, rock-mineralogy, reservoir temperature.
Importance of pH alteration during the core flooding test.
Optimal ion composition for smart water.

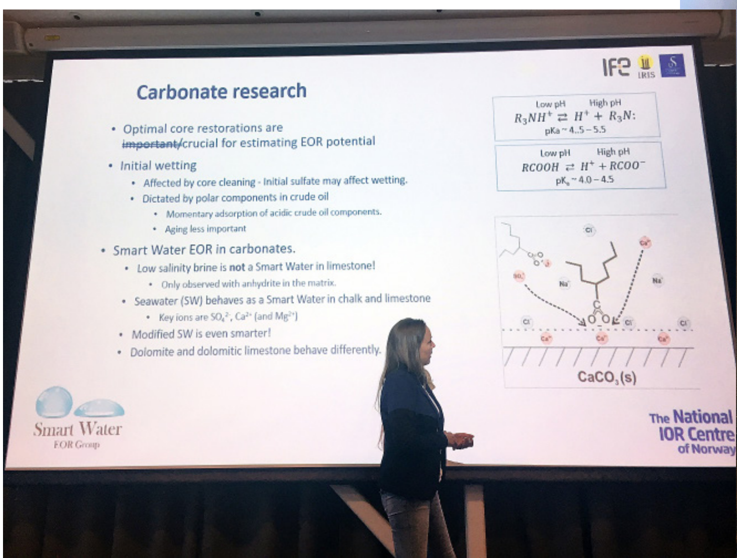
Pilots/field and reservoir management group:

IOR methods work in the lab (upscaling is on its way)
  • Need large scale testing
  • In many cases uncertainty is reduced by having an on-shore pilot
  • Vital step towards full field pilots
Improved work-flow:
  • Instrumentation in new fields
  • Integrated model, reservoir model + economic evaluation
  • Include all important uncertainties in the ensemble based HM: e.g. wetting conditions
  • Include optimization, injection strategy
Feasibility and safety
  • Environmental aspect of the pilot
Data and data quality
  • Need all types of data
  • Tracer is a good idea, need data!
    • Simulate weak tracers on field scale
    • Explore different scales
  • Different behavior of preserved and restored cores: no effect of low-salinity flooding in restored core.
  • Initial wetting conditions in reservoir important.
Pilot test to validate the tools, **IOR Centre: Implementation of reservoir model, going from the lab to field.**

work plan 2019

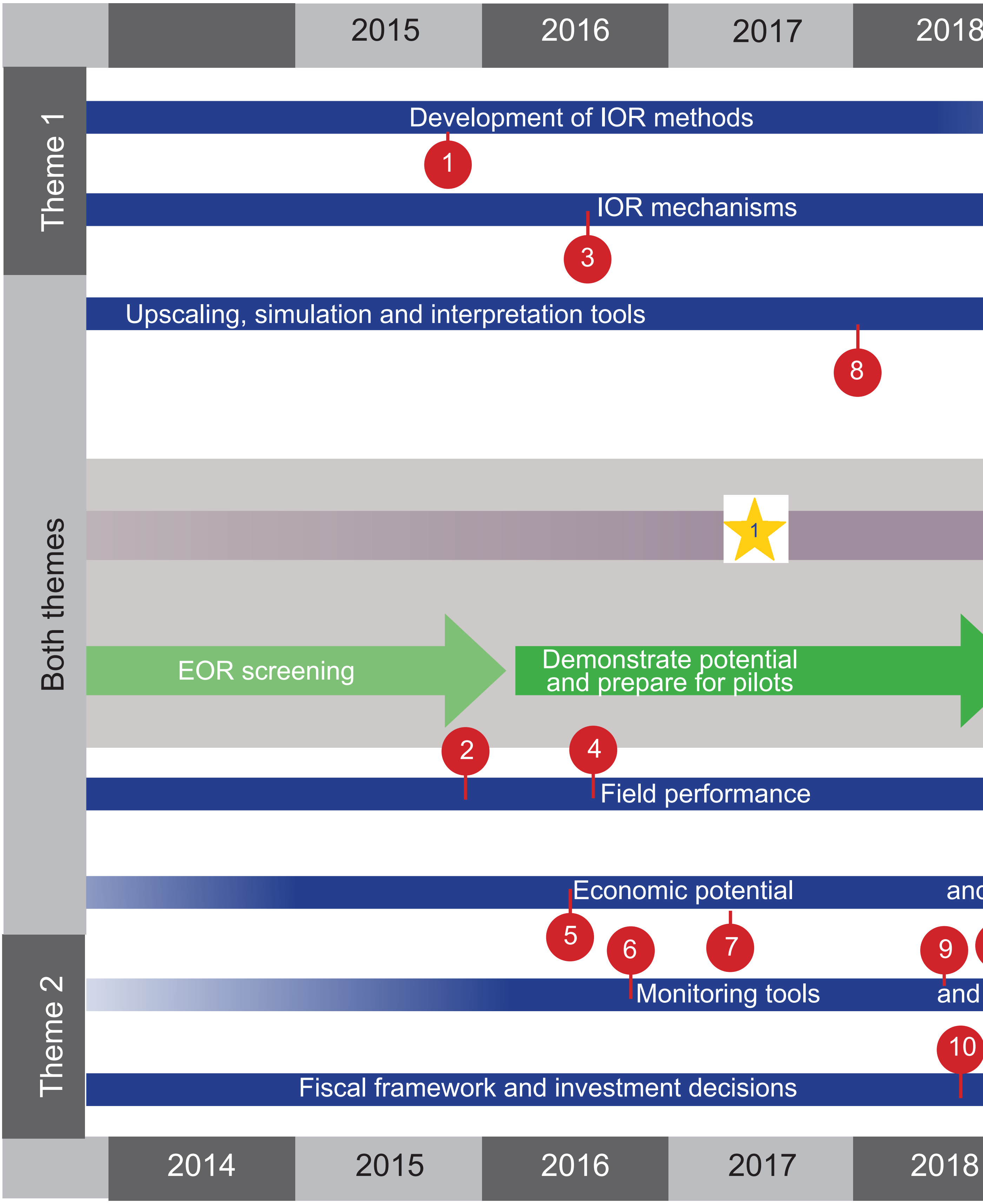
Robert Moe, ConocoPhillips

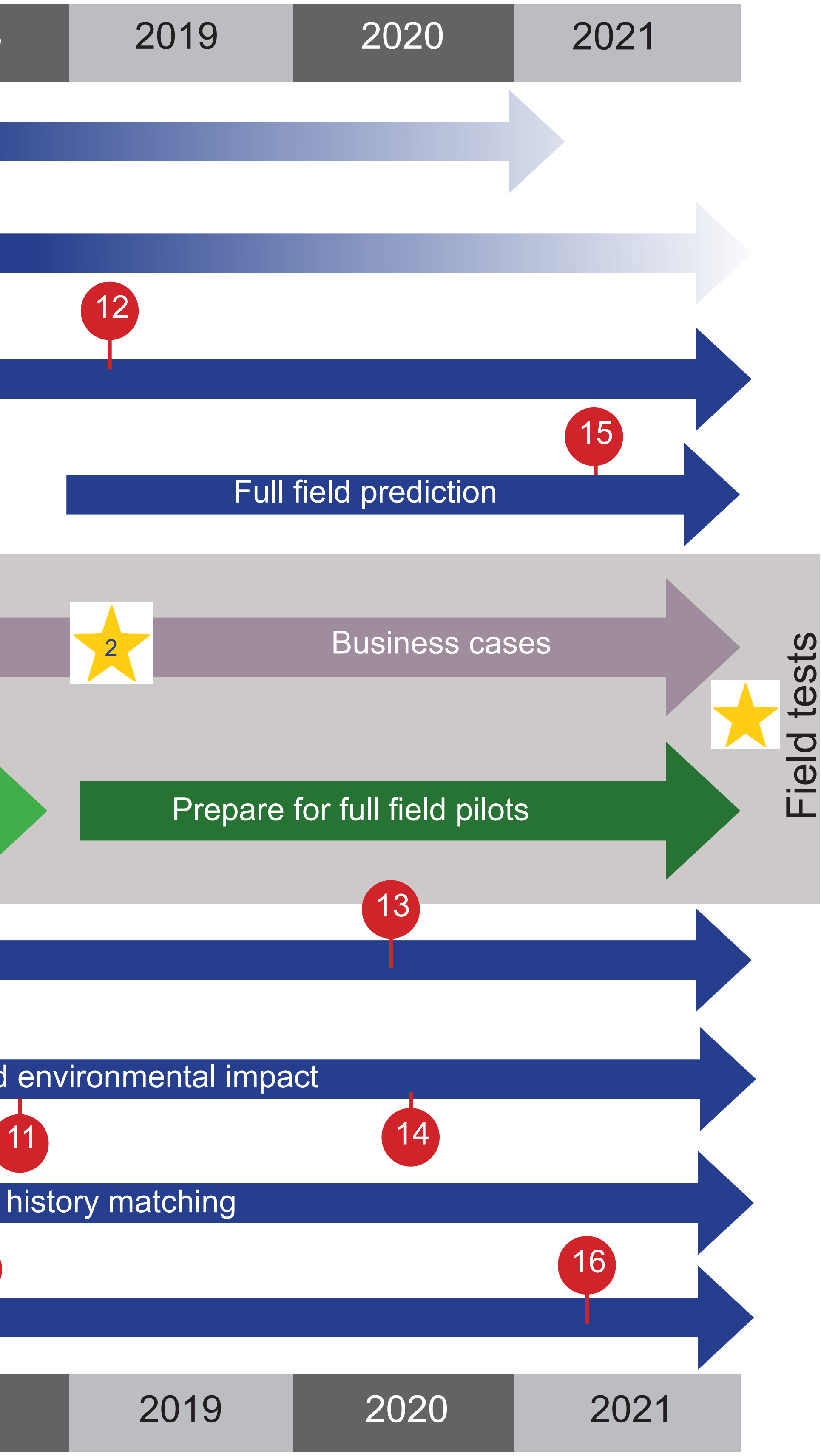
Patrizia Pisicchio and Leili Moghadasi, ENI Milan (left) and Ana Todosijevic, Wintershall



Tina Puntervold, The National IOR Centre of Norway

The Roadmap


2015
2016
2017
2018
Theme 1
Development of IOR methods
1
IOR mechanisms
3
Upscaling, simulation and interpretation tools
8
Both themes
1
EOR screening
Demonstrate potential and prepare for pilots
2
4
Field performance
Economic potential
5
6
7
9
Monitoring tools
Theme 2
10
Fiscal framework and investment decisions
2014
2015
2016
2017
2018

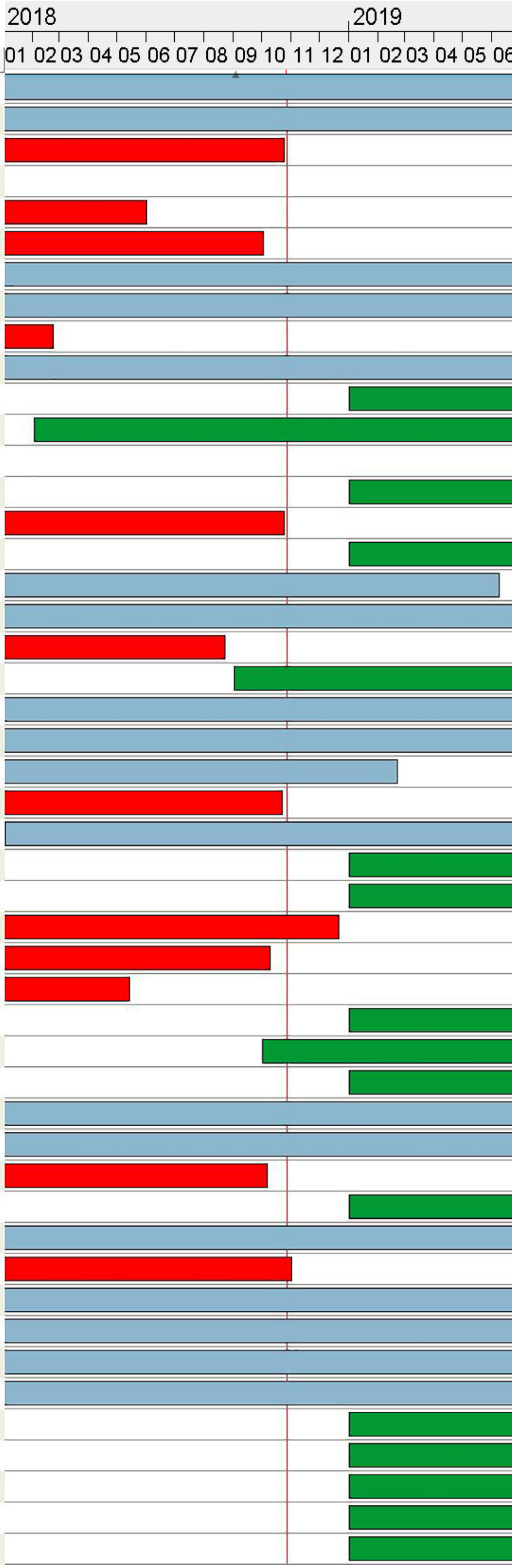


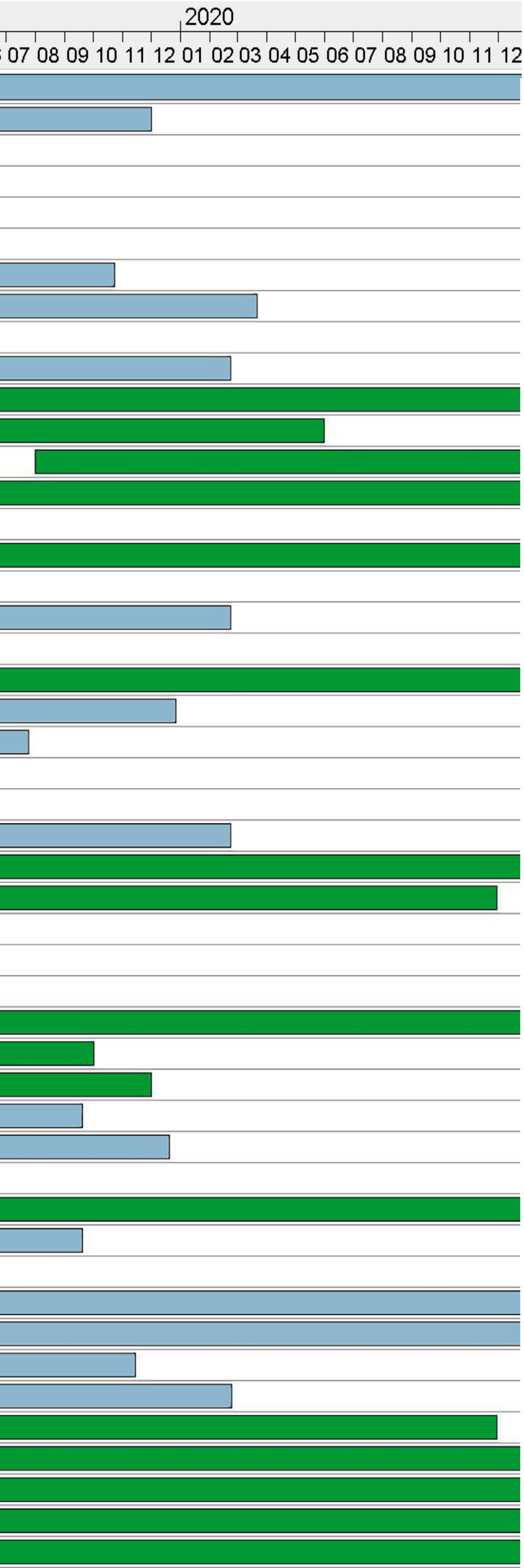
Milestones

1. Selection of suited field for single-well tests (access to field data)
2. Single-well pilot tests:
Smart water injection
Polymer injection

1. Selected IOR methods
2. Field data in place (injection, production and tracer data, 4D seismic and reservoir model/geo-model/ geomechanical model)
3. Input model parameters (from pore, core, sub-micron experimental and modeling R&D activities)
4. Large scale polymer shear degradation test
5. Economic potential of IOR methods
6. Monitoring tools: 4D seismic (front detection), tracer data (residual oil S_{or})
7. Conditioning of injection fluids
8. Reservoir simulation, geomechanics (e.g. Eclipse, Visage), tracer and IOR fluid simulation (IORSim)
9. Full field history matching with 4D seismic and tracer data
10. Viability of methods (fiscal framework and taxation)
11. Environmental impact of selected IOR methods
12. Tool-box for interpretation of pilot-tests
13. Pilot-tests conclusions (volumetric sweep/injection and production strategy, S_{or}, compaction impact, economic potential)
14. Economic potential of pilot-tests
15. Recommendation for comprehensive and full-field tests
16. Economic potential of full-field tests at NCS

Name	Begin date	End date
1.1.1 DOUCS - Deliverable Of an ...	01/04/14	01/02/21
1.1.2 Core plug preparation proc...	01/08/14	01/12/19
1.1.3 Wettability estimation by o...	02/11/15	23/10/18
1.1.4 Core scale modeling of EO...	01/01/16	01/10/17
1.1.5 Application of metallic nan...	01/05/15	30/05/18
1.1.6 Effect of wetting property ...	01/09/15	01/10/18
1.1.7 Thermal properties of reser...	02/11/15	23/10/19
1.1.8 Flow of non-Newtonian flu...	01/12/15	22/03/20
1.1.9 Integrated EOR for heterog...	01/01/16	20/02/18
1.1.11 Permeability and stress st...	02/01/17	23/02/20
1.1.12 Understanding the initial ...	01/01/19	01/12/21
1.1.13 Reservoir wettability and i...	01/02/18	01/06/20
1.1.14 Mineralogical influence o...	01/08/19	01/07/21
1.1.15 Upscaling of Polymer and ...	01/01/19	01/12/21
1.2.1 Micro- and nano-analytical...	01/09/15	23/10/18
1.2.3 Applying the analytical tool...	01/01/19	01/12/21
1.3.1 Pore scale simulation of m...	02/01/17	08/06/19
1.3.3 Micro scale simulations of ...	02/01/17	23/02/20
1.3.4 Description of the rheologi...	01/07/15	21/08/18
1.3.6 Development of a simulati...	01/09/18	01/09/21
1.4.1 IORSim development	01/01/14	27/12/19
1.4.2 Environmental fate and eff...	01/06/15	24/07/19
1.4.3 Lab scale Polymer Test in p...	01/01/16	20/02/19
1.4.4 Smart Water for EOR by M...	01/05/15	21/10/18
1.4.5 Polymer rheology at micro-...	01/01/18	23/02/20
1.4.6 Risk Management / ERA	01/01/19	01/12/21
1.4.7 Improve IOR models in IOR...	01/01/19	01/12/20
2.5.1 Development and testing o...	01/01/16	20/12/18
2.5.2 Single-Well Chemical Trace...	01/01/16	08/10/18
2.5.3 Development of water/oil ...	01/04/15	12/05/18
2.5.4 Nanoparticle tracers for pe...	01/01/19	01/12/21
2.5.5 Lanthanide ester complexe...	01/10/18	01/10/19
2.5.6 Dynamic flooding propertie...	01/01/19	01/12/19
2.6.1 Adding more physics, chemi...	01/01/14	19/09/19
2.6.2 Advanced Numerical Meth...	01/01/16	20/12/19
2.6.3 CO2 Foam EOR Field Pilots ...	02/11/15	05/10/18
2.6.4 Upscaling of chemo-mecha...	01/01/19	01/12/21
2.7.1 Production optimization	01/01/14	19/09/19
2.7.3 Statistical Technique in Red...	02/11/15	31/10/18
2.7.4 Data assimilation using 4-D...	01/01/14	30/11/21
2.7.5 Interpretation of 4D seismi...	03/11/14	12/12/21
2.7.7 4D seismic and tracer histo...	19/01/15	14/11/19
2.7.8 Elastic full-waveform inver...	02/01/17	24/02/20
2.7.9 IOR Pilot Projects – Learni...	01/01/19	01/12/20
2.7.10 The Value of Data and Da...	01/01/19	01/01/21
2.7.11 Data assimilation using 4D...	01/01/19	01/12/21
2.7.12 Developing optimal strate...	01/01/19	01/12/21
2.7.13 4D seismic frequency-dep...	01/01/19	01/12/21





Gantt Chart

theme 1 & 2

Ongoing projects

Finished projects

New projects

The projects

1.1.1 DOUCS – Deliverable of an Unbeatable Core Scale Simulator

Duration: February 2016 – February 2021

Project manager(s): Aksel Hiorth (UiS/NORCE) and Arild Lohne (NORCE)
PhD student(s): Siv Marie Åsen (UiS), Irene Ringen (UiS)
Postdoc: NN
Key personnel: As above
Theme: 1
Task: 1
Budget 2019: 2.700.000 NOK

The purpose of this project is to develop a numerical tool, IORCoreSim, to interpret all kinds of special core analyst lab experiments. By using IORCoreSim, the key parameters needed to simulate water flooding and EOR processes at pilot and sector scale are extracted from the lab experiments.

OBJECTIVE

To develop a tool for improved simulation of EOR processes at core, sector and pilot scale.

KNOWLEDGE GAPS

There are only a limited number of simulators available that can handle geochemical interactions, multiphase flow and flow of non-Newtonian fluids in porous media. Some simulators may have the ability to simulate geochemical interactions but there are no generally accepted feedback mechanisms from the interactions to the flow parameters, such as relative permeability, capillary pressure and/or viscosity.

Many of the IOR methods studied at the IOR Centre are of the type where several mechanisms are at work at the same time, e.g. low salinity flooding (which could affect microscopic sweep efficiency), combined with polymers (to increase macroscopic sweep efficiency) and sodium silicate (for deep reservoir plugging) mixed with different types of injection waters.

It is therefore important to have a simulator that describes the chemical systems and is able to feed back the correct effect on the effective multiphase flow functions. The model will be used to simulate and interpret laboratory core floods and extract model parameters from the lab data (history matching). Given that temporal and scale dependency is adequately represented in the models, then the derived parameters can be used for scaling laboratory results to the field scale.

PLANS 2019

Continue the work on using the improved geo-chemical model on various experimental data relevant for low salinity and smart water injection. Improve the representation of polar oleic species in existing models and their potential influence on effective flow functions (relative permeability and capillary pressure). Different mechanisms suggested in the literature will be analysed with respect to consistency across datasets and scaling to larger models. The outcome should be identification of most likely mechanism(s) and eventual short-comings in existing models.

- Upgrade the pressure solver to properly handling three phases in fine grid with capillary pressure. This is relevant for experiments involving water, oil and gas (e.g., CO2-flooding), as well as for including effect of phase behaviour in micellar (surfactant) flooding.
- Investigate the influence of sub-grid heterogeneities on the polymer models. This may improve predictions of field scale polymer flooding.
- Submitting an abstract on associative polymer for the EAGE IOR 2019 conference in Pau.

DELIVERABLES 2019

Further development of IORCoreSim, a tool for simulation of EOR processes at the core scale and for investigating upscaling of laboratory results.

This project delivers to:
IOR mechanisms; and Economic potential and environmental impact

1.1.2
Core plug preparation procedures

Duration: 2014-2019 (Phase 1)

Project manager: Ingebret Fjelde (NORCE)
Key personnel: IOR- and Petroleum Lab groups
Theme: 1
Task: 1
Budget 2019: 700.000 NOK

The purpose of this project is to check how the core preparation procedures can influence results when investigating the potential for EOR in the lab.

OBJECTIVE

To identify critical steps in core preparation procedures.

KNOWLEDGE GAPS

Since reservoir rock state changes during sampling, mud contamination, storage and cleaning (by organic solvent and water) of reservoir core plugs, better procedures are required for the preparation of reservoir core plugs to ensure that representative wettability conditions are established for SCAL and EOR experiments. Water flooding results are used as a reference for EOR flooding experiments. If the potential estimate for the reference is wrong, the potential estimates for the EOR methods will also be wrong.

The focus is to ensure efficient cleaning of the reservoir core plugs,and investigate the effects of mud contamination on rock properties.

PLANS 2019

- Determine the effects of mud invasion on rock properties using preparation procedures for native and restored core plugs:
    1. Outcrop core plugs exposed to mud and not exposed to mud are compared
    2. Effluent composition is monitored to follow removal of contaminations
    3. Outcrop rocks of different compositions are used
    4. Both water-based mud and oil-based mud are included in the study
    5. Rock is analysed both before and after cleaning to identify mud residues
- For the focused EOR-methods in the Centre, determine the effects of mud contamination on the determined potentials.
- Compare saturation functions determined for native and restored reservoir core plugs. Input from oil companies are required for this study.
- Determined how important mud contamination is for the upscaled measurements.

DELIVERABLES 2019

Reports:
- Effects of mud invasion on rock properties.
- Effect of mud invasion on the determined potentials for the focused EOR-methods in the IOR Centre.
- Comparison of saturation functions for native and restored reservoir core plugs.
- Effects of mud contamination on the upscaled properties.

This project delivers to:
Development of IOR-methods, IOR-mechanisms, Economic potential and environmental impact, as well as other categories

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

Duration: November 2015 – October 2019

Project manager(s): PhD student Tijana Voake (UiS)
Key personnel: Anders Nermoen (NORCE), Ida Lykke Fabricius (DTU), Reidar Inge Korsnes (UiS) and Merete Vadla Madland (UiS)
Theme: 1
Task: 1
Budget 2019: 274.000 NOK

The purpose of this project is to investigate how temperature variations in chalk reservoir induced by the injection of cold water and cross flow may affect the mechanical strength of chalk. Calcite has anisotropic thermal expansion coefficients and this may lead to additional weakening. A better knowledge of the interplay between temperature effects and rock mechanical strength is of great importance to assess risks of thermal fracturing.

OBJECTIVE

The focus of this PhD project is destabilisation of chalks due to thermal cycling, caused by injection of low temperature flooding fluid. Can thermal expansion anisotropy at a grain level lead to the degradation of inter-granular cementation in chalks?

Chalks stiffness and strength are dictated by a combination of electrostatic and intergranular cementation forces. We predict that anisotropic thermal expansion coefficients cause weakening of the chalk if cementation is present.

KNOWLEDGE GAPS

The effects of temperature changes have only been investigated by comparing mechanical properties at two or more different temperatures.

However, the effect of temperature cycling has not been studied and this is a scenario that more accurately mimics the nature of a reservoir rock that has undergone oil production and fluid injection.

PLANS 2019

Further studies on two types of water- and oil-saturated chalk will be conducted, and a comparison using three different testing methods is planned to be written in three journal paper.

DELIVERABLES 2019

Journal papers and a thesis completion.
Tensile strength weakening by temperature cycling has been observed in water saturated chalk samples, but not in dry. Neither oil or water saturated chalk samples displayed evidence of shear or hydrostatic strength weakening due to temperature cycles, however water saturated chalk with greater amount of contact cement accumulated significantly more irreversible strain than the samples tested at the constant temperature.

This project delivers to:
IOR mechanisms; and Economic potential and environmental impact

1.1.8
Flow of non-Newtonian fluids in porous media

Duration: December 2015 – March 2020

Project manager(s): PhD student Irene Ringen (UiS)
Key personnel: Aksel Hiorth (UiS/NORCE), Olav Aursjø (NORCE) and Arne Stavland (NORCE)
Theme: 1
Task: 1
Budget 2019: 1.095.000 NOK

The purpose of this project is to design lab experiments that will provide information about the transport properties of polymer-based fluids in porous media. Polymer fluids are complex and there is currently no complete theoretical understanding of their transport properties in a reservoir where polymer molecules are exposed to temperature, salinity, and pressure gradients. This project will generate data and models that will be used in IORCoreSim and IORSim (Task 4) to predict the fate and effect of polymer flooding for improved oil recovery.

OBJECTIVE
To develop physical (mechanistic) models based on laboratory experiments that are capable of describing the sweep efficiency of non-Newtonian fluids in porous media for flooding conditions representative of the Norwegian Continental Shelf (NCS).

KNOWLEDGE GAPS
It is difficult to evaluate the field performance of polymer flooding using current simulation models. The models that describe polymer flooding are usually crude and do not take into account all of the chemical reactions that can take place when the pore fluid interacts with the rock. This is necessary in order to be able to predict how the polymer solution will propagate through the reservoir and displace the oil.

In this project we will develop experimental techniques where the properties of the polymer solution, the properties of the porous media (grain size, mineralogy, wettability), pressure and temperature are systematically changed.

The experimental data will be combined with numerical models both at a pore scale (Lattice Boltzmann technique), at a core scale (Darcy scale models), and thermodynamic models for the solution in order to suggest physical sound models that can be used on the Darcy scale in order to predict behaviour from centimetre to kilometre scale. These models may be used to evaluate the economics of polymer flooding in oil reservoirs.

PLANS 2019
Designing an experimental set-up that can quantify the fate of low salinity polymer solutions when injected into formations with high saline brine. Investigating how the viscosity of the solution and retention will change as the injected, low salinity brine is mixed with formation water.

DELIVERABLES 2019
Improved understanding of how salts and polymer is transported to investigate the potential for hybrid low sal and polymer EOR.

Submitting an abstract to the IOR NORWAY 2019 on the topic described above. Publish the work in a peer review journal.

This project delivers to:
IOR mechanisms, Development of IOR methods and Economic potential and environmental impact

1.1.11
Permeability and stress state

Duration: February 2017 – February 2020

Project manager(s): PhD student Emanuela I. Kallesten (UiS)
Key personnel: Merete V. Madland (UiS), Reidar Inge Korsnes (UiS), Pål Østebø Andersen (UiS), Udo Zimmermann (UiS), Edvard Omdal (ConocoPhillips)
Theme: 1
Task: 1
Budget 2019: 1.095.000 NOK

The purpose of this project is to understand how stress state and pore pressure affect the permeability of compacting rocks at reservoir conditions. However, a permeability model based solely on the concept of effective stress (overburden minus pore pressure) does not entirely explain laboratory observations. This project will generate a consistent set of experimental data including reservoir parameters that, together with stress state, influence fluid flow in porous rocks and rock permeability. This will enhance the understanding of permeability behaviour under reservoir conditions, increase model accuracy and improve permeability prediction.

OBJECTIVE

Development of petroleum reservoirs including primary depletion of the pore pressure and repressurization during water injection naturally leads to changes in effective stresses of the rock formations. These changes impose mechanical deformation of the rock mass with subsequent altering of its petrophysical properties. Besides mechanical compaction, chalk reservoirs are also susceptible to mineralogical and textural changes as an effect of the injecting fluid's chemical composition and temperature. It is then essential to investigate the combined effect of all these processes, in order to predict fluid flow, oil recovery and to select optimal injection brines.
The main objective of this project is therefore to study permeability evolution in chalk/carbonates at different stress states and thermochemical influence that replicate actual reservoir conditions. A secondary objective is to model and predict permeability based on the interpretation of the experimental data.

KNOWLEDGE GAPS

While the dependency between matrix permeability and porosity of compacting rocks is well recognized, studies of the effect of specific stress paths causing compaction, along with temperature and mineralogy variations on permeability are still insufficient. Besides contributing to a better understanding of the interplay of these parameters on permeability, the project also includes a study of selected authentic reservoir rocks. This is not only a unique opportunity for validating conceptual tests on outcrop chalk so far, but it may also conclude the search for an adequate outcrop chalk equivalent for future laboratory tests.
Bridging these gaps is important when considering the impact of water-related IOR techniques.

PLANS 2019

The focus in 2019 will be on completing the characterization of the selected North Sea reservoir rocks and the study of the effect of temperature and pore pressure in chalk. Single-phase flow tests at different stress states, and at elevated temperatures will allow highlighting the effects of each of the factors that influence rock permeability. The tests include both inert fluids, which do not affect the rock surface and fluids that will alter the rock morphology, texture and strength.
Two other test setups will focus on the effect of stress state on pre-fractured chalk and Carman-Kozeny modelling of permeability, respectively.

DELIVERABLES 2019

The results from the study on the selected reservoir rocks will lead to:

- A thorough characterization of the North Sea reservoir chalk in terms of its chemical composition, mineral structures and textures
- The submission and publication of two peer-reviewed international journal papers
- The results from the thermochemical and pore pressure tests will lead to:
- Systematic analysis of permeability evolution in shear failing outcrop, as well as reservoir chalk cores
- Modeling of fluid flow in reservoir chalk
- The submission and publication of two peer-reviewed international journal papers

The doctoral dissertation will be ready for submission within 2019 and it will include a synopsis of the results, the data interpretation, and main conclusions.

This project delivers to:
Development of IOR methods, IOR Mechanisms, Upscaling, simulation and interpretation tools and Economic potential and environmental impact

1.1.12
Understanding the initial wettability of reservoirs

Duration: January 2019 – December 2021

Project manager(s) / PhD student(s): NN
Key personnel: Tina Puntervold (UiS), Skule Strand (UiS), Carita Augustsson (UiS), Jan Ludvig Vinningland (NORCE), Mona W. Minde (UiS)
Theme: 1
Task: 1
Budget 2019: 1.095.000 NOK

The purpose of this project is to link reservoir wettability to the properties of the crude oil, rock mineralogy and formation water composition.

OBJECTIVE

This PhD-study contains several parts with the following objectives:

Analyse rock-brine interactions to evaluate if crude oil components should be able to wet mineral surfaces when introduced at reservoir temperature.
Identify mineral distribution in the matrix/pore wall system, that are important for the brine-solid interactions, and thus also for the wettability induced by crude oil interactions.
The oil components with affinity to mineral surfaces, will be identified in effluent analyses of produced oil.
The potential for modifying core wettability and observing Smart Water EOR effects will be investigated for specific crude oil – brine – rock systems.
Model the dominating crude oil – brine – rock interactions at mineral surfaces, focusing on short-term dynamic ion exchange between oil and brine components and the mineral surface.

KNOWLEDGE GAPS

Any EOR method aiming at improving the water-wetness of the reservoir rock is dependent on the state of the initial rock wettability. The initial reservoir wettability is generated through chemical interactions between reservoir rock, formation water and crude oil components, influenced by reservoir temperature over geological time. The importance of reservoir chemistry, e. g. brine and oil chemistry and especially rock mineral chemistry is often overlooked in oil production processes. However, the chemistry affects the initial wettability of the reservoir, and thereby also the fluid location and flow during oil production. This study focuses on improving the understanding of the initial wettability of the reservoir rock (mainly sandstone rocks), by investigating chemical interactions between the different reservoir phases; crude oil, brine and rock.

PLANS 2019

The PhD student will be in place, then he/she will perform a literature review, and become familiar with experimental materials and equipment. Experimental research on crude oil properties will commence, in addition to microscopic work on rock material.

DELIVERABLES 2019

Improved understanding of the crude oil components responsible for reservoir wettability.

This project delivers to:
Development of IOR methods, IOR Mechanisms and Full field prediction

1.1.13
Reservoir wettability and its effect on water based recovery processes

Duration: February 2018 – June 2020

Project manager(s): Postdoc Iván D. Piñerez Torrijos (UiS)
Key personnel: Tina Puntervold (UiS), Skule Strand (UiS)
Theme: 1
Task: 1
Budget 2019: 1.095.000 NOK

The purpose of this project is to understand the parameters affecting both the initial wettability in carbonate reservoirs and the potential for wettability alteration by water-based EOR methods.

OBJECTIVE

To optimize core cleaning and core restoration procedures for representative wettability.
To improve the understanding of the factors influencing the initial wetting in carbonate reservoirs. The generated knowledge on core restoration and initial wettability will be used to increase the understanding of Smart Water EOR potential.

KNOWLEDGE GAPS

The initial wetting of a reservoir sets a limit for the EOR potential during “Smart Water” injection. For this reason, an improved understanding of the factors influencing the wetting can help to control and better forecast oil production during water-based floods.

To preserve and reproduce the original reservoir wettability is a challenging task. Wrong core restoration procedures can lead to incorrect wettability and thus induce serious errors when evaluating the EOR potential by water-based methods, relying on wettability alteration.

The oil and gas industry is currently not paying enough attention to the three main reservoir phases, crude oil, brine and rock, to describe initial wetting and wettability alteration processes during oil production. Thereby, there is a need to improve the chemical knowledge on interactions between these phases, especially during core restoration processes.

PLANS 2019

Parametric studies will be carried out on outcrop carbonate rock material. The parameters to induce different wetting states in the material will be the polar components present in the crude oil, the brine compositions, and the mineralogy of the core.

The initial wetting will be assessed using spontaneous imbibition and chromatographic wettability tests. Systematic core restoration procedures will be performed to optimize the core cleaning and restoration procedures.

Viscous floods will be run to evaluate the production performance of different injection brines at different wetting states. These results can be used to estimate the potential for wettability alteration with “Smart Water” injection brines.

DELIVERABLES 2018

Improved core restoration protocols that aim to obtain a better reproduction of the initial wetting of a reservoir system.

Increased understanding of the impact of initial wetting on the EOR potential and oil recovery performance during a “Smart Water” flood.

This project delivers to:
Development of IOR methods, IOR Mechanisms and Full field prediction

1.1.14 Mineralogical influence on reservoir wetting and Smart Water EOR processes

Duration: August 2019 – July 2021

Project manager(s) / Postdoc(s): NN
Key personnel: Tina Puntervold (UiS), Skule Strand (UiS)
Theme: 1
Task: 1
Budget 2019: 456.000 NOK

The purpose of this project is to study the effects of sandstone mineralogy and mineral properties on the initial reservoir wetting and on wettability alteration by water-based EOR methods.

OBJECTIVE

The objective of this study is to investigate the physical properties of typical sandstone reservoir minerals, their chemical surface reactivity and its impact on initial wetting and wettability alteration by ion-modified Smart Water.

Simplified models to be used in reservoir simulators will be suggested.

KNOWLEDGE GAPS

How does the distribution of minerals in the pore space affect the wetting? How does this distribution affect the adsorption at the mineral fluid interface (both ions and polar components from the oil phase)? How to represent the initial wetting in reservoir simulators?
The initial wetting is of great importance when it comes to evaluating the potential for Smart Water flooding. Although some initial studies have been performed, there still lack a systematic investigation on how the mineralogical composition of the reservoir rock, crude oil and formation water composition, and reservoir temperature affects the initial wetting. This knowledge will be used to investigate the potential for wettability alteration during water flooding.

PLANS 2019

The plans for 2019 include getting the Post Doc in place and starting up with mineral surfaces characterizations, both mineralogical, chemical and physical.

DELIVERABLES 2019

Waterflooding of core samples to improve the understanding of rock-fluid interactions that are influencing initial reservoir wettability and the Smart Water EOR potential.

This project delivers to:
Development of IOR methods; IOR mechanisms; and Upscaling, simulation and interpretation tools

1.1.15
Upscaling of polymer and Smart Water processes

Duration: 2 + 1 years

Project manager(s) / Postdoc(s): New postdoctoral fellow
Key personnel: Aksel Hiorth (UiS/NORCE), Arild Lohne (NORCE), Arne Stavland (NORCE)
Theme: 1
Task: 1
Budget 2019: 1.095.000 NOK

The purpose of this postdoc project is to further develop the models in IORCoreSim and specifically investigate how the core scale models can be upscaled and implemented in reservoir simulation tools, such as IORSim and OPM.

OBJECTIVE

Develop IOR models on reservoir simulation scale that are consistent with core- and pore-scale displacement mechanisms.

KNOWLEDGE GAPS

How to best capture the effect of IOR chemicals in large homogenous blocks? How do EOR processes at a core scale translate to a larger scale? What are the most important parameters from smaller scales that are important to describe flow on a larger scale?

In the reservoir the fluids experience a range of different conditions; varying temperature and pressure, matrix flow and fracture flow, low and high flow rates. For all these reasons core scale experiments does not directly translate to field scale. Currently there are no consensus on a methodology on how to upscale the core scale results to larger grid blocks.

PLANS 2019

One of the main findings in the polymer simulation work in the IOR Centre was that much of the advanced polymer behaviour was only relevant close to the injector well (and potentially the producer). Building on those results we will suggest improved well models to be used in IORSim and/or OPM to capture shear thickening and mechanical degradation.

Next, we will investigate how to translate the Smart Water core scale results in chalk to reservoir scale. The postdoc student will develop Smart Water models in the IORCoreSim simulator based on core scale experiments. IORSim will be used to investigate how the Smart Water propagate on larger scale. The IORSim simulations will be calibrated to produced water chemistry (preferentially to the Ekofisk field). If possible, we will also test the predicted spatial distribution of chemical alterations with field observations, e.g. compaction data, 4D seismic observations, well logs.

DELIVERABLES 2019

- Improved field scale (synthetic) polymer model
- IORSim geochemistry simulations on field case(s)
- Development of Smart Water models

This project delivers to:
IOR Mechanisms, Upscaling, simulation and interpretation tools, Full field prediction and Field performance

1.2.3
Applying the analytical tool box to specific EOR related experiments to enhance oil recovery and to assist upscaling

Project manager: Udo Zimmermann
PhD student(s): NN and Emanuela Kallesten
Key personnel: Mona Minde (UiS), Reidar Inge Korsnes (UiS), Merete V. Madland (UiS)
Theme: 1
Task: 2
Budget 2019: 1.095.000 NOK

Duration: January 2019 – December 2021

This project will deepen the understanding of textural alterations of the regional geology during water injection. One research focus will be «fractured» chalk samples, a second would be the investigation of the role of clays and other non-carbonate minerals in chalk during flooding experiments and a third approach would be to study the «zone» of increased porosity which seems to be progressing through a core during flooding with e.g. $MgCl_2$, as detected by MLA.

We like to push forward the analytical techniques used in previous study with chalk samples containing hydrocarbons. This is because we believe that the textural alterations during flooding is of particular importance to the flow of oil and water in the reservoir, and although the current techniques have proven to be quite good, there is still more to be gained by advancing them further. Our developed tool box of analytical methods assists in the opportunity to deliver quick results when cooperating with other tasks and projects (e.g. for polymer injection studies) and includes the study of the interaction of wet-phases and solid phases on a nano- and sub-nano scale with the necessary microscopes. These textural and mineralogical data will be utilized by the core scale modelling activities in Task 1.

OBJECTIVE
To understand Smart Water effects at micro- and nano-level and link these alterations to changes in geo-mechanical parameters of reservoir rocks, now on specific applied areas: fractures, the role of clays/non-carbonate minerals and high porosity zones. These data will be crucial for upscaling of Smart Water.

KNOWLEDGE GAPS
This project will help to fully understand which processes are governing the alterations in texture, chemistry and mineralogy when flooding fractured chalk and those containing non-carbonate minerals. Fractures, non-carbonate minerals and the accumulation of such phases in fractures are topics of permanent interest as these applied fields are of most interest for EOR processes. Moreover, the discovery of porosity increase during flooding at specific areas needs to be substantiated and understood. We understand this area as of specific interest as it may be a common case in a reservoir during flooding in reflecting a disequilibrium, Such a heterogeneous alteration process might be important for the release of or to mobilize HC. Hence, here are our focus on the interaction of wet and mineral phases. All results are interwoven and interdependent with rock mechanical processes, as they are related sensu lato to estimate compaction and porosity/permeability evolution, focus of EOR processes. Last but not least, significant expertise will be added to the university with the arguably only specialists in mineralogical processes on micron and nano-level in the Centre.

PLANS 2019
We aim to contribute to several international conferences and to bundle some research in a peer-reviewed international publication. Generally, the three research foci shall be able to establish substantial data-sets for the different peer groups at the Centre.

DELIVERABLES 2019
The project envisages to (i) describe, quantify and understand the new growing minerals and their interaction with the host rock in fractures after flooding, (ii) describe the mineral-fluid interaction between injection fluid, carbonate minerals and non-carbonate minerals and if this interaction affects significantly the EOR experiments, (iii) study an area of increased porosity produced by injection fluids and its significance for EOR processes with the determination and further characterisation of new grown minerals and wet phase-minerals interaction processes, (iv) offer our toolbox to gain quick and reliable information about the character of the flooded sample and (v) deliver quantitative data for modelling processes for upscaling and to substantiate large-scale testing.

This project delivers to:
IOR mechanisms; and Upscaling, simulation and interpretation tools

1.3.1
Pore scale simulation of multiphase flow in an evolving pore scale

Duration: 2017-2019

Project manager: Jan Ludvig Vinningland (NORCE)
Key personnel: Aksel Hiorth (UiS/NORCE), Espen Jettestuen (NORCE), Olav Aursjø (NORCE)
Theme: 1
Task: 3
Budget 2019: 850.000 NOK

Injecting water into an oil reservoir leads to chemical interactions that alter the geometry of the pore space and the wettability of the mineral surfaces. A distance away from the injection point, the injected water reach equilibrium with the formation. How far away from the injector are the chemical interaction active, and how fast are the mineralogical alterations in the active region? How is oil release affected by wettability changes on the pore scale? What are the dominating mechanisms? These questions are particularly important when low salinity or optimized brines are injected in order to improve the microscopic sweep.

Using high-resolution digital chalk geometries obtained from real rocks (from the project "Three-dimensional imaging and pore-scale modelling of carbonate rocks") as input to a numerical geo-chemical pore scale model, we will quantify permeability, wettability and remaining oil during two-phase flows.

OBJECTIVE

- Investigate numerically the pore space evolution during water injection by quantifying permeability, wetting changes, and trapped oil in high-resolution digital chalk geometries obtained from real rock samples.
- Study how different pore space configurations can affect the oil recovery for a given wettability change.
- Use pore scale simulations to better understand which mechanisms are important for spontaneous imbibition experiments.

KNOWLEDGE GAPS

Injecting water into an oil reservoir leads to chemical alterations of the minerals on the pore surfaces. How fast are the chemical reactions, and how far from the injection point are they relevant? This is of particular importance when injecting a low salinity brine or optimized brine to improve the microscopic sweep.
Another important question is how small a sample can be and still yield a measurement that is representative for the whole? At which spatial scale are we no longer able to measure bulk values? This is a key question when we try to bridge the gap between pore- and core-scale measurements.
In spontaneous imbibition experiments, the pore space geometry influence both the diffusive transport of new brines into the pores, and the local oil saturation due to the local curvature. Pore scale simulations is an excellent tool to investigate the importance of these effects, and it can contribute to a better understanding of spontaneous imbibition experiments.

PLANS 2019

- Perform spontaneous imbibition simulations using different pore space geometries to investigate low-salinity mechanisms and get better interpretation of spontaneous imbibition experiments
- Perform size-sensitivity studies of capillary pressure and permeability using differently sized sub-samples of the high-resolution geometries.

DELIVERABLES 2019

- Relative permeability and capillary pressure curves for different pore geometries
- Journal publications, conference contributions, and a written report.

This project delivers to:
Development of IOR methods, IOR mechanisms, Upscaling, simulation and interpretation tools, Full field prediction and Economic potential and environmental impact

1.3.3
Micro-scale simulation of viscoelastic polymer solutions

Duration: 2018-2020

Project manager(s): Espen Jettestuen (NORCE)
Key personnel: Jan Ludvig Vinningland (NORCE), Olav Aursjø (NORCE) and Aksel Hiorth (UiS/NORCE)
Theme: 1
Task: 3
Budget 2019: 850.000 NOK

The projects will study how the distribution of stress in a viscoelastic polymer solution will affect the interaction between the water and oil phases. The effect of having non-Newtonian stress components, due to the presence of polymer, has been hypothesized to be a contributing factor to increased oil recovery in polymer-flooding. We will have an increased focus on boundary conditions for the polymers. In addition, we want to simulate a pure polymer flooding in a porous media, to assist in interpreting the polymer-flooding experiments conducted under Task 1.

OBJECTIVE

- Include both non-slip and strain-rate dependent slip boundary conditions for the polymer fluid, to include the effect of having a polymer depletion layer along the wall.
- Assess the effects of pore geometry on the effective rheology for single phase polymer fluids, as observed in experiments.
- Investigate the microscale mobilisation of remaining oil due to the additional non-Newtonian stresses exerted by the polymer fluids.

KNOWLEDGE GAPS

Injection of polymer solutions increases the effective viscosity ratio between oil and the invading fluid which reduces the viscous fingering effects on larger scales. It is crucial to understand how the effective polymer viscosity is affected by the geometry of the porous rock to be able to appropriately predict the effectiveness of the polymer flooding.

On a pore scale, additional effects due to the non-linear rheology could be influential to the forces between the polymer fluid and the oil. It is conjectured that these effects could mobilise the trapped oil, leading to possible changes in the oil recovery.

In addition, the interactions between polymers and solid boundaries can lead to a depletion layer where the viscosity is close to water viscosity. This will lead to a lower increase in the effective viscosity, in comparison to a homogeneous distributed polymer solution.
These interactions are yet to be fully understood.

PLANS 2019

In 2019 we plan to:

- Continue to use a FENE-P type model as our polymer model.
- Further develop the code for oil-polymer solutions, including wetting properties and interfacial tensions.
- Include the slip boundary conditions in the in-house lattice Boltzmann code.
- Conduct a parameter study of the developed models, using a set of artificially generated pore geometries.
- Benchmark model against existing experimental data.

DELIVERABLES 2019

- Improved understanding of pore scale transport of polymer.
- Core scale transport models of polymer consistent with pore scale behaviour.
- Document and include all developed methods in the in-house lattice Boltzmann simulator.

This project delivers to:
Development of IOR methods; IOR mechanisms; and Economic potential and environmental impact

1.3.7
Simulation of complex non-Newtonian flow

Duration: September 2018 – September 2021

Project manager(s): PhD student Bjarte Hetland
Key personnel: Aksel Hiorth (UiS/NORCE), Dmitry Shogin (UiS) and Espen Jettestuen (NORCE)
Theme: 1
Task: 3
Budget 2019: 1.095.000 NOK

The purpose of this project is to investigate non-Newtonian flow in micro channels. Non-Newtonian effects such as normal forces will be investigated in various pore geometries. One of the aims is to determine when the viscoelastic effects are important for oil displacement, and if they could contribute significantly to oil recovery.

OBJECTIVE

- Develop a pore scale simulation tool that is capable of simulating flow of non-Newtonian fluids in complex geometries, including micro channels – taking the tensor nature of these fluids into account.
- Determine if and when the non-Newtonian effects are important for displacement of oil.
- Calibrate the model against known analytical and experimental results.

KNOWLEDGE GAPS

Do the non-Newtonian nature of polymeric fluids affect the displacement of oil from a porous medium? Is the microscopic sweep affected by normal forces? Existing tools for evaluation of polymer floods takes a simplified approach in which the tensor nature of the fluids is ignored. While such tools might give reasonable results to steady-state flows in simple geometries, they are not suitable for the complex flows (i.e. complex geometries and time-dependent flow) in the porous rocks of an oil reservoir.

To obtain realistic results for such flows, it is necessary to solve the equations of fluid motion together with constitutive equations based on microscopic physics. Two relevant models are the FENE-P dumbbell/bead-spring-chain model for diluted polymer solutions and the Phan-Thien-Tanner model for concentrated polymer solutions.

Recent work has shown promising results with combining the Lattice Boltzmann method with the physically realistic FENE-P model.

PLANS 2019

- Further develop a modular simulation software that makes it easy to experiment with different physical models for fluid flow. We will optimize performance for complex flows of non-Newtonian fluids.
- Test the tool by comparing simulations to known analytical and experimental results.

DELIVERABLES 2019

- A first version of the simulation model, calibrated to analytical results.
- Publication of the model.

This project delivers to:
IOR mechanisms and Upscaling, simulation and interpretation tools

1.4.1
Development and calibration of IORSim

Duration: 2019 ->

Project manager(s): Jan Sagen (IFE)
Key personnel: Aksel Hiorth (UiS/NORCE), Terje Sira (IFE), Jan Nossen (IFE), Egil Brendsdal (IFE), Steinar Groland (IFE), Børre Antonsen (IFE), Jarle Haukås (Schlumberger)
Theme: 1
Task: 4
Budget 2019: 3.500.000 NOK

The purpose of this project is to develop a simulator, IORSim, which improves the capabilities of industry standard reservoir simulators to simulate IOR processes. This is done in a modular way by letting the industry standard reservoir simulator carry out the fluid flow predictions, while IOR-Sim simulates the transportation of chemicals, interactions and effects on the flow parameters (relative permeability and capillary pressure). This allows us to take advantage of the improved pore- and core-scale models developed in tasks 1, 2 and 3 directly in realistic field cases.

OBJECTIVE

To develop a simulator that uses industry standard reservoir models and incorporates important physio-chemical mechanisms from the lab scale to predict the impact of an IOR strategy.

KNOWLEDGE GAPS

How do EOR processes studied on the core scale translate to a larger scale? What are the optimal injection strategies based on information from the core scale? What are the important physical and chemical mechanisms on a field scale for a successful EOR implementation?

Together with a reservoir simulator, IORSim provides an upscaling tool from core scale to field scale, with the option to quickly and accurately simulate IOR processes. Its major strength is that the simulation of species is performed separately from the rest of the fluid flow calculation in the reservoir. The advantage of this is twofold.

Firstly, IORSim makes it possible to perform advanced geochemical IOR simulations within any existing reservoir simulator. It will therefore fill a large gap for the oil companies, which have invested a lot of resources in building reservoir cases within the concept of one specific reservoir simulator on which they rely quite heavily. Secondly, the separation of the flow calculation and the chemical species calculation enhances accuracy and efficiency with regard to computing time.

PLANS 2019

- Extended testing of realistic, large Eclipse IORSim cases including the SNORRE silicate pilot
- Further develop well model to include species transport and heat conduction
- Implement heat conduction and physical dispersion in IORSim
- If additional resources beyond 3 MNOK are available:
    1. IORSim – INTERSECT coupling
    2. IORSim – OPM coupling via Eclipse type of files or direct coupling to OPM
    3. Include thermal effects of overburden and underburden
    4. Include geomechanical effects in IORSim. Possible pre-project to study possibilities with IORSim.

DELIVERABLES 2019

- New release of IORSim – a simulator that can be used with ECLIPSE to predict transport of IOR chemicals
- Conference paper/presentation

This project delivers to:
Upscaling, simulation and interpretation tools and Economic potential and environmental impact

1.4.2
Environmental fate and effect of EOR polymers

Duration: June 2015 – June 2019

Project manager(s): PhD student Eystein Opsahl (UiS)
Key personnel: Roald Kommedal (UiS) and Aksel Hiorth (UIS/NORCE)
Theme: 1
Task: 4
Budget 2019: 0

Produced polymers has the potential to become an environmental Achilles' heel for polymer based EOR in Norway. We investigate the long-term marine fate and effects of EOR polymers using novel methods based on light scattering1 to create comprehensive structure activity relationships to aid the environmental risk assessment of polymer flooding EOR.

OBJECTIVE
To provide understanding about the behaviour and effects of EOR polymers in the marine environment at low concentrations.

KNOWLEDGE GAPS
In general, the fate and long-term effects of EOR polymers in the environment is not well understood. The main issue with EOR polymers is the lack of powerful analytical tools for environmental monitoring and characterization. This project prioritizes the development of methods for the isolation and characterization of polymers in seawater and/or produced water with the aid of light scattering. With capable methods in place, comprehensive structure activity relationships for the marine degradation and potential adverse effects are being developed, which has not been done before and is of great value to environmental risk assessors.

PLANS 2019
After having honed the environmental polymer characterization techniques until late 2017, since then the time has been spent completing laboratory scale testing for a range of polymers related to EOR with respect to marine biodegradation, weathering, and associated eco-toxicological impact, wherein absolute polymer characterization is an integral part.

The eco-toxicological study, which is based on exposing cell culture isolated from the gills of rainbow trout to polymer2, is close to completion. The write-up on this work is still in its infancy.

The marine accelerated weathering study, based on OECD test guideline No. 3163 adapted to sea water and polymers, simulating years of marine exposure, has been completed as of mid 2018. This work is to be published in the very near future.

The experimental part of marine biodegradation study, based on OECD test guideline No. 3064, is finished and remains to be published. The write-up remains for this work as well.

There is plans to examine the eco-toxicity and biodegradability of weathered polymer, similar to Bejgarn et al.5. However, there might not be enough funding within this project to see that bit completed.

DELIVERABLES 2019
- Dissemination of work in scientific journals
- PhD defence
- PhD thesis
- Other work related to the characterization of polymers and eco-toxicological studies to be published in collaboration with other projects
- Presentation IOR NORWAY 2019

This project delivers to:
Economic potential and environmental impact

1.4.3
Large scale yard test and supporting lab activities

Duration: Phase II 2016 ->

Project manager(s): Arne Stavland and Amare Mebratu
Key personnel: Siv Marie Åsen (PhD)
Theme: 1
Task: 4 (and 1)
Budget 2019: 4.217.000 NOK

This project aims to fill the gap between lab scale and pilot scale. It is important to study EOR chemicals not only at cm scale cores, but also in several m scale porous media. In longer (and larger) systems it is possible to investigate the interplay between matrix flow and fracture flow. Furthermore the temperature profile can be varied along these systems, allowing to study the interplay between temperature and different flow regimes. Supporting lab experiments will be performed to quality assure the larger scale tests, and to investigate if it is possible to reproduce part (or all) of the observation in the large scale tests in smaller core samples.

OBJECTIVE

To investigate the behaviour of chemical systems in larger (m) scale compared to lab (cm) scale.

KNOWLEDGE GAPS

Are core scale experiments sufficient to predict the behaviour of EOR chemicals at a field scale? Do simulators capture all of the important parameters? How can data be generated that can calibrate reservoir simulators?

Can thermo-thickening associative polymers be used for in-depth fluid diversion. Are core scale experiments performed at different temperatures sufficient to predict the behaviour of polymers at a field scale?

The crucial point when it comes to upscaling of lab scale processes is that there must be data from the larger scale to which the models can be calibrated. The challenge with off shore pilots is that they are expensive, and maybe more importantly the subsurface is unknown. Therefore, it is sometimes a huge challenge to interpret the pilots. We suggest to perform larger scale experiments in well controlled geometries, the trade-off is clearly that it might be a challenge to recreate in-situ conditions.

PLANS 2019

Analyse the results from the 2018 large scale test with associate polymers. Perform additional lab experiments to quality assure the Yard test. Expand the set up to non-homogenous fracture flow.

We plan to publish the results, where we will compare behaviour of associate polymers at different scales.

DELIVERABLES 2019

Final report and knowledge of how to perform large scale experiments in porous media, presumably with new knowledge about the transport properties of theromo-thickening polymer molecules in porous media.

This project delivers to:
Upscaling, simulation and interpretation tools; Field performance; IOR mechanisms; and Economic potential and environmental impact

1.4.5 Polymer rheology at micro- and Darcy scale

Duration: January 2018 – December 2020

Project manager: PhD student Siv Marie Åsen (UiS/NORCE)
Key personnel: Aksel Hiorth (UiS/NORCE), Rune Time (UiS), Arne Stavland (NORCE), Espen Jettestuen (NORCE)
Theme: 1
Task: 4
Budget 2019: 1.095.000 NOK

The purpose of this project is to investigate polymer rheology in porous media through thorough experimental investigation at different scales, accompanied by modelling, to determine what governs the onset of shear thinning, shear thickening and mechanical degradation, and if possible, propose methods of mitigating mechanical degradation.

OBJECTIVE

The primary objective is to perform dedicated experiments at micro and Darcy scale to verify/substantiate or reject models that explains the behaviour of polymer solutions in porous media.

In addition to traditional investigation, the polymer will be studied with novel/advanced techniques such as microfluidics, imaging techniques and instruments for analysing the distribution of molecular weight. This will be done in cooperation with ongoing projects in the IOR Centre. Modelling tools devolved in the Centre will be used to model the polymer behaviour at pore scale, lab scale and field scale. Results from phase II of the large-scale polymer test can be included.

KNOWLEDGE GAPS

1. What determines mechanical degradation of synthetic polymers in a porous medium, and can it be mitigated?
2. Why does associative polymers display a thickening behaviour in a porous rock at high temperature?
3. What determines the time constants for shear thinning and shear thickening?
4. What is the effect of in-situ hydrolyzation of PAM to HPAM?

PLANS 2019

- Synthesize and model results from Large scale phase II on associative polymers.
- Establish a cooperation with party that has microfluidic equipment for studying polymer solutions and perform tests.
- Design, perform and interpret microfluidic and core scale experiments.
- Compile results from tube flow experiments at different scales for a journal paper.

DELIVERABLES 2019

- Journal paper from Large scale test phase I including analogue small-scale experiments.
- Conference presentations and journal paper from large scale phase II.
- Results from micromodels.
- Improved experimental set-up and models for examining effects of associative polymers.
- Improved understanding of mechanical degradation to be implemented in models for polymer injection.

This project delivers to:
IOR mechanisms, Development of IOR methods, Upscaling, simulation and interpretation tools and Economic potential and environmental impact

1.4.6
Risk Management/ERA

Duration: January 2019 – December 2021

Project manager / PhD student(s): NN
Key personnel: Roger Flage (UiS), Steinar Sanni (NORCE/UiS) and Merete Vadla Madland (UiS)
Theme: 1
Task: 4
Budget 2019: 1.537.000 NOK

The purpose of this project is to develop and implement risk analysis methods and models in support of the IOR Centre efforts to assess and evaluate overall environmental impacts and risks associated with different IOR solutions (products or processes) resulting from the IOR Centre research activities. The aim is to use the concrete risk analysis results in the decision-making process regarding R&D priorities at the Centre, and more broadly to contribute to the general development of methods, models and the foundations of environmental risk assessment.

OBJECTIVE

To develop tools for risk-informed decision-making related to IOR solutions developed at the Centre. This project will connect with the other research activities in the Centre by gathering information about the solution developed, assessing the associated environmental risk, and providing decision support to the further R&D activities. It will thus be an activity that runs through the entire Centre activities.

KNOWLEDGE GAPS

Environmental risk assessments (ERAs) are routinely carried out in the Norwegian petroleum industry, as a basis for decision-making on risk acceptance and risk-reducing measures such as oil spill response systems. Quantitative ERAs related to oil spills are typically performed according to the industry guideline «Method for environmental risk assessment» (DNV, 2007). This guideline is well-established in the industry; however, it is based on a risk conceptualisation that is no longer fully in line with that recommended by the Petroleum Safety Authority Norway (PSAN).

Quantitative ERA methods for operational discharges have been developed in Norway, whereof the tools for discharges to sea have been in mandatory use by all operators on the Norwegian Continental Shelf (NCS) for their produced water discharges since 2006. Other North Sea countries are presently phasing in these tools. Similar relevant tools for drilling discharges are also developed jointly by NCS operators, and are in use by some. To evaluate environmental risk of emissions to air the operators are using different methods. No common quantitative tools have yet been developed for this purpose. NORCE Environment has taken part in the development of the above tools, and is presently using them to provide ERA services to the operators on the Norwegian and Danish continental shelves.

PLANS 2019

- PhD student in place by January
- PhD student coursework (20 ECTS spring semester, 10 ECTS autumn semester)
- Review of existing methods for environmental risk assessment, submitted as a conference paper contribution for the European Safety and Reliability (ESREL) conference 2020
- Identification and structuring of IOR solutions developed at the Centre
- Screening of the IOR solutions and selection of a first case study
- Start developing case study and identify need for method development

DELIVERABLES 2019

- ESREL paper
- List of IOR solutions
- Risk potential characterisation of IOR solutions (output of screening)
- Case study description and plans

This project delivers to:
Development of IOR methods, Full field prediction and Economic potential and environmental impact

1.4.7 Improve IOR models in IORSim

Duration: 2 years

Project manager(s) / Postdoc(s): NN
Key personnel: Aksel Hiorth (UiS/NORCE), Jan Sagen (IFE), Jan Nossen (IFE), Arne Graue (UiB), Egil Brendsdal (IFE) and Steinar Groland (IFE)
Theme: 1
Task: 4
Budget 2019: 821.000 NOK

The research partners in the IOR Centre has developed a simulator, IORSim, which improves the capabilities of industry standard reservoir simulators for simulating IOR processes. This is done in a modular way by letting a reservoir simulator (for example Eclipse) compute the fluid flow, while IORSim simulates the transportation of chemicals, interactions and effects on flow parameters like relative permeability and capillary pressure.

OBJECTIVE

Improve IOR models in IORSim to predict the behaviour of IOR chemicals in realistic field cases.

KNOWLEDGE GAPS

How do EOR processes at a core scale translate to a larger scale? What are the optimal injection strategies based on core scale information? What are the important physical and chemical mechanisms for successful EOR on the field scale?
Together with a reservoir simulator, IORSim provides an upscaling tool from core scale to field scale, with the option to quickly and accurately simulate IOR processes. Its major strength is that the simulation of species is performed separately from the fluid flow calculation in the reservoir.
So far, we have only coupled IORSim to Eclipse. This is done via files. Coupling IORSim to OPM gives more flexibility since OPM is open source, and the coupling may be done via files or directly via a communication protocol. The numerical stability and accuracy as well as the generality of such a coupling remains to be assessed.

PLANS 2019

We will further develop capabilities in IORSim to simulate systems to improve conformance. We will continue to develop the sodium silicate module in IORSim, but also extend the program to include the associated polymers being tested in the Yard test. Furthermore, investigations will be made to investigate the potential of using IORSim to simulate the CO2 foam pilot performed in the US (project 2.6.3).

The Postdoc student will also be investigating the pros and cons of coupling IORSim directly to OPM (Open Porous Media). The coupling between IORSim and OPM has certain advantages. Since the source code is fully available in this case, it will be possible to modify IORSim as well as OPM to extend the functionality of the two-way coupling. Examples here are the influence of the IORSim geochemistry on wetting properties, relative permeabilities, viscosities and other fluid properties in OPM.

DELIVERABLES 2019

- Improved models for systems designed to improve conformance
- IORSim-OPM coupling
- Publications

This project delivers to:
Upscaling, simulation and interpretation tools, Full field prediction and Economic potential and environmental impact

2.5.4
Nanoparticle tracers for petroleum reservoir studies

Duration: January 2019 – December 2021

Project manager / PhD student: NN (UiS)
Key personnel: Mahmoud Ould Metidji (IFE), Alexander Krivokapic (IFE),Tor Bjørnstad (IFE), Merete V. Madland (UiS), Sissel O. Viig (IFE)
Theme: 2
Task: 5
Budget 2019: 1.245.000 NOK

The aim of this research is to examine the usefulness of nanoparticles as tracers for interwell operation (ITT) and for use as tracer carriers in single-well huff-and-puff operation (residual oil saturation by SWCTT) in dedicated laboratory and small-scale field experiments. Successful outcome will offer completely new classes of tracer tools for reservoir and production management.

OBJECTIVE

The main objective is twofold:

1. Further development of C-dots for detection of high-permeability streaks/fractures between injection and production wells.
2. Development of nanoparticles as simultaneous carriers, hereafter called nanocarriers, of passive and phase-partitioning tracers in single-well measurement of residual oil saturation in the near-well region.

KNOWLEDGE GAPS

C-dots (sizes 2-10 nm) have, to some extent, been studied and reported in the previous project 2.5.1. The particles were successfully synthesized and characterized, but several questions remain to be resolved as subjects for this PhD-work. Keywords are non-agglomeration at high concentration, fluorophore doping for higher analytical specificity, percolation through fractured porous media, particle separation and analysis in produced waters.

Use of nanocarriers for tracer compounds is a completely new concept in reservoir and production technology. It consists of nanoparticles with internal porous space to accommodate and lock in tracer molecules of various kinds, for instance passive and phase-partitioning tracers. After injection of such particles to a selected distance in a porous medium, the particles can be unlocked and the tracers released by influence of an external triggering mechanism (for instance change in salinity or pH). In this project we concentrate on development of such technology for SOR-measurements in the near-well area by huff-and-puff operations. This technology has the potential to reduce the operational time from days to hours because no well shut-in time is needed since it is not based on ester compounds which need time to hydrolyse. A successful development of this technology will constitute a major forward leap in SWCTT for S_{or} determination.

Also, necessary knowledge transfer between relevant simulation tasks (4, 6 and 7) and pilot projects will be ensured.

PLANS 2019

We are planning for the following main activities the first year:

1. Evaluate potential nanostructures with internal voids large enough to accommodate several water and water-oil partitioning tracer molecules. Actual particle types are dendrimers, liposomes or silica-based nanoparticles.
2. Start synthesis of selected particles.
3. Evaluate tracer encapsulation and sealing strategies.
4. Preliminary tests on selected tracer encapsulation concept.
5. Evaluate release mechanisms for the selected particle and lock-in mechanism (eg. pH, salinity, etc.).
6. Engage in obligatory and selected theoretical courses at UiS (eventually at UiO).

DELIVERABLES 2019

- First results of the particle selection process and the introductory synthesis tests will be reported in the semi-annual report for June 2019.
- Poster presentation of the PhD-project concept on the IOR Norway 2019 conference.

This project delivers to:
Field performance, Monitoring tools and history matching, Upscaling, simulation and interpretation tools, Full-field prediction & Economic potential and environmental impact

2.5.5 Lanthanide ester complexes for SWCTT: focus on their partitioning behaviour, quantification procedure and dynamic performances

Project manager(s): Tor Bjørnstad (IFE)
Key personnel: Mahmoud Ould Metidji (IFE), Alexander Krivokapic (IFE), Sissel Opsahl Viig (IFE)
Theme: 2
Task: 5
Budget 2019: 830.000 NOK

Duration: January 2019 – October 2019 (continuing from 2018)

This research aims to improve existing technology and develop new technology for measuring S_{or} in reservoirs, based on the use of tracers for the flow of injected fluids. The application of this technology will help define the best IOR strategy for selected reservoirs by examining the near-well zone.

OBJECTIVE

Terbium complexes comprising an ester function (ethylester, butylester), designed for near-well push-and-pull operations, have been successfully synthetized within project 2.5.2. Liquid chromatography using C18 columns coupled with time-resolved fluorescence allowed separation of the different forms of the complexes with high specificity. However, results from static batch experiments to measure partition coefficients at room temperature and 80°C using two different model oils (different polarities) and a crude oil from the Norwegian continental shelf were not in accordance with the chromatographic findings with the C18 column. This discrepancy will be subject for further examination in the new project.

The second objective of the new project is to perform core-flooding experiments the first at IFE core-flooding setups and then extended to larger-scale laboratory facilities now being built-up at Halliburton's premises in Tananger.

KNOWLEDGE GAPS

Traditional high-volume ester-based SWCTT tracers are intended to be replaced by new ester compounds based on lanthanide complexes. The gain is considerably lower detection limits resulting in substantial reduction in chemical volumes, reduced physical and environmental footprint and lower operational cost.

PLANS 2019

Five main activities (+ 1 optional) are planned:

1. Continuing synthesis of lanthanide chelate esters. Synthesis of hexylester compound and di-esters (either di-ethylester or di-butylester) using the already well-established procedure reported in project 2.5.2.
2. Continuing static batch stability testing. Hydrolysis kinetics of the butylester compound at 70°C have previously been established with positive results using a synthetic production water. Such tests will be extended to other esters using different temperatures to allow for optimal planning of field projects with various well temperatures.
3. Understand the partitioning behaviour by static partitioning tests. The partition coefficients will be determined under different conditions by varying the oil composition and the water salinity (and composition).
4. Core flooding for dynamic behaviour study. A specific set-up for laboratory core-flooding tests will be set up at IFE to reproduce a SWCTT test. We will consider testing of the best candidates tracers in a larger scale set-up (Halliburton).
5. Developing an analytical procedure for tracer quantification in the oil phase. This will mainly focus on quantifying the ester concentration in the oil phase after static batch-type experiments in order to confirm the K-value obtained only from the ester quantification in the aqueous phase. The possibility of the tracer being at the O/W interface has to be checked.
6. Large-scale production of the tracer (optional). If time allows, we will design for a larger-scale production of the tracer and estimate the production cost.

DELIVERABLES 2019

- New SWCTT method provided.
- Results from static and dynamic laboratory experiments are planned published in 1 conference paper and 2 journal papers.

This project delivers to:
Field performance, Monitoring tools and history matching, Upscaling, simulation and interpretation tools, Full-field prediction and Economic potential and environmental impact

2.5.6
Dynamic flooding properties of new PITT tracers

Duration: January 2019 – December 2019 (with possible extension)

Project manager: Tor Bjørnstad (IFE)
Key personnel: Sissel Opsahl Viig (IFE), Mario Silva (IFE) and Øyvind Brandvoll (IFE)
Theme: 2
Task: 5
Budget 2019: 900.000 NOK

The aim is to examine the dynamic flooding properties of new water-oil partitioning tracer compounds (PITT-tracers). Such tracers are used for S_{or}-determination in water- or gas-flooded volumes between wells. These new potential tracer compounds have been proposed and studied in a recent project. The dynamic testing will be done in flooding experiments with cores or packed porous media under known residual oil saturation. Size of the flooding equipment will be varied from bench-top setups to several meter scale in yard tests and possibly to small-scale real field tests. Does the technology hold its promises over varying flooding distances?

OBJECTIVE

To examine the dynamic flooding properties of new PITT tracer compounds. These compounds were developed and studied for thermal and chemical stability, stability against sorption to rock and water-oil partitioning in a recent PhD-project (2.5.3).

KNOWLEDGE GAPS

Tracer technology can provide information that benefits all stages of the production chain. PITT tracers provide unique data about fluid circulation and remaining oil saturation in flooded volumes of the reservoir. However, their use is still limited due to the existence of very few qualified compounds with the desired properties. Hence, there is a need to develop more oil/water partitioning tracers.

Such potential tracer compounds have been selected and studied in a previous IOR Centre project (2.5.3). Seven compounds were found to have sufficient thermal and chemical stability and suitable phase-partitioning characteristics (K-values) for a range of reservoir properties. Knowledge about the dynamic properties of the tracer candidates remains to be established. Therefore, the present project aims at exactly this: Will the PITT tracer candidates percolate freely through reservoir rock without unwanted interactions? Will they be able to reproduce the known values of the oil saturation on cores/columns by using the K-values determined in static batch experiments in the laboratory?

PLANS 2019

We are planning the following main activities in 2019:

1. Set up a suitable bench-top core-flooding equipment at IFE holding a consolidated core or sandpack of sandstone.
2. Prepare the core to a known residual oil saturation (S_{or}) after water flooding.
3. Inject a short pulse of a passive tracer together with the partitioning candidate tracers and record the individual production (or dispersion) curves. Based on the first moment of the dispersion curves, calculate the S_{or} using the K-values previously determined in equilibrium batch experiments. A correct S_{or} value means that the kinetics of the phase-partitioning equilibration is fast, and there is no visible time delay in diffusion processes in bulk liquids or over phase boundaries.
4. Reproduce these measurement principles at larger scale (yard scale test) preferably at the installations being constructed at Halliburton's premises in Tananger.
5. Tests will be conducted with different oils (model oil and black oil), and temperature, pH and linear flow rate will be the main testing parameters.
6. (Optional, possibly for 2020: If the financial situation allows, - conduct a small scale interwell flooding experiment at a test site in Colorado together with Cornell University and University of Colorado).

DELIVERABLES 2019

- Journal paper describing the outcome of the dynamic tests
- Upon positive outcome of the dynamic tests – offer a new selection of PITT tracers qualified in lab-tests and ready for real pilot field tests.

This project delivers to:
Field performance, Monitoring tools and history matching, Upscaling, simulation and interpretation tools, Full-field prediction and Economic potential and environmental impact

2.6.1 Adding more physics, chemistry and geological realism into the reservoir simulator

Duration: January 2014 – December 2021

Project manager(s): Robert Klöfkorn
PhD student: Dhruvit Berawala (UiS)
Postdocs: Trine Mykkeltvedt (NORCE), Birane Kane (NORCE)
Key personnel: Ove Sævareid (NORCE), Tor Harald Sandve (NORCE), Svein Skjæveland (UiS) and Pål Andersen (UiS)
Theme: 2
Task: 6
Budget 2019: 2.525.000 NOK

This project addresses forward simulation of IOR methods. This project also aims to contribute towards providing a tailor-made simulator that includes the necessary modelling methodologies and simulation capabilities to simulate increased oil recovery pilots on the Norwegian Continental Shelf.

OBJECTIVE

The main objective is to provide innovative modelling methodology and simulation capabilities for IOR. This includes the following research topics:

- Field scale simulation of tracer tracking and «modified water» injection
- Representation of brine-dependent multiphase flow at different scales in terms of mathematical models
- Transferring lab-scale mechanisms to field scale
- Field scale simulation of fractured porous media
- Including spontaneous imbibition effects controlled by water-rock chemistry at field scale
- Studying of higher order methods for simulation of IOR processes
- Develop and test mathematical models related to SCAL and how to transfer measurements to input data for reservoir simulation
- Implementing the results from above in the Open Porous Media (OPM) framework

KNOWLEDGE GAPS

Standard reservoir simulators do not account for the mechanisms listed above in the «objective». The project will investigate which of these missing effects are crucial for full field simulation of IOR processes, and will seamlessly implement the needs into OPM.

PLANS 2019

In 2019 we are planning the following activities at UiS:

1. Investigation of complex fluid mechanisms and geomechanical effects in low-permeable reservoirs.
2. Numerical modelling of CO_2 injection for improved recovery.
3. Development of statistical models for production forecast in fractured reservoirs. Research activities at UiS includes one PostDoc and one PhD student along with 4-5 MSc students who will write their thesis.

At NORCE, we are planning following main activities:

1. Collaboration with PhD project 2.6.2 in the integration of higher order methods in OPM.
2. Integrating and testing a model for tracking tracers in OPM.
3. Integrating and testing a model with «modified water» injection in OPM.
4. Implementation of a state-of-the-art solver for incompressible Navier-Stokes equations modeling non-Newtonian fluid flow.
5. Investigation of possibilities of coupling of OPM with PorePy (developed at UiB) for fractured flow modelling possibilities in OPM.

These activities will contribute to milestone 12 on the roadmap, and ultimately towards the goal of full field scale tests. Dissemination is expected and planned.

DELIVERABLES 2019

- Submitting and publishing several journal papers describing and illustrating the developed simulation methodologies for improved accuracy of simulation results.
- Attending workshops and conferences disseminating the above results.
- Submitting abstract(s) and presenting at the SPE Europec, EAGE IOR and SCA Symposium
- Contributing to OPM releases (2019.04 and 2019.10), which should include several of the above described functionalities

This project delivers to:
Upscaling, simulation and interpretation tools, Full field prediction, Monitoring tools and history matching and Economic potential and environmental impact

2.6.2 Advanced Numerical Methods for Compositional Flow Applied to Field Scale Reservoir Models

Duration: January 2016 – December 2019

Project manager(s): PhD student Anna Kvashchuk (UiS)
Key personnel: Robert Klöfkorn (NORCE) and Steinar Evje (UiS)
Theme: 2
Task: 6
Budget 2019: 1.621.000 NOK

This project addresses the forward simulation of IOR methods, and particularly investigates different numerical methods that can be applied to implement a compositional flow module for modeling the IOR/EOR. In the end, the project contributes to pilot simulations by providing a «full field simulation tool» for water based IOR/EOR methods.

OBJECTIVE

The main objective of this project is to investigate and establish higher order numerical methods for modelling IEOR processes in reservoir simulation tools. Prototype implementations will be provided within the Open Porous Media (OPM) project and a compositional flow module for the black oil flow simulator in OPM will be provided. The key elements will be:

- Higher order approximations, including thermal effects, with appropriate coupling to the flow simulator.
- Inclusion of field scale «smart water» simulation where thermal effects cannot be neglected.
- The PhD project consists of three main parts: studying and implementing higher order schemes, coupling the scheme with the black oil flow model and a field scale study. All of the activities will be carried out within the OPM code base.

KNOWLEDGE GAPS

Standard simulators do not account for the mechanisms described in the «objective», nor are higher order numerical methods present in everyday field scale simulations. Note that higher order methods are also addressed in the other Task 6 project, but both the application (polymer vs. compositional) and basic methodology (finite volume vs. discontinuous Galerkin) are different. There are also important distinctions to be made compared with IORSim, which is based on classical (diffusive) techniques amended with grid refinement. This project's achievements therefore also contribute directly to the development of IORSim.

PLANS 2019

The plans for 2019 include the following four main activities:

1. Continuation of investigation into numerical methods for reservoir flow
2. Finishing the integration of higher order methods OPM-flow
3. Testing the developed methods for simplified tracer transport and «smart water» cases
4. Studying a field case using the newly developed techniques.

DELIVERABLES 2019

- Submitting and publishing journal papers in particular one paper about integration of higher-order methods in OPM with application to field case. Higher order methods is especially needed when simulating EOR chemicals.
- Attending RSC conference in Galveston, TX.
- OPM release containing the above mentioned technology.
- Continued collaboration with the OPM, Dune, and DuMuX community and extension of collaborations with UiB.

This project delivers to:
Upscaling, simulation and interpretation tools, Full field prediction, Monitoring tools and history matching and Economic potential and environmental impact

2.6.4 Upscaling of chemo-mechanical compaction to field scale models

Duration: 2019-2021

Project manager / Postdoc: NN (UiS)
Key personnel: Robert Klöfkorn (NORCE), Tor Harald Sandve (NORCE), Merete Vadla Madland (UiS), Reidar Inge Korsnes (UiS), Emanuela Kallesten (UiS)
Theme: 2
Task: 6
Budget 2019: 821.000 NOK

The purpose of this project is to extend the simulation capabilities of OPM through coupling with an open-source multiphysics code to model reservoir compaction in connection with oil recovery. Moreover, we aim to integrate the effect of geochemical processes on mechanical deformation and the resulting feedback on the flow simulation, with the purpose of understanding and improving reservoir sweep efficiency.

OBJECTIVE

This is a Postdoc project is linked to both Theme 1 and Theme 2. The project will integrate lab and field research, and moreover contribute to upscaling of lab-results into full field simulation tools.

The main objectives of the project are:

- a) To investigate different coupling strategies for the flow and mechanics solvers
- b) To construct appropriate constitutive models that incorporate the effect of chemical processes on mechanical rock properties in connection with the «full system» (i.e. poro-chemo-mechanical) simulations
- c) To explore the possibility of using the full system simulations to construct simplified but sufficiently accurate phenomenological models that relate localized chemo-mechanical effects to fluid pressure.

KNOWLEDGE GAPS

Standard reservoir simulators are mostly built to model flow but not mechanical deformation, and hence lack the capability to simulate reservoir compaction based on the fundamental governing equations. While it is possible to achieve the latter by combining different commercially available simulators, such an approach almost always requires coupling to be done externally which results in longer execution times for the overall simulation. Furthermore, commercial codes are often limited with regard to the specification or modification of material models, and do not always allow for the use of entirely new user-defined models.

A substantial amount of experimental research has already been carried out at the Centre on the interaction of chemical and mechanical processes in connection with reservoir compaction. However, the incorporation of such effects in compaction models is not yet mainstream, and in particular valuable contributions can be made both in the proposition of new constitutive laws that take this into account, as well as the development of simulators that can natively run such models.

PLANS 2019

The initial stage of the project will consist of preparation or modification of an open-source multiphysics solver in a way that allows for seamless coupling with OPM. The aim for 2019 is to achieve functional coupling between flow and mechanics, the latter preferably with elasto-plastic constitutive models that will be used as a base on which to incorporate the effects of chemical processes later on in the project.

DELIVERABLES 2019

- Report on the status of code coupling. Ideally, we should have the ability to perform fast poro-elastoplastic simulations using OPM in combination with the chosen multiphysics solver.
- Attending workshops and conferences
- Draft manuscript on OPM/multiphysics coupling to be submitted for publication in a suitable journal

This project delivers to:
Upscaling, simulation and interpretation tools, Full field prediction

2.7.1
Production optimization

Duration: 2014-2021

Project manager(s): Geir Nævdal (NORCE)
PhD: NN (cf. Task 2.7.12)
Key personnel: Yuqing Chang (NORCE) and Rolf J. Lorentzen (NORCE)
Theme: 2
Task: 7
Budget 2019: 1.243.000 NOK

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. This project will develop methodology to optimise future production for evaluating the economic potential of the reservoirs. We aim for a flexible approach that can also consider environmental constraints.

OBJECTIVE

The main objective of this project is further development of ensemble-based methods for production optimization and adapting the ensemble-based production optimization methodology to cases relevant for The National IOR Centre of Norway. Secondary objectives are:

- Further improvement of the methodology
- Adaption and testing of methodology on cases relevant for The National IOR Centre of Norway

KNOWLEDGE GAPS

Ensemble based tools for production optimization has been developed over the last decade, with a special focus on waterflooding. In our setting it will be important to expand this to include cases covering injection of polymer and smart water. The ensemble-based tools are computationally demanding due to the number of simulations required. We will investigate if certain changes of the methodology (choice of step size, etc.) can make it more efficient. In addition, an idea for reducing the computational burden using model reduction has been introduced in an associated PhD project (Aojie Hong). This idea might be taken further in subsequent work. The formulation of the optimization problems should also be considered, as it might be more efficient to solve optimization problems with fewer variables even if some solutions that are possible with a more flexible formulation of the problem are missed.

PLANS 2019

We plan to work on three aspects in 2019:

1. We will identify suitable case studies and start working on optimization of EOR based injection strategies (polymer injection and/or smart water).
2. Study the effect of different formulations of the optimization problems. In particular if formulations with fewer degrees of freedom can be more efficiently solved and therefore advantageous to formulations with larger number of parameters.
3. Development of proxy model and optimization based on utilizing proxy models. Here we would start by testing if existing frameworks for developing proxy models are suitable, but also look into new approaches for developing proxy models based on machine learning.
4. In cooperation with a new PhD student, described in project 2.7.12, we will integrate of Task 6 and Task 7 research and investigate the integrated tools on field-like cases.

DELIVERABLES 2019

- This project aims to develop and demonstrate new methodologies that contribute to optimal injection strategies, based on total oil recovered, maximum economic output and minimal environmental impact.
- If the planned testing gives positive results we plan to write 2-3 conference papers, that can be further developed into journal papers.

This project delivers to:
Economic potential and environmental impact & Fiscal framework and investment decisions

2.7.4
Data assimilation using 4D seismic data

Duration: 2014-2021

Project manager(s): Geir Nævdal (NORCE)
Postdoc: Kjersti S. Eikrem (NORCE)
PhD: NN (cf. Task 2.7.11)
Key personnel: Xiaodong Luo, Tuhin Bhakta, Rolf J. Lorentzen (NORCE), Morten Jakobsen (UiB/NORCE)
Theme: 2
Task: 7
Budget 2019: 2.487.000 NOK

This project is the main project addressing history matching at the IOR Centre. The project focuses on being able to meet the target of full field history matching using 4D seismic and tracer data. The first demonstration case was to history match the Norne field using production and 4D seismic data. Further on we will add tracer data into the workflow. We will also further develop the methodology to strengthen the work-flow's robustness with regards to different field types.

OBJECTIVE
The primary objective of this project is to include 4D seismic data in ensemble-based history matching for full fields. The secondary objectives include:

- Establishing real fields and gathering the data required
- Investigating which form of 4D seismic data is most suitable for inclusion
- Developing suitable rock physic models
- Uncertainty quantification of the seismic data
- Adapting the ensemble-based methods to work with the large amount of seismic data

KNOWLEDGE GAPS
If information from 4D seismic data is incorporated into reservoir models, this is typically done through manual matching by geologists and interpretation of the data by geophysicists. A workflow that includes the use of 4D seismic data directly in assisted history matching has not been established. History matching using 4D seismic data is a challenging and substantial large task, as pointed out by the many secondary objectives that must be handled, and this project will address these challenges.

PLANS 2019
In 2018 we finished a demonstration of the developed workflow on the Norne dataset utilizing both production and 4D seismic data. In further work, we would start investigating the addition of tracer data in the work-flow. In the Norne field study we used 4D seismic data in the form of acoustic impedances, but it would be beneficial to get better knowledge of the strength and weaknesses of using different seismic attributes. In 2019 we plan to further develop the work-flow to be robust and able to handle the different challenges of different field types at the Norwegian continental shelf.

In addition, we are investigating the use of full-waveform inversion for 4D seismic history matching. This activity is mainly done in cooperation with the Petromaks2 Researcher Project that was awarded as an IOR Centre spin off project in 2016.

DELIVERABLES 2019
- A journal paper describing the Norne field study would be completed.
- In the Norne field study we utilized impedances and densities for history matching. To calculate impedances and densities from available AVA data a Bayesian approach, as described earlier by our cooperation partner Dario Grana, was used. A paper describing this methodology will be finalized.
- If potential conferences are identified, we plan to submit early versions of the planned papers (listed under 2019 plans) to such.
- The workflow for ensemble-based history matching of 4D seismic data will be further developed and tested for robust use on different fields.
- By including 4D seismic information into an ensemble of reservoir models we aim to improve reservoir management, improve uncertainty quantification, and, finally contribute to improved decision making and optimal strategies leading to improved volumetric sweep.

This project delivers to:
Monitoring tools and history matching, Full field prediction, Field performance, Economic potential and environmental impact & Fiscal frame work and investment decisions

2.7.5
Interpretation of 4D seismic for compacting reservoirs

Duration: 2019-2021

Project manager: Tuhin Bhakta (NORCE)
Key personnel: Geir Nævdal (NORCE) and Randi Valestrand (NORCE)
Theme: 2
Task: 7
Budget 2019: 1.085.000 NOK

The project aims to improve history matching using 4D seismic data for compacting reservoirs. To achieve this, we further develop methods for better usage of 4D seismic data to interpret and decouple the compaction and production related effects. This is also important for monitoring gas, water and pressure fronts in compacting reservoirs.

OBJECTIVE

The objective of this project is to address and develop the workflow that can handle the extra complexity of compacting reservoirs by including 4D seismic data in history matching. The objectives can be stated in short- and long-term goals:

- Short term: Interpreting 4D "LoFS" data for updating/estimating reservoir/petrophysical parameters
- Long term: Use interpreted data for ensemble-based history matching

KNOWLEDGE GAPS

Quantitative usage of seismic data in assisted history matching workflow remains a challenge till to date. The problem arises due to improper petro-elastic model (PEM) to simulate forward seismic response, the inefficiency of handling "big data" problem for seismic data, lack of adaptive localization algorithm that can be used for any kind of data/observations, and many more. The issue becomes even more complicated in compacting reservoir scenarios due to the production related compaction. A recent study on history matching the Norne field indicates that important progress is made in handling several of these issues, but further work is needed to handle special issues due to compaction effects.

Here, we will focus on applying the tools developed for history matching the Norne field; and exploiting good quality 4D seismic data coming from various "LoFS" of the Ekofisk field to investigate if we can do a proper history matching for a compacting reservoir utilizing 4D seismic data.

PLANS 2019

We are planning two activities in 2019:

1. Data assimilation using 4D seismic data for a compacting reservoir: This task will be a major undertaking and needs to start with careful planning to define its scope. For instance, we need to decide whether we should aim for a full field history matching, or limit the study, for instance, by using a sector model. We will investigate and implement our recently developed assisted seismic history matching workflow (4DSHM) in the Ekofisk reservoir field. The method is based on sequential assimilation of production and seismic data, using ensemble-based Bayesian inference methods. The study needs to be defined in close collaboration with the provider of the field data (ConocoPhillips). It should also be noticed that this project is extensive, and collaboration with project 2.7.4 on the methodological development is planned.
2. Uncertainty quantification of the estimated parameters: We will continue to work on our new improved workflow for estimating changes in dynamic reservoir parameters for compacting reservoir parameters. The method has successfully implemented on both synthetic and real compacting field scenarios. However, more investigation is required to perform proper uncertainty quantification in the case of real field data. We would investigate the different localization schemes in this regard.

DELIVERABLES 2019

Based on the plans described above, we plan to have at least one report to describe the outcome for each of the two activities. If permission for publication is received, it would be natural to present the results at appropriate conferences.
This project delivers to the development of a work-flow for inclusion and integration of any type of data, including 4D seismic data, with the ultimate goal of improved volumetric sweep.

This project delivers to:
Upscaling, simulation and interpretation tools, Monitoring tools and history matching, Field performance, Full field prediction and Economic potential and environmental impact

2.7.7
4D seismic and tracer data for coupled geomechanical/ reservoir flow models

Duration: Duration of Schlumberger's in-kind contribution

Project manager: Jarle Haukås (Schlumberger)
Key personnel: Wiebke Athmer, Jan Øystein Haavig Bakke, Aicha Bounaim, Marie Etchebes and Michael Niebling (all Schlumberger)
Theme: 2
Task: 7
Budget 2019: 1.500.000 NOK

This project is investigating the coupling between fluid flow and geomechanics / tectonics and the use of 4D seismic data in history matching of coupled models. The project brings geomechanics / tectonics and high-resolution simulation models into the history matching picture with the purpose of understanding and improving reservoir sweep efficiency.

OBJECTIVE

The main objective of the project is to investigate rational methods for building and updating coupled fluid flow / geomechanical models. This includes

- Incorporating faults and fractures consistent with seismic data in history matching
- Linking 4D seismic observations to tectonic history and stress exchange in the reservoir and surrounding rock

High-resolution field scale models will be used to analyse sweep efficiency and predict effects of e.g. water diversion.

KNOWLEDGE GAPS

In fractured reservoirs, the understanding of how dynamic stress changes in the reservoir open and close the fracture systems as a result of the injection strategy is of key importance with regard to optimal depletion.

For compacting reservoirs, the stress changes caused by injection and production must be understood to improve oil recovery. A methodology will be developed to use the assimilated models for safer well placement, better well performance and well integrity and improved sweep efficiency, considering dynamic stress changes in the reservoir and the surrounding rock.

PLANS 2019

For 2019 the focus will be on:

1. Evaluating and improving an ensemble of models to better span observation data
2. Simulating and analysing water diversion and associated 4D effects

DELIVERABLES 2019

- Methodology for ensemble mismatch analysis
- Workflow for analysing and simulating water diversion effects using 4D seismic data and an ensemble of high-resolution models controlled by inputs from seismic data

This project delivers to:
Monitoring tools, history matching and Economic potential and environmental impact

2.7.8 Elastic full-waveform inversion

Duration: January 2017– January 2020

Project manager: PhD student Karen Synnøve Ohm (UiS)
Key personnel: Wiktor Weibull (UiS) and Arild Bulland (UiS/Equinor)
Theme: 2
Task: 7
Budget 2019: 1.095.000 NOK

This project aims to improve the interpretation of seismic data through full-waveform inversion. The methodology proposed provides valuable information for both the exploration and production stages of the petroleum value chain.

OBJECTIVE

Accurate and well-resolved estimates of the subsurface parameters from seismic data are essential for both exploration, as well as increased recovery of oil and gas reserves. This is particularly true as exploration moves towards subtler traps in complicated geological environments. At the same time, the ability to detect small changes in elastic parameters due to fluid substitution can greatly aid the development of increased oil recovery strategies. Full waveform inversion (FWI) is a well-known method for estimating subsurface parameters from seismic data. FWI can be used with single vintage seismic data to improve knowledge of the subsurface, or it can be used to estimate changes in subsurface parameters in a time-lapse fashion from 4D seismic data. This makes this technology well adapted for both the exploration and production stages of the petroleum value chain. Elastic FWI can be used to estimate both P-wave and S-wave impedances or their changes over time from multicomponent seismic data. There are still major challenges in applying FWI to field scale datasets.
One problem is related to the high cost of the method. Another well-known problem is the non-uniqueness of the problem. Any attempt to use FWI must therefore tackle these challenges.
Despite these problems the FWI is becoming more commercially active, due to its advantages with providing high resolution images of the subsurface. However, due to the high cost in FWI, little has been done in producing a good estimate of the uncertainty of the inversion. Producing a good estimate of the uncertainty will be beneficial with regards to picking horizons and volume estimations, and will benefit the value chain at all points. Today the quality control of the FWI is done in situ with well ties and well logs and other geophysical methods. Previous attempts to estimate the uncertainty in FWI have been focused on using the Hessian, as the inverse Hessian acts like a posterior covariance close to the minimum of the error function. The Hessian is however, complex to estimate and will not work for large scale FWI problems. So, to find an estimate of the uncertainty one need to find a method that will work for the well-known problems of FWI and be cost efficient. Attempts to investigate the uncertainty must look to other arenas with similar problems regarding non-linearity and non-uniqueness, such as data assimilation. Once we have a tool to estimate uncertainty, we can try to minimize it. This will be done by testing the effects of using different acquisition geometries. Going further one can also analyse the uncertainty associated with the employed wave theory (i.e. Acoustic, Elastic, Viscoelastic, etc.) The project aims at developing strategies to tackle the above mentioned problems, and to do so we have also set the following key objectives:

1. To develop and test a statistical method based on the ensemble approach to estimate the uncertainty associated with the estimated models in FWI.
2. Investigate the effect that the acquisition geometry has on the uncertainty in FWI.
3. Investigate the effect of imperfect physics (i.e. the choice of wave equation) on the uncertainty of FWI.

KNOWLEDGE GAPS

There has yet to be a method for estimating the uncertainty in the FWI, especially one that will work commercially. This project will be an attempt to breach this gap.

PLANS 2019

The focus in 2019 will be to start testing of the implemented ensemble methodology to estimate uncertainty, the methodology will be tested on synthetic 2D and 3D datasets for acoustic and elastic waves.

DELIVERABLES 2019

A new method for estimating the uncertainty in the FWI will be implemented and tested. The results from the reference tests (2D and 3D) will lead to:

- Submission of abstracts to workshops and/or conferences and presentation of articles
- Publication of journal paper

This project delivers to:
Monitoring tools and history matching; Field performance, Full field prediction; and Economic potential and environmental impact

2.7.9 IOR Pilot Projects – Learning by Doing

Duration: 2019-2020

Project manager(s) / Postdoc(s): NN (UiS)
Key personnel: Reidar B. Bratvold (UiS)
Theme: 2
Task: 7
Budget 2019: 1.095.000 NOK

The purpose of this project is to study the impact of uncertainty about the benefits of a technology on adoption and information gathering decisions related to IOR projects. We will develop and implement a decision and data analytics framework for the purpose of generating decision supporting information for IOR projects with a particular focus on the IOR pilot project decisions.

OBJECTIVE

The objective of the project is to resolve one of the key challenges that complicate the IOR project decision: Uncertainty. In this project we will use learning-by-doing (sequential learning) approaches leveraging Bayes' theorem and dynamic programming to identify and value optimal information gathering sequences, given realistic constraints, for IOR pilot projects for the purpose of understanding and, possibly, reducing uncertainty.

KNOWLEDGE GAPS

This project will provide a framework that can be used to identify optimal information gathering sequences for the purpose of supporting new technology adoption in IOR projects.

PLANS 2019

In this project, we will develop and implement a decision and data analytics framework for the purpose of generating decision supporting information for IOR projects with a particular focus on the IOR pilot project decisions. We will use learning-by-doing (sequential learning) approaches leveraging on Bayes' theorem and dynamic programming to identify and value optimal information gathering sequences, given realistic constraints, for IOR pilot projects.

The key activities for 2019 are

- Filling the postdoc position
- Framing IOR implementation decision
- Develop model to value and optimize information gathering

DELIVERABLES 2019

This project aims in the coming two years to deliver an improved decision making and uncertainty analysis for the planning and implementation of IOR projects (smart water injection, polymer/surfactant injection, etc.) by using a generic decision-driven data-assimilation approach.

Based on the key activities of 2019 we expect the following dissemination:

- One journal paper
- 1-2 conference papers

This project delivers to:
Economic potential and environmental impact & Fiscal frame work and investment decisions

2.7.10
The Value of Data and Data Analytics for IOR Operations

Duration: 2019-2021

Project manager(s) / PhD student(s): NN
Key personnel: Reidar B. Bratvold (UiS) and Remus Hanea (Equinor/UiS)
Theme: 2
Task: 7
Budget 2019: 1.095.000 NOK

The purpose of this project is to use decision and data analytic approaches based on Bayes' theorem to identify and value relevant and material data in IOR contexts. Value-of-Information (VOI) analysis will be used to evaluate the benefits of collecting additional information (such as seismic data and pilot test data) before making the decision on whether to invest in gathering this additional information. Such information gathering may be worthwhile if it holds the possibility of changing the decision (e.g., a production or IOR strategy) that would be made without further information. VOI attributes no value to "uncertainty reduction" or "increased confidence" per se.

Rather, value is added by enabling the decision maker to better "tune" his/her choice to the underlying uncertainty. Thus, data and information value is forever an entanglement of uncertainty and decision making; one cannot value information outside of a particular decision context. VOI analysis can also be used to rank different data types based on their values so that the collection of the most valuable data can be prioritized.

OBJECTIVE

The objective of the project is to develop decision and data analytical methods specifically tailored to IOR decisions. This requires the identification of data and information relevant to IOR decisions. In most cases, the number of meaningful relationships in the data –those that speak to causality rather than correlation and testify to what really drives IOR relevant decision parameters – is orders of magnitude smaller than the data itself.

KNOWLEDGE GAPS

This project will provide new efficient reservoir-modeling systems and data-processing workflows, that can be used to leverage the ever-increasing volume of data to support IOR type reservoir management decisions.

PLANS 2019

In this project, we will use decision and data analytic approaches based on Bayes' theorem to identify and value relevant and material data in IOR contexts. One of the most useful features of decision analysis is its ability to distinguish between constructive and wasteful data and information gathering. Value-of-Information (VOI) analysis evaluates the benefits of collecting additional information (such as seismic data and pilot test data) before making the decision on whether to invest in gathering this additional information. Such information gathering may be worthwhile if it holds the possibility of changing the decision (e.g., a production or IOR strategy) that would be made without further information.
The key activities for 2019 are

- Filling the PhD position
- Reviewing and identifying relevant data analytics methdos and approaches
- Framing IOR decision and data analytics contexts
- Initiate the develop of a decision and data analytics framework for supporting IOR decisions

DELIVERABLES 2019

VOI attributes no value to «uncertainty reduction» or «increased confidence» per se. Rather, value is added by enabling the decision maker to better «tune» his/her choice to the underlying uncertainty. Thus, data and information value is forever an entanglement of uncertainty and decision making; one cannot value information outside of a particular decision context. VOI analysis can also be used to rank different data types based on their values so that the collection of the most valuable data can be prioritized. In this project we aim to deliver methodology and demonstrate these on proper cases.

In 2019, the student will focus on literature review, PhD courses at UiS and start developing and implement the VOI methodology.

- Literature review
- PhD courses at UiS

This project delivers to:
Economic potential and environmental impact & Fiscal frame work and investment decisions

2.7.11 Data assimilation using 4D seismic and tracer data

Duration: 2019-2021

Project manager(s) / PhD student: NN
Key personnel: Xiaodong Luo (NORCE), Rolf Lorentzen (NORCE), Wiktor Weibull (UiS), Rachares Petvipusit (Equinor)
Theme: 2
Task: 7
Budget 2019: 1.095.000 NOK

This is a PhD project which aims to assimilate both 4D seismic and tracer data, in addition to the conventional production data, for improved reservoir characterization. This project involves tailored strategies to handle different types of field data, and improved workflow for more coherent assimilation of these field data into reservoir models.

OBJECTIVE

This is a PhD project is linked to project 2.7.4 and the tracer projects, 2.5. The project will integrate previous research from these two together, and demonstrate the added value on field cases. The main objective of this project is to develop an ensemble-based workflow that can be used to assimilate multiple types of field data (4D seismic, tracer and production) into reservoir models in a most coherent way. For this purpose, the following research tasks will be carried out:

- More efficient ways to handle big seismic data;
- Optimal ways to assimilate different types of field data;
- Proper uncertainty quantification for estimated reservoir models.

KNOWLEDGE GAPS

4D seismic and tracer data are often qualitatively employed for reservoir monitoring and management, but are relatively less used in a quantitative way for reservoir characterization through a certain computer-assisted history matching framework, due to various reasons arising from both theoretical and practical aspects.

In the past few years, a series of investigations inside the NIORC has led to the establishment of an efficient ensemble-based 4D seismic history matching framework that appears to work for the real seismic data from the Norne field. Even with this significant progress, there are still numerous remaining issues that are worth of further investigations. Such issues include, for instance, more efficient ways for sparse representation of big 4D seismic data, proper characterization of uncertainties in estimated reservoir models, and coherent assimilation algorithms that are designed to extract maximum information from available field data, while incurring as minimum conflicts as possible.

PLANS 2019

Dr. Petvipusit at Equinor will be the mentor of the PhD student from the industry side, and help to set up a synthetic case study in the REEK model, which is a reservoir model used for R&D purposes inside Equinor. At this stage, the synthetic case study will focus more on history matching tracer and production data, whereas 4D seismic data may also be included later.

In parallel to the synthetic case study, there will be some new developments on the side of data assimilation methods. More specifically, one plan is to further enhance the efficacy of correlation-based automatic and adaptive localization, making it more efficient in terms of handling big seismic data, and more accurate in terms of history matching performance.

DELIVERABLES 2019

The PhD student is expected to start in 2019 and spend substantial time on university courses. As such, the PhD student will have reduced capacity for research in the first year. Nevertheless, it is anticipated that the research activities in 2019 will lead to the following deliverables in the year 2019 or 2020:

- An ensemble-based history matching framework to jointly assimilate both tracer and production data;
- Enhanced correlation-based localization to improve the performance of the ensemble-based history matching framework;
- One or two research report(s) that would be submitted to suitable conference(s) and/or peer-reviewed journal(s).

This project will, in cooperation with other activities in Task 7 and Task 5, deliver improved methodology for: localization, sparse representation of 4D seismic, improved uncertainty quantification, and extraction of maximum information available in field data. In return this will lead to improved reservoir management with the goal of improved volumetric sweep.

This project delivers to:
Monitoring tools and history matching, Inter-well/full field prediction, Field performance, Economic potential and environmental impact & Fiscal frame work and investment decisions

2.7.12 Reservoir Optimization and Model Evaluation

Duration: 2019-2021

Project manager / PhD student(s): NN (UiS)
Key personnel: Rolf J. Lorentzen (NORCE), Robert Klöfkorn (NORCE), Aksel Hiorth (NORCE/UiS)
Theme: 2
Task: 7
Budget 2019: 1.095.000 NOK

This project will study optimization and modelling of EOR injection strategies with the aim of increased total oil recovered, maximum economic benefit and minimal environmental impact. The planned research and implementation will significantly improve prediction of EOR effects and thus improve decision making for the Norwegian Continental Shelf. An important part is also to educate a PhD student.

OBJECTIVE

This is a PhD project is linked to project 2.6.1 and 2.7.1 and Theme 1. The project will integrate previous research performed in the Centre, and demonstrate the added value on field cases. The PhD candidate will focus on field scale modeling and simulation of EOR methods. Special focus will be on developing optimal strategies for e.g. polymer, smart water, or CO2 injection using synthetic models and the Open Porous Media (OPM) framework. In addition, a detailed study on impact of discretization methods for evaluation of EOR methods for oil fields will be carried out. More specifically, the following objectives are identified:

- Quantifying the value of e.g. polymer and smart water techniques on relevant North-Sea cases.
- Evaluating the impact on decision making when using higher order numerical methods for simulating the subsurface flow.
- Further development of ensemble-based optimization methods.

KNOWLEDGE GAPS

Considerable time and effort have been spent to develop EOR strategies and implementing the necessary model improvements to simulate the corresponding subsurface flow. However, little effort has been put down on evaluating the actual economic benefit of such strategies. In addition, many studies have shown that less accurate low order numerical methods, which are typically used in commercial but also other research simulators, provide inaccurate results in the representation of fronts and mixing zones.

This problem is further amplified by the chemical reactions of the EOR processes, as studied in the Centre. Thus, there is potential for finding better EOR strategies, and improving uncertainty quantification, when combining higher order numerical methods and ensemble-based optimization techniques. There is also a potential to improve ensemble-based techniques that are implemented for reservoir optimization. Currently, only unconstrained methods are implemented. Some effort is made in the Centre for better convergence rate, but also here it is room for improvement.

PLANS 2019

The PhD student will mainly focus on completing the necessary university courses required as part of the degree. In addition, a search for suitable field cases for investigating optimization of EOR strategies, will be initiated. The PhD candidate will also start to follow and familiarize with ongoing integration of improved discretization into the simulation framework.

DELIVERABLES 2019

The main deliverables for 2019 will be identification of suitable field cases for evaluating EOR strategies, higher order numerical methods, and optimization methods.
This project will deliver improved methodologies useful to evaluate the economic benefit of EOR.

This project delivers to:
Simulation and interpretation tools, Full field prediction, Field performance, Economic potential and environmental impact & Fiscal frame work and investment decisions

2.7.13 4D seismic frequency-dependent AVO inversion to predict saturation-pressure changes

Project manager(s) / PhD student: NN (UiS)
Key personnel: Wiktor Weibull (UiS), Xiaodong Luo (NORCE), Tuhin Bhakta (NORCE)
Theme: 2
Task: 7
Budget 2019: 1.095.000 NOK

Duration: 2019-2021

This research project deals with the problem of seismic reservoir characterization and improved recovery. It focuses on the development of an appropriate theoretical background and workflow, for including frequency dependence into the 4D (time-lapse) seismic AVO inversion and analysis to estimate viscoelastic properties, pressure and fluid saturation changes. The project is split in several phases.

OBJECTIVE

First, the methodology will be developed and run through feasibility tests and validation using synthetic seismic data, before moving to real data.Develop the theoretical foundation for frequency-dependent 4D seismic AVO inversion.

1. Performing feasibility analysis with synthetic data to predict elastic moduli changes, in addition to saturation and pressure changes, using 4D seismic AVO inversion including frequency dependence. These results will be compared with results obtained without including frequency dependence.
2. Apply the method to real 4D seismic data and compare the results to those obtained using conventional frequency independent AVO analysis and inversion.
3. Testing the workflow using frequency-dependent time-lapse in AVO attributes and spectral decomposition analysis, in order to predict fluid movements, and comparing the AVO attribute results without including frequency dependence.

The main problems that will be addressed in this project are:

- Development of equations associated to time-lapse frequency-dependent AVO inversion.
- Investigation of the effect of including frequency dependence on the ability to solve the inverse problem and look for optimal ways to optimize this solution.
- Define an appropriate rock physics model linking saturation-pressure and elastic properties changes with frequency dependence.
- Evaluate the ability of the method to distinguish between the effect of attenuation and associated dispersion, from other sources of frequency dependence on the elastic parameters.

KNOWLEDGE GAPS

The main motivation behind the project is that by including frequency dependence in the 4D seismic AVO inversion, we can potentially improve the accuracy of the results and at the same time bring additional information about the reservoir formation. This can potentially improve the recovery from hydrocarbon reservoirs.

PLANS 2019

2019 will be the first year of the PhD student and the candidate will take courses, do a literature rewiev and start develop the theoretical foundation for frequency-dependent 4D seismic AVO inversion.

DELIVERABLES 2019

The theoretical foundation for frequency-dependent 4D seismic AVO inversion will be developed and implemented.
As an outcome of the proposed methodology, the deliverance 2019-2021, a possible future estimation of permeability, fluid mobility and viscosity from 4D seismic AVO inversion with frequency dependence might be possible.

This project delivers to:
Monitoring tools and history matching; Field performance, Full field prediction; and Economic potential and environmental impact

Budget

Budgets 2019

(all figures in 1000)

NUMBER	PROJECT NAME	UiS	NORCE	IFE	Schl./Hal.	Others	Total
1.1.1	DOUCS – Deliverable of an Unbeatable …		700				700
1.1.1	DOUCS – Deliverable of an Unbeatable …		2 000				2 000
1.1.2	Core plug preparation procedures		700				700
1.1.7	Thermal properties of reservoir rocks, …	274					274
1.1.8	Flow of non-Newtonian fluids in porous …	1 095					1 095
1.1.11	Permeability and stress state	1 095					1 095
1.1.12	Understanding the initial wettability of …	1 095					1 095
1.1.13	Reservoir wettability and its effect on …	1 095					1 095
1.1.14	Mineralogical influence on reservoir …	456					456
1.1.15	Upscaling of Polymer and Smart Water …	1 095					1 095
1.2.3	Applying the analytical tool box to …	1 095					1 095
1.3.1	Pore scale simulation of multiphase …		850				850
1.3.3	Micro-scale simulation of viscoelastic …		850				850
1.3.7	Development of a simulation tool for …	1 095					1 095
1.4.1	Development and calibration of IORSim ...		1 000	2 000	500		3 500
1.4.2	Environmental fate and effect of EOR …						0
1.4.3	Large scale yard test and supporting …		890		2 000		2 890
1.4.3	Large scale yard test and supporting …		1 327				1 327
1.4.5	Polymer rheology at micro- and Darcy …	1 095					1 095
1.4.6	Risk Management/ERA	1 537					1 537
1.4.6	Risk Management/ERA	821					821
2.5.4	Nanoparticle tracers for petroleum …	1 095		150			1 245
2.5.5	Lanthanide ester complexes for SWCTT ...			830			830
2.5.6	Dynamic flooding properties of new PITT			900			900
2.6.1	Adding more physics, chemistry, and …	1 095	1 430				2 525
2.6.2	Advanced numerical methods for …	821	800				1 621
2.6.4	Upscaling of chemo-mechanical …	821					821
2.7.1	Production optimization		1 243				1 243
2.7.4	Data assimilation using 4D seismic data		2 487				2 487
2.7.5	Interpretation of 4D seismic for comp. …		1 085				1 085
2.7.7	4D seismic and tracer data for coupled …				1 500		1 500
2.7.8	Elastic full-waveform inversion	1 095					1 095
2.7.9	IOR Pilot Projects – Learning by Doing	1 095					1 095
2.7.10	The Value of Data and Data Analytics for ..	1 095					1 095
2.7.11	Data assimilation using 4D seismic and …	1 095					1 095
2.7.12	Reservoir Optimization and Model …	1 095					1 095
2.7.13	4D seismic frequency-dependent AVO …	1 095					1 095
0.0.0	Management & International in-kind	6 810	2 750	200		350	10 110
	Total	**29 061**	**18 112**	**4 080**	**4 000**	**350**	**55 603**

Projects UiS

T1: PhD Irene Ringen (1.1.8)	1 095
T1: PhD Tijana Voake (1.1.7)	274
T1: PhD Emanuela I. Kallesten (1.1.11)	1 095
T1: Postdoc Ivan D. Pinerez Torrijos (1.1.13)	1 095
T1: Postdoc NN (1.1.15)	1 095
T1: Postdoc NN (1.1.14)	456
T1: PhD NN (supervisor Tina Puntervold) (1.1.12)	1 095
T2: PhD NN (supervisor Udo Zimmermann) (1.2.3)	1 095
T3: PhD Bjarte Hetland (1.3.7)	1 095
T4: PhD Eystein Opsahl (1.4.2)	0
T4: PhD Siv Marie Åsen (1.4.5)	1 095
T4: PhD NN (supervisor Roger Flage) (1.4.6)	1 095
T4: Postdoc NN (1.4.7)	821
T4: Steinar Sanni (1.4.6)	442
T5: PhD NN (supervisor Tor Bjørnstad) (2.5.4)	1 095
T6: PhD Anna Kvashchuk (2.6.2)	821
T6: PhD Dhruvit B. Satischandra (2.6.1)	1 095
T6: Postdoc NN (2.6.4)	821
T7: PhD Karen Synnøve Ohm (2.7.8)	1 095
T7: PhD NN (supervisor Reidar Bratvold) (2.7.10)	1 095
T7: PhD NN (supervisor Xiaodong Luo) (2.7.11)	1 095
T7: PhD NN (supervisor Rolf Lorentzen) (2.7.12)	1 095
T7: PhD NN (supervisor Wiktor W. Weibull) (2.7.13)	1 095
T7: Postdoc NN (2.7.9)	1 095
Mgmt: UiS Management (50 % Merete, 50 % Aksel, 80 % Iren)	2 801
Mgmt: UiS Management (50 % Merete og 100 % Kjersti)	2 008
Mgmt: Running expenses, travels, meetings, workshops	1 000
Mgmt: IOR NORWAY	1 000
TOTAL BUDGET UIS	**29 061**

Projects NORCE

T1: Core Scale (mgmt)	350
T1: DOUCS – Postdoc (60 %) (1.1.1)	700
T1: DOUCS – Deliverable Of and Unbeatable Core Scale Simulator (1.1.1)	2 000
T1: Core plug preparation procedures (1.1.2)	700
T2: Nano Scale (mgmt)	100
T3: Pore Scale (mgmt)	350
T3: Pore scale simulation of multiphase flow in an evolving pore scale (1.3.1)	850
T3: Micro-scale simulation of viscoelastic polymer solutions (1.3.3)	850
T4: Upscaling and Environmental Impact (mgmt)	350
T4: IORSim development project (1.4.1)	1 000
T4: Large scale yard test and supporting lab activities (1.4.3)	890
T4: Large scale yard test and supporting lab activities (1.4.3)	1 327
T6: Reservoir simulation tools (mgmt)	350
T6: Adding more physics, chemistry & geological realism into the reservoir simulator (2.6.1)	1 430
T6: Advanced numerical methods for compositional flow applied to field scale reservoir models (PhD project) (2.6.2)	800
T7: Field scale evaluation and history matching (mgmt)	350
T7: Production optimization (2.7.1)	1 243
T7: Data assimilation using 4D seismic data (2.7.4)	2 487
T7: Interpretation of 4D seismic for compacting reservoirs (2.7.5)	1 085
Mgmt: NORCE Management (Randi Valestrand)	900
TOTAL BUDGET NORCE	**18 112**

Projects IFE

T4: IORSim development (1.4.1)	2 000
T5: Nanoparticle tracers for petroleum reservoir studies (PhD project) (2.5.4)	150
T5: Lanthanide ester complexes for SWCTT: focus on their partitioning behaviour, quantification procedure and dynamic performances (2.5.5)	830
T5: Dynamic flooding properties of new PITT tracers (2.5.6)	900
Mgmt: IFE Management (Sissel O. Viig)	200
TOTAL BUDGET IFE	**4080**

Projects others

T4: In-Kind Halliburton (1.4.3)	2 000
T4: In-Kind Schlumberger (1.4.1)	500
T7: In-Kind Schlumberger (2.7.7)	1 500
TOTAL IN-KIND HALLIBURTON/ SCHLUMBERGER 2019	**4 000**
Mgmt In-kind international	350
TOTAL INTERNATIONAL IN-KIND	**350**

FUNDING 2019 – PRELIMINARY

UiS	23 053
User partners	18 200
Schl/Hallib in-kind	4 000
RCN	10 000
In-kind international	350
Total funding 2019	**55 603**
UiS	29 061
NORCE	18 112
IFE	4 080
Schl/Hallib in-kind	4 000
In-kind international	350
Total committed 2019	**55 603**

Budget 2019 (all figures in 1000)

Description	UiS	NORCE	IFE	Schlumb/ Hallib	GEO/ ISEI/DTU others	Total
Task 1: Core Scale	6 205	3 400	-	-	-	9 605
Task 2: Mineral fluid reactions at nano/submicron scale	1 095	-	-	-	-	1 095
Task 3: Pore scale	1 095	1 700	-	-	-	2 795
Task 4: Upscaling and environmental impact	3 453	3 217	2 000	2 500	-	11 170
Task 5: Tracer technology	1 095	-	1 880	-	-	2 975
Task 6: Reservoir simulation tools	2 738	2 230	-	-	-	4 968
Task 7: Field scale evaluation and history matching	6 570	4 815	-	1 500	-	12 885
IOR Management	6 810	2 750	200	-	350	10 110
Total budget	**29 061**	**18 112**	**4 080**	**4 000**	**350**	**55 603**

IOR NORWAY 2019
«All for IOR, IOR for all»

JOIN US! 19-20 MARCH
VENUE: TJODHALLEN, UIS
WWW.UIS.NO/IOR

NFiP PETROLEUM RESEARCH SCHOOL OF NORWAY

The National IOR Centre of Norway

The National IOR Centre of Norway is well known for its annual conference, IOR NORWAY. The 2019 conference takes place 19-20 March, in Tjodhallen at the University of Stavanger.

The topic for this year's conference was decided after a competition held amongst the Centre's PhDs and post-docs. Aojie Hong, the first PhD who graduated at the Centre, won with the suggestion «All for IOR, IOR for all». «"All for IOR" means we are using all possible technologies and resources to improved oil recovery, and "IOR for All" means all people (the whole society) will benefit from the improved oil recovery,» Hong says.

Save the date! Complete agenda and workshop topics are found at www.uis.no/ior.

Dates: 19-20 March 2019
Venue: University of Stavanger

Icebreaker reception: 18 March
Conference: 19-20 March
Conference dinner: 19 March
Expected attendees: 250–300

Important dates:

Registration opens: 19 November 2018
Registration deadline: 8 March 2019
For more information, please visit www.uis.no/ior

With funding from
The Research Council of Norway

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