Introduction
More than 50% of the oil in existing fields on the Norwegian Continental Shelf (NCS) cannot be produced with current methods, either because the oil is immobile or because the chosen injection strategies lead to insufficient sweep efficiency. A number of Enhanced Oil Recovery (EOR) pilots have been performed on the NCS, but very few EOR methods have found a field-wide implementation. EOR methods have been studied for decades and many of the basic mechanisms are understood on a laboratory scale, but challenges still remain in upscaling EOR technologies from laboratory to field. Based on our experience (e.g. [1]) a joint collaborative effort of researchers and engineers from research institutes, service companies and oil companies is necessary to carry out a successful EOR field test. An EOR strategy should focus on optimal injection fluids to improve both microscopic and macroscopic sweep by upscaling core scale results to reservoir scale, and to conduct in-depth studies to evaluate the full field EOR impact. Fields differ and designing chemicals for injection requires knowledge about reservoir properties.

The Centre will provide the industry access to world-class experts, cutting edge technologies, and well-qualified candidates for future recruitment. We will promote multidisciplinary collaboration driven by the needs of the industry and form an arena for knowledge sharing and networking. Targeted workshops and open seminars, including an annual IOR seminar for example in cooperation with FORCE and an annual seminar jointly with the center of research based innovations within Drilling and Well for Improved Oil Recovery (SBBU) hosted by IRIS. The Centre will work actively to make field production data available to the research community in form of benchmark cases to enable other researchers to evaluate and compare their own reservoir simulators (see e.g. the SPE Comparative Solution Project, http://www.spe.org/web/csp/).

The Centre’s research partners, UiS-IRIS and IFE, have a solid track record of performing fundamental and applied research of high relevance to the industry, focusing on understanding of IOR processes at different scales ranging from pore- to core- to field scale. Verification of developed technologies against field data and innovative ways of applying tools and solutions have been instrumental in the success to bring R&D into industry applications. The established way of working closely with the industry will be continued and further exploited in the new Centre. We will have a close dialogue with the SBBU and IO Centre to promote synergies and avoid overlap.

Primary objective: The Centre’s goal is to perform R&D that will develop new knowledge and competence and contribute to the implementation of environmentally friendly technologies for maximizing NCS oil recovery through improved volumetric sweep of mobile oil, and mobilization and displacement of immobile oil.

Secondary objectives:

- Robust upscaling of recovery mechanism observed on pore, and core scale to field scale
- Optimal injection strategies based on total oil recovered, economical and environmental impact
- Educate a total of 13 PhDs/4 postdocs and 20 PhDs/6 postdocs during the 5 and 8 year period, respectively. There will be 50 MSc students per year.
- Promote collaboration and attract outstanding national and international researchers and PhD/postdocs and engage them in the research tasks in the Centre
- Contribute to coordination of research in the field of improved oil recovery by inter alia publications and providing access to open data sets.

In this application the term Enhanced Oil Recovery (EOR) includes "new, advanced injection techniques beyond standard water and gas injection". The term Improved Oil Recovery (IOR) is
used in a broader sense (i.e., encompasses EOR) to describe any field process or combinations thereof, that is used to economically increase the ultimate oil recovery. In this proposal, referral to IOR excludes the use of for example drilling of wells, completions, and Integrated Operations (IO) since these are main themes in other centres already.

1. Status

In 1974, Melrose and Brandner [2] discussed the term microscopic displacement efficiency and the role of capillary forces in determining the residual oil saturation after waterflooding. One way of minimizing the capillary forces is by the use of surfactants, which may reduce the interfacial tension by as much as a factor of 10,000 [3, 4], and significantly lower the residual oil saturation ($S_{or}$). Injection of miscible hydrocarbon gas and CO$_2$ also target the immobile oil. Gas injection, both miscible and immiscible, is proven technology at the NCS, injection of CO$_2$ has a large potential, but is still not used due to factors like lack of enough CO$_2$ and high cost. Improving the macroscopic or volumetric sweep by injection of polymer or water/gas diversion techniques to recover more mobile oil have undergone field applications today, two examples are Total’s Dahlia field and Statoil’s Snorre field. Research on polymers and water/gas diversion techniques for several fields are ongoing at IRIS. Water injections with lower salinity have recently been studied and tested both at UiS, IRIS [5, 6] and other places. The underlying physical and chemical mechanisms are still discussed, such that the full potential is therefore difficult to predict. BP has, however, performed injection of low salinity water from the start at their new Claire field. Combining low salinity water with other techniques like surfactant and polymer injection show promising results, since both the macroscopic and microscopic efficiency are influenced. Such hybrid EOR methods are the future for water based EOR, providing better cost efficiency combined with lower chemical consumption.

Experiences on EOR pilots on the NCS are water-alternating gas (WAG) injections in for example Gullfaks, Snorre, Statfjord and Ula and the microbial enhanced oil project at Norne. EOR methods have been studied for decades, the basic mechanisms are understood, but challenges regarding upscaling, and environmental impact emerge when technologies are taken from the lab- to field scale. Oil companies have experience with EOR technologies in onshore fields, but how to transfer the technology offshore, where the well spacing is much larger, is of current interest. Based on our experience (e.g. [1]), a joint effort of researchers, service companies and oil industry is necessary to carry out a successful test.

One of the critical physiochemical parameters regarding an EOR process is the wetting state of the reservoir, and it is important to represent it correctly in the lab. An interesting example is surfactant flooding, which is only properly described in water-wet systems where the residual oil after water flooding is in the form of discontinuous droplets [3, 4]. Recent work at IRIS [7, 8] questions the validity of the relationship between the residual oil saturation ($S_{or}$) and the local capillary number for mixed-wet or oil-wet cores. The main recovery mechanism in surfactant flooding in mixed-wet rock has been found to be improvement of oil relative permeability and thereby acceleration of oil production and reduction of water production. Recent research on polymer flooding also indicates that polymers may have a more pronounced effect in oil-wet cores than earlier assumed, simply because the film flow close to the rock surface increases [9]. Thus, it is important to have numerical models that can translate chemical and multiphase flow from pore-, core and field scale. This has been done to some extent by integrating geochemical models into pore [10], core [11], and field scale models [12] for investigating the water weakening phenomenon and wettability alteration in chalk. It was demonstrated, by both numerical models and experiments that the disequilibrium between injected water and the rock led to textural changes in the rock. These textural changes [13] can be large enough to lead to enhanced compaction followed by seabed subsidence and account for the additional oil production observed in spontaneous imbibition experiments.

For optimal utilization of the fields reservoir characterization is an important task. The field of history matching with dynamic datasets to improve the reservoir understanding goes back more
than forty years, with papers on automatic history matching published in the mid-seventies. Increased computational power and advances in geological modeling and reservoir simulation have led to increased research focus on history matching over the last decade. Moreover, a shift has been seen from searching for a single model achieving the best match to the data to approaches that also quantify the uncertainty [14].

To capture the geological heterogeneities of a reservoir requires a fine parameterization of the permeability and porosity of the reservoir. Working with large parameter sets is possible through the use of the ensemble Kalman filter (EnKF). The EnKF was first introduced for data assimilation problems in oceanography [15]. The strength of the EnKF is that it can handle large scale non-linear models. It is non-intrusive as the update is done by using statistics from an ensemble of simulations and these statistics are used to update the models to take into account available measurements.

The application of EnKF for updating reservoir simulation models was initiated by IRIS [16] and [17]. Here, it is of major impact to use the measurements to update the parameters of the models, not only the dynamic variables as in previous work done on the EnKF. The approach was immediately recognized as very promising for history matching and several groups started to work this direction, both within academia (Centre of Integrated Petroleum Research (CIPR), University of Oklahoma (OU), University of Tulsa (TU)) and in the industry (including Hydro, Statoil and Eni). The suitability of the EnKF approach to history matching was also demonstrated by the fact that case studies on real field cases were published rather rapidly (see e.g. [18], [19]).

Joint projects with participants from IRIS, CIPR, OU and TU have led to several joint seminars, research exchange, the introduction of a yearly EnKF workshop organized by IRIS, and the yearly COREC seminar open to the Ekofisk license organized by ConocoPhillips (CoP) and UiS-IRIS. An important outcome was also a review paper on EnKF for history matching [20]. Lately, the EnKF research community has been focusing on iterative filters, facies modeling, localization of the filter to avoid spurious correlations and development of variants of EnKF combined with other filters like the particle filter [21]. In the ongoing IRIS-CIPR project, supported by PETROMAKS, CoP, Eni, Petrobras, Statoil and Total, the main focus is on increasing the geological realism in the models, especially by updating facies models. Initial work in this direction includes [22-24].

2. Research methodology
The ultimate goal of the Centre is to contribute significantly towards increased oil recovery on the NCS. An investment decision in any IOR scheme is the responsibility of the asset licensees, and their principal needs are:

- The devised IOR scheme is technically robust (i.e. low probability of failure) and financially sound in operation.
- The investment cost and prognoses of production are robust and financially attractive.

The Centre will further develop knowledge and experience required to suggest the most appropriate EOR fluids for a given reservoir. In order to achieve this we have divided the Centre’s work into two main research themes. Within each theme we will work closely with a service company; Halliburton (Theme 1), and Schlumberger (SLB) (Theme 2). This will secure that the work will be focused towards application, and we will have access to national and international EOR experience gained by these companies. Theme 1 will focus on developing a core to field program; the work in this theme is generic. Based on core scale experiments, we will suggest optimal or sequences of EOR fluids that will improve the recovery. The core scale results will be upscaled and possible modification to the EOR fluids will be suggested. Furthermore, the reservoir cores will be subjected to nano and pore scale investigations where it is needed to further increase the understanding of the recovery mechanism, and thereby increase the possibility of a field scale optimization. In Theme 2, the main focus is to develop methods that provide guidance on how to flood a specific field as efficiently as possible. An important step in this direction is by integrating as much as possible of available field data into the reservoir simulation models in order to capture as many aspects of the field as possible. We will develop the tools and methodologies required to include the available data into an internally consistent model, and by this closing the gap between the essential phenomena
observed in reservoirs and field data. Close collaboration with the service industry and operators will secure that we will have available field data for evaluation of the new methods developed in the Centre.

Environmental impacts of the different EOR methods and chemicals will be assessed to evaluate the fate of the chemicals in the environment and the potential harmful effects of different methods on the ecosystem. EOR methods that minimize the energy cost and the environmental impact will be promoted by the Centre.

Publication and dissemination will be important in all the research tasks in the Centre. Scientific results will be presented at the annual IOR conference organized by the Centre, relevant international conferences and national meetings in Norway prior to publication in high impact peer reviewed international journals. See publication plan in 9. Progress plan.

3. Research themes

3.1 Theme1: Mobile and immobile oil and EOR methods

Theme 1 will focus on understanding, modeling, and upscaling the microscopic and macroscopic displacement efficiency when various EOR fluids are injected into a porous rock. EOR operations in both chalk and sandstone formations will be considered. We will cover challenges relevant for the entire NCS. The environmental impact of the EOR methods will be assessed.

Primary objective of Theme 1: 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.

Secondary objectives of Theme 1:

- Develop methods of how to upscale pore-, and core oil recovery to field scale
- Develop methods that can predict transport of chemical compounds from core to field
- A fundamental understanding of wettability and its role in porous media flow from pore-, to core and field scale
- An understanding of the impact and long term effect of EOR technologies on the reservoir
- Evaluate the environmental impact of the EOR methods.

There are several well-studied chemical injection technologies applicable for the fields on the NCS. Thorough laboratory- and modeling studies have been performed, but there are still research challenges. Field or pilot tests have been rare due to uncertainty of the potential for improving the recovery. Most crucial to improve for all methods is a proper simulation of the mechanisms on a field scale. In Figure 2 we have outlined our proposed work-flow, starting with core scale experiments and core imaging.

Task 1: Core scale

The aim is to construct models that capture the transport mechanisms observed in core scale experiments. The dominant transport mechanisms may be different in homogeneous and heterogeneous media, respectively. In particular, in heterogeneous reservoirs slower transport mechanisms like diffusion and segregation can be more important than in reservoirs dominated by viscous displacement. Naturally fractured core material or artificial cores made by slicing homogenous cores will therefore be studied. The Darcy scale models will couple chemical reactions to changes in the flow functions like capillary pressure and relative permeability. The aim of the experimental program is to (i) determine remaining oil saturations as a function of the degree of heterogeneity, rock mineralogy, wettability, oil and brine chemistry (e.g., smart water); (ii) determine full capillary pressure and imbibition curves as a function of brine (smart water) and oil chemistry; (iii) develop methods for monitoring the saturations and chemical composition in situ; (iv) generate samples to be investigated by SEM and nano scale measurements techniques; (v) investigate MEOR efficiency mechanisms and effects on reservoirs.
Figure 2: Workflow for Theme 1: Based on reservoir core scale experiments we will select optimal EOR fluids or sequences of EOR fluids, analyze the core before and after testing, perform pore- and core scale simulations, optimize the fluids or sequence of fluids (green arrows). Based on the core scale results, we will upscale to field scale and suggest how to optimize the EOR injection process and fluids.

**Task 1.1: Reactive flow modeling**

The main research task is to further develop mathematical models relevant for lab experiments in the context of (i) water weakening effects in chalk- and sandstone reservoirs; (ii) studies of how oil recovery depends on brine (smart water) compositions for sandstone and chalk reservoirs; , with wettability alteration as a central issue [11, 25]. Two main activities within this research task are therefore:

- The models are formulated on Darcy scale (lab scale), however, efforts should be made to couple the models to relevant pore scale modeling in order to (i) develop more realistic relative permeability and capillary pressure curves and (ii) incorporate more realistic coupling mechanisms for wettability alteration as a function of water-rock chemistry.
- Proposing comprehensive models that allow us to study effects, captured by the pore scale models obtained from research Task 2, on a larger scale.

There are limited models available that describe Darcy scale flow without using relative permeability and capillary pressure curves. However, recent advances made by [26] show promising results and will be further developed, to include variable temperatures and wetting properties in the Diffuse-Interface Model.

**Task 1.2: Core scale experiments**

One main activity will be to develop methods to determine in situ saturation profiles and water chemistry changes during flooding using resistivity measurements and the application of X-ray and NMR techniques. Core scale experiments will be conducted on bead packs with a well-defined mineralogy, with outcrop- and reservoir cores. Permeability, porosity, and mechanical properties will be determined throughout the test procedure. Experiments at in situ conditions may be designed to capture the essential stress and pore pressure history of oil fields, under depletion, water flooding, re-pressurization, and secondary depletion [27]. Homogeneous outcrop cores can be fractured to investigate interaction between the fractures and the matrix. The brine chemistry will be varied (surfactants, polymers, pH buffers, ionic composition, microorganisms or nutrients for microbial growth etc.), and crude- and model oil (white oil with surface active compounds added) will be used to change the wetting state. The use of model oil is important in order to determine how to upscale the interactions and behavior of organic compounds at nano scale to the Darcy scale. Adsorption/desorption studies of polar organic components in synthetic oils and crude oils on mineral surfaces and core material, the parameters that affect the rock wettability could be further investigated through imbibition studies and chemical analytic method. Additionally chromatographic tests on both mixtures of rock minerals and core material, the ions in multicomponent brines with high surface reactivity and which also contribute to the “Smart Water” effect could be traced. Through a better understanding of the ion-rock interactions we will optimize the EOR-potential for smart water on reservoir cores.
**Task 1.3: MEOR impact on reservoir microbiology**

Microorganisms in the reservoir can lead to EOR through the microbial production of different types of chemicals or directly through their activity and production of biomass [28, 29]. Microbial processes have shown to alter the permeability, surface wettability, fluid viscosity or selectively plug the oil depleted zones in the reservoir. The injected microbes may also affect the indigenous reservoir microbiology [30, 31]. We will investigate the different MEOR mechanisms to understand the impact of such technologies on in situ reservoir microbial communities. The microbial communities within cores will be studied using a metagenomic approach and molecular tracing of particular microbes to observe how different MEOR methods affect the indigenous communities as well as the fate of the organisms added to the core. The different MEOR-techniques will be evaluated in the light of oil production curves during flooding. The correct upscaling of the core and other laboratory experimental results give insight into the larger scale effect ensuring a successful implementation of MEOR in field.

**Task 2: Mineral fluid reactions at nano/submicron scale**

What alterations observed on nano/submicron scale are important for changes in surface properties, such as wettability change? Furthermore, how should the properties of water and oil film coated mineral surfaces be quantified? The alterations could be textural changes, such as formation of secondary minerals or dissolution of primary minerals, or it could be changes in surface properties such as surface charge or water/oil films. Thus one of the main aims in this task is to determine the mechanisms and quantify the interactions between well-defined brine and oil chemistry with clean mineral surfaces. Research based on electron microscope studies, such as SEM, cryo-SEM, MLA (mineral liberation analysis), microprobe and ionprobe (and ICP-MS multi collector with laser ablation) can be used to quantify amount and type of minerals present before and after the rock has been exposed to different fluid or gases. But to build good models with predictive power, the interaction energies between molecules and the rock surface need to be quantified. This type of studies requires advanced measuring equipment, such as atomic force microscopy (AFM), low energy electron diffraction, X-ray photoelectron spectroscopy combined with geochemical modeling and molecular dynamics simulation. Even replacement of one mineral by the same mineral with a different trace element composition may alter the interface energy and wettability. In order to measure and model such changes time resolved chemistry and force measurements must be combined with molecular dynamics and surface complexation models.

**Task 2.1: Mapping of minerals and textural changes of minerals exposed to brine**

Significant textural changes have been observed after flooding cores with various brines, and these textural changes lead to enhanced compaction [13, 32], and possibly wettability change [33, 34]. Tests have shown that textural changes are not distributed uniformly throughout the core, and the exact location of the mineral re-emplacement is of crucial importance both to understand the conditions at which the re-emplacement occur and in the upscaling of the results to field scale. SEM studies will be used for visual inspection of mineralogical alterations caused by rock-fluid interactions. This has been done with great success in recent studies at UiS. Secondary minerals initially form as nano scale coatings on the grain surfaces (Figure 3). It is therefore required to include methods suitable for submicron imaging and compositional analysis (e.g., transmission electron microscope, nanoSIMS). UiS is currently in the process of acquiring a new transmission electron microscope (TEM) which will be well-suited for this purpose. The SEM available at UiS is equipped with a cryo unit which will be used to freeze down samples and investigate fluid distribution of oil and water inside the pore space.
Task 2.2: Quantification of rock-fluid interactions

The stability of the water film between a mineral surface and the oil phase determines if there is a potential for the wettability to change [35]. After the water film has collapsed, active components in the oil phase can be absorbed on to the mineral surface and change the wettability. The nature of the oil components (chain length, number of carboxylic groups etc.) and the density of adsorption sites will determine if the rock becomes strongly oil wet or more moderately oil wet [36, 37]. By the use of AFM the surface characteristics of mineral surfaces exposed to different fluids can be measured. The properties of the AFM tip can also be changed and thus information about water film properties will be studied. Studies of single mineral crystals that are normally present in reservoir rocks will be the main focus area. In addition to AFM measurements, zeta potential measurements will be done for minerals in different brines. The nano scale measurements will be modeled with thermodynamics models such as surface complexation models [38] and molecular dynamics simulations [39].

Task 3: Pore scale

What are the relevant processes and mechanisms acting at single pores and grain contacts that can impact MDE? By using numerical reactive flow models on the pore scale we will investigate how rock-fluid interactions and wettability might be changed by pure geometrical effects, size and shape of the pore space and by chemical reactions such as mineral dissolution, changes in surface charge and potential, the addition of surfactants and polymers. The major goal is to predict the behavior of capillary pressure, and relative permeability as a function of different brine and oil chemistry. The pore scale simulators will be compared with pore scale fluid flow experiments, and imaging of pore scale distribution of phases as a function of various wetting states.

Task 3.1: Extensions of existing pore scale simulators

Pore scale modeling has been an extensive research area at IRIS the last years. Geochemical thermodynamic models, describing mineral dissolution, surface charge and ion exchange have been incorporated into lattice Boltzmann (LB) models describing fluid flow[10]. Two phase capillary pressure has been determined from 2D SEM images [40-42]. Significant progress in understanding rock-fluid interactions at the pore scale can be made by applying these models. However, there is still a need for quantitative comparison between models and experiments with measurement and control of both the exact pore geometry, and rock fluid interactions in order to evaluate these models. Furthermore, extensions will be developed in order to include more complex chemical interactions with surfactants and polymer solutions.

Multiphase LB models are comprehensively computationally demanding, and the interface resolution could be insufficient to describe film flow and interfacial configurations near contact lines and triple junctions in multiphase systems. Thus, an IRIS in-house 3D level set (LS) based model (see Figure 4), which offers a sub-voxel representation of the interfaces, will be further developed to investigate two- and three-fluid displacement mechanisms at mixed and uniform wetting conditions in realistic 3D digital rock samples. The implementation will be based on
extending the works of [43-45]. The developed LS based model aims at providing novel insights into the role of wettability on capillary pressure relations and hysteresis [46] trapping mechanisms and correlations, unconventional constitutive relations [47, 48], three-fluid displacement mechanisms [49], and saturation dependencies of three-phase capillary pressure [50] in realistic porous rocks. The models are flexible and can be used to investigate further the suggested mechanisms obtained from the nano scale investigations.

Non-wetting fluid configuration in a sphere pack as determined by level set model. The colour map represents dimensionless mean curvature on the fluid interfaces. Green colour represents the solid surface.

Carbonate sample where magnesium enriched saline water is introduced from the left and magnesite is precipitated (shown in solid, bright colours).

Figure 4: IRIS-inhouse pore scale tools. (Left) Level set based method. (Right) LB based method.

**Task 3.2: Flow experiments in artificial 2D porous media**

To study the basic processes at the mesoscopic scale, it is important to control both the flow properties and the pore structure to validate pore scale models and to improve insight into displacement mechanisms. Quasi 2D porous media are easy (and cheap) to manufacture and an ideal starting point for comparison between experiments and analytic -and numerical modeling. We propose the use of microfluidic devices produced by soft lithography in polydimethylsiloxane (PDMS) bonded to thin sections of transparent minerals like calcite and quartz. This will allow for a high degree of control of geometry, fluid flow rate and pressure differences. The main experimental tasks will be the imaging of the fluid flow and imaging of the mineral surfaces. The flow imaging will rely on fluorescence markers or on interferometry or phase contrast to follow the change in refractive index between different fluids and fluid mixtures. The fluorescence markers may be fluorescing beads from 10-5000 nm or single molecules that are only soluble in one phase (oil or brine) or that are grafted onto oil molecules. To study surface processes it is, of course, important that the experimental technique identifies the flow as close to the surface as possible. This will be achieved by using total internal reflection fluorescence (TIRF) microscopy, which can be used in situ. The experimental flow data from the microfluidic reactive multiphase flow may be quantitatively compared to LB simulations.

White light interferometric techniques will be used to measure the evolution of the mineral surface topography with a depth resolution of about 1 nm. The topography evolution is linked to the surface reactions that will be modeled and implemented in the LB simulations. It will be especially valuable to study how the reactivity of the mineral surface affects the wettability. These studies will make the link between core size experiments, mini-core tomography studies and reactive flow simulations on the pore scale. As input to the understanding and modeling of these experiments the submicron scale experiments and geochemical modeling are invaluable.

**Task 3.3: Imaging of pore scale fluid distribution**

The next level in approaching reservoir flow processes is to pass from idealized 2D models to realistic (and real samples) 3D porous media. In 3D one may no longer follow the details of the flow, reactions and boundary conditions everywhere; this will be input from the previous tasks. It is possible, however, to image the distribution of the different fluids in the porous media using cryo-SEM imaging (described under research Task 1), NMR, and X-ray tomography. These
measurements before and after flooding will be performed on commercially available tomographs (for example NGI in Oslo and at NTNU). In particular oil trapping at various wetting conditions will be investigated. Porous media consisting of both artificial and real rocks will be used. Improved predictive capabilities of residual oil saturation after a flooding process will come from further parametric studies (classification of crude oils, brines and rocks) and advances in the basic understanding of how crude oil induces wetting changes on a mineral surface as shown in several publications [36, 51-56].

One step further from 3D to 4D imaging of fluid distribution (3D plus time resolution during the flooding process) will be performed at the tomography beamline (ID19) of the European Synchrotron Radiation Facility (ESRF). We will develop a rotatable beryllium core holder for flooding experiments in the high intensity beamline that requires only a few minutes for each scan with a resolution of about 1 micrometer [57].

**Task 4: Upscaling and environmental impact**

What are the most important parameters from smaller scales that are important to describe flow on a larger scale? Environmentally friendly chemical EOR methods, such as injecting water of specific composition (e.g., low salinity, smart water), surfactants, and polymers have proven their potential on core scale. But, additional oil produced at the core scale does not necessarily imply that the field recovery will be similarly increased. Cores are usually 5-7 cm in length and molecular diffusion and end effects are important, contrary to field conditions. In the reservoir, transport is dominated by advection with an average flow rate that varies a lot depending on the distance from the injector or producer. The injected water is usually much colder than the reservoir and this causes cold fronts to move through the reservoir. Different parts of the reservoir are therefore at different temperatures, and as a consequence chemical changes occur at different rates depending on the local temperature. The effects of temperature gradients and variations in flow rates are generally not considered in core flooding experiments since the injection rate and temperature are kept constant. In addition, the injection of seawater on NCS over the last 30 years has changed the chemical composition of the formation water and altered the reservoir host rock as well as its in-situ microbial communities. The unflooded outcrop rocks commonly used in core experiments may therefore not be very representative of production reservoir. For all these reasons core experiments do not directly translate to the reservoir scale and can only calibrate models designed to make this translation.

In the development of new EOR methods assessments of potential disadvantages of emissions to both air and sea will be included, estimation of costs (energy) relative to the gain (EOR) and forecasting of expected level of subsidy (e.g. wind turbines). The selection and choice of appropriate EOR methods to be implemented in the reservoir should also depend greatly on the potential environmental impact of the chemicals to be used, following their transport, use, disposal and discharge through produced fluids.

**Task 4.1: Adding thermo-chemistry to reservoir simulation for better EOR prediction**

The purpose of this task is not to build a full scale reservoir simulator with complicated well control that can optimize a full field EOR implementation. Rather we propose to construct, calibrate, and apply a thermo-chemical reservoir model to better predict the results of different EOR strategies in a sector model. We will do this by (1) adding temperature, mineral alteration, and EOR methods to a multi-phase streamline reservoir simulator, (2) calibrating this model to the temperature, mineral, pore chemistry, and recovery that has occurred in a representative sector of an oil reservoir (full field optimization is covered in Theme 2), and (3) predicting the relative impact of injecting a tailored water chemistry (ionic composition, surfactants, polymer, alkaline, etc.) for EOR on this sector. The streamlines will change over time as the porosity and permeability change partly as a result of chemical reaction, oil production, and water flooding. By this approach it is also possible to link the observed reservoir compaction in an internally consistent manner. Large amounts of data are available on the chemical composition and temperature of the produced water, chemical tracer data, production history, etc., that can be used to calibrate a thermo-chemical model to a specific section of a reservoir.
The research prototypes developed can be implemented in the Open Porous Media (OPM) code base where IRIS is an active contributor. OPM is an open development project which offers field scale simulation capabilities, advanced grids and well control.

**Task 4.2. Environmental impact**
The main objective in this task is to assess the potential environmental impacts of EOR methods on the ecosystem, and the energy cost/gain on implementing a specific EOR method. The environmental impact studies will require: (1) Characterization and cataloging of the chemical compounds, and the potential harmfulness of the derived components. (2) Fate of EOR chemicals in the environment (emission to air, disposal by the production well, transport away from the site by ocean current, particulate adsorbed substances and free/dissolved chemicals) needs to be understood in order to establish realistic exposure scenarios for impact studies. Based on these studies a set of best practice and lab-based (with chemicals as well as artificial PW) and in-situ exposure studies will be suggested in order to understand both the impact of EOR chemicals on key organisms and on the ecosystems as a whole.

**3.2 Theme 2: Mobile oil: Reservoir characterization to improve volumetric sweep**
Theme 2 will focus 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. We will, together with NPD, prescreen reservoirs at the NCS to shape and focus the R&D work in the center (Task 7.4) and make sure the selection of reservoirs reflects challenges for the entire NCS, and improve the methodology to evaluate the economic potential of IOR/EOR projects (Task 7.3). These two tasks will be prioritized in the early phase of the center. The outcome of this prescreening will also be reflected in the R&D focus of Theme 1. To ensure a consistent modeling workflow all available data might be assimilated at once instead of the recursive updating applied by the EnKF approach. However, sticking to an ensemble based approach and using ideas from EnKF based methods would enable the development on non-intrusive methods that can exploit the use of parallel processing and exploit advances in computational power. A range of reservoir simulators will be used including commercial reservoirs simulators, such as ECPLISE and STARS, open source simulators like OPM, and in-house reservoir simulators such as the streamline simulator described in Theme 1 and BUGSIM (based on UTCHEM). We will focus on the following areas within Theme 2: Further development of tracer technology; Improvement of reservoir simulation tools; Robust production optimization; Better history matching through improved data assimilation tools; Evaluation of economic potential; and; Investigating the connection between the reservoir complexity and recovery factor potential.

**Task 5. Tracer technology**

**Task 5.1 Well-To-Well partitioning tracer technology**
We will further develop the Well-To-Well (WTW) partitioning tracer technology. Concurrent injection of a passive water tracer and a water/oil partitioning tracer into an injection well will result in a delay of the partitioning tracer relative to the passive water tracer due to a large-scale chromatographic effect. The delay is proportional to the water-contactable average oil saturation. After years of laboratory development at IFE, this method was recently successfully demonstrated in a French landbased reservoir (Lag rave) [58].

We propose to further develop new water/oil partitioning tracers: It is important to have a suite of possible tracers with various partitioning coefficients to optimize for varying reservoir conditions, and assure their quality in laboratory as well as in dedicated large-scale field experiments.

**Task 5.2 Single-Well-Push-And-Pull**
In this task we will further develop the Single-Well-Push-And-Pull (SWePAP) tracer technology for near-well applications. Fluid saturations in the near-well zone (out to about 10 m from the well) can
be measured with SWePAP tracer technology. It is based on injection of a water/oil partitioning compound (typically ethyl- or n-propyl-ester), which after injection and well shut-in, reacts with water and produces a passive water tracer. Upon back-production of remaining ester and the formed water tracer, chromatographic delay of the ester relative to the water tracer is proportional to the average oil saturation in a cylinder of the reservoir section around the well. This technique has traditionally been used in several hundred land-based wells around the world, especially in USA. It is very cumbersome to apply this traditional technique in off-shore situations, and new development is needed on the tracer compound itself, taking into account a sizable reduction in chemical volumes and corresponding reduction in detection limits. The main objective of this part of the Centre program is to contribute to a robust, stable and secure single well chemical tracer test applicable for off-shore wells and which satisfy environmental concerns on the use of chemicals.

Task 6. Reservoir simulation tools

Task 6.1: Adding more physics, chemistry, and geological realism

Insight into different fluid-rock mechanisms that can mobilize oil through wettability alteration is a central part of Theme 1, see Task 1. Such mechanisms must be transferred to full field simulators. Central tasks then are:

(i) Include dynamic flow functions that are controlled by fluid-rock interactions
(ii) Take into account combined fracture-matrix flow where flow in fracture-dominated regions is driven by viscous forces whereas matrix flow is more or less dominated by spontaneous or forced imbibition.

We will formulate fluid flow equations that include geomechanics, chemical composition, and interactions between fluid and rock minerals, temperature (injection wells) and systematically rank the importance of phenomena and approximate behavior by correlations to produce sets of robust modeling equations that capture features observed on the field scale. One way of investigation is to develop three-phase capillary pressure and relative permeability correlations that use Gibbs Free Energy to determine allowable saturation paths in a ternary diagram [59], and validate the correlations by pore network models and the Variational Level Set method. We will also develop trapping correlations for use in the three-phase capillary pressure and relative permeability correlations to predict residual saturations behind complex displacement processes.

In addition we also aim to develop methods to map faults and other geological macrostructures onto the numerical grid, and make a geologically consistent reservoir model. Research prototype software modules will be produced and included in full field simulators (e.g. OPM, UTCHEM, in-house simulators where we have source code) and in collaboration with the commercial suppliers in the consortium. A few pilots with clear challenges related to macroscopic sweep efficiency will be used to test and validate models.

Task 6.2: Modeling of near well zone scenarios

IFE has earlier developed Rocx which is a near well model couple to the multiphase simulator Olga. Olga – Rocx is today a state-of-the art tool for simulating coupled dynamical processes in the well and near-well zone. Simulation of such processes is a relatively new area which has been constantly growing the past 15 years. Commercially, Olga – Rocx is marketed by SPTGroup. The near-well area is a new area as such, bridging the well area and the reservoir discipline within the oil companies.

There is a lack of adequate simulation tools for near-well tracer and chemical experiments, and the market potential for such studies are large. After a coupling of Rocx with a simple well model we can simulate and interpret tracer studies of the near well zone. In particular we plan to use the data assimilation techniques of Task 7 for better interpretation and utilization of the information in the field setting.
Task 7: Field scale evaluation and history matching
How much extra oil can be recovered by adding a new well in a specific location? What is the uncertainty in this estimate? How to history match the production data with the reservoir model? To quantify the benefit of a specific IOR measure, good reservoir models and dynamic simulations are needed to evaluate expected cumulative oil production and associated net present value (NPV).

Task 7.1 Robust production optimization
At a comparative study consisting of a history matching and a production optimization part the groups obtaining the highest NPV were obtained by groups applying ensemble based methods for history matching [60]. The optimization of the waterflooding process was done by different methods, and both the ensemble based optimization [61] and an approach with a more engineering based approach with fewer optimization variables [62] aimed more at exploiting engineering insight seems viable. We will investigate further different optimization approaches for injection strategies of relevance for the NCS starting with waterflooding and WAG and continuing to EOR processes. In the evaluation we will take into account the fact that the reservoir model is uncertain and search for robust solutions under this uncertainty [63].

Task 7.2 Data assimilation at field scale
History matching now has a stronger focus on uncertainty quantification than before, see e.g. [20, 64]. This is inspired by ideas from data assimilation, in particular the use of the EnKF, and more recently other ensemble based methods. Integration of geological, geophysical and monitoring data into a good reservoir model is required for the successful implementation of any technique for improved recovery. Data assimilation to better characterize the reservoir and history matching of field scale observations aimed to pin-point the location of the remaining hydrocarbon reserves will be important and improve reservoir understanding by integrating the existing geological model and fluid-flow observations. A seamless connection between the reservoir simulation model and seismic 4D data sets will provide an efficient and effective means of evaluation of field scale EOR processes.

Task 7.2.1 Data assimilation using 4D seismic data
Joint history matching of production data and 4D seismic data are challenging as it might be difficult to combine these data into one objective function. Recently it has been suggested to use ideas from image processing to interpret the seismic information [65] and combining this with ensemble based method seems to be a promising area for further research. Usually 4D seismic data are inverted before history matching which means that special care needs to be taken to evaluate the uncertainty of the data used for data assimilation. In a recent paper [66] only an interpretation of the water front was used from the 4D seismic data, simplifying the assimilation, but such an approach might actually throw away information present in the seismic data.

In the last decade the resolution of seismic data has been improved significantly through techniques as broadband seismic. EnKF methods have been used for joint history matching of production data and 4D seismic data. However, the introduction of broadband seismic with finer resolution in the seismic data requires further development of ensemble based methods.

Task 7.2.2 History matching with flow dominated by faults and fractures
In [67] the fault transmissibility multiplier is updated utilizing tracer data. A more challenging problem is tuning the position of the fault and the top and bottom of the reservoir. This can to a certain extent be done within the classical EnKF framework [68]. Currently the EnKF and its variants are based on using a common discretization grid representing the reservoir. We suggest investigating re-parameterizations that mitigate this necessity. A natural starting point for the research would be to exploit ongoing work in earth modeling at IRIS-UIS [69].

For system of fractures one might in certain cases use models to upscale the fracture systems to parameters relevant for seismic and reservoir modeling as for instance has been done in [70].
Task 7.2.3 Improved history matching under compaction
Data assimilation with a coupled geomechanical and reservoir simulator has been demonstrated in [71] combining production and subsidence data. We will investigate rational methods for building coupled geomechanical/reservoir flow models. Techniques for data assimilation of these models will be developed taking into account 4D seismic and production data. Finally, methodology should be developed to utilize the assimilated models for safer well placements taking into account dynamic stress changes. Here it will be important to also take into account the information gained on the geomechanical properties of the overburden (Young’s modulus etc.).

Task 7.2.4 Improved history matching under changing wettability
Several parameters of the reservoir might actually change during the production of the reservoir. In addition to changes introduced due to compaction, changes in relative permeability and capillary pressure due to i.e. injections of polymers are of great importance. Development of history matching using a recursive approach as EnKF might be highly beneficial.

Task 7.3 Evaluation of economic potential
A realistic evaluation of the economic viability is essential to any IOR/EOR projects. Input parameters like oil and gas prices, discount rates, capital and operational costs will be reviewed by industry experts. We will use the same type of valuation model as in the petroleum industry, and tax issues will be addressed. When capital and personnel are scarce a particular relevant metric is net present value (NPV) index, in which the value generated is seen in relation to the use of scarce input factors. We will also analyse the effect on production over time (relevant for production targets of the companies), and effects on accounting metrics like Return on average capital employed (RoACE). Finally, we will discuss how the IOR/EOR projects affect bonus schemes prevalent in the oil companies and we will challenge them also to consider EOR from day one.

Task 7.4 Reservoir complexity and recovery factor potential
What is the connection between the reservoir complexity and the recovery factor potential? A review based on available information about the fields at NCS would serve as a starting point for such an investigation. The relevant criteria for describing the different reservoir types must be identified, and the relation between these criteria and the recovery factor must be quantified. Such a study has recently been done for Danish chalk oil fields [72], and it would be natural to make comparison with fields outside the NCS. This study might benefit from related work, including work within IRIS such as field screening tests where the potential of specific EOR methods is evaluated [73, 74]. The results of a study using a coarse description of the reservoirs would serve as a reference for more detailed studies.

4. Research training and recruitment
Conferment of PhD degrees will be offered by UiS. The percentage of female PhDs/postdocs is planned to be higher than 40%. There will be at least 6-7 PhDs at UiS each year and 6 postdocs distributed as follows; IFE (1), TNO (1), UiS (1), IRIS (3). From the experience gained from other large projects that include international collaborators, we have found it is necessary to exchange senior research personnel in addition to (post)-graduate students, to secure good cooperation and progress. We will encourage all senior personnel to spend 2-3 weeks each year, and PhDs/postdocs to spend up to 6 months, at one of our international collaborators. Regarding MSc programs: UiS starts a new two-year MSc with emphasis on IOR-EOR in Fall 2013. The program will be closely integrated with the ongoing two-year MSc in Petroleum Geoscience Engineering. Combined there will be 50 graduates each year from these programs. The knowledge gained through the Centre will benefit the MSc students directly, both in the course spectrum and in the offerings of thesis topics. Also, the Centre will form an important scientific basis for the new MSc program in mathematics and physics that will start in Fall 2013. These new programs will further strengthen UiS’ position as the university in Norway with the most extensive and relevant curriculum in Petroleum Technology.
The Centre will have a direct influence on the PhD program in Norway through UiS’ participation in the Board of the National Research School in Petroleum (NFiP), and also through Prof. Graue’s activity as a Director and Chairman of NFiP. 153 PhD students in Norway participated in NFiP’ activities in 2012. The Centre together with NFiP will as such impact the petroleum education, both in terms of recruitment, quality, number of candidates and international cooperation; beyond the international agreements UiS holds, NFiP has MoU with 5 top ranked universities in Europe and US. To support the petroleum geophysics team at UiS we will engage outstanding national geophysicists in part time Professor Positions (Prof. II) at UiS and establish collaboration with strong national geophysics groups. UiB (Prof. Morten Jakobsen and his group) and Prof. Martin Landro and his team at NTNU have already been invited to collaborate.

5. Importance to the industry

New injection technologies, chemicals and “smart water”, better simulation tools and integration of seismic data, better reservoir models and tracer technology are R&D from the Centre that can add significant value for operators and ultimately the Norwegian society. The research on environmental issues in the Centre is of great importance. It is crucial for the industry to gain knowledge on the possible environmental impacts of their activities not only do they have to report to national and international authorities, but also because such knowledge is a key for establishing preparedness and plans to manage the environmental risk.

The challenges regarding oil recovery differ for small and large oil companies, for small to large fields and for fields under development and mature fields. Close collaboration with the operators will ensure the overall success of a given solution. Deployment of solutions into field operations will not be funded by the Centre (ref. State Aid limitations (EFTA)). However, the Centre will benefit from the well-established partnerships with service companies like Schlumberger and Halliburton and IRIS, IFE and TNO have experienced teams that can provide technical support in the transfer of R&D into field operations.

Education and placement of MSc students and PhD/postdocs into industry organization for exposure to IOR/EOR relevant issues lead to improved recruitment of future industry IOR expert personnel, and graduates from the Centre will bring IOR knowledge and updated innovative research to the oil companies.

The experience of UiS and IRIS through working with concrete schemes for fields like e.g. Ekofisk, Heidrun, Rimfaks, Norne and Snorre provides clear evidence that a ‘field specific approach’ works. According to ConocoPhilips, the research from UiS and IRIS has added value and contributed to the increase in the reserve estimates in the Ekofisk field. Professor Tor Austad (UiS) and the UiS-IRIS team in Centre for Oil Recovery (COREC) were honored with the Norwegian Petroleum Directorate's IOR prize for their work on recovering more oil from chalk reservoirs[75]. Also the research on how to optimize the water chemistry to increase oil recovery has led to new and innovative solutions. The research on improving macroscopic sweep using polymer, polymer gels and other chemical systems show great potential. The silicate that will be pumped down in the Snorre field is an environmentally friendly silicate system designed at IRIS. The research in the lab was started in 2008 and IRIS has been involved in all stages of the pilot project. Today the tanker “Siri Knutsen” from Knutsens shipping company is rebuilt for this purpose and this summer silicate will be pumped in the Snorre field to reduce water production. We foresee more solutions like this which are beneficial for the shipping industry as well as the chemical industry. The potential for innovation and added value for the industry outside petroleum is large.

Within reservoir simulation, a main EOR contribution from IRIS has been modeling of gel placement by extending the UTCHEM simulator and the participation in the Open Porous Media (OPM) Initiative where IRIS has had an important integrating role. The IRIS SWORD software, a tool for fast analytical EOR computations, is in the process of being commercialized by IRIS Software AS.
The introduction of ensemble based methods to update petroleum reservoirs in history matching started at IRIS in 2002, and is now in the process of being taken into operations in Statoil and Eni and commercialized by several software vendors.

The assessment of environmental impacts of produced waters and drilling mud at sea have led, in the past 10 years, to a number of innovations at IRIS, ranging from methodological developments on biological markers of contaminants (the biomarker toolbox) to operational and realtime monitoring technologies. The latter is commercialized by Biota Guard AS a daughter and spin-off company of IRIS, as the so-called BiotaGuard system, a monitoring platform integrating physical sensors, chemical sniffers and mussel/crab-based biosensors.

The innovative solutions from IFE are also well known in the Petroleum industry and in particular their simulator OLGA and their work on tracer technologies.

The Centre will be located close to the center of research based innovations within Drilling and Well for Improved Oil Recovery (SBBU) located and hosted by IRIS, the geographic location and annual workshops with SBBU will ensure knowledge transfer between the centers and networking.

6. Organisation
The Centre is planned as a consortium of three research partners UiS, IRIS and IFE and a number of industrial partners. UiS will be the host institution. The Centre director is Dr. Merete V. Madland (UiS). She will have two assistant directors of research: Dr. Aksel Hiorth (UiS/IRIS) and Dr. Geir Nævdal (IRIS) and one representing academy, Prof. Svein Skjæveland (UiS). The assistant Centre director will be Dr. Kristin M. Flornes. They all have relevant management experience with international research projects and constitute the management team of the Centre.

The Centre director is in charge of the overall progress and performance of the Centre and reports to the Centre responsible (UiS) and the Centre board. The two assistant directors will support the director, conduct research, and together with senior scientists they support and advice doctorate students and postdocs. A full-time executive secretary will assist the management team. The Centre administration will be located at UiS. A General Assembly for all partners will be organized annually. The General Assembly will elect the Centre Board. The Centre board will include representatives from UiS, IRIS, IFE, and industry partners. The Centre's industry partners have the majority of the board to ensure industry relevance and involvement. The Research Council of Norway and other relevant stakeholders will have observer status.

The research will be organised in 2 R&D themes with 7 main Tasks, which are specified by a research plan covering deliverables, milestones and methodology (see 9. Progress plan). A senior scientist from UiS, IRIS, and IFE core group of researchers will serve as task leaders. As an overall strategy in these tasks, we will involve researchers coming from different research environments (IOR/EOR, reservoir, chemistry, geology, geochemistry, geophysics, mathematics, nanoscience/technology, biochemistry, environmental, industrial economy) from the partners as well as national and international collaborators.

<table>
<thead>
<tr>
<th>No.</th>
<th>Main research task</th>
<th>Task Lead</th>
<th>Participating partners</th>
<th>No. PhD/postdoc</th>
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<td>Field scale evaluation and history matching</td>
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<td>UiS, IFE, SLB, TNO</td>
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</table>

Through exchange of researchers and PhD students, joint open workshops and seminars we plan to further develop the existing close links established between the research environments at UiS, IRIS, IFE, the University of Bergen (UiB) (e.g., Prof. Arne Graue - Task 3), the University of Oslo (UiO) (e.g., Prof. Dag Dysthe -Task 2), NTNU (e.g., Prof. Curtis Whitson -Task 6), Uni CIPR (Prof. Dean
Oliver- Task 7), and SINTEF ICT (Prof. Knut-Andreas Lie -Task 6). We intend to establish formal cooperation agreements with relevant projects and relevant research groups, including environmental impact research groups. We are committed to establishing open arenas for collaboration for the entire Norwegian IOR-research community.

The board will establish a Technical Committee (TC) where the industrial parties nominate their own experts on each of the Centre’s R&D themes. The TC is to be established with the objective of being a dialogue partner with the R&D management team.

7. International cooperation

We will emphasize research exchange programs for students and researchers, collaboration in the Research Tasks, and participation in other activities like conferences, workshops and expert panels for the industry partners. UiS is one of the participating institutions in NorTex Petroleum Cluster which is a collaborating initiative with universities and industry in Norway and Texas to facilitate coordinated collaboration on petroleum education and research between participating institutions. The Cluster will assist in facilitating industry funding for adjunct and chair positions at the collaborating universities; especially emphasizing the NorTex collaboration.

A fruitful and productive collaboration with Professor Lawrence M. Cathles III of Cornell University has already been established. Through the Centre this collaboration will be further strengthened. Particularly interesting research areas covered by Professor Cathles’ are the physical and chemical phenomena that occur when two fluid phases are present. He has developed geochemical models describing induced chemical changes when fluids flow through rocks, across temperature gradients, under varying pressure and salinities.

The Institute for Study of the Earth’s Interior (ISEI) in Misasa (Japan) is a Center of Excellence for the 21st Century and is one of the most prestigious laboratories in geosciences, cosmo sciences and micro-/nano technology in the world. The director, Professor Dr. Eizo Nakamura, is personally interested in the Centre. The pedigree and the track record of this institution are exceptional as are the analytical facilities all positioned in an ultra-clean environment of exceptional quality. We plan for exchange of both visiting scientists as well as PhDs/postdocs who will gain invaluable experiences in the field of analytical procedures and techniques. This can in turn only be of benefit for building competence and thus transfer of exceptional experience to our IOR Centre.

The three Danish institutions GEO, GEUS and DTU collaborate closely and have been partners in projects with UiS-IRIS for many years through e.g. Joint Chalk Research. They all have unique and valuable expertise useful in Theme 1 in the Centre. GEUS and DTU are in addition involved in the new national research center to boost oil and gas research in Denmark. Efforts will be made to coordinate our research with the Danish centre.

The two Dutch institutions TNO and TU Delft collaborate closely and have been collaborating with IRIS for a number of years in the field of history matching, EnKF and production optimization. With their expertise in seismic, 4D seismic, and history matching they will give valuable contributions in the Tasks on history matching.

8. Gender equality

To promote gender equality, it is necessary to provide female leaders and researchers on all levels of the Centre. The IOR-Centre is fortunate that the team has already several senior female scientists; Dr. Merete Vadla Madland will be the Centre director (project manager), in addition to numerous senior female researchers who are already a part of the UiS-IRIS IOR team. Our recruitment goal will be 40-60% female involvement at all levels of experience. During the recruitment and job announcement we will particularly encourage females to apply to become leaders in the field of IOR, and we will use the University’s stated policy on gender equality. This requires a long-term strategy and a nationwide recruitment campaign aimed at female MSc and PhDs and postdocs from science departments at Norwegian and international universities.
9. Progress plan

Tasks & Subtasks - Themes 1 & 2

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<th>Pore scale</th>
<th>Upscaling &amp; env. impact</th>
<th>Tracer technology</th>
<th>Reservoir simulation tools</th>
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M2a, M2b, M3b, M3c, M1b: Establishing working procedures and determining standard experimental methods for the Centre completed M2b, M3a, M1a, M4a, M4e: Prototype models developed, tested against data, and improvements identified M4b: Screening of environmental impact completed, M4d: lab routines and best practice established M1c, M1d, M2f, M3d, M4d: Generation of data at a range of chemical and physical conditions to investigate microscopic and macroscopic displacement efficiency completed M2e, M3d, M1c, M4c, M4d: Important displacement mechanisms incorporated and tested against data M5c-d, M6c-d, M7h-n: Methodology incorporated and tested against field data. Improvements and bottlenecks identified.

10. Budget

See budget with payroll and indirect expenses, procurement of R&D services, cost codes etc. in the online application. Below is the budget for the tasks. 25.1 MNOK of the UiS budget is not distributed in tasks, but set aside for administrative matters, collaborative actions and contingency.

11. Cost per partner

<table>
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<th>Year</th>
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*SLB* = Schlumberger. Halliburton (2 MNOK/y), SLB (2 MNOK/y), ISEI (0.2 MNOK/y) and GEO (0.15 MNOK/y) are specified with in-kind in the budget. Prof. A. Graue (UiB), Prof. C. Whitson (NTNU) and Prof. D. Dysthe (UiO) will contribute with in-kind (not included in the budget).
12. Contributions distributed per partner

The universities will contribute with salaries for the involved persons, while library services and office facilities are free of charge. We have asked potential industry partner to contribute 2 MNOK/year to the Centre. Many oil companies and two service companies have confirmed their support for the Centre (see attached Letters of Interest).

(*) Halliburton (2 MNOK/year), Schlumberger (2 MNOK/year have agreed to contribute in-kind in the Centre. (***) Contributions from UiS 10 MNOK/year, ISEI 0.2 MNOK/year, and GEO 0.15 MNOK/year. (****) Budget from RCN will be 50MNOK at 30.11.2018

13. Environmental impact

The research conducted by the Centre will, when EOR projects are applied to fields, lead to:

- Accelerated and more energy efficient production, both for new and for existing fields (for example injection of water blocking agents will improve the water injection and prevent energy on pumping pure water for circulation.)
- Sustainability due to the utilization of the existing infrastructure (installations and pipelines) when prolonging the production in the existing fields
- Solutions (operational and chemical) to prevent risks of discharges of environmental toxic chemicals.

References


The National IOR Centre of Norway

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