

National Centre for Sustainable Subsurface Utilization of
the Norwegian Continental Shelf

Annual report 2023

NCS  2030

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Introduction

The National Centre for Sustainable Subsurface Utilisation of the Norwegian Continental Shelf (NCS2030) is one of three research centres for petroleum in Norway. NCS2030 was granted by the Research Council in 2021, started in 2022, and has a duration of up to 8 years. The University of Stavanger (UiS) is the host, and NORCE, IFE, and the University of Bergen (UiB) are research partners. The centre is funded by the Research Council of Norway (NFR), 6 oil- and energy companies, and by resources from the 4 academic partners and 2 technology suppliers.

NCS2030 contributes to solving the sustainability dilemma; make use of the nation's resources to ensure stable energy security and access, while reducing the emissions of greenhouse gases to reach climate goals. More than 70 interdisciplinary researchers are associated with the Centre and work on more than 26 ongoing research projects.

An important activity is to educate future experts on sustainable utilization of the Norwegian continental shelf. During 2023, 8 master's students have graduated, and 7 PhD candidates have got a good start. The Centre will employ additionally 4 post-doctoral fellows and 10 PhD candidates, and the number of master's students related to the centre is expected to increase.

In 2023, the centre management has visited industry partners to discuss activities, results and new opportunities. Awareness about centre activities has been raised among the industry partners' employees and areas for deep and specific collaboration have been defined. Furthermore, the centre has increased the scope of its research activity through associated- and spin-off projects. "Energy Norway", the annual conference organised by the centre, will take place 15-17 April 2024, and its first day will be devoted to a workshop on digitalisation.



An important activity is to educate future experts on sustainable utilisation of the Norwegian continental shelf. The picture is from Energy Norway 2023. Master student Deniz Seyfeli (to the left) is presenting his poster. Photo: Elisabeth Tønnessen / UIS

Partners

Academic partners



User partners



Observers



Management, board and committees



Alejandro Escalona
Centre director
University of Stavanger



Ying Guo
Assistant director
NORCE



Christian Dye
Innovation director
IFE



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R&D director
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Kjersti Riiber
Communications adviser
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Board



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Equinor Energy ASA

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Robert Berendsen (Landmark Graphics AS)
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Johanna N. Ravnås (Wintershall Dea Norge)
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Egil Boye Petersen (Aker BP ASA)
Paul Spencer (Vår Energi ASA)
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Thomas Lerdahl (OKEA ASA)

Scientific Advisory Committee



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Bochum University, DE

Lesley James (Memorial University of Newfoundland, CA)
Lorena Moscardelli (University of Texas at Austin, US)

Innovation Committee



Egil Boye Petersen
Chair
Aker BP ASA

Helge Bøvik Larsen (UiS)
John Zuta (NORCE)
Johan Kristian Sveen (IFE)
Geir Ersland/Arne Graue (UiB)
Robert Berendsen (Landmark Graphics AS)
Michael Nickel (Slb)
Tao Yang (Equinor Energy ASA)
Paul Spencer (Vår Energi ASA)
Kent Høgseth (DNO Norge AS)
Johanna N. Ravnås (Wintershall Dea Norge)
Thomas Lerdahl (OKEA ASA)

Objectives

The primary objective of NCS2030 is to fill knowledge gaps and provide solutions for maximizing value creation of subsurface resources to reach the net-zero emission (NZE) goals on the Norwegian Continental Shelf (NCS).

The vision of the NCS2030 centre is to facilitate an energy-efficient, multi-purpose utilization of the subsurface into a “Sustainable Subsurface Value Chain” to reach the net-zero emission goals on the Norwegian Continental Shelf. Four main research areas are identified, namely **Subsurface energy systems, Net-zero emission production, Digitalization and Society**. The research activities are organized into eight work packages (WPs): six WPs in research, one WP in education and outreach and one WP in management.

Norway is one of the most important and secure providers of energy to Europe. We have major opportunities to become a frontrunner in the sustainable energy transition to renewable energy and NZE hydrocarbon production. To transform the Norwegian Continental Shelf into sustainable utilization, a new way of thinking across disciplines and societal acceptance is required. Therefore, it is important to integrate research, education, and innovation to build knowledge and develop technologies towards the optimal utilization of the NCS.

CENTRE OBJECTIVES

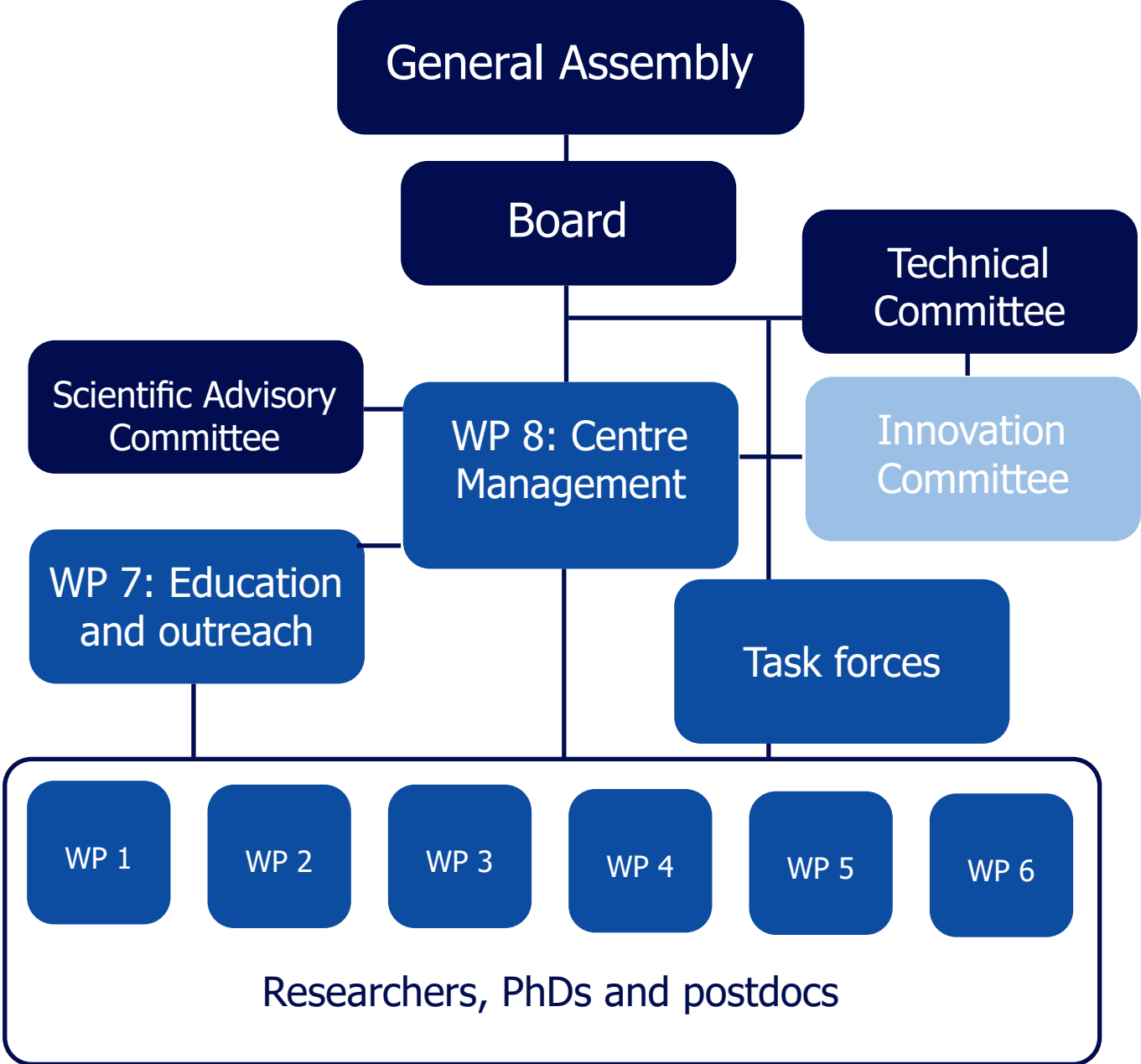
- Build integrated near field subsurface holistic models for increasing reserve base and evaluate the potenti-

- al of geological CO₂ and H₂ storage;
- Develop new improved oil recovery solutions for improved and accelerated hydrocarbon production at low environmental footprint;
- Develop data-driven and machine learning approaches to integrate subsurface characterization, uncertainty quantification and management workflows;
- Recommend field cases with high potential for NZE production;
- Create awareness and acceptance of NCS2030 activities;
- Establish an innovation platform for technology development with industry;
- Attract and train future scientists and skilled professionals for the energy transition and disseminate results.

The centre will collaborate broadly with academia and hands-on with industry partners and innovation companies.



Governance structure



Message from Chair of Board

Dear readers,

It is my pleasure to present to you the second annual report from the NCS2030 Petrocentre.

This large research and industry consortia is now really up and running and it is good to see the work packages and the projects progressing, with scientific achievements and results being achieved.

Amidst the comprehensive research work, 2023 has been filled with high activity level for the centre, including the Energy Norway conference, task forces, company visits, seminars and team buildings taking place.

At the NCS2030 Petrocentre, we aim to



educate a new generation of professionals, build expertise, and find solutions to key challenges in the energy transition. The centre's goal remains ambitious – to maximize the value creation of energy resources on the Norwegian Continental Shelf while simultaneously achieving net-zero emissions.

While it may be tempting to think that NCS2030 is just in the starting phase, there is precious little time to act upon solutions due to the sheer scale and complexity of the work involved.

It's a reminder to ourselves that research takes time, and the tasks to solve are hugely extensive. This underlines the need for top-notch competence, engagement, collaboration, and commitment from all parties involved, as they will be key in helping us achieve the objectives.

The NCS2030 Petrocentre plays an important role in providing competence and future solutions for the energy transition. Let us continue to work with a sense of urgency as we move closer towards our 2030 deadline.

I am eagerly looking forward to continuing to follow-up and be a part of the NCS2030 journey.

*Camilla Vavik Pedersen (Equinor)
Chair of Board*

Director's view

2023 has been a year of centre consolidation and settlement of activities after a successful start in 2022. We wanted a closer dialogue between industry and research partners with one-to-one visits to define areas of interest, promote the centre's research within the different organizations and discuss candidates for case studies. We also performed a one-day general task force meeting showing in-depth research activities and an online workshop on solutions for decarbonizing the Norwegian Continental Shelf.

With 150 participants in 2023, the Energy Norway conference represents an established arena for sharing knowledge and networking between research institutes, government agencies and industry. During the conference, we had the pleasure of having the members of the Scientific Advisory



Committee visiting for the first time, where they shared experiences with PhDs and researchers, resulting in good and constructive feedback to the centre management.

Recruitment of PhDs and postdocs continues. Now 7 PhDs are directly financed by the centre, and 5 PhDs and 2 postdocs are related via associated projects. Some of our PhDs are already building network and collaborating with our international partners. Further, master thesis projects and placement of students via practical training and summer jobs have been a success. It is important to notice that research learnings from the centre are being included in our courses as part of the energy transition.

In 2023 we saw the start of the innovation process, where 14 project pitches were presented to the innovation committee. Several projects are now in further discussions for maturing the concept towards applications. This is a complex process that takes time, and we are working hard to improve it in 2024. In parallel, we continue to have an expanding portfolio of associated projects and a couple of spin-off projects are being settled. Together with the Low Emission Center in Trondheim, we are exploring research collaborations within surface and subsurface integrated solutions for reducing emissions.

Thanks to all members of the centre for excellent work and support during 2023 and looking forward for this coming year.

Alejandro Escalona
Centre Director

The University of Stavanger is the host of NCS2030, and NORCE, IFE and the University of Bergen are research partners.

2023 has been a year of increased cooperation between the centre's partners with focus on building research awareness, identify case studies and spin-off projects. Researchers in the centre are collaborating more and more between the different partner institutions and all are quite active in the discussions. The task force seminar was a good example of sharing activities between different projects and building internal awareness to all, both research and industry partners. Both CSSR and NCS2030 petrosenters supported the NFR infrastructure application "National Laboratories for Reservoir and Geoenery Research" where partners of both petrosenters are actively represented. The main objective of the application is to provide a platform for excellence in subsurface research and innovation to maximize offshore resource utilization while minimizing energy.

The centre has visited most of the industry partners in 2023. The individual partner has chosen what to focus on in the meeting, and the invitation has gone out widely in the partners' organisation. Some of the meetings have focused on the centre's activities at an overall level, while others have gone more in-depth on topics of interest to that partner. Several of the meetings have resulted in further dialogue between the centre's researchers and experts at the companies.

We expect that this process will continue in 2024.

Another interesting process was the spin-off project idea pitch to the innovation committee. 14 different ideas relevant for further expansion of the research activities were presented to the industry for recommendation to further discussion and maturation with the interested companies. Furthermore, the centre is building collaboration with the other two petrosenters to increase the impact of the research activities. With the CSSR petrocentre there is ongoing collaboration in digitalization and hydrogen and CO₂ storage. With the Low Emission Centre there are ongoing discussions to build collaboration on the area of energy and emission management that couple both surface and subsurface operations and leads to net-zero emission production.



Visiting the Low Emission Centre, SINTEF. Photo: Kjersti Riiber

Research activities and achievements

In this section you will find highlights from last year's research in each work package (WP).

The last year's research has provided increased understanding of how fluids move in the subsurface, and its implications for temporary storage of hydrogen (H₂), permanent storage of CO₂, and petroleum production. Is the movement of these fluids, the rock interactions, and leakage important? In the centre, this is investigated with both observations of the seabed, seismic surveys, experiments in laboratories, and modelling. CO₂-tracers have been developed to show how CO₂ moves and interacts with fluids and minerals. Methods to use naturally occurring tracers to understand how various parts of the subsurface are connected or not, have also been developed.

MODELLING AND DIGITIZATION

Within modelling, and the use of an ensemble of models, improvements have been made to existing reservoir modelling methods by including uncertainty in measurements. These methodologies allow for better quantification of uncertainty of the reservoir models, better prediction of fluid production and facilitate better decisions by the companies. This will ultimately lead to emission reduction.

Within digitization and machine learning, we are also looking at how to use, safely and efficiently and without moving and sharing, large amounts of proprietary data from

different hosts to train models (federated knowledge cloud).

Within net-zero emission production, the focus has been on energy-efficient methods for oil and gas production, reducing water production and injection, which significantly reduces CO₂ emitted from platform gas turbines. This means improved and accelerated oil production, reducing the amount of water that is injected and produced, and unlocking resources near existing infrastructure. Methods that have shown promising results are advanced polymers, wettability alteration methods (smart water), carbonated water (CO₂ dissolved in water), and CO₂/water-foam. In addition, methods that have been effective for producing tight chalk reservoirs (e.g. the Ekofisk field) will be investigated for tight diatomite reservoirs (silica-based).

REDUCING EMISSIONS

To evaluate the overall effect on CO₂ emissions, life cycle analyses are carried out. Preliminary results show that chemicals that are effective at very low concentrations, e.g., polymers, are promising. Methods that use CO₂ will have the advantage that most of the CO₂ remains in the reservoir. In the future, tools (e.g. eCalc™) that can calculate and optimize the reduction in CO₂ emissions will be used. In the work packa-

Research activities and achievements



Stephane Polteau is presenting research from WP1 (Near-field resource evaluation) in a meeting with Equinor.

Photo: Kjersti Riiber

ge for society, politics and the economy, one looks at how associated framework conditions affect the transition, investments and the risk of overinvestment, both nationally and in an international context. Electrification of the platforms is one way to reduce CO₂ emissions. Preliminary results show that electrification will lead to increased electricity prices onshore, and that electricity produced from offshore wind farms alone will not be enough to reach expected CO₂ reductions.

HYDROGEN STORAGE

In the future energy mix, overproduction of energy from renewable sources, such as sun and wind, can be utilized to produce H₂, which in turn can be stored underground for periods of energy underproduction. This re-

quires large and safe storage locations, hence preliminary volume calculations have been made for H₂ stored in artificial built caverns in natural salt structures in the North Sea. Storage in salt caverns requires the understanding of salt impurities, leakage risks and microbes that may eat the H₂. Other geological structures for H₂ storage are also being investigated.

PUBLISHED PAPERS

From the NCS2030 centre's research, 24 peer-reviewed articles and reports and 50 meeting and conference presentations have been published in 2023. The scope of the centre's activities is increasing, through the start of several associated and/or affiliated projects and spin-off projects.

Near-field resource evaluation

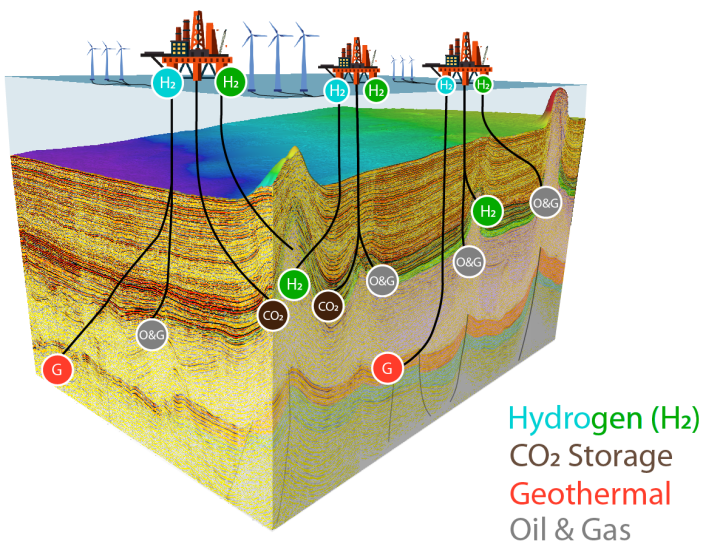
The growth in energy demand, combined with climate change, requires the use of new integrated strategies and multi-disciplinary methods for the long-term sustainable exploration and exploitation of subsurface energy resources and storage capacity to reach the NZE goals by 2050. Specific targets are:

- Produce an integrated holistic geological model and workflows for a selection of nearby existing infrastructure (hubs; ca. 50 km radius) to provide energy and storage opportunities.
- Unlock yet-to-find reserves in mature, near-field areas and provide new energy opportunities to extend the life of existing infrastructure.

ACHIEVEMENTS 2023

Research activities in the work package on near-field resource evaluation focused on developing and validating techniques to analyze the internal facies and fracture zones of salt diapirs. These methods find applications in investigating hydrocarbon traps, reducing the risk of salt cavern creation, and moni-

toring geohazards associated with salt tectonics. In addition, we further evaluated salt structures present in the southern portion of Norwegian North Sea as candidates for H₂ storage. The results of this exercise provide a workflow that can be applied in new areas, and new knowledge regarding location, dimension, depth of salt structures, potential number of caverns, and potential H₂ energy stored. We also developed and validated a geochemical tool based on the SrRSA method (Strontium Residual Salt Analysis) to characterize the fluid connectivity in sedimentary basins using core cuttings. This method is relevant for overburden management to prevent leakage over CO₂ storage sites and optimize the decommissioning of wells. Finally, we investigated the use of an ensemble-based workflow for underground hydrogen storage (UHS) in a 3D subsurface model. This workflow was developed in collaboration with WP5, and can be useful for subsurface characterization and monitoring within the context of UHS in porous media (aquifers and depleted hydrocarbon fields).



Leader: Stéphane Polteau (IFE)

Reservoir utilization for energy transition

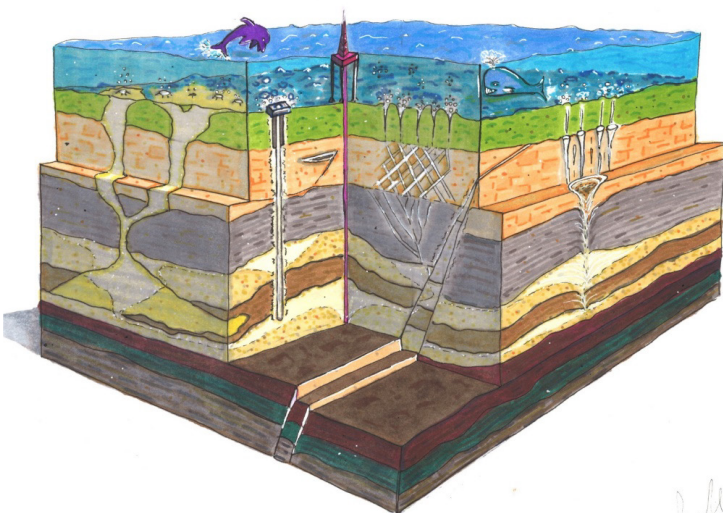
Achieving the NZE target by 2050 requires further development of CO₂ sequestration sites and exploration of alternative energy, such as H₂ and heat. Therefore, developing methods and tools that can enhance the capacity of geological sites for storage (CO₂ and H₂), and production of geothermal energy on the NCS is of importance. Specific targets:

- Improve the reservoir energy production strategy with carbon capture and storage.
- Describe and understand H₂ storage and retrieval mechanisms in different geological formations.

ACHIEVEMENTS 2023

In WP2, our emphasis has been on understanding the coupled thermo-hydro-mechano-chemical processes involved in fluid flow in sedimentary basins relevant for underground CO₂ and H₂ storage. Specifically, we have been working on the development of numerical models able to reproduce natural leakage mechanisms and fault stability, understanding the processes involved in injection and back production of H₂ in porous media, and the experimental advancement of tracers and tracing methods for the energy transition on the NCS. Numerical studies have uncovered the potential formation of chimney structures during fluid injection,

which could enhance injectivity and storage capacity by mitigating compartmentalization. However, this process also poses risks if chimneys reach the caprock, jeopardizing storage integrity and leading to CO₂ leakage. We have initiated discussions on numerical modeling practices for diverse NCS fields in collaboration with industry partners. Our primary objective for future collaboration is to model the reactivation of faults and weak planes to predict potential leakage and seismic activity, with the problem setup now finalized. Additionally, we've identified a new set of highly relevant CO₂ tracers, and a high-pressure cell has been constructed to facilitate the examination of phase-partitioning tracers under different conditions. Geochemical simulations have unveiled a deficiency in realistic input data, particularly in relation to reaction kinetics. Literature studies have highlighted the dependence of H₂ loss and transport on reservoir rock properties, fluids, and conditions, with some NCS natural gases containing a small amount of H₂. In alignment with our research, we've designed a practical training course for MSc students from UiS. Our international presence has grown, leading to invitations for keynote presentations at several international conferences.



Leader: Viktoriya Yarushina (IFE)

Work Package 3

Net-zero emission (NZE) production

In WP3 one aim is to develop improved oil recovery concepts for improved, accelerated, profitable and sustainable hydrocarbon production at low environmental footprint.

ACHIEVEMENTS 2023

In October 2022, PhD student Hilde Halsøy was hired at University of Bergen to work with utilizing CO₂ in foam applications to improve reservoir sweep efficiency. Experimental design and conditions for optimizing CO₂ foam have been identified based on the characteristics of some reservoirs on the Norwegian Continental Shelf. Currently, experimental work aims to determine optimal foam qualities, injection rates, and surfactant concentrations at reservoir conditions which are key input parameters for numerical modeling. One key highlight of this year was completing coreflooding with PET/CT imaging and the first results revealed increased sweep efficiency and CO₂ trapping using foam compared to pure CO₂ or CO₂ WAG (water alternating gas injection).

In June 2023, PhD-student, Veronika Abdulina, was employed at University of Stavanger to work with tight reservoirs and to contribute

to finding IOR solutions for such reservoirs. She started her research concentrating on diatomite rocks, a rock type with very high porosity and generally low permeability. This rock type can host considerable amounts of hydrocarbons and potentially store large amounts of CO₂, but the low permeability challenges hydrocarbon production and fluid injectivity.

Reservoir rock material from the Norwegian continental shelf has been sampled from the Norwegian Offshore Directorate core storage. Several characterization tests have been performed, with the aim to identify characteristic rock properties that need to be present in analogue material to be used for further parametric studies.

Through international collaboration with Institute of Geoenergy and The Foundation for Research and Technology (FORTH), both located in Greece, and the Technical University of Denmark (DTU), potential outcrop analogues have been collected, and work is currently ongoing to evaluate their potential as good analogues for further studies related to wettability and IOR-studies.



Leader: Tina Puntervold (UiS)

Work Package 4

Efficient water management

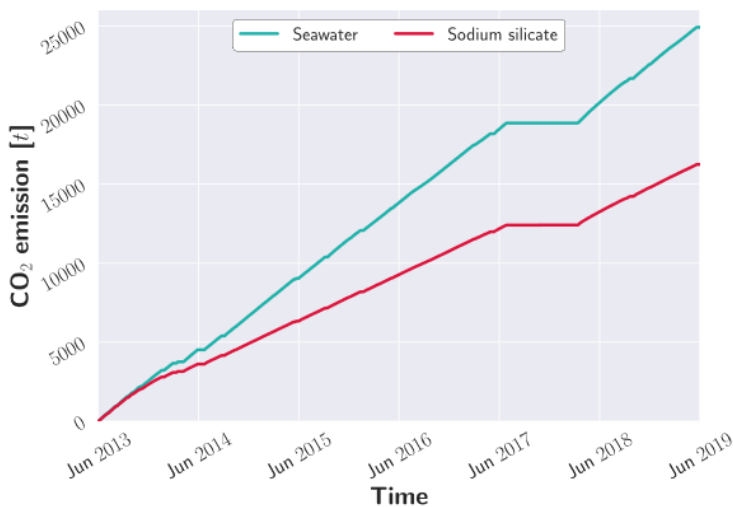
The amount of water injected, produced and discharged to sea in aging fields on the NCS is increasing. Water handling is energy-intensive and costly, and represents about 50% of the total energy for field operation. Therefore, efficient water management is crucial for field economics and emission reduction. Specific aims of WP4 are:

- To further investigate solutions for improved macroscopic sweep of reservoirs.
- To minimize injection water recirculation with reduced energy needs, thus reducing CO₂ emissions.

ACHIEVEMENTS 2023

IORSim software developed within [the National IOR Centre of Norway \(2013-2021\)](#) has been further validated for its capability of modelling of deep water diversion using silicate. The IORSim software has been further improved for its computing speed, more

seamless integration with existing reservoir models, enhanced user experience and advanced data interpretation. The Snorre silicate pilot has been used to study the pilot performance and the emission reduction effect. A history-matched model for the pilot segment with 892 800 cells (512 550 active) was used as basis for IORSim/Eclipse backward mode simulation, both near- and in-depth wellbore gelation kinetics and distribution was studied to understand the impact of the pilot. The production and injection history in the 8 years period from before the silicate injection (2021-2023) to 2019 has been used. The main benefit of the 3 months silicate pilot has been more clearly identified to be less water cut injected (~ 2.9%), resulting in less water injection needed (~1000 Sm³/day) with a CO₂ emission reduction estimate of about 9000 tons in 6 years. The methodology can be used for future field implementation of the in-depth water diversion.



E4 Injection pump CO₂ emissions



Leader: Ying Guo (NORCE)

Work Package 5

Digital subsurface for decisions

Large amounts of subsurface data are available, but current workflows and programmes for subsurface understanding are not optimal, resulting in inadequate utilization of datasets. Using an ensemble of model predictions to support robust decision-making is in its infancy; thus, we must establish consistent decision-making methods. Digitalization and machine-learning are required components, and we must integrate knowledge and competence building to make more informed decisions. We will establish a digital infrastructure to provide usable data, high-performance computing power, and visualization tools.

ACHIEVEMENTS 2023

In WP5, we conducted industry-relevant methodology developments and applied these to the industry's problems. In 2023, we focused on developing data-driven and machine-learning approaches to integrate subsurface characterization, uncertainty quantification, and management workflows for better decisions, with the main deliverable: New digitalisation workflows with improved functionalities and computational efficiencies. In 2023, we have published a lot of our early-stage centre methodological developments, especially we would like to mention:

- The development of the Federated Knowledge Cloud is going forward. In 2023, we used the Federated Computation to analyze DISKOS Digital Palynological Slides. The results show that federated computation ensures data privacy and promotes cross-domain sharing, making it suitable for the energy industry's multi-site data use. We also applied federated computation using Blockchain, showing that Blockchain facilitates collaboration between organisations by enhancing data integrity and

security, transparency, and audibility.

- The development of scenario evaluation tools consists of many steps. In 2023, we published a modified version of Bayesian stacking that we tested on models with large data sets. We submitted two other essential results for publication: The first considered developing multilevel methods for calculating Bayesian model evidence, and the second focused on using multilevel methods for deriving model diagnostics.
- We have continued implementing our methodological developments for ensemble-based reservoir management in open-source tools. Primarily, we have developed and implemented new advanced history-matching algorithms with correlation-based localization in Python Ensemble Toolbox (PET) and Ensemble-based Reservoir Tool (ERT), and we have integrated and used eCalc in the ERT and PET workflows.
- For CO₂ and H₂ utilization and storage, we have applied an ensemble-based workflow to subsurface characterization and monitoring for underground hydrogen storage in a 3D subsurface model, in collaboration with WP1 and the CSSR petrocentre.



Leader: Geir Evensen (NORCE)

Deputy leader: Randi Valestrand (NORCE)

Work Package 6

Energy policy, economy and society

The role of the Norwegian Continental Shelf (NCS) in the future energy system depends on the national and international business regulations, societal acceptance and licence to operate.

The targets of WP6 are to:

- Address the competitiveness of the NCS in national and international contexts.
- Contribute to sound climate mitigation policies.
- Understand and explain the risk and uncertainty of investments related to WP1-WP5.

ACHIEVEMENTS 2023

- Policies like taxes have significant impacts on investments. Coordinated royalty tax policies across oil-producing countries can contribute to reductions in global carbon emissions, while uncoordinated policies will result in high carbon leakage. The costs of such supply-side climate policies fall relatively heavily on consumers

due to higher oil prices, while producers may benefit.

- A focus on expected positive profitability, built into the Norwegian oil and gas licensing system, seems to have safeguarded against low profitability investment projects and reduced the danger of investments in assets that could be stranded.
- Cost-efficient electrification of NCS? Offshore wind alone is not sufficient to reach the 55% reduction target by 2030 with current deployment plans. Electrification leads to higher average electricity prices in Norway (11% at highest) and electrification is partly enabled by increased imports from Europe.
- Companies based in Western countries have played an important role in investments in oil and gas production globally. What have been the roles of such Western oil companies in the politics of authoritarian states and the current geopolitics?



Leader: Torfinn Harding (UiS)

Education and outreach

The diversification in the energy sector requires skilled professionals with subsurface competences, knowledge in the multiple energy sources, storage options, digitalization and an understanding of the Norwegian Continental Shelf. However, the number of students in energy related topics at the universities in Norway has dramatically declined and the supply of people with subsurface competence is approaching a critical low level. To address these challenges, the specific targets are:

- Attract the next generation of scientists and skilled professionals for the energy transition.
- Educate new professionals at Msc and PhD level in the future energy competences in collaboration with the industry.

ACHIEVEMENTS 2023

Outreach and education are widely accepted and known to be an important aspect of research, and the NCS2030 is no different. WP7 has made considerable progress in implementing new systems to better support education and outreach goals of the Centre. Good and organized systems help to achieve success. In 2023, we actualized several new internal systems. First, we have organized regular monthly, public webinars. The

webinars are open to the public, recorded, and posted on YouTube. The volunteer-based webinars are proving to be popular. At the end of 2023, we have already scheduled webinars for 2024. Second, we have created two self-entry lists so that we can track the number of students who are involved in the NCS2030 in some way. One list focuses on student placement. We can differentiate between paid and unpaid positions; part-time or full-time; and employment, internship, or training. The other list focuses on thesis projects. We can quickly access copies of the thesis in the system. Both lists provide an overview of student, advisor/supervisor/mentor, project/thesis title, work package, and semester. We did not have 100% success in all our new systems, but those that have had a rocky start provided us with lessons on how to improve in the future. In particular, we organized an online meeting with potential thesis supervisors and students. While the event itself was insightful and provided good information to the students, the follow-up on the activity and reconnecting students and thesis supervisors can be improved in timing and be made more meaningful.

In 2024, we hope to continue the realization of good systems to increase our successes in public outreach and education.



Leader: Lisa Watson (UiS)

Centre activities

At the centre gathering at Clarion Hotel Energy in December, the researchers had to get out of their comfort zone.

The themes for the gathering were presentation skills and research collaboration. Actress and associate professor in drama at UiS, Berit Aarrestad, gave an introduction to a method for actors as tips for mediators. When preparing to convey the text you are presenting, you should open it up, she said.

«It can be really helpful to reflect and make choices based on your personal experience of the text,» Aarrestad explained.

PRESENTATION SKILLS

Here are some advice from Aarrestad:

- Divide the text into small parts that revolve around the same thing.
- Emphasize the words that are the bearer of the mind goods?
- What words are insignificant?
- Find images, which you can retrieve for the different parts of the text.
- Does the text have a turning point?
- Does the text have a conclusion?

RESEARCH COLLABORATION

For the second part of the gathering, Andrew Kilmartin (project support at University of Stavanger) gave a more «traditional» presentation on research collaboration opportunities. The main question Kilmartin was asking was this: «Will collaboration improve how we discover, frame, analyse, evaluate and present our results & options?»

He asked the researchers to think about how they cooperate – and with whom – to reach the goals at work package level. The researchers also discussed obstacles to cooperation. What are these obstacles? And if a barrier was removed, would the issues be resolved or the outcomes be different?

The gathering ended with a traditional Christmas dinner at Clarion Hotel Energy at Tjensvoll.



A happy crowd ready to learn presentation skills. In the front, Professor Alejandro Escalona.

Presentation skills course and teambuilding



Associate Professor Berit Aarrestad, University of Stavanger.



Shoes off, on the floor.

Photos: Kjersti Riiber



Researcher Lawrence Hongliang Wang, IFE.



PhD student Mahmood Fani, UiS.



PhD student Jassem Abbasi, UiS.



A critical (but nice) audience gave feedback to the presenters.

Energy Norway 2023

Energy Norway was arranged 13-15 March 2023.
Theme: Subsurface for energy security and sustainability.

The conference is an annual meeting place for subsurface professionals in Norway and international communities, policy makers, regulatory bodies, and students. The theme for the 2023 edition was «Subsurface for energy security and sustainability». The energy situation in Europe has affected all aspects of our lives. As for the NCS2030 centre, it has made the research focus in energy security and climate goals more relevant. How can we best use our energy resources? Is nuclear power a good alternative in Norway? At Energy Norway 2023, we invited researchers, authorities and industry to discuss energy security and sustainability.

THE SKJÆVELAND AWARD

An important part of the Energy Norway conference is to involve our students, from master to PhD level. Each year we arrange a poster competition, the Skjæveland Award, where students are encouraged to participate with a scientific poster as well as a one-minute stand-up to present their research. The award is given to a young researcher who shows excellence, courage and innovation in his research, and should motivate for further bold moves towards optimizing oil and gas production.

In the 2023 edition of the conference, Jungwon Seo from UiS was awarded the Skjæveland Award. This award got its name after Professor Emeritus Svein M. Skjæveland. Skjæveland has for many years contri-

buted in teaching, research, management and organisation within the petroleum department and IOR Centre at UiS.

INTERNATIONAL DELEGATES

Energy Norway has acted as a catalyst for building the NCS2030 network, but also as a meeting point for the existing collaboration. Both the Twinn2set project with Forth in Greece and IFPN in France (EU twinning programme), and the Intpart project with the University of Campinas (Unicamp), Brazil (focus on IOR) were active participants at the conference in 2023. In connection with the fact that representatives from these collaborative projects were in Norway, several seminars were also arranged. Here, opportunities were identified for further collaboration within energy conversion and efficient field production.

CONFERENCE TOPICS

Our aim is that Energy Norway will continue to be an important meeting place for subsurface professionals in Norway and international communities, policy makers, regulatory bodies and students. Main topics in 2023 were:

- The future of the Norwegian continental Shelf
- Energy security and reduced emissions
- Pathways to achieve net-zero targets
- Reservoir management for reduced emissions
- Subsurface storage opportunities and digital subsurface



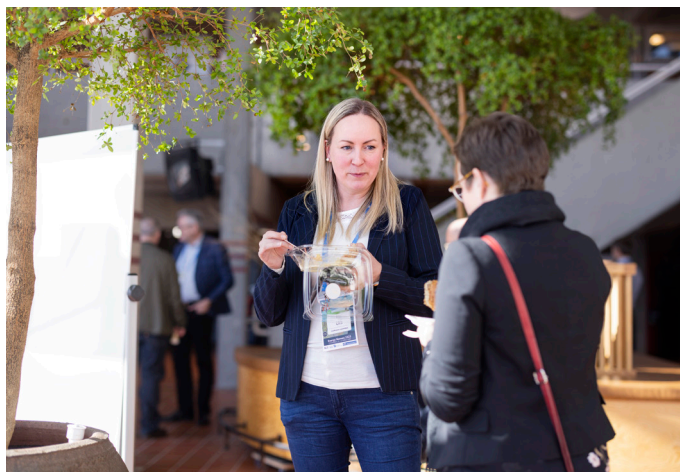
Professor Alejandro Escalona, centre director NCS2030.



Director General Torgeir Stordal, NPD. Photos: Elisabeth Tønnessen/UIS



PhD student Jungwon Seo (left) won the Skjæveland award.



Associate Professor Tina Puntervold having a lunch conversation.



One of the most important parts of attending conferences is making new contacts. Here Senior Scientist César Patiño (IEA) and Director Rune Volla (NFR) are exchanging email addresses.

Communication, conferences and collaboration

NCS2030 researchers have been present and/or given presentations at the following events and meetings in 2023, including internal events for PhD students and industry partners.

TASK FORCE SEMINAR

The centre invited industry partners to a task force seminar 31st May. The goals for the seminar were to discuss technical challenges and opportunities in the centre's projects, and engage industry and research personnel in our work. During the one-day seminar the participants got time to network and discuss possible collaboration opportunities. Our researchers used the opportunity to highlight the centre's work. At the end of the day, time was spent to discuss the workplan for 2023-2024.

PHD STUDENT GATHERING

In November 2023 all PhD students and postdoc researchers affiliated with the centre were invited to an informal gathering at Thon Hotel in the city centre of Stavanger. The goal for the meeting was to introduce all the PhDs/postdocs, and to get to know each other better. In addition to short project presentations from each candidate, the project coordinator presented the centre and the PhD administration at the University of Stavanger, and the Dean of research, Helge Bøvik Larsen, gave a throughout and inspirational talk on the scientific expectation for receiving a PhD degree.

PARTNER VISITS

In 2023, the centre has visited industry partners to discuss activities, results and new opportunities. Awareness about centre activities has been raised among the industry partners' employees and areas for deep and specific collaboration have been defined. Furthermore, the centre has increased the scope of its research activity through

associated- and spin-off projects. Companies visited summer and autumn 2023: WintershallDea, DNO, Aker BP (Stavanger), Equinor and OKEA (Trondheim).

EPIC, RESEARCH CENTRE IN BRAZIL

In October 2023 NCS2030 researchers visited the EPIC research centre at the University of Campinas in Brazil. The collaboration through the INTPART project aims to establish long-term excellent collaboration within Improved Oil Recovery (IOR) education and research groups in Norway and Brazil. Between interesting scientific discussions and networking the researchers were granted a visit to the Brazilian Synchrotron Light Laboratory (LNLS), which is part of the Brazilian Center for Research in Energy and Materials (CNPEM), located in Campinas. Dr. Nathaly Lopes Archilha gave a tour of the Sirius, one of the most advanced synchrotron light sources in the world, and showed how it could be used for X-ray imaging and applied to fluid flow in porous media.

EU-PROJECT TWINN2SET, GREECE

Researchers from UiS are involved in an EU-project on CO₂ and hydrogen storage in collaboration with the FORTH institute of geoenergy in Greece and IFPEN in France. In September 2023 we visited Crete island in Greece for a Twinn2Set project meeting, a workshop on "Enhancing the Research Management and Administration Skills", and a geological field trip in the Chania region of the island. We also collected diatomite outcrop rocks relevant for WP3 research activity.



Task Force Seminar, May 2023.

Photo: Kjersti Riiber



PhD gathering, November 2023.

Photo: Kjersti Riiber



Professor Alejandro Escalona presenting at DNO, Stavanger.

Photo: Jostein Løvås, DNO



NCS2030 researchers visited the EPIC research centre at the University of Campinas in Brazil.

Photo: Private



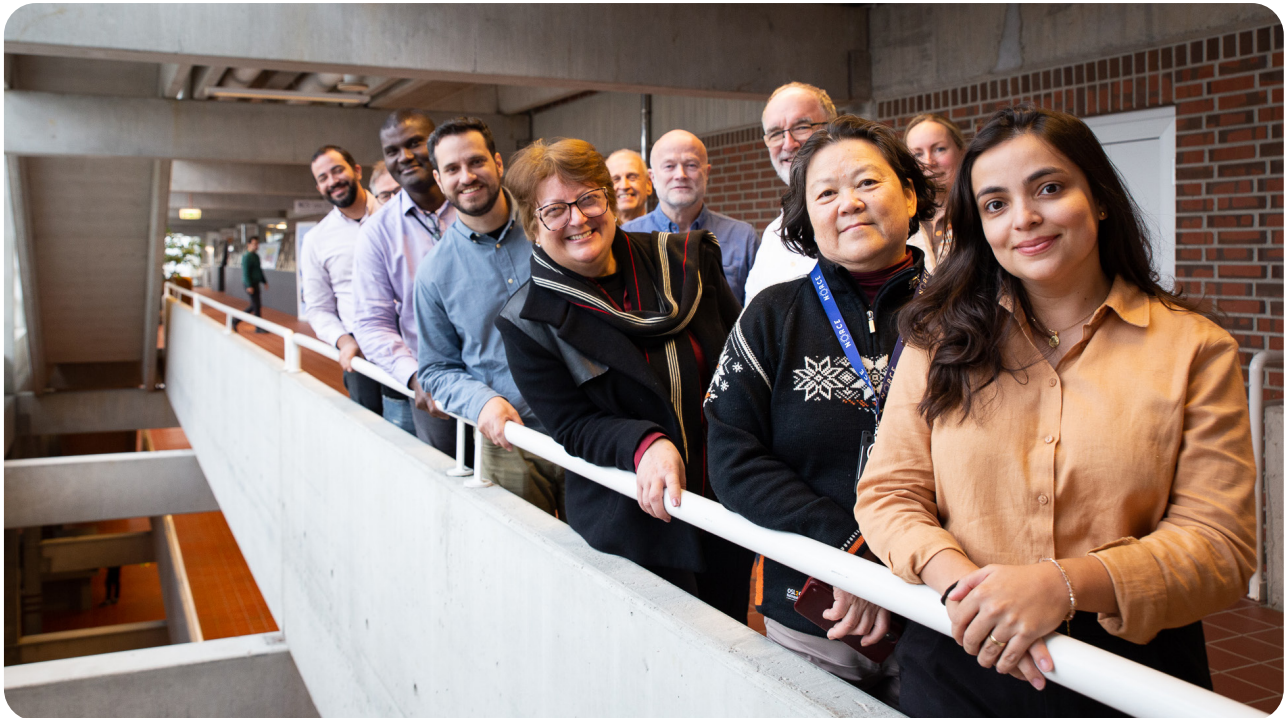
Veronika Abdulina, a PhD-student from NCS2030 working with diatomite reservoirs came along to learn about Greek diatomites from Dr. Spyros Bellas at FORTH, and to collect outcrop rock samples to be used for testing in the research laboratories at UiS.

Photos: Tina Puntervold



Collaboration

During its second year, the centre has had international cooperation through associated projects, new project applications, exchange and mentoring from and for foreign universities.



Visit from researchers from the University of Campinas (Unicamp), Brazil.

Photo: Kjersti Riiber

The "Energy Norway" conference has acted as a catalyst for building new networks, but also as a meeting point for existing collaboration. Both the Twinn2set project with Forth in Greece and IFPEN in France (EU twinning programme), and the Intpart project with the University of Campinas (Unicamp), Brazil (focus on IOR) were active participants at the conference in 2023. In connection with the fact that representatives from these collaborative projects were in Norway, several seminars were also arranged. Here, opportunities were identified for further collaboration within energy conversion and efficient field production.

Furthermore, a contribution has been made to the UTFORSK project HyTack (Tackling the Challenges in Hydrogen Economy through Education and Research), where there is collaboration with universities in India and Japan. Within ensemble modeling

of CO₂ and H₂ (use and storage) there is collaboration with the University of Stuttgart, Germany. Within fluid flow in sedimentary basins, there is collaboration with the University of Lausanne, Switzerland. It is expected that the collaboration and the ongoing projects will lead to new applications, increased collaboration and more exchange.

Several EU applications have been submitted or are being planned. The submitted applications are within geothermal, hydrogen storage and CO₂ reduction and will strengthen the foundation for the centre's further development within these areas.

The following proposals have been submitted to Horizon Europe:

- Twinn2connect (with Turkey on geothermal utilization for hydrogen production)
- Anchiale (Turkey, advanced geothermal systems to reduce CO₂ emissions)

The centre's first PhD candidate Daniele Blancone (WP1) has completed a research stay at The University of Texas in Austin, USA. There, experiences were exchanged about energy storage in salt structures and quantification of capacity. The results from this stay will be important for the candidate's further research, and will expand the centre's expertise in this area. Eventually, several of the PhD candidates will go on exchange to international partners. The center also wants to offer research stays in Norway for students and researchers from abroad. In 2023, a student from the University of Petroleum in Beijing, China visited Norce for almost a year. We also got a visit from a PhD student from Crete, Greece.

Our PhD candidate in tight reservoirs has a co-supervisor from our partner DTU (Technical University of Denmark). Through newly established collaborations with Universiti Teknologi Petronas in Malaysia and Kwame Nkrumah University of Science and Technology in Ghana, one of the centre's researchers will supervise two MSc students.

Spin-off projects: Analytical solutions tool-

box for Multiple Core Analysis (UiS, Valide), Well Fate (IFE, UiS, UiT, UiO) and Store-H₂Safe (UiS, Teesside, Equinor).

INTERNATIONAL COLLABORATORS

- University of Texas at Austin, USA
- Stanford University, USA
- Virginia Tech, USA
- University of Aberdeen, Scotland
- Imperial College, England
- Teesside University, England
- University of Basilicata, Italy
- Danish Technical University, Denmark
- RWTH Aachen University, Germany
- University of Stuttgart, Germany
- University of Lausanne, Switzerland
- Memorial University of Newfoundland, Canada
- Center for Petroleum Studies, Brazil
- Federal University Rio de Janeiro, Brazil
- University of Campinas, Brazil
- Edith Cowan University, Australia
- University of New South Wales, Australia
- Forth, Greece
- IFPEN, France
- University of Petroleum in Beijing, China
- Universiti Teknologi Petronas, Malaysia
- Kwame Nkrumah University, Ghana



Representants from FORTH, Greece and NCS2030 visited lab facilities at NORCE, Stavanger. From left Alejandro Escalona, Ying Guo, Pål Østebø Andersen, Spyros Bellas, Tina Puntervold, Raouf Gholami and Nikos Pasadakis. Photo: Mariana Barney

Education & recruitment

An important activity is to educate future experts on sustainable utilization of the Norwegian continental shelf. During 2023, 7 PhD candidates have gotten off to a good start.

Daniele Blancone

In WP1, the main goal of the project *Salt characterization and modelling for the future energy mix* is to determinate the composition, sealing and thermal properties of the Upper Paleozoic evaporites of the Zechstein Group in the Norwegian North Sea, with the aim of investigate the potential of these sedimentary rocks for both geological storage (both CO₂ and H₂) and possible application for geothermal energy production.

Seasonal availability of energy produced from renewable resources such as wind and solar is one of the main challenges for a complete energy transition. The storage of energy carriers in subsurface formations can provide a solution to this problem, allowing us to store energy when the production is higher than the demand, and withdraw it when we need. Hydrogen (H₂) storage

(as energy carriers) in underground human made caverns in salt domes is one of the best options for storing H₂ since salt has low permeability and low reactivity ensuring good containment for stored materials. The goal of the first part of my PhD was to assess the H₂ storage potential of salt domes in the southern Norwegian North Sea (NNS), before moving to a detailed characterization for internal heterogeneities in the most profitable areas, if there are. To do that we created a database with all the salt structures in the area of interest, we set up some boundary condition according to the literature available (dimension, depth shape) and the we used the GeoH₂ salt Storage and Cycling App (developed at University of Texas at Austin) to evaluate the potential of the area. We generate cavern density maps in the area and provide new knowledge re-



Daniele Blancone

garding the location, dimension, depth of salt structures, potential number of caverns, and potential H₂ energy stored. According to our results, salt caverns in the area have the potential to store enough H₂ energy to meet Norway's seasonal demand.

Hilde Halsøy

Hilde Halsøy is one of the PhD candidates in task force 2, Net zero CO₂ emissions. She started her PhD work in October 2022. Her main supervisor is Zachary Paul Alcorn (UiB).

This project (*Optimizing CO₂*

Foam for EOR and CO₂ Storage) develops a combined CO₂ enhanced oil recovery and CO₂ storage technology using CO₂ foam mobility control. CO₂ foam is a field proven and laboratory proven technique to mitigate poor CO₂ sweep efficiency

for increased oil recovery and CO₂ storage potential. However, all foams are thermodynamically unstable and can easily break. Thus, a thorough understanding of foam stability and the effect of surfactant concentration, temperature, pressure, and the

presence of oil is required. In addition, a more thorough understanding of size-dependent displacement mechanisms is needed to improve predictive modeling of CO₂ foam. The integration of experiments and modeling from the core-level to the field-level will lead to new fundamental knowledge and optimized CO₂ foam EOR and CO₂ storage strategies.

PROJECT HIGHLIGHTS

- Oral presentation at the 15th International Symposium on Wettability and Porous media at University of Wyoming.
- Completed corefloods at a range of foam qualities and injection velocities, at reser-

voir pressure and temperature, in the presence and absence of oil.

- Identified the optimal injection velocity and foam quality at specific reservoir conditions.
- Provided data for numerical modeling by investigating multiphase foam flow on the core-scale with a detailed description of the mechanisms for foam generation and stability.
- Completed PET/CT in-situ imaging of CO₂ foam flow in a heterogenous core system.
- Co-author on submitted journal article “Pore-Level Investigation of the Impact of Oil on the CO₂ Foam Stability at High Pressure.”



Hilde Halsøy

- Co-author of conference paper “CO₂ Foam Flow Dynamics at Reservoir Conditions” presented at SPE ATCE 2024 in Houston.

Jungwon Seo

My study (*Federated Knowledge Cloud for Subsurface Digitalization across Multiple Sites*) focuses on creating a federated knowledge cloud aimed at fostering a sustainable subsurface value chain as part of the NCS2030 centre. We have explored how to train machine learning models in a privacy-preserving environment without transferring data, utilizing blockchain and federated learning techniques. The objective is to develop a system capable of learning from the dispersed data within the NCS2030 network, where various participants collaborate, without the need for centralized data storage. Moreover, our current research is exploring ways to leverage the rapidly advancing Large Language Model (LLM) for the digital transfor-

mation of NCS2030. We are investigating the potential of LLM to manage code distribution and oversee the overall workflow as an integral component of the Federated Knowledge Cloud. Notably, LLM has shown promise in detecting malicious code in distributed software. I have published a paper on these methodologies at CloudCom2023 in Napoli. Furthermore, recognising the prevalence of tacit knowledge in the energy sector and research, we have proposed a strategy for its efficient management using LLM, which was submitted for presentation at the 85th EAGE Annual Technical Programme in Oslo.

ABOUT THE CANDIDATE

I am a computer science professional from South Korea with a



Jungwon Seo

background in both academia and industry. I completed my bachelor’s degree in Seoul and my master’s degree at UiS. With several years of experience working as a software engineer, I am now pursuing a PhD under the supervision of Chunming Rong and Nan Zhang at UiS.

Education & recruitment

Mahmood Fani

Mahmood Fani embarked on his PhD journey in March 2023, delving into enhancing recovery methods while concurrently mitigating emissions, employing innovative hybrid techniques. Among these methods, his primary focus is carbonated water utilisation. This approach involves leveraging CO₂ in Carbon Capture, Utilization, and Storage (CCUS) processes, which can be injected to enhance oil production while simultaneously sequestering CO₂ underground.

However, the injection of CO₂ into aquifers presents a dual challenge. While it aids in storing CO₂, it also induces acidity in the environment. Mahmood's

research is multifaceted, as he evaluates the optimal amount of CO₂ safely stored in aquifers. This assessment analyzes the geochemical interactions between the injection fluid and the reservoir minerals. By understanding these interactions, Mahmood aims to enhance the efficiency of subsurface CCS (Carbon Capture and Storage) projects.

This research contributes to the advancement of sustainable energy practices and addresses critical environmental concerns associated with CO₂ sequestration. Mahmood's work holds promise for optimizing CCS/CCUS techniques, thus fostering



Mahmood Fani

a greener and more efficient approach to energy production and emissions reduction.

Veronika Abdulina

Nowadays there is a question how to maintain the amount of hydrocarbons production at a high level since most of the conventional reservoirs have already been discovered and developed. That is why the focus is aimed at tight reservoirs for which it is essential to improve oil and gas recovery technologies.

The project "*Net-zero emission production – Tight reservoirs solutions*" will discuss the solutions for improved oil recovery (IOR) in unconventional (tight) reservoirs. Unconventional formations have poorer quality and require challenging development to achieve profitable production. To extend a field's

producing life, enhanced oil recovery (EOR) methods should be adopted. There is a great potential for such EOR methods as Low salinity/Smart water injections.

The chemical interactions that influence reservoir wettability, as well as possible wettability change and displacement efficiency during water injection/spontaneous imbibition, will be examined in laboratory tests. Working with various types of rock will determine the permeability effect, and reservoir material will be used when it is accessible. The main goal of this project is finding methods for IOR in unconventional reservoirs. With better understand-



Veronika Abdulina

ing of tight reservoirs properties, their phases and interactions, the project will identify if water-based EOR methods improve oil recovery in such reservoirs or if this fluid can be used as a stimulation fluid.

Behzad Amiri

The energy transition plays a critical role in addressing the challenges posed by global warming. The primary objective is to achieve net-zero emissions, which entails employing strategies such as Carbon Capture and Storage (CCS) and hydrogen-based fuels to counterbalance greenhouse gas emissions effectively. Underground Hydrogen Storage (UHS) is vital in storing green energy over extended periods. Depleted oil and gas reservoirs, as well as saline aquifers, are considered significant alternatives for UHS within the porous media.

Using geological porous formations for hydrogen storage

will be considered. UHS can bring several challenges that have implications for both efficiency and safety. To address them, reservoir management based on field characterization, uncertainty quantification, model update, optimization and machine learning are utilized. The process entails the optimization of strategies in accordance with the collected information and observed performance of the reservoir, the utilization of real-time monitoring, and the ongoing evaluation of the system. The goal is to maximize effectiveness and minimize environmental impacts.

Numerical reservoir modelling



Behzad Amiri

using many realizations for characterizing uncertainty and optimization incurs computational expenses. To manage this, proxy models will be employed to identify the connections between input-output parameters in the fluid flow simulations.

Mostafa Mohammadi

Exploration and production companies in the oil and gas industry utilize forecast methodologies to inform their decision-making processes, encompassing diverse aspects of field development such as well drilling plans and well control settings. These predictions are inherently complex due to multiple sources of uncertainty, stemming from factors like market dynamics and geological uncertainties.

A robust forecast is one that effectively quantifies these uncertainties. Nonetheless, numerous research studies indicate that oil production predictions consistently contain inherent biases, lacking sufficient consi-

deration for uncertainties, even with advancements in computation and technology.

In this project, *Debiasing Probabilistic Forecasts*, the probability of success and probabilistic forecasts for hydrocarbon volumes in place at the exploration phase will be assessed.

Through this research study, we will assess the quality of exploration forecasts and explore potential factors that may be associated with the precision of these predictions. At this step, the results should be compared to the results for the production data. Ultimately, our aim is to identify and analyze biases existing in both exploration and

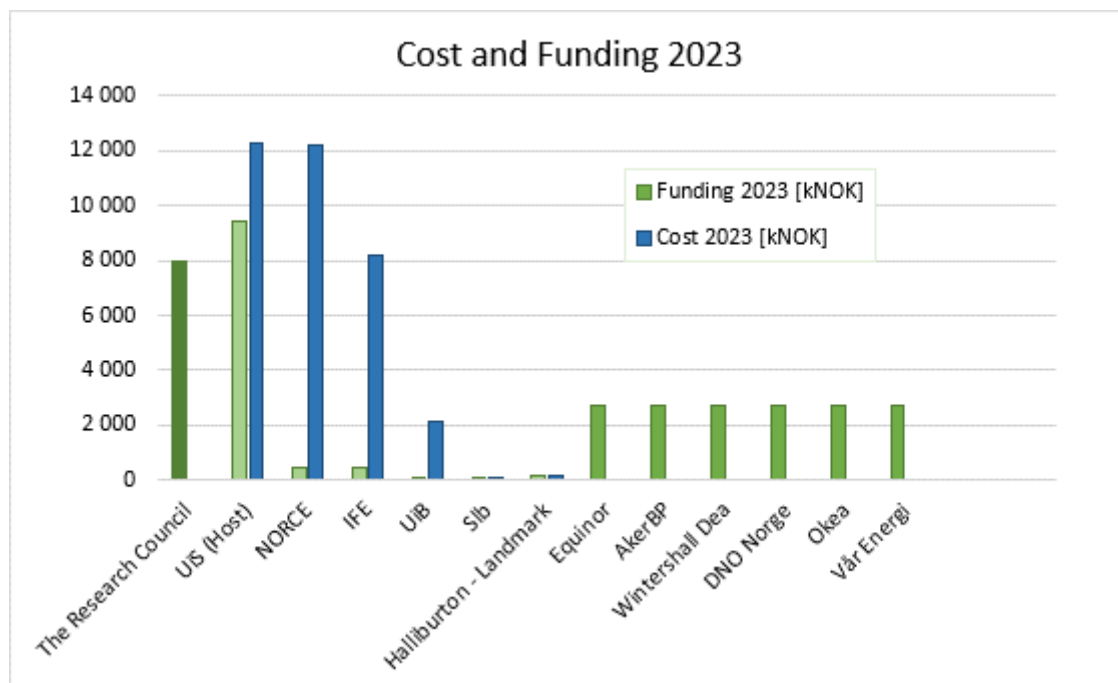


Mostafa Mohammadi

production stages, comparing them and suggesting approaches to reduce these biases. Finally, our research can be extended to explore other energy generating sectors.

Economy

	Cost 2023 [kNOK]	Funding 2023 [kNOK]	Funding 2022- 2029 [kNOK]
UiS (The Host Institution)	12 241	9 424	75 321
NORCE	12 213	435	6 730
IFE	8 162	451	5 636
UiB	2 115	53	9 483
Sib	73	73	10 000
Halliburton - Landmark	162	162	10 000
User Partners		16 403	120 000
RCN		7 965	80 000
Total	34 966	34 966	317 170



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