LOWEMISSION

2023 ANNUAL REPORT

Contents

By numbers

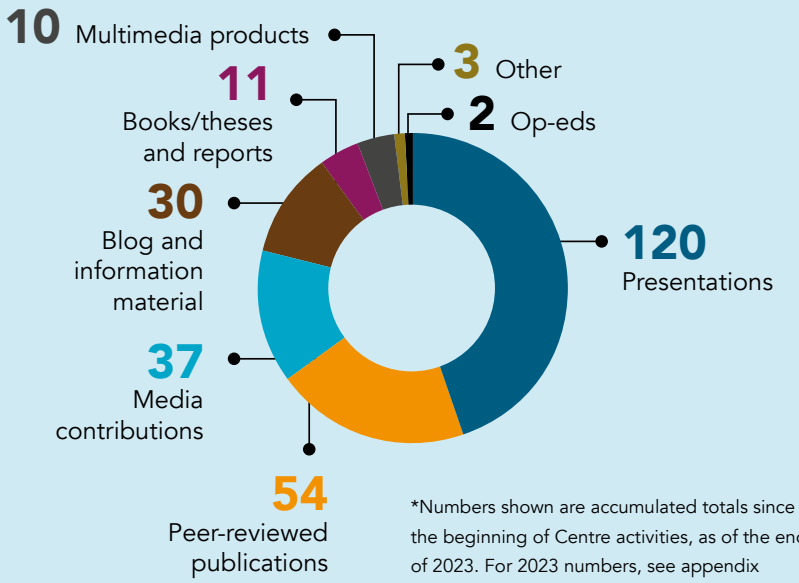
32
INDUSTRY PARTNERS

2
RESEARCH PARTNERS

344
MNOK

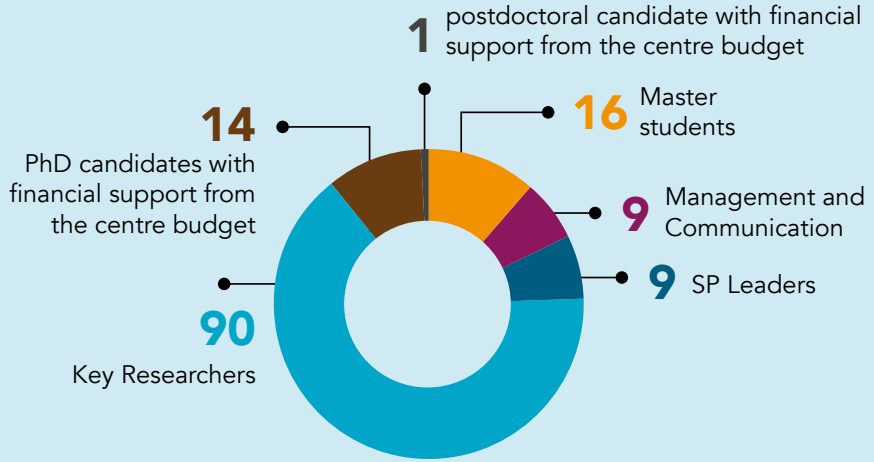
8
YEARS

COMMUNICATION AND DISSEMINATION*



*Numbers shown are accumulated totals since the beginning of Centre activities, as of the end of 2023. For 2023 numbers, see appendix

PEOPLE



About LowEmission

LowEmission is a research centre for low-emission technology for petroleum activities on the Norwegian continental shelf (NCS). The Centre brings together a consortium of world-leading Norwegian and international industrial entities, including vendors, operators and energy companies, with globally recognised research groups at SINTEF and NTNU, and other top-rated universities and research institutes. Its mission is to pave the road towards zero-emission production of oil and gas from the NCS.

LowEmission develops new technology solutions and concepts for offshore energy systems and integration with renewable power production technologies. This will accelerate the development and implementation of low-emission offshore technologies on the NCS. It will also help Norwegian industry meet its 2030 goal of reducing its greenhouse gas emissions by 50% – and moving towards the 2050 goal of zero emissions from new facilities. LowEmission is a platform for innovation, and strong interaction within the Centre will generate spin-off projects and technology transfer possibilities for industry.

Testing of innovative heat storing solutions with phase change materials for reduced footprint. For electrified fields without spare heat from gas turbines efficient heat management and heat production is crucial.

2023 Achievements

LowEmission has now entered the second half of its lifetime, we are now reflecting on projects and results while looking forward to future accomplishments.

As of 2023, 13 PhD and one PostDoc candidates have been affiliated with LowEmission. In 2023, six PhD candidates completed their academic tenure, with the date of their thesis defences set in late 2023 or early 2024. Five of these have been employed by partners in the Centre. Additionally, 17 MSc students have now completed their projects since the Centre was established.

This report features research results from some of the Centre's PhD candidates. Descriptions of all the PhD and Postdoctoral candidate projects can be found on pages 76-81.

2023 saw an increased focus on innovation in the Centre activities. Following the last year's innovation mapping process, wherein innovations were systematically documented, an innovation sprint was conducted in collaboration with the innovation advisory company Entreprenerdy. This pilot is a programme that aims to give selected, motivated innovation teams from the consortium the knowledge, tools, and resources to realise the full potential of their innovations.

Another significant activity this year has been the development of subproject roadmaps.
The roadmaps serve as a guiding framework for continuous technology development, and aim to spark further innovation, up-scaling and faster implementation of the technologies. During this process, researchers and industry partners looked at Norway's climate goals for 2030 and 2050, and the activities required to progress the technologies needed to meet those goals.
A foundation document of the midway objectives for the Centre was developed and further distilled down to a final visual product for the LowEmission roadmaps.

LowEmission shares knowledge with scientists, industry, society, politicians and the public, and thereby aids decision-making and climate policy development for the Norwegian O&G industry.

In 2023, researchers and candidates from across the Centre presented their results at multiple international conferences.

LowEmission participated at several events during Arendalsuka 2023. LowEmission also hosted an event called *Hvordan kutte utslipp på norsk sokkel i en strømpriskrise?* ("How to reduce emissions on the Norwegian Continental Shelf in an electricity price crisis").

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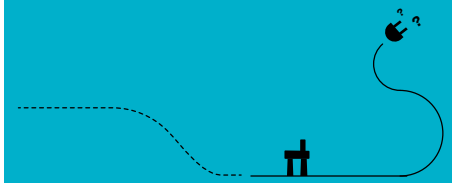
Here are different **solutions** for cutting CO_2 emissions:



1. Offshore wind
2. Hydrogen with offshore wind
3. Natural gas with CCS
4. Hydrogen with CCS
5. Energy efficiency
6. Electricity from land

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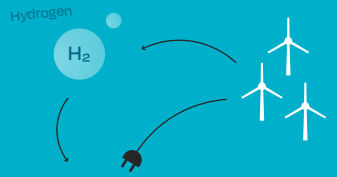
1. Offshore wind

Offshore wind can electrify the NCS and contribute to the national power grid

LOWEMISSION



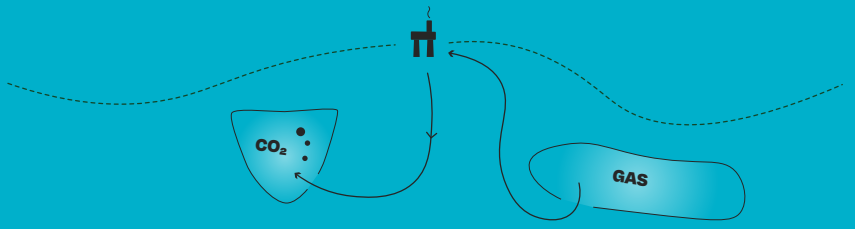
2. Hydrogen with offshore wind

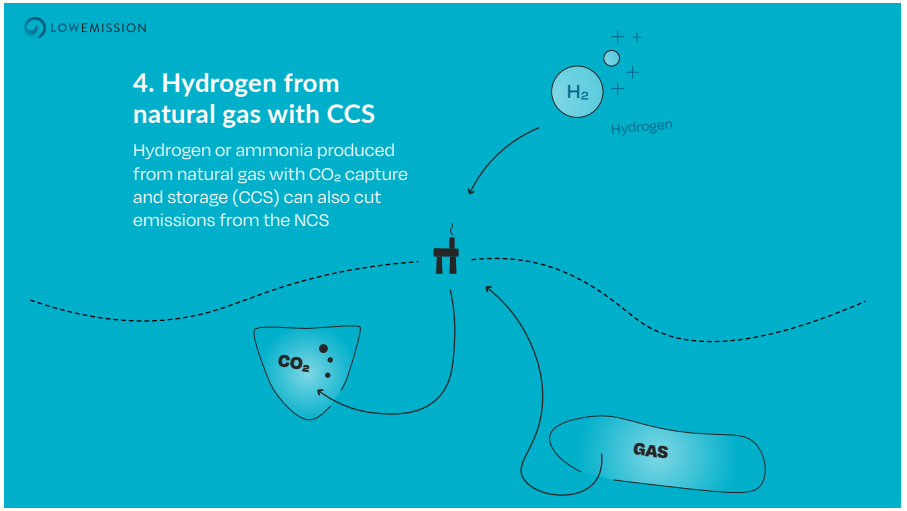
Excess wind energy can be converted into hydrogen or ammonia, which can be used as a power source when there is not enough wind

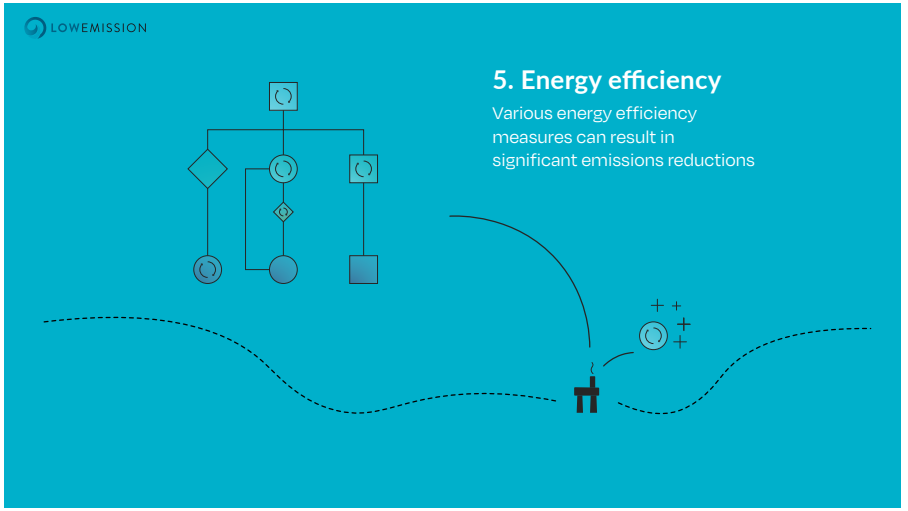
LOWEMISSION

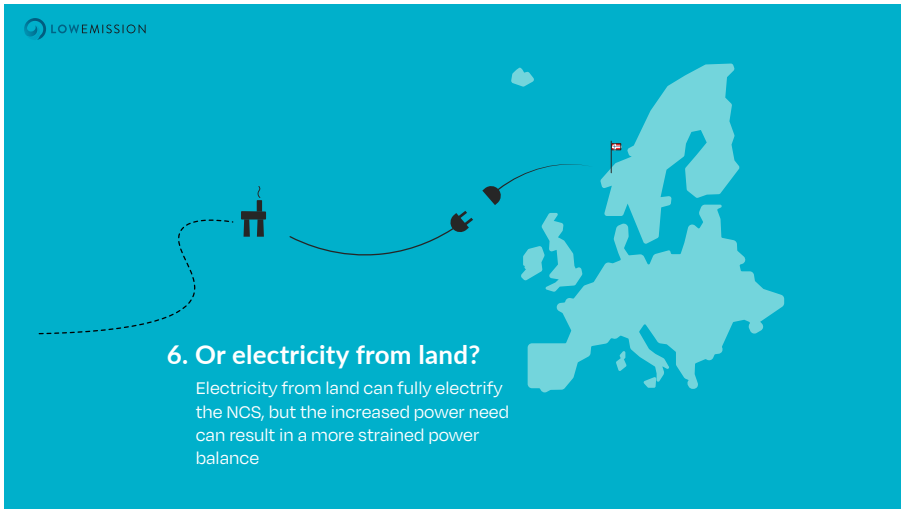
3. Natural gas with CCS

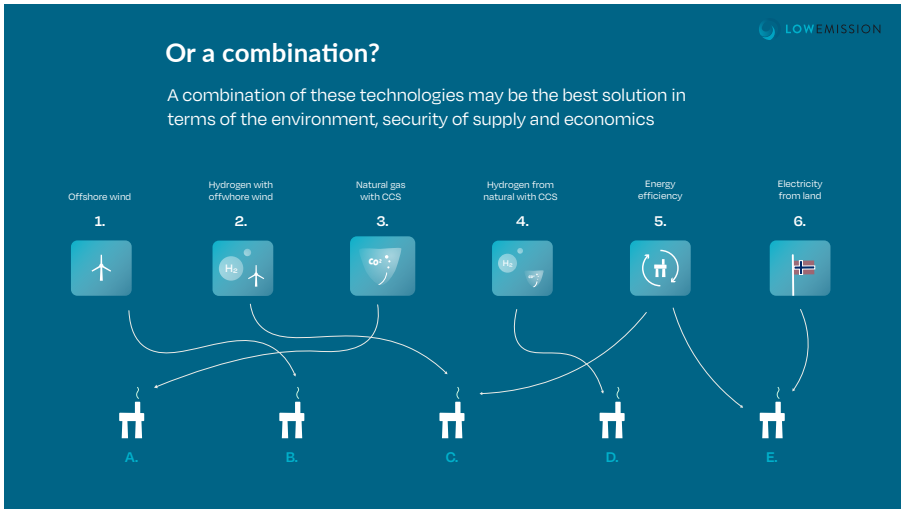
Capturing CO_2 directly from gas turbines can be a way to cut emissions from the NCS

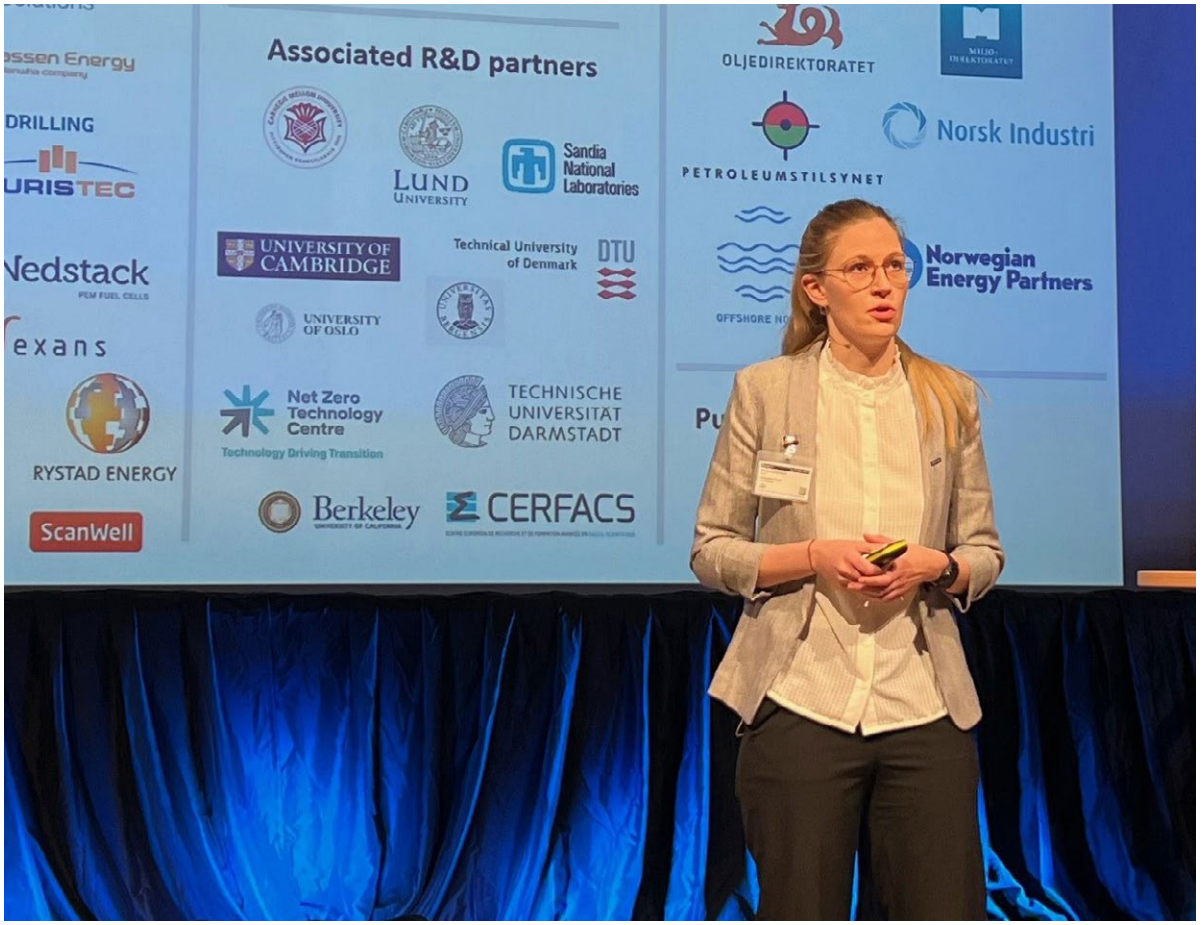



LOWEMISSION
4. Hydrogen from natural gas with CCS
Hydrogen or ammonia produced from natural gas with CO_2 capture and storage (CCS) can also cut emissions from the NCS
H_2
Hydrogen
CO_2
GAS


LOWEMISSION
5. Energy efficiency
Various energy efficiency measures can result in significant emissions reductions


LOWEMISSION
6. Or electricity from land?
Electricity from land can fully electrify the NCS, but the increased power need can result in a more strained power balance

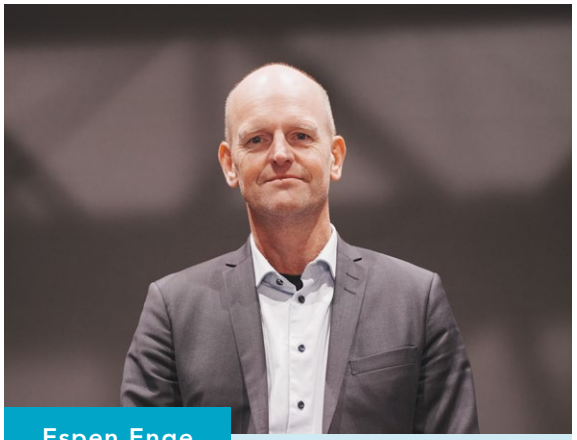

LOWEMISSION
Or a combination?
A combination of these technologies may be the best solution in terms of the environment, security of supply and economics
Offshore wind
1.
Hydrogen with offwhore wind
2.
Natural gas with CCS
3.
Hydrogen from natural with CCS
4.
Energy efficiency
5.
Electricity from land
6.
A.
B.
C.
D.
E.



The event was hosted in collaboration with Offshore Norge, SINTEF Energi, FME NorthWind, FME HYDROGENi and FME NCCS. The event served as a platform for in-depth discussions on emission-reduction strategies on the NCS, bringing together experts, researchers, and policymakers to explore sustainable alternatives. LowEmission received significant visibility at Arendalsuka, and Centre Director Stefania Gardarsdottir participated in several events.

LowEmission was also featured at the OG21 Forum in 2023, during the session *På lag med Europa: Teknologi som sikrer norske energi-leveranser gjennom det grønne skift*et («In line with Europe: technology that safeguards Norway's role as an energy provider through the green shift). Centre Director Stefania Gardarsdottir presented the Centre and two examples of research activities: wet cable design and cold flow technology.

A message from Centre Chair Espen Enge



Espen Enge

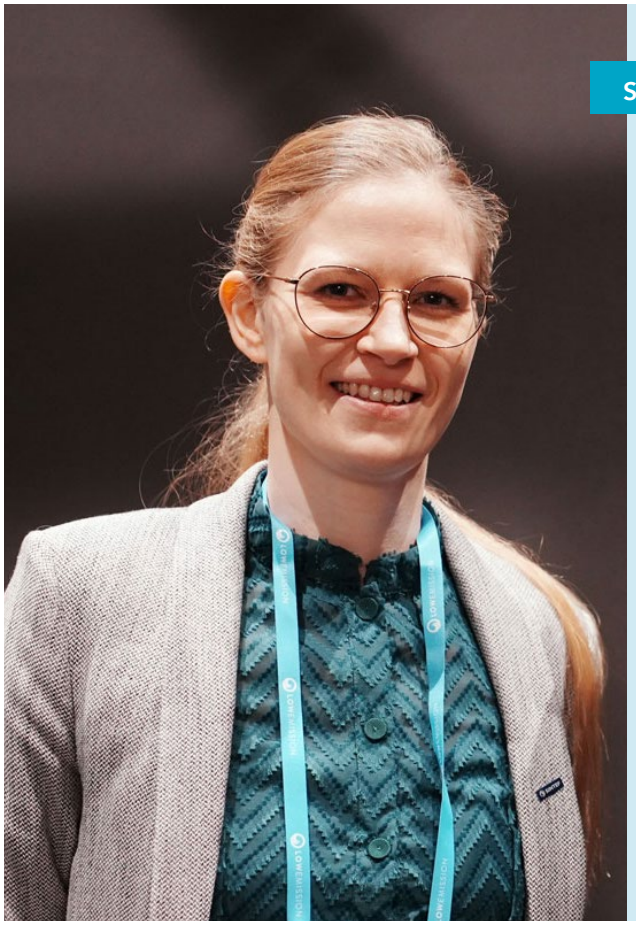
Espen has 28 years of operational and project leadership experience from the E&P sector, working for many of the major operating companies on the NCS. He is currently responsible for the Technology, Projects & HSE division on the leadership team for Repsol Norge. Espen has had several board engagements for other companies, and holds a MSc degree from NTH (now NTNU) and a Master of Management degree from BI.

In 2024, the LowEmission research centre enters its 5th year of operation. The Centre has generated significant interest and engagement in the industry due to the technologies it is developing. Industry partner participation has continued to increase from the initial partners in place when the centre kicked off in 2019. The Centre has overachieved in its targets for publications, and I am very happy to see that already six of the PhD candidates have now completed their work and were quickly hired by industry partner companies. Developing competence and capacity for change and innovation in this manner is also a key outcome of the centre.

In 2023, to enhance our overview of the status and direction of the different technologies being developed in the Centre, we decided to establish so-called "roadmaps" for the key technologies. Seeing the result presented at the consortium days at the end of last year reinforces our conviction that this was a valuable effort for the Centre. Sharing and communicating the R&D status, as well as the required activities and associated timelines for actual implementation, is a crucial part of the Centre's work. The overall climate goals of both LowEmission and society cannot be achieved by the Centre alone, so information sharing is key.

In 2024, more of the centre's budget has been allocated to case study activities. While case studies have always been a part of the Centre's activities, expanding this activity, where technologies are tested for real use cases, is also essential for achieving implementation. The dialogue with researchers and industry partners around a case study is valuable in itself, and also helps uncover key constraints and hinderances for implementation that may lie outside the technology itself. Identifying such potential obstacles is crucial to understanding and including them in the holistic view of the potential of the technologies being developed.

A message from the Centre Director Stefania Gardarsdottir



Stefania Osk Gardarsdottir

Stefania is a research manager at SINTEF Energy Research and holds a PhD in Energy Technology. Her field of expertise is CO_2 capture in power and industrial processes as well in connection with hydrogen production from natural gas. Her work includes process modelling and simulations, techno-economic evaluations of capture processes, and value-chain analyses of the full hydrogen and CO_2 capture and storage chain. Stefania co-leads the SINTEF Foundation's strategic focus area on hydrogen and is also the director of the LowEmission Research Centre.

In 2023, the geopolitical tensions in Europe significantly influenced the energy market. The demand for new and reliable energy sources, coupled with accelerated ambitions for decarbonisation, has driven us in LowEmission to intensify our focus on technology development and innovations for implementation.

2023 has also stood out when it comes to climate change, with extreme weather events and record-high temperature measurements. We are almost halfway through the 2020's, and we are still not where we should be in terms of meeting the 2030 goals of the Paris Agreement. Oil and gas extraction accounts for a significant portion of greenhouse gas emissions. To fulfil its climate commitments, Norway must prioritise emission reductions from oil and gas production on the Norwegian continental shelf as a crucial climate measure.

One of the most important tools for reducing emissions from the NCS is electrification. At the same time, the energy situation in Europe, with continuing high energy prices, has influenced

the political debate around the electrification of the NCS and how the industry evaluates its decarbonisation projects. The high energy prices have increased awareness of the need for technology development and research into various emission-reduction solutions on the NCS, in addition to electrification with power from the mainland.

All this has motivated LowEmission partners to work towards an even faster energy transition. The situation has also contributed to more focus on the development of new technologies for an emerging international market. Although some electrification projects have become more challenging to implement due to high electricity prices and the debate about a future power shortage, our experience is that the interest in the technologies developed by LowEmission has strengthened. Specifically, more partners want to reduce the time gap between research and implementation of new solutions. The Centre is the perfect meeting place to initiate such acceleration, and concrete examples from this year include the Centre's work on developing technology roadmaps and innovation sprints, as well as the development of spin-off projects at higher TRL levels (IPN and Demo initiatives).

The strong emphasis on innovations and technology development in the Centre was also reflected in this year's annual consortium days, held in Trondheim on 25-26 October. The event brought together around 100 researchers and industry representatives to discuss ongoing projects, roadmaps and innovations in LowEmission. The consortium days serve as a valuable meeting place for the researchers in the Centre to gain the industry perspective.

2023 was also the year when we witnessed the graduation of our first generation of PhD students, and we are thrilled to see several of them now employed by our LowEmission partners.

Heading into the last three years of the Centre operations, I look forward to continuing to build the strong collaborative atmosphere in the Centre, and to see new research questions and ideas emerge while more mature technology development spins off from the Centre into new, industry-driven initiatives towards implementation.

Vision and goals

LowEmission aims to develop technologies and solutions needed to reduce offshore greenhouse gas emissions on the Norwegian continental shelf by 50% within 2030 and to move towards zero emissions in 2050.

GOALS

The sub-objectives of LowEmission are to:

- Develop solutions for co-optimising power supply and demand in the offshore energy system
- Reduce cost of low emission oil and gas technologies by 5-50 %
- Develop a digital energy management tool for planning energy use of fields and the CO_2 footprint of operational choices over the life of the field including short- and long-term uncertainty
- Provide 10-15 innovative solutions for offshore emission reductions
- Generate 8 KSP, 10 IPN, 4 DEMO and 4 EU spin-off projects
- Educate 19 PhD/Postdocs, 30 MSc candidates, and train/recruit 20 experts in offshore low-emission technologies
- Disseminate and communicate project results in 70 journal and conference papers, present in O&G specific workshops and meetings such as ONS and OTC, and disseminate news articles
- Perform brown- and green-field case studies to demonstrate actual emissions reductions

The successful outcome of LowEmission will enable the industry partners to:

- Facilitate rapid deployment of low-emission technologies and system solutions that reduce offshore
- O&G-related GHG emissions
- Increase value creation in the Norwegian O&G industry
- Commercialise products based on LowEmission results in the international market
- Create new digitalised decision-support and planning tools for operators and vendors
- Perform relevant case studies with emphasis on the system perspective

Research plan and strategy

The vision of LowEmission is to pave the road towards zero-emission production of oil and gas from the NCS through industry-driven research and innovation, aiming to become an international knowledge Centre on offshore low-emission technologies. From the start, the Centre has focused on balancing long-term research efforts and dynamic, more short-term activities, and after three and a half years of operation, the R&D activities are by and large on track.

Annual working plans are developed each year through technical discussions and meetings between researchers and industry representatives within the subproject families. These discussions help design the plans, develop new case study suggestions, and stimulate ideas for spin-off activities. The PhD candidates are included in subprojects family meetings with industry partners, and present in webinars and annual consortium meetings, pitch their work in oral and poster presentations, and so forth. Their research forms part of and is integrated into the annual working plans. The Technical Committee of Innovation and Commercialisation reviews the plans and recommends changes and approval for the Board.

For the list of research topics to remain dynamic, and always reflect the most promising emission reduction possibilities, LowEmission has executed yearly calls for case studies. This stimulates even stronger interactions between researchers and industry actors in their subproject families as they investigate promising topics and test out concepts based on real-life data. The case study proposals are reviewed and evaluated by the Technical Committee of Innovation and Commercialisation. The case studies have proven to be a fruitful arena for idea generation and have led to several spin-off activities, such as the Knowledge-building Projects for Industry SafeAm and ZeroLog, which are co-funded by the LowEmission partnership and the Research Council of Norway and were granted funding in 2023.

As the Centre is now entering the last three years of operation, increased efforts will be put into innovation activities, such as the innovation sprint carried out in 2023 (see pages 72-73 in the report), to further stimulate and advance the Technology Readiness Level of technologies developed in the Centre and to create spin-off activities aiming for piloting and demonstration.

LOWEMISSION ROADMAPS DEVELOPMENT

Since March 2023, the Centre has been working on developing roadmaps for the major technologies that it is researching. The purpose is to create a guiding framework for continuous technological improvement, and a path towards a more sustainable future with low emissions in the petroleum industry on the Norwegian continental shelf.

During the process researchers and industry partners together have looked at goals toward 2030, visions toward 2050 and the activities required to progress the technologies. Setting the midway objectives in a systematic document has acted as a foundation for the process and discussions, and this again has been further

distilled down to a final visual product the LowEmission roadmaps.

We hope the LowEmission roadmaps can facilitate conversations cutting across disciplines, draw together industry partners, and strengthen collaborations and partnerships. The LowEmission roadmaps will help us to communicate a clear message on the requirements to progress emission reducing technologies, sparking further innovation, up-scaling and faster implementation.

Right: LowEmission *researcher Heiner Schümann with the real-fluids flow loop at the Multiphase Laboratory at Tiller. The facility is used amongst others for demonstrating and developing the ColdFlow concept for handling hydrate and wax without need for intensive pipeline heating or usage of production chemicals. Experimental results are used for a case study evaluating the concept for a real NCS field*

Gender equality

Approximately a third of members in the Centre management, the Board and the Technical committee of LowEmission are women. This represents an increase in the proportion of women from last year, especially among subproject leaders, where we have gone from one to three female subproject leaders. The Centre Director and Centre Manager are women.

The Centre follows SINTEF and NTNU's guidelines for recruitment. The Centre wishes to improve the gender balance amongst the PhD candidates and affiliated MSc students, and encourages female applicants through open announcements, striving for gender balance when hiring new employees or recruiting PhD candidates and Postdocs. Increasing the visibility of female researchers and already recruited Ph.D. candidates at important recruitment events for bachelor students is an example of specific measures for attracting female candidates. The two new PhD candidates hired in 2023 are a woman and a man. NTNU has developed a plan for equal opportunities and recruiting women to the university, and encourages female professorships through mentor and skill development programmes.

LowEmission aims to give employees and collaborators the same opportunities regardless of gender, ethnicity, functional ability, sexual orientation, age, and religion.

Sectoral labour mobility

LowEmission, with its wide involvement from both academia and industry partners, is in a unique position to bridge the gap between those two worlds. All of the Centre's PhD students are connected to a subproject family. These are groups of industry contacts that have expertise linked to each subproject of the Centre. This integrates PhD candidates into the activities of the Centre, and gives them the chance to join events and meetings, which the Centre's scientists and industry experts participate in.

Industry partners expressed a wish to collaborate more closely with the Centre's academic community. We are working on finding ways to better integrate students with industry partners, for example through co-supervision, internship creation, or linking each student to relevant industry contacts. Examples of sector mobility stimulated by the centre in 2023:

1. An internal employee from TotalEnergies was seconded to SINTEF Energy Research, and collaborated with SP2 researchers in an experimental campaign related to ammonia combustion.
2. Co-publication between researchers and industry partner Cybernetica related to work in SP1/SP5: “Model predictive control of compact combined cycles in offshore power plants integrating a wind farm” published in Computer-aided Chemical Engineering.
3. Of the six doctoral candidates who completed their dissertations in the centre, five have been employed by Centre partners (Equinor, Aker Solutions, SINTEF, NTNU) and associated academic partners (CERFACS).
4. A former PhD candidate at LowEmission who did not complete their position within the centre’s framework was employed by Equinor but continues to collaborate with the centre’s researchers and co-publish results from ongoing work.

Decomposed ammonia – a new and powerful alternative for cutting emissions offshore

By Adriana Reyes Lua and Mario Ditaranto

Offshore oil and gas activities require large amounts of power, which is traditionally generated with gas turbines running on part of the natural gas produced at the site, since this is a convenient and inexpensive fuel that is normally available in large quantities. Moreover, gas turbines are well fitted to offshore operational requirements and are relatively compact. This aspect is also very advantageous, as space and weight capacity are very limited offshore, and installation of large and heavy equipment is associated with high costs.

Due to their widespread presence, gas turbines are also the main greenhouse gas emission source offshore. This is the case particularly in regions where emission reduction measures, such as limiting non-emergency flaring, have already been implemented. For example, gas turbines fuelled with natural gas are responsible for approximately 85 % of the Norwegian oil and gas sector's CO_2 emissions[1]. Putting this into context, these emissions are responsible for around 27 % of Norway's overall emissions[2]. Therefore, decarbonising offshore operations, especially

those from power generation, is necessary for reaching net-zero emissions goals.

INNOVATIVE CONCEPTS FOR LOW CARBON OFFSHORE SOLUTIONS

There are several different alternatives to reduce the need of natural gas fired turbines for generating power offshore. However, there is not one solution that fits all installations, and the most appropriate solution will depend on various factors, such as location, remaining lifetime, and type of installation, among others[3]. It is now becoming clear that there is a need to develop low emission technologies not yet on the market.

In the LowEmission Research Centre, some of these innovative concepts are being developed within the subprojects, each of them dedicated to a group of technologies. A key tool to explore potential synergies among the concepts developed and the resources available within the centre are the Case Studies, where we study potential applications and solutions, also considering the industry's interests.

One way to fully decarbonise offshore activities is to operate the gas turbines with carbon-free fuels such as hydrogen (H_2) or ammonia (NH_3). With this alternative, we could still have the operational advantages of gas turbines, but without producing CO_2 when generating power and heat. The use of carbon-free fuels is particularly interesting for installations where implementing other effective emissions reduction solutions such as electrification is not possible, for example, due to location.

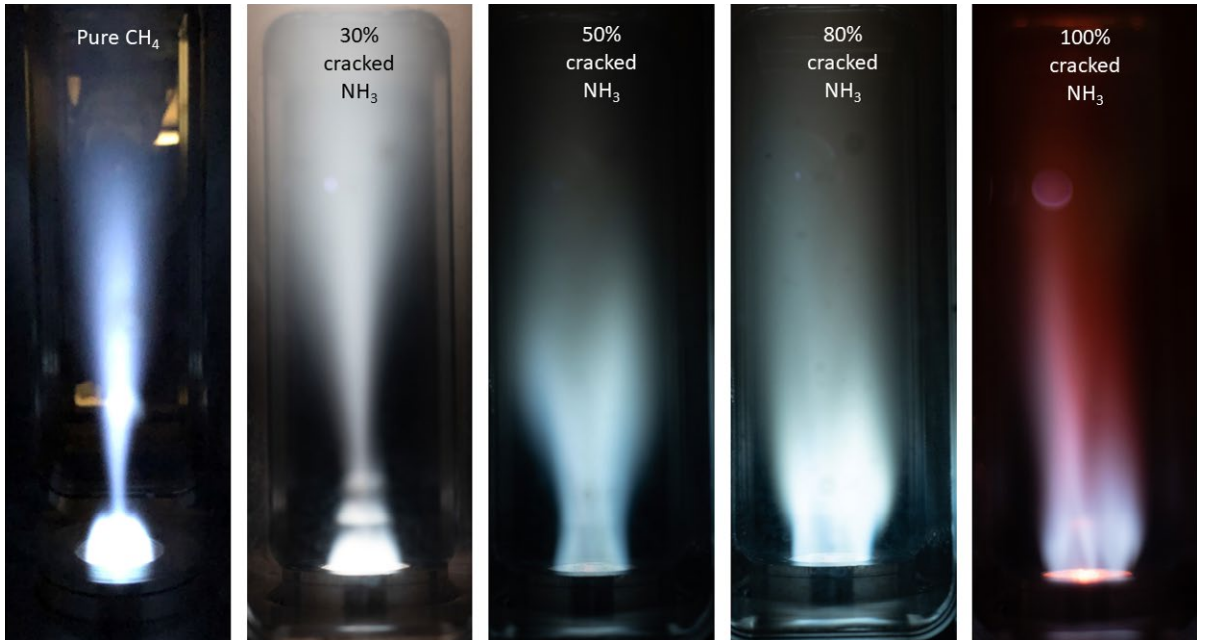
AMMONIA AS AN ALTERNATIVE FUEL

Ammonia is an attractive alternative fuel because it is already transported commercially in a large scale, and shipping technology is mature, so we know that it would be possible to transport ammonia produced onshore to offshore facilities. In addition, ammonia is energy dense, meaning a small volume contains a higher amount of energy compared to other fuels. Ammonia is produced combining three hydrogen (H) atoms and one nitrogen (N) atom. The overall carbon footprint to produce ammonia can be low if the used hydrogen comes either from steam reforming with carbon capture and storage (CCS) or from electrolysis using renewable energy sources.

However, operating gas turbines on ammonia is not completely straightforward. Pure ammonia is not a convenient fuel for gas turbines because it has combustion limitations. Therefore, the fuel should be a blend, and this is studied in the LowEmission Centre. In 2020, SINTEF Energy Research researchers studied the effect of small and large shares of ammonia in methane in the LowEmission Case Study "Partial decarbonization of the Johan Castberg FPSO by ammonia addition in fuel"[4]. This would only achieve partial decarbonization because the fuel would still contain the carbon in the methane, but it could be a first step.

A solution for full decarbonization is to partially decompose ("crack") the ammonia to produce a blend of nitrogen, hydrogen, and ammonia. This blend would not contain carbon and can be used as gas turbine fuel. Ammonia decomposition is commercial, but the current technology has significant drawbacks for offshore deployment.

In 2021, SINTEF Energy researchers worked together in the LowEmission Case Study "Reduced-carbon operation of Elgin and Franklin O&G fields"[5], proposed by TotalEnergies.



Photos: Mario Ditaranto, SINTEF

Flame stabilized over a typical gas turbine swirl burner with different fuel composition showing that the more hydrogen in the fuel (ie higher degree of cracking) the more stable the combustion (the flame "occupies" more space closer to the burner).

These fields are located in the North Sea, between Norway and Scotland, and were an ideal candidate for identifying key dimensional parameters, technological constraints as well as benefits, from carbon-free fuels supply up to their combustion in gas turbines.

LOWEMISSION SPIN-OFF DECAMMP – DECOMPOSED AMMONIA FOR CARBON-FREE POWER GENERATION

To address the technological constraints identified in the LowEmission case study, we proposed the successful KSP spin-off proposal DECAMMP, "Decomposed ammonia for carbon-free power generation", led by SINTEF Energy Research and starting in 2023.

DECAMMP will contribute to overcoming key technical barriers to ammonia decomposition offshore, such as the lack of affordable catalysts that work at relatively low temperatures. This would enable the surplus energy available in offshore installations to be utilised for the decomposition process.

DECAMMP will also develop the required compact reactor technology, with an integrated reactor model for ammonia decomposition implementing experimental kinetics and flow properties at relevant scale and operating conditions. These advancements will be integrated while developing the concept of an energy-efficient process that considers offshore requirements and operational demands. This will be done considering the ammonia/hydrogen (NH_3/H_2) blends that are optimal for gas turbine operation and overall emissions reduction.

DECAMMP is supported by the LowEmission industrial partners, including operators and gas turbine producers, which will also give important input to assure the relevance and applicability of the results. Johnson Matthey, with a large experience in developing sustainable technology solutions, is also part of the DECAMMP consortium and will provide valuable input. On the research side, DECAMMP will combine the efforts of SINTEF Energy, SINTEF Industry and NTNU.

There is currently a large fleet of operating gas turbines worldwide that could benefit from the results of DECAMMP. The DECAMMP project will enhance Norway's position as worldwide example for promoting and developing low-carbon offshore solutions. While the concept is aimed at offshore applications, where the impact will be substantial, power generation using ammonia with low-temperature cracking is expected to also play a role in the future onshore integrated low-carbon power system.

REFERENCES

1 Ministry of Petroleum and Energy and the Norwegian Petroleum Directorate. Emissions to air 2021.

2 Statistics Norway. Emissions to air 2021. Last accessed on 2nd January, 2023.

3 Voldsund et al. "Low carbon power generation for offshore oil and gas production". Energy Conversion and Management: X. January 2023

4 LowEmission Webinar – Case study Partial Decarbonization of Johan Castberg by Ammonia Addition in Fuel

5 LowEmission, Case studies 2021

6 DECAMMP SINTEF website

Message from the Leader of the Technical Committee of Innovation and Commercialization

Cedric Fayemendy, leader of the Technical Committee of Innovation and Commercialization in LowEmission, Vår Energi

The Centre is supported by 32 industry partners, ranging from operators, services providers and vendors in the energy sector. The Technical Committee of Innovation and Commercialisation (TCIC) represents industry, and works closely with the Centre to focus on industry relevant challenges.

While renewable energy capacity grew at a record pace in 2023, fossil fuels still comprise about 80% of the total primary energy consumption. Despite policy and technological progress, the ambition to limit global temperature rise to 1.5 degrees Celsius is becoming increasingly difficult to achieve. We are still far from being on track to meet the targets and ambitions set out in the Paris Agreement (COP21). Additionally, increased levels of geopolitical conflict have made the energy transition more fragmented. Positive trends and developments are often offset by negative ones.

How do we foresee the development path towards 2030 and 2050? What are the key steps for developing and implementing

new technologies? How do we spark further innovation? It is with these questions that LowEmission passed the halfway mark in 2023 and entered its second half-life.

During 2023, the TCIC worked together with the Centre to intensify its focus on technology development and innovation for implementation. Strong attention and reflection on technology road maps (goals, visions, and technology possibilities) for the years to come were established to facilitate upscaling and faster implementation.

The technology development and innovation were accelerated by the Innovation sprint in collaboration with Entreprenerdy. The TCIC together with Centre management conducted a selection process and identified three teams to participate in the rapid maturation of their technology. The Innovation sprint is a great process to stimulate positive synergies with parallel ongoing activities like the SP-Roadmaps and Case studies.

2023 concluded with the consortium days held in Trondheim on the 25-26 October, where industry experts and scientists presented and exchanged information on the latest technology developments. Collaboration is key for the Centre's deliveries.

The industry recognizes the good and important work performed by the Centre, which is reflected in the strong involvement from existing Centre partners and the interest from other industry actors to join the Centre.

The way forward to decarbonise the offshore support fleet

By Victoria Gribkovskaia,
Task leader SP9 in LowEmission

The offshore support fleet, crucial for the oil and gas operations on the Norwegian Continental Shelf, faces a pressing need for decarbonization. Platform supply vessels (PSVs) contribute ca 1 million tonnes of CO_2 annually, making them the largest greenhouse gas source in the offshore logistics supply chain. The government's directive to implement zero- and low-emission solutions by 2030 sets the stage for transformative change.

With 16% of the Norwegian-owned offshore fleet already embracing low-emission technologies, the path to zero emissions involves navigating challenges like limited energy carrier availability and high costs. The ZeroLog project, an initiative within the LowEmission Research Centre, strives to chart this course collaboratively. By uniting O&G operators, ship owners, and industry experts, the project aims to analyze and optimize fleet planning, vessel operations, and design modifications.

REQUIREMENTS FOR LOW AND ZERO EMISSION SOLUTIONS

Platform supply vessels (PSVs) account for about 1 mill. tonnes of CO_2 emissions per year[1], and represent the largest greenhouse gas (GHG) emission source in the offshore logistics supply chain[2] for oil and gas (O&G) operators at the Norwegian Continental Shelf (NCS). The Ministry of Climate and Environment lists the implementation of zero- and low-emission solutions in the offshore vessel fleet as the second step towards reducing maritime domestic fleet emissions[3], and the government's strategic document "*Hurdalsplattformen*" signals an intention to introduce requirements for low-emission solutions by 2025 and zero-emission by 2030 for offshore supply vessels[4].

Given the predominantly young age and high-quality specifications of the existing PSV fleet, realization of a zero-emission fleet is expected to consist of a period with fleets including both ships utilizing marine gas oil (MGO), retrofits and newbuilds utilizing novel energy carriers. There exist no emission-free PSVs as of today, however,

Photo: Total E&P Norge A/S/Norwegian Petroleum Museum

three percent of the global offshore vessel fleet has adopted low-emission solutions.

Sixteen percent of the Norwegian-owned offshore vessel fleet uses low-emission solutions, such as hybrid electric propulsion systems and LNG/LPG[5]. Power system suppliers are also developing systems for future energy carriers such as hydrogen, ammonia, biogas, and methanol. However, availability of these energy carriers is scarce, energy density is lower, costs are expected to be high and will require infrastructure development for production, distribution and bunkering. Hence, future zero-emission ships for offshore logistics need to be designed as part of a system where access to, storage capacity for, and cost of energy are of greater importance than today, while still maintaining the required levels of offshore supply service and operational performance.

OFFSHORE SUPPORT FLEET OF THE FUTURE

The existing offshore support fleet is large and highly specialised, but young, which will require slow but steady transition towards zero emissions.

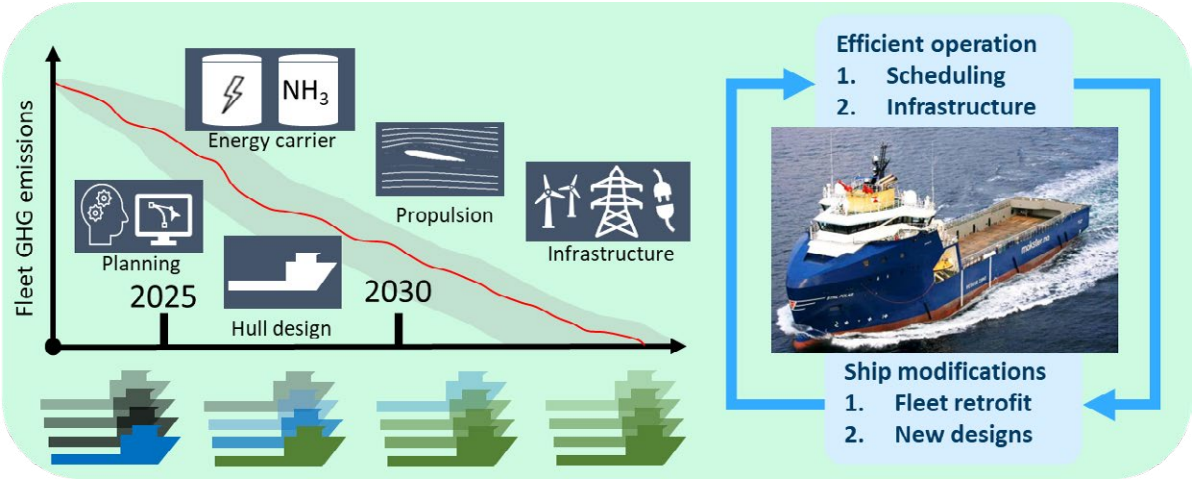
With a multitude of low- and zero-emission options and opinions on how these will come info practical use in the future, there is no simple answer to decarbonisation of the offshore fleet. The answer does not lie in just upgrading the fleet to zero-emission fuels.

Operators on the NCS are in need for a common understanding and the ways forward towards future sustainable offshore fleets and logistics. Thus, one of the project's goals is to facilitate exchange of ideas and cooperation between all partners on defining and agreeing on future scenarios for PSV upgrades with low- and zero-emission technologies, availability of new energy carriers and infrastructure, and expected changes to the PSV fleet's operational profile.

ZEROLOG – RESEARCH FOR LOW- AND ZERO-EMISSION FLEET REALIZATION

In the LowEmission Research Centre SINTEF researchers have been working in close dialog with O&G operators on the development of digital tools for analysis and optimisation of fleet planning, vessel operations, vessel performance and vessel design. The ZeroLog project will build on the results achieved and develop a framework for unified analysis of future ship modifications and vessel operations. The project consortium extends on the LowEmission partners by adding the ship owner/operator Simon Møkster Shipping, energy storage solution supplier Corvus Energy, ship designer and system integrator Sirius Design & Integration, and integrated logistics services provider EndVision.

Research partners include SINTEF Ocean, SINTEF Industry, NTNU and SNF. The research partners will advance their research efforts on the topics of energy system and hydrodynamic vessel performance, fleet level and operational planning,



KSP ZeroLog approach for the way towards sustainable zero-emission offshore support fleet.

vessel design, resource sharing and cooperation. All partners together will work towards identifying and analysing the relevant fleet compositions and renewal strategies towards 2030 and 2050 goals.

Starting with today's fleet of marine gas oil powered ships, alternatives for introducing retrofitted ships and ships utilizing novel energy carriers will be evaluated. Additional attention will be given to identifying potential barriers and important system level factors for low- and zero-emission fleet realization. Advice for next steps for realisation of ambitions towards 2030, knowledge gaps and technology development needs towards 2050 will be documented in project results.

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Featured LowEmission partner: Linda Karlsen, Aker Solutions

Linda Karlsen
Aker Solutions

Aker Solutions is one of LowEmission' s more than 30 partners. We asked Linda Karlsen who is Vice President and head of Performance & Quality – Life Cycle at Aker Solutions three questions about the NCS and collaboration in LowEmission.

In your view, what is the most important research challenge regarding emissions reductions on the Norwegian Continental Shelf (NCS)?

I believe that the key to addressing this challenge lies in developing effective technologies and methods to reduce our emissions through close collaboration between researchers and the industry. Accelerating the time to market for new technology will be crucial.

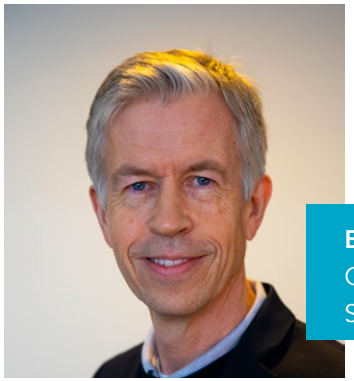
What does Aker Solutions hope to get out of LowEmission?

Aker Solutions is dedicated to solve global energy challenges for future generations. To achieve this, we believe in the power of close collaboration between researchers and the industry. The LowEmission Centre serves as a platform for this joint effort, where we can discuss, prioritize, and focus on important tasks at the intersection of research and industry, to create a greater impact together.

What motivates the industry to reduce emissions on the NCS?

The motivation is high and for several reasons I believe. Regulatory compliance to reach our climate targets, environmental responsibility, economic benefits from improved efficiency, innovation in low-emission technology, market pressures favoring environmentally conscious companies, and Norway's ambition to lead in sustainable petroleum production. I think these factors collectively incentivize the industry to pursue a low-carbon future.

Featured LowEmission partner: Erik Fiskaa, ConocoPhillips Skandinavia



Erik Fiskaa
ConocoPhillips
Skandinavia AS

ConocoPhillips is one of LowEmission' s more than 30 partners. We asked Erik Fiskaa, Manager Innovation and Technology, at ConocoPhillips Skandinavia AS three questions about the NCS and collaboration in LowEmission.

In your view, what is the most important research challenge regarding emission reductions on the Norwegian Continental Shelf (NCS)?

Research and development is required to innovate and achieve technological progress in many fields. ConocoPhillips Skandinavia AS (ConocoPhillips) participates in a broad range of R&D projects that can be adapted to our business needs and contribute to achieve our net-zero ambition by 2050, Scope 1 & 2 emissions. We are following up projects demonstrating early potential more closely to achieve success on targeted technologies. Development of new technologies that are ready for testing, pilot trials and close to be released for commercial use is important for the industry and for the company.

As such, ConocoPhillips joined the LowEmission Centre in 2019, a Joint Industry Project (JIP) pursuing low emission technology for petroleum activities for the offshore Norway industry. Various solutions are being evaluated, with the aim of rapid deployment by the late 2020s.

A significant reduction in greenhouse gas emissions has been realized in the Greater Ekofisk Area due to capital investments and pursuing new technologies. Further reductions will require more targeted technologies, progress, demonstration, and piloting of technology close to commercialization.

What does ConocoPhillips hope to achieve from LowEmission?

ConocoPhillips has adopted a Paris-aligned climate-related risk framework, with an ambition to achieve net-zero operational emissions by 2050. To reach that goal, a wide array of technological developments will need to be applied by the industry, and R&D plays a vital role in this space. Technologies that can be piloted

and applied within our milestones ahead are important to our success.

We are following the nine subprojects, monitored by our technical experts. The Compact Once Through Steam Generator project has potential for further utilization of waste heat, while studies on rotating equipment can provide new insights on mixed and carbon free fuels. Our Houston Technology and Low Carbon Teams are also following the LowEmission research for potential global application.

What motivates the industry to reduce emissions on the NCS?

We believe our competitive advantage and business success depend on effective environmental management and emission reductions of greenhouse gases. Within our license to operate environment in Norway, we are working to continuously improve and take advantage of new technology and innovations. For 2024 and the years ahead, we will continue our efforts to systematically reduce emissions and use energy more efficiently across all aspects of our operations.

Our contribution to a more sustainable world

LowEmission's research in cleaner offshore energy systems and integration with renewable power production technologies contributes to reaching the UN's Sustainable Development Goals. The following three are the ones we deem most relevant to our areas of research, and for which we hope to achieve significant impact.

Our research in carbon-free firing of gas turbines, fuel cells, and reducing the cost of electrification contribute to goal 7: Affordable and Clean Energy.

The improvements in energy efficiency we are working on may often be applied to other industries, and as such contribute to goal 9: Industry, Innovation and Infrastructure.

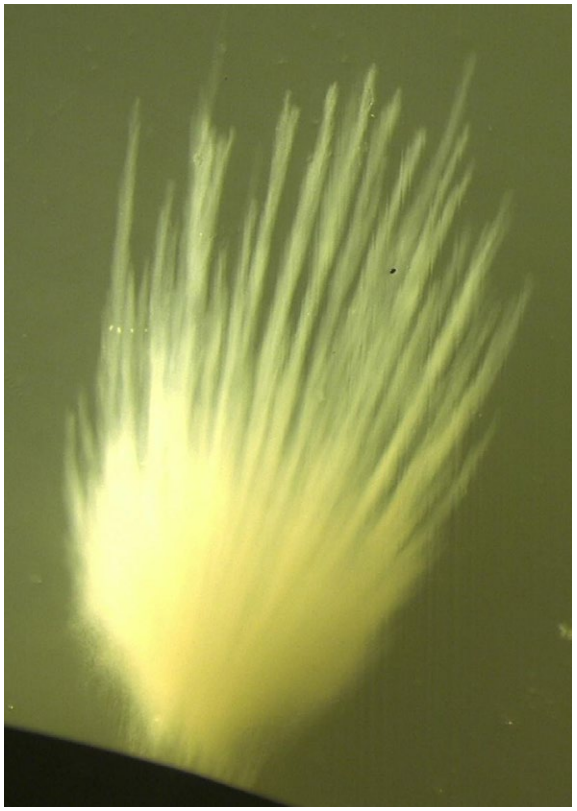
Improving energy efficiency and enabling the use of renewable energy are steps that help achieve goal 12: Responsible Consumption and Production

The Key to Cable Longevity: Understanding water treeing in power cables

By: Amar Abideen,
LowEmission PhD candidate
Co authors: Frank Mauseth, NTNU
and **Øystein Hestad,** SINTEF

Understanding the aging process in power cables is crucial for the electrification of the Norwegian Continental Shelf (NCS). In LowEmission research centre, there are many undergoing research tasks on reducing the cost of electrification (SP3). Understanding the longevity of power cables is essential to support increased electrification efforts, as it allows for a stable and efficient supply of electricity to offshore facilities. Water treeing is a major aging mechanism in power cables. While progress has been made in understanding water tree growth, the initiation mechanism remains uncertain. Improved insights are crucial for developing efficient cables and supporting electrification on the NCS.

Amar Abideen prepares a segment of subsea cable for laboratory aging at SINTEF Energy Lab in Trondheim.



Example of a vented water tree growing from the outer screen found in a service aged cable.

A LITTLE GLIMPSE ON CABLE HISTORY

Since the 60s, extruded cross-linked polyethylene (XLPE) has been widely used in HV cables laid in wet environments[1]. Few years later, high failure rate was reported, which after further investigation found that the insulation breakdown was associated with the growth a tree-like water structure. The water structures were observed close to the breakdown channel, which suggested causality[2]. This was due to water diffusion into the insulation since XLPE is not water tight, which make water ingress into the insulation inevitable.

Numerous research work was conducted since the late 80s, which aimed to answer critical questions regarding this mechanism of cable degradation. A possible solution to limit this ageing was to introduce an additional layer of water barrier around the insulation system (commonly made of lead) to protect the insulation system from water. This is referred to as 'Dry' cable design. The downside of such a design is the additional weight and costs.

Deploying cables without a water barrier (wet design) in comparison to dry design provides: i) Lighter ii) Cheaper iii) Potentially less environmental constraints (in case lead is banned in the future). However, the absence of water barriers make the cable more susceptible to water treeing.

The water treeing initiation and growth mechanism are complex. In fact, it is difficult to categorize different operation factors if their contribution is either on water tree initiation or growth. Specially, when different factors can coincide. In this blog, we briefly go through two of the predominant theories concerning the initiation of water trees.

WATER TREE INITIATION MECHANISM

The exact path from having water presence within the insulation to the formation of tree-like structures is still vague. There are plenty of theories proposed of which, two are predominant: 1) Mechanical Damage Theory and 2) Stress Induced Electrochemical Degradation theory.

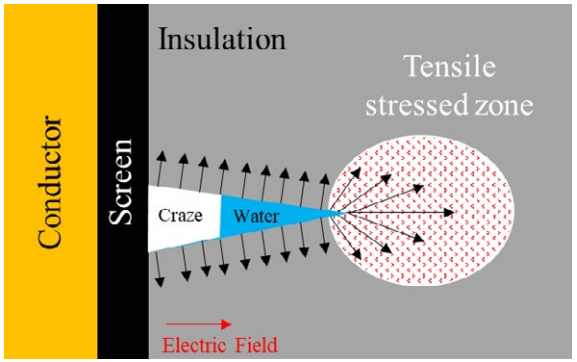
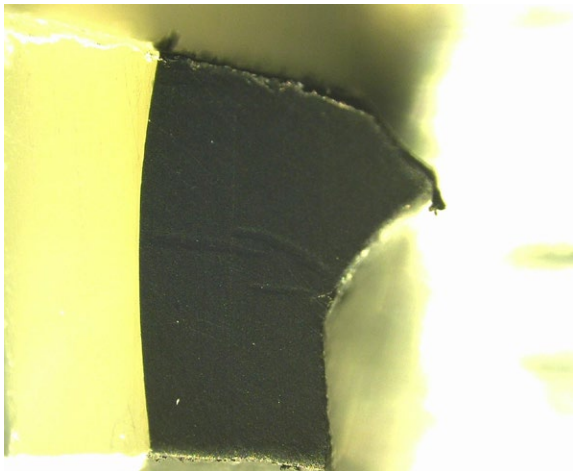


Illustration of water treeing in mechanical damage theory.

Mechanical damage theory explain that the inception of a water tree is due to having mechanically overstressed zones. It is presumed that mechanical and electric stresses can cause to the formation of voids and micro-cracks within the polymeric insulation. This damage can develop further into crazing as the water condenses within the voids and microcracks. The situation can be worsened with the presence of high electric field, which can enhance the diffusion of water



Example of SIED structures found on a service aged cable near the root of a vented water tree.

and as a result increase the water content within crazing zones[4]. Furthermore, inhomogeneous field around crazes can occur due to the water having a much higher permittivity. This induces additional Maxwell stresses around the tip, which will facilitate further expansion of the crazed zones (see the figure to the left).

Stress Induced Electrochemical Degradation theory (SIED) is currently the predominant theory in the electrochemical school of thought for Al conductors. This is because the theory is entirely built around the corrosion of Al conductor being responsible for introducing potential inception sites within the conductor screen, leading to the growth of vented water trees from the inner conductor.

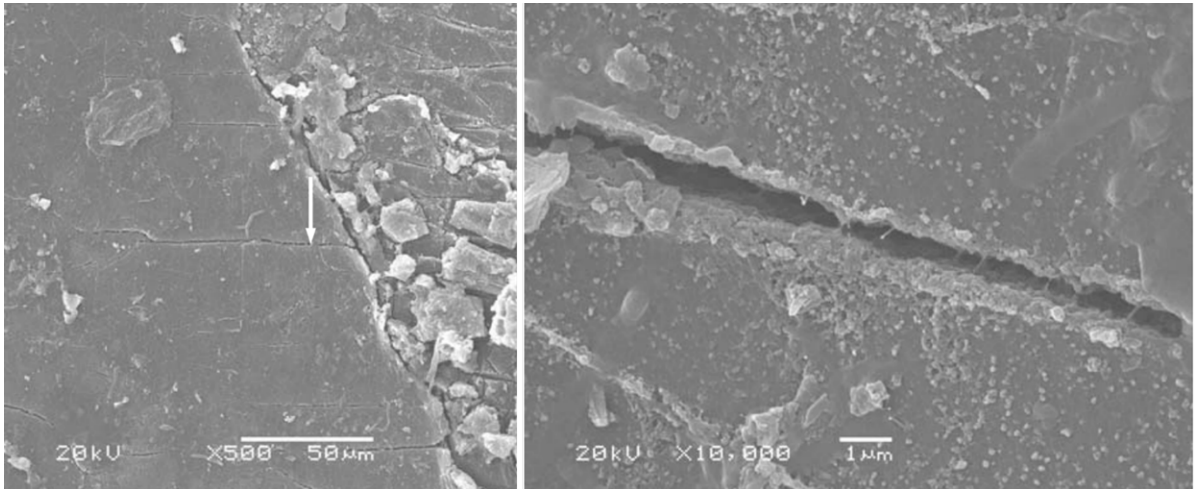
This phenomenon was first reported after observing structural changes near the root of vented water trees grown within accelerated aged test samples[5,6]. In follow-up study, the authors hypothesized that the presence of water will lead to a formation of a galvanic cell between the aluminum (anode) and the screen (cathode), which facilitate the corrosion of the aluminum conductor[7]. This phenomenon was named "Stress Induced Electrochemical Degradation". In later work, it was reported that the growth of these structure is a consequence of a mechanical damage caused by the hydrogen gas pressure build up upon the oxidation of aluminum[8]. Up to this point, all the previous studies produced this

High concentration of vented water trees "following" certain strands.

phenomenon in the laboratory, and it was not reported in service.

The first time this phenomenon was reported on service aged cables in 2009[9]. Cables were pulled out of service due to failure and high density of vented water trees were observed after the removal of the outer screen. An interesting observation was the vented water trees 'following' certain of conductor strands.

In[9], it was argued that damage due to hydrogen gas pressure build-up is less likely to occur. This argument was on the basis of the significance



SEM micrographs showing fibrils bridging the microcracks.

molecular weight of hydrogen gas has making it difficult to obtain sufficient pressure to mechanically damage to the polymeric insulation. Instead, the formation of microcracks initiated by environmental stress cracking (ESC) was suggested after observation of fibrils bridges via SEM, which is commonly occurs in ESC.

In this blog, we went briefly through a summary of the research done in regards to the initation mechanisms of water treeing, which is a major critical aging mechanism for power cables. Whilst there was much work done in the past, some pieces to the puzzle are still missing. With better understanding, a more efficient cables can be developed, and electrification can be facilitated. Thus, there is an emerging need of utilizing more material characterization methods to reveal more information about the initiation of water trees.

Read the full article:
Abideen, Amar; Mauseth, Frank; Hestad, Øystein Leif Gurandsrud; Faremo, Hallvard. (2022) Review of Water Treeing in Polymeric Insulated Cables. Proceedings of the Nordic Insulation Symposium. volum 27 (1).

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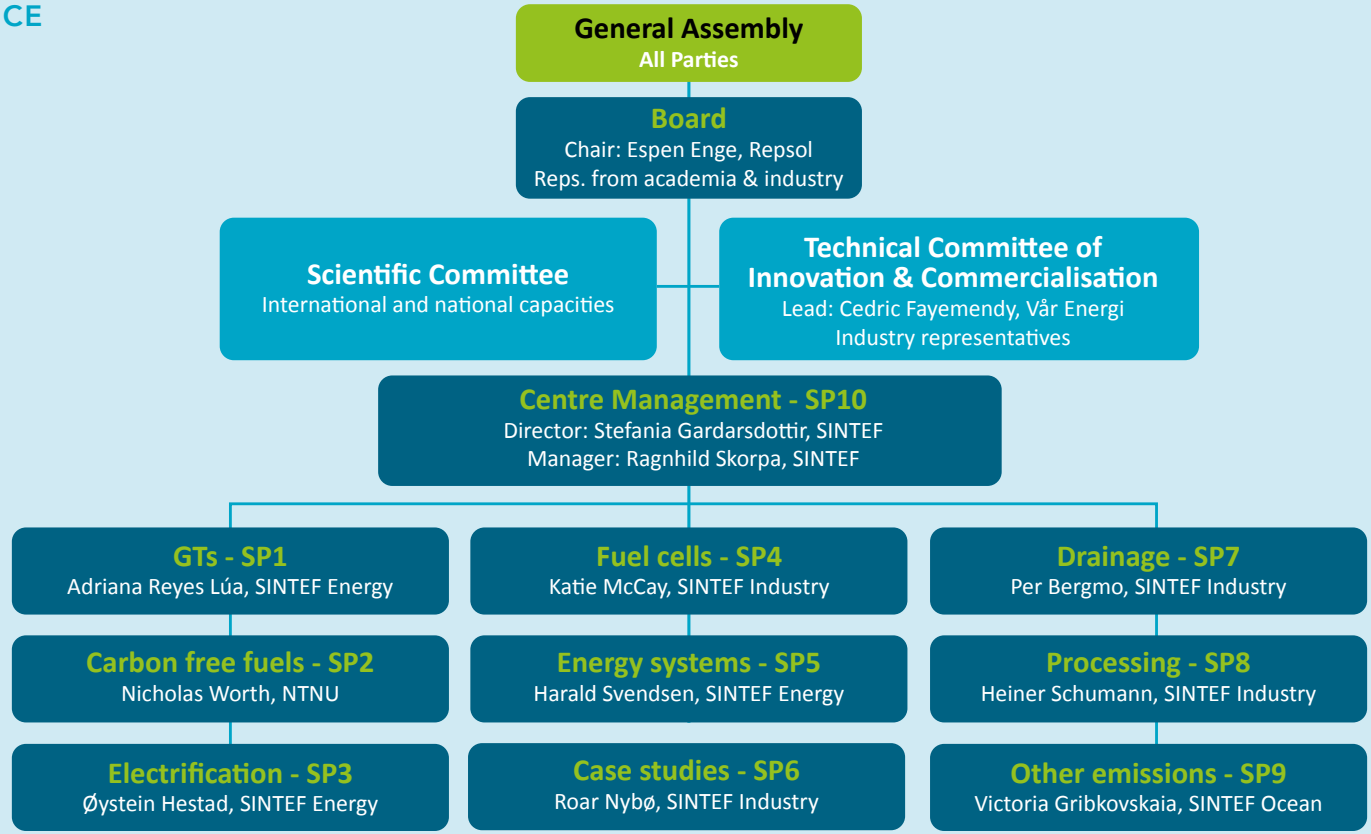
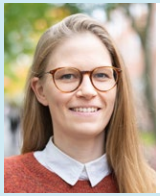
Organisation

GOVERNANCE STRUCTURE



CENTRE MANAGEMENT TEAM 2023



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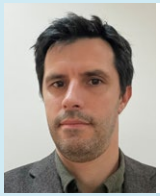

Cedric Fayemendy

Lead for Technical Committee of Innovation & Commercialisation
Principal R&D engineer Low Carbon Solutions
Vår Energi

Lars Magne Nonås

Centre Operations
Research Manager
SINTEF Ocean

James Dawson

Lead for Scientific Committee
Professor
NTNU

Helen Berntsen Auflem

Centre Coordinator
SINTEF Energy Research

BOARD

The LowEmission Board is the operative decision-making body of the Centre and is accountable to the General Assembly which consists of all partners in LowEmission. The Board is led by Chair Espen Enge from Repsol, with representatives from SINTEF, NTNU and industry.

Espen Enge (Chair)	**Repsol**
Tor-Christian Ystgaard	**ABB**
Astrid Jørgenvåg	**Altera**
Linda Karlsen	**Aker Solutions**
Erik Fiskaa	**ConocoPhillips**
Hege Rognø	**Equinor**
Leif Gunnar Hestholm	**AkerBP**
Olav Bolland	**NTNU**
Anngjerd Pleym	**NTNU**
Bjørn Sanden	**Nexans**
Lennart Näs	**Siemens Energy**
Mona J. Mølnvik	**SINTEF Energy Research**
Rune Bredesen	**SINTEF Foundation**
Håkon Tjøstheim	**Vår Energi**
Michael Charles	**Wintershall Dea**
Vanessa Richon	**TotalEnergies**
Lars Erik Walle (Observer)	**Research Council of Norway**

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REINERTSEN NEW ENERGY
RYSTAD ENERGY
ScanWell
slb
SERAM COATINGS
SIEMENS energy
T.EN TECHNIP ENERGIES
Thomassen Energy a Hanwha company

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SINTEF

NTNU

Public financing

The Research Council of Norway

Associated Research Entities

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Carnegie Mellon University

CERFACS

Net Zero Technology Centre
Technology Driving Transition

Lund University

Sandia National Laboratories

DTU Technical University of Denmark

Technische Universität Darmstadt

University of Cambridge

Universitetet i Bergen

Universitetet i Oslo

Associated agencies

Norsk Industri

Offshore Norge

Havtil

Norwegian Energy Partners

Sokkeldirektoratet

COOPERATION BETWEEN PARTNERS

An important arena for industry engagement is the subproject families, where each of the Centre's nine subprojects have established a group of technical experts from the industry partners who directly contribute with their expertise. The subproject families discuss matters such as strategies, operational plans for the coming year, communication and dissemination activities, and research results, as well as perform quality assurance of results and publications.

Interactions between the subproject families and other governance bodies in the Centre, the Board and the Technical Committee are also vital. Larger events such as our annual consortium days and webinars create arenas across the partnership to meet and exchange ideas, catch up on the latest results from the research, inspire each other and interact. Closely linked to this are various innovation activities, which by nature require and evoke partner interactions.

SCIENTIFIC COMMITTEE

International academic collaboration is important to ensure quality and excellence in LowEmission. The Scientific Committee (SC) in LowEmission is currently composed of four internationally recognised researchers in a variety of different topics relevant to the centre, as well as a secretary. The composition of the SC can be expanded as needed. Its purpose is to support and assess the scientific progress of the centre by assessing the output of the academic programme in terms of research and dissemination. The SC will provide continuous assessment and provide the centre with recommendations for improvement and highlight emerging topics that should be considered by the centre. The SC meets on a yearly basis at the beginning of the academic year.

TECHNICAL COMMITTEE OF INNOVATION & COMMERCIALISATION

LowEmission strives to be a dynamic centre, targeting challenges of high relevance to industry. To continuously focus on industry-relevant challenges, a Technical Committee of Innovation and Commercialisation (TCIC) was established in 2019. The TCIC consists of and is led by industry, and its purpose is to evaluate commercial potential and identify spin-off projects. This includes reviewing annual working plans, case studies and KSP spin-off proposals, and evaluating progress in subprojects as well as advising the Board on new research directions. The TCIC will also put stronger efforts on facilitating innovation activities in the years to come. Mr Cedric Fayemendy (Vår Energi) is the current leader of the TCIC.

WEBINAR SERIES

In the fall of 2023, five webinars presented results from newly completed case studies. The topics were:

- Supplying the Norwegian Continental Shelf with offshore wind power. Andrew Smith, Master of Science, SINTEF Energy Research
- Emission reduction potential of cold flow demonstrated for a real field case. Heiner Schümann, Senior Research Scientist, SINTEF Industry.

- Advanced power fluctuation control for combined wind, gas, and steam turbine systems. Kang Qiu, Master of Science, SINTEF Energy Research
- Impact of wind turbines on gas turbine operation and power system stability. Hallvar Haugdal, Research Scientist, SINTEF Energy Research
- Offshore CCS – Carbonated water injection. Per Bergmo, Research Scientist and Torleif Holt, Senior Research Scientist, SINTEF Industry

We are also planning a webinar series for 2024.

CONSORTIUM DAYS

The annual LowEmission consortium days were held on 25-26 October in Trondheim. LowEmission research scientists and industry partners gathered to share ideas, discuss, and explore innovative solutions for reducing emissions on the Norwegian Continental Shelf. The event gathered over 100 participants.

The two-day event featured a packed agenda with presentations focused on research and

technology development on the first day and innovation for accelerating implementation on the second day. The consortium days are an occasion for research scientists and industry representatives to exchange ideas and discuss the latest technological developments and innovations.

Keynote speakers for the conference were Ann-Cathrin Vaage, from Offshore Norge, who presented a status and progress update for emission reductions at the Norwegian Continental Shelf in 2023. Vaage also presented the findings in a report by Thema Consulting that was published earlier this year, showing that electrification of the NCS has a positive global climate effect. Lennart Näs and Karl Johan Nogenmyr from SIEMENS Energy reflected on the road to full decarbonisation and the mission to bridge the intermittency, green fuels roadmap, fuel utilisation, grid stability, and acceleration through collaboration and partnerships. Leif Gunnar Hestholm from Aker BP presented Aker BP's climate strategy and main measures to achieve decarbonisation of its portfolio.

Anne Tone Fjermestad from Vår Energi presented their strategy for decarbonisation. Fjermestad also highlighted the importance of partnering with LowEmission research centre and other strategic partners with regards to decarbonisation efforts.

Centre director Stefania Gardarsdottir presented a summary of the Centre's activity over the past year, as well as plans ahead. Chair of LowEmission Board, Espen Enge from Repsol, highlighted how LowEmission can help the industry speed up the innovation in the sector, and implement new solutions. Enge also talked about activities within the Centre, for example the case study activities that started last year and will be even more prominent moving forward. He also encouraged industry partners to come forward with good potential case studies to bring into the Centre.

The agenda included various presentations from industry experts and scientists, addressing topics such as gas turbine technology, carbon-free thermal power cycles, subsea cable design, energy system integration, and offshore logistics optimization. The overarching theme of the event was how research and innovation can contribute to technology development and how innovation can accelerate the implementation of low and zero-emission solutions for the Norwegian Continental Shelf. LowEmissions SP-leaders presented the new roadmaps, there were pitches form the Centre's PhD candidates, and ten technical pitches, as well as presentations from the innovation sprints – among other excellent presentations and discussions.

RESEARCH AND RESULTS

SP1

Efficiency enhancement of gas turbines

Adriana Reyes Lúa
Research Scientist
SINTEF Energy Research
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+47 451 66 065

This subproject focuses on the design of Combined Cycle Gas Turbines (CCGTs) where the exhaust heat of one or several gas turbines is used in a bottoming cycle for additional power generation and increased efficiency. For this, we need new, compact, and efficient heat recovery heat exchangers. Design of efficient CCGTs includes development of effective control strategies for gas turbine and CCGT operation.

MAIN OBJECTIVE

The main objective of SP1 is to reduce the emissions related to offshore gas turbine operation. A larger share of part-load operation of gas turbines is expected due to the inclusion of renewable energy sources into the offshore energy system. One goal of SP1 is therefore to increase the part-load efficiency of the gas turbines, and this is addressed in Task 1.2. Using the exhaust gas from a gas turbine to run a bottoming cycle to produce steam or additional electricity is another measure to reduce emissions. Bottoming cycles are typically implemented on onshore power plants, but the design and operation objectives of these

systems are not developed for offshore operation. Bottoming cycles have been implemented or are being implemented in some offshore installations. However, the weight and footprint of a bottoming cycle system need to be minimal to enable widespread implementation. In Task 1.3 we develop more compact and lightweight designs considering thermodynamic optimisation, possibly using other working fluids than steam. Analysing their operation and proposing optimal operational strategies for the CCGTs designed for offshore operation is the goal of Task 1.1.

MAIN RESULTS IN 2023

- Finalization of main work on control of bottoming cycle for power production
- Initial work on model of bottoming cycle for heat and power production.
- PhD candidate in task 1.2 submitted thesis (defence expected in April 2024).
- Analysis of effect of low-carbon and carbon-free fuels on performance of compact bottoming cycle.
- Advanced optimization of heat exchanger size and performance
- Peer-reviewed publications:
  - Montañés et al. "Operation and control of compact offshore combined cycles for power generation" *Energy*. doi: 10.1016/j.energy.2024.130315
  - Qui et al. "Model predictive control of compact combined cycles in offshore power plants integrating a wind farm". *Computer Aided Chemical Engineering* doi: 10.1016/B978-0-443-15274-0.50246-8
- Participations in international conferences:
  - ESCAPE-33. European Symposium on Computer-Aided Process Engineering. Qui, Kang. "Model predictive control of compact combined cycles in offshore power plants integrating a wind farm", Athens, Greece, 18-21 June (https://escape33-ath.gr/).
- Lead in Case Studies (2023-2024)
  - Energy storage and power management solutions for reducing part load operation of gas turbines. Cooperation with SP8.
  - Offshore GTCC- OTSG tube diameter optimization.

IMPACT AND INNOVATIONS

- Results for dynamic analysis and control for compact offshore steam bottoming cycles for power production using advanced control structures implemented in a detailed dynamic model.
- Initial work for understanding the impact on bottoming cycles of using low-carbon and carbon-free fuels for gas turbines.
- Development of a simulation tool for design and off-design performance assessment of offshore combined heat and power cycles.
- Spin-off projects
  - DECAMMP KSP spin-off to kicked-off in September 2023.
  - SafeAm KSP spin-off to begin in 2024.
  - Demo COTSG (Demonstration Project for the Industrial Sector 2023) – pilot demonstration of compact once through heat exchangers. Results by RCN. Project to start in 2024.

SP2

Carbon-free firing of gas turbines

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This subproject conducts research and development of gas turbine combustion concepts for hydrogen and ammonia firing, with the aim of achieving a 100% reduction in CO_2 emissions from gas turbines. The potential use of these fuels will be investigated through targeted improvements to current combustion technology and the development of new combustion technology.

MAIN OBJECTIVE

SP2 aims to advance capabilities for carbon-free firing of gas turbines (GTs) and internal combustion engines (ICEs), to reduce emissions on the Norwegian Continental Shelf. The research methodology in SP2 follows three main tracks:

1. In collaboration with Siemens and TU Darmstadt, investigate how to optimize NH_3/H_2/N_2 blends in order to reduce hydrogen reactivity and provide a potential step-in fuel for natural gas.
2. In collaboration with Ansaldo, investigate the GT combustion system handling of hydrogen reactivity preferably without dilution, in order

to offer robust aerodynamics that are flashback resistant.

3. Investigate the use of ammonia as a hydrogen vector to fuel internal combustion engines (ICEs), by examining injection strategies, ignition, and hydrogen piloting.

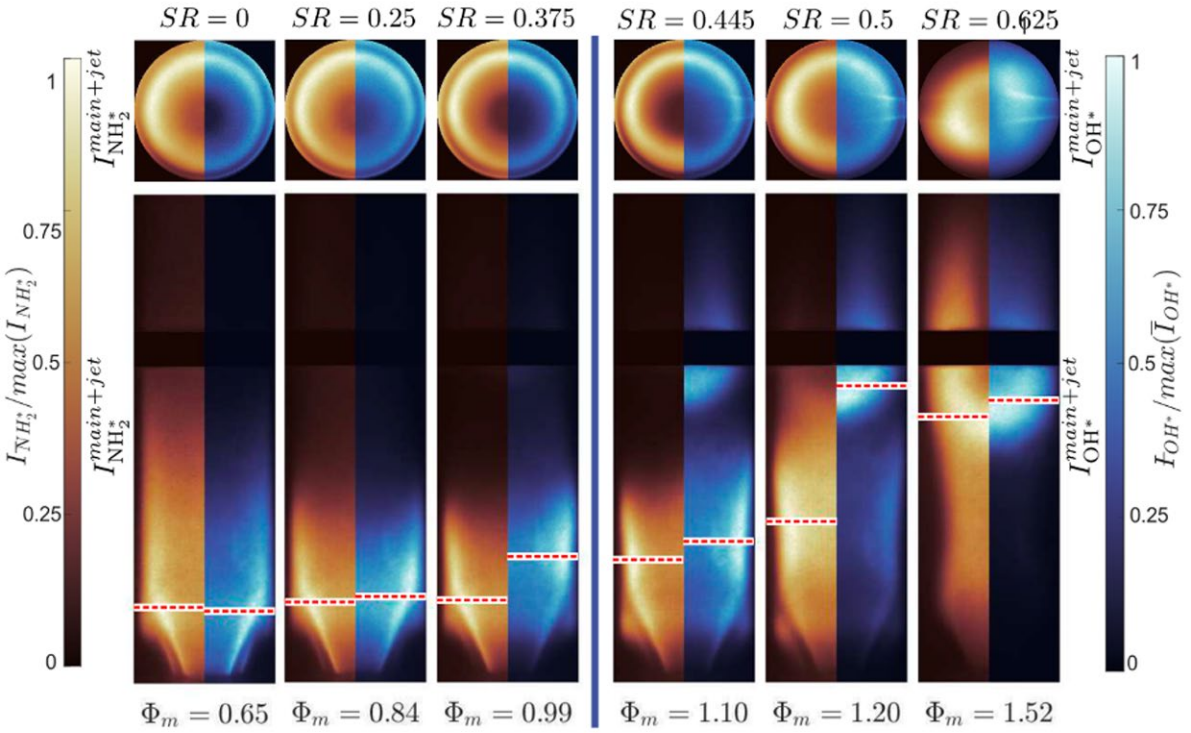
MAIN RESULTS IN 2023

- WP1.1 The local structure of $NH_3/H_2/N_2$ flames have been investigated through Raman/Rayleigh measurements, at TU Darmstadt, using a laminar opposed jet burner. Preliminary Raman scattering measurements and testing of a new custom grating for NH3 species has now been conducted. A technical report was delivered describing a novel calibration approach and measurements of main species and temperature in counter flow flames.
- WP1.2 Staging strategies were investigated in CH_4/H_2 and $NH_3/H_2/N_2$ flames at atmospheric pressure at NTNU using a simplified axially staged burner, presented at the ASME 2023 Turbo Expo, Boston, USA, and published in the ASME journal of Gas Turbine Engineering. A data set investigating the stability of H_2 flames was also presented at the Symposium on Thermoacoustics in Combustion, Zürich.
- WP1.3 An experimental campaign with $NH_2/H_2/N_2$ fuel blends at pressurised conditions up to 10 bar was conducted using the SINTEF swirled burner (SSB), and reported in a paper for the 2023 European Combustion Meeting, Rouen, France. Combustor Reactor Network modelling of the SGT-A35 burner system was presented together with NO_x emissions measurements from ammonia methane blended flames at the ASME 2023 Turbo Expo, Boston, USA. It was shown that even small amounts of ammonia in methane leads to unacceptably high NO_x emissions.
- WP2.1 The first successful attempt to numerically predict the occurrence of flashback in a simplified *Flamesheet-type* combustor was made using Large Eddy Simulation (LES). A joint paper, written in collaboration with TU Delft, reported the validation of the LES model at the 2023 ASME Turbo Expo, Boston, USA, which will form the basis for further parametric investigations in 2024.
- WP2.3 A new PhD student, Jiyong Shin, started in October 2023, and work commenced on the low order modelling of burners for carbon-free fuels.
- WP 3.1 Detailed chemical modelling and simulations have been conducted, to improve our understanding of ammonia injection and fueling on engine performance, emissions, ignition, and flame structure/speed. Additionally, DNS has been conducted in collaboration with CERFACS to better understand thermo-diffusive instabilities. In 2023 papers were presented at the European Combustion Meeting (Rouen, France, 2023), and the 63rd International Conference of Scandinavian Simulation Society (Trondheim, Norway). The PhD Jessica Gaucherand defended her PhD thesis on November 28th 2023, concluding this activity.

IMPACT AND INNOVATIONS

The research planned in SP2 encompasses technology development and gas turbine combustion chamber optimisation, and ICE novel fueling strategies, and it is therefore

particularly well-suited to result in technical innovations. The increased understanding of zero carbon combustion physics and chemistry in this subproject will support the development practical combustion technology.



Mean chemiluminescense imaging of the flames with a NH3 powersplit xNH3 = 0.75, where all flames have the same total amount of air and fuel and the amount of air in the secondary is gradually increased from left to right. From Ånestad et al. (2023)

SP3

Reduced cost of electrification

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This subproject develops new technology for electrifying offshore installations. We are investigating a novel approach using wet design of high-voltage offshore cables in combination with subsea compensation units to enable long-distance AC power transmission. This will enable the use of lighter cables without the need for a metallic barrier to prevent water ingress and facilitates reduced costs for the production and installation of the cable.

Subsea cable connectors (wet-mate connectors, dry-mate connectors, and penetrators) are vital components of oil and gas installations and future offshore renewable energy systems because they allow quick and reliable connection of subsea modules to main components while providing versatility and modularity of expensive equipment. These will also be essential for realising subsea transformers at higher voltages and subsea compensation units. Concepts for subsea connectors developed partly in SP3 have now been lifted out of the LowEmission centre and will be further developed in a spin-off KSP (KSP SeaConnect) partly funded by the

LowEmission consortium. This will continue in close collaboration with LowEmission.

MAIN OBJECTIVE

Today, the gas turbines used for offshore power production emit large quantities of greenhouse gases (GHG). Electrification from shore has the potential to drastically reduce these emissions. While the technology is already available, it is not often used as the cost of electrification remains high. The emphasis of SP3 is on reducing these costs without sacrificing system reliability for the energy system and critical components.

The main objectives are to:

- Identify/develop cost-efficient, reliable power components for offshore/subsea power distribution
- Test components/insulation systems based on models of typical load patterns
- Develop models for estimation of global GHG emission reduction due to electrification

MAIN RESULTS IN 2023

- In 2023, we have updated and improved the dataset which is feed into EMPIRE, taking advantage of the added capabilities and size thanks to the new Julia version. Changes include updated European demand figures for electricity and heat consumption; updated data for oil fields, better formatting of the data files (as csv, tsv, and excel files) and minor adjustments in EMPIRE to account for format changes in the dataset. These changes are documented in the respective deliverable DSP3_2023_02, finalised in September.
- Subsea connectors: Material characterization and numerical simulations were conducted. An experimental setup for testing cable samples with slip-on terminations was prepared, and all the planned experiments were finalized. The main findings were compiled in a conference article for JiCable '23, presented in June 2023 at the conference and later in an SP-family meeting for the SP3-family. A technical pitch for the work summary was also shown in the consortium days. The results suggest that a solid foundation has been established for further work on subsea connectors in the spin-off project, KSP SeaConnect.
- PhD: Investigation of the degradation mechanism of insulation system with corroded aluminum conductors. A modern MVAC cables was aged for different durations (up to six month) considering two experimental variables, which are: 1) salt/tap water as strand fillings (to initiate corrosion and SIED) and 2) thermal relaxated cables (to reduced frozen-in-strains). Additionally, a methodology is established for investigation of the mechanism of SIED inception/growth using Atomic force microscopy (AFM) to be used on both laboratory and service aged cables. The main focus in 2024 will be on analysing the laboratory and service aged samples and preparing journal publications.
- Investigation of SIED mechanism revealed what we believe to be a link between the increased adhesion between conductor screen and conductor due to the formation of a corrosion layer on the conductor surface with the formation of SIED structures in the conductor screen. The methodology and the first results have been presented at JiCable'23. Conference paper uploaded to the e-room and presented for the SP3-family.
- A case study dedicated to the effect of corrosion on adhesion between semi-conductors and aluminum was started in June 2023. The main purpose of this study is to give an indication of the influence of the

corrosion layer on degradation of the inner semiconductor seen as a precursor for water treeing (so called SIED mechanism). The goal will be to evaluate the adhesion between aluminum and semi-conductive materials to be tested to understand the mechanism behind SIED degradation and recommend good combinations of materials that prevent the growth of water trees due to an excessive adhesion between the conductor and the semi-conductive material. The idea is also to develop a more realistic model system where the corrosion layer evolves between the semi-conductor and the metal, more like what happens in a subsea cable. The main activity in 2023 has been on the development of this more realistic model system, and improvement of the experimental setup. The case study will continue in 2024. In addition to more realistic model systems, we will also initiate long term ageing (up to 36 months) of cables with strand fillers to investigate corrosion on the conductor surface and correlate the results obtained with the model systems described above. This is done to test if the investigated degradation mechanism is an issue with modern cable designs. Such degradation has never been observed for modern designs but is still the main uncertainty when moving towards wet designs. The activity in 2024 will mainly consist in starting long-term ageing experiments and performing one outtake after 6 months.

- First phase of study on effect of temperature cycling on water treeing in XLPE was finalized in 2022, and presented at ICD 2022. Results show that thermal cycling with rapid cooling will significantly increase water treeing in cables with ionic contaminants. The second phase with investigation of thermal cycling of test objects with slow cooling is underway and the results will be presented in a journal paper in 2024 (delayed due to issues with the ageing setup, see list of deviations at the end of this report). This is relevant for example for offshore wind farm cables, which are subjected to large and frequent temperature variations. This study shows that it is important to ensure the cleanliness in such cable insulation systems and identify and remove severe sources for water treeing.

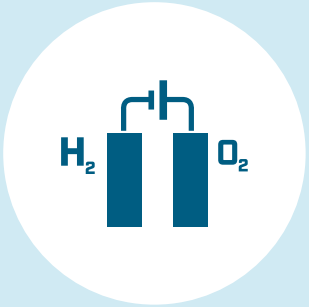
IMPACT AND INNOVATIONS

- HV wet design cables: New hypothesis for the main cause of the Stress-Induced Electrochemical Degradation (SIED) mechanism for water tree degradation of subsea cables proposed, initial results are in line with the hypothesis. Important work on methodology for investigation of root cause of water treeing will be used and further refined in spin-off project GP Ocean Grid Research.
- HV wet design cables: Importance of cleanliness of insulation for cables exposed to load variations demonstrated in model system experiments (temperature cycling). To be published in journal paper in 2024.

- HV Subsea Connectors: A novel approach of applying additional external radial pressure on the field grading rubber material was investigated to facilitate a controlled yet significantly increased interfacial pressure. The conceptual experiments were finalized, and results were published. This concept will be further studied and developed in the spin-off project, KSP SeaConnect (initiated in 2023, results to be presented to SP-family).
- Implementation of methodologies to measure the environmental impact of offshore electrification

SP4

Fuel cells for zero emission heat and power



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This subproject investigates the use of fuel cell technology for the offshore energy system. It considers the varying requirements of heat and power, system sizing constraints as well as hydrogen management and hybridisation strategies. Specific research includes experimental evaluation and modelling of high- efficiency, compact and robust systems fuelled with hydrogen and/or ammonia. The development of reversible fuel cell technology for production of electricity and pressurisation of dry hydrogen is ongoing.

MAIN OBJECTIVE

SP4 aims at investigating the use of fuel cell technologies in the offshore energy system. The planned research covers two technologies with the following ambitions:

- Low temperature PEM fuel cell (PEMFC) systems, aiming at finding the optimal operational strategies of large-scale PEMFC power plants.
- High temperature reversible proton ceramic fuel cells (PCFC) (i.e., H+-SOFC) assessing the

materials and long-term stability for production of electricity and pressurized dry H_2.

In addition, the integration of both types of fuel cells into a hybrid offshore energy system will be investigated. Hybridisation with intermittent renewable energy or gas turbines will be evaluated based on space and power requirements, and the total CO_2-emissions reduction can be calculated for each hybridisation scenario.

MAIN RESULTS IN 2023

- Based on results from 2022, a testing plan for long-term (>1000 h) cycling of a PEMFC stack was developed. A maritime relevant drive cycle was identified from several candidates, with additional high-degradation operation modes integrated to determine the magnitude of reversible and irreversible degradation during cycling. The 1.6 kW (10 -cell) short stack was manufactured and is ready for testing in early 2024.
- A publication has been prepared based on results from experimental activity on reversible operation of PCFCs. In this activity, the optimisation of a steam/air electrode has resulted in a 50% reduction in electrode resistance, with a long-term durability test (>1750 h) showing a low degradation rate when operated in reversible mode. During pressurized operation, the overall degradation rate was below 2%/khr in both modes of operation, although the largest degradation rate is observed during the fuel cell operation. Additional investigation of the impact of processing parameters, and cycling interval for reversible operation was performed.
- Members of SP4 have been directly involved in KSP CleanOFF Hub – Clean Offshore Heat and Power Hub, looking into using renewable energy with hydrogen-based energy storage for the offshore sector.

IMPACT AND INNOVATIONS

Identification of relevant maritime fuel cell testing procedures and quantification of degradation rates at various operating conditions will provide valuable input to models of fuel cell hybrid systems for a variety of end uses.

Collecting information on the impact of frequent and rapid load cycling on PEMFC performance and lifetime will allow to establish dedicated investigation for identifying mitigation strategies and prevent sudden fails and shorter life span, while also increasing understanding of differences between stack and system level operation. Understanding the operativity, advantages and limitations of reversible proton ceramic fuel cell technology would support innovative solutions for the production of electricity and pressurization of dry H_2 offshore.

SP5

Energy systems – digital solutions

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This subproject considers the integration of renewable power supply and low emission technologies developed in the other subprojects into well-functioning offshore energy systems. The aim is to develop methods, models and digital tools for optimisation and accurate analysis of such systems, enabling reliable, electrically stable, and cost-effective system designs and operations with low or no CO_2 emissions. Key outputs are digital solutions that leverage optimisation methods, computing power, and the large amount of data available publicly and among operators.

MAIN OBJECTIVE

Consider the integration of low-emission technologies into offshore energy systems and develop methods, models and tools to support design and analysis.

- Start work on a new model focusing on decarbonization of the whole Norwegian continental shelf (NCS), instead of focusing on one installation at a time.

- Apply previously developed models to analyse operational performance (Oogeso) and power system control strategies for stable and efficient electrical systems with less gas turbines and more power electronics (PowerFactory)
- Improve integrated physics-based modelling and data-driven analysis methods to evaluate energy demand and emissions
- Initiate work considering zero emission pathways for the entire NCS
- Prepare and submit 5 or more scientific papers

MAIN RESULTS IN 2023

- Publication of an open-source version of the hybrid energy system investment optimisation model (HyOpt), including improved documentation
- Preliminary results from – computer tool to assess decarbonisation of the entire NCS. Impact: Reduced costs of NCS emission reductions through optimal policy decision.
- Improved wind power representation in electrical (PowerFactory) model of the LowEmission oil and gas open (LEOGO) reference platform.
- Published results on NCS long-term energy demand estimation and initial work on holistic decarbonisation pathways assessment.
- Development and demonstration of for integrated asset modelling and a REST API for accessing simulation results
- Scientific paper publications exceeding target, with journal articles in the IEEE Open Journal of Industry Applications (power converters), IEEE Transactions on Power Systems (frequency reserves), IEEE Transactions on Power Systems (predictive control), and several conference proceedings articles.
- Two PhD candidates successfully completed their theses and started new jobs (Daniel Mota and Hongyu Zhang).
- Good progress on phd topic model predictive control for hybrid systems (K Hoang)

IMPACT AND INNOVATIONS

- Optimisation software: HYOPT for investment decision support: Find optimal solution to provide low emission offshore system, considering variable demand and wind power and energy storage; REORIENT for integrated investment, retrofit, and abandonment planning of energy systems under short-term and long-term uncertainty; OOGESO for operational optimisation and simulation: Reduce CO_2 emissions by operating hybrid energy systems in an optimised way. Development of methods and decision support tools to simulate and calculate the effect of different operating strategies;
- New process: Integration of offshore wind turbines to supply well beyond 30% of the electricity demand of oil and gas platforms. Open electrical model (LEOGO) useful to explore, and share information about potential power system stability problems and solutions.
- New process: Exploitation of flexibility in energy demand (e.g. pumping for water injection) to reduce need for energy storage in combination with wind energy.
- Methodology for coupling models for reservoirs, top-side processing and energy system to allow detailed analyses and joint optimisation of the system

SP6

Case studies & innovation

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This subproject performs industry-driven case studies, each over a one-year period, to show emissions reductions from the implementation of technologies on the Norwegian Continental Shelf fields. The case studies are frequently grounded in specific offshore fields or specific challenges faced by LowEmission partners and often seek to increase the technology readiness level of R&D from the centre.

MAIN OBJECTIVE

The goal of LowEmission case studies is to develop technology concepts that can lead to a minimum 5% reduction in offshore energy consumption and/or CO_2 and methane emissions. The industry-driven case studies are conducted over a one-year period to show emissions reductions from implementing technologies on the Norwegian Continental Shelf (NCS). Studies depend on industry partners making available data necessary to evaluate emission, weight and cost reductions.

MAIN RESULTS IN 2023

Eight new case studies were initiated in 2023 through an industry-led nomination prosses. The seven case studies will be completed in Q2 2024 and presented in a LowEmission webinar series. The case studies range from studies which inform field development and production strategies on a decadal scale, to emission reduction efforts which can be carried out in a matter of months from 2025-2026 onward. The eight case studies are as follows:

Offshore GTCC- OTSG tube diameter optimization

Weight and size constraints are a challenge on offshore installations. This case study considers weight and size savings on the Once Through Steam Generator by optimizing the diameter of the tubes in various sections.

Formation of micro-cracks in a high voltage cable screen induced by aluminum corrosion

Wet-design power cables with aluminium conductors are lighter than traditional cables with copper conductors, which is an advantage in deep water applications. However, investigations have found micro-cracks in the interface between the semi-conductive screeen and the metallic strands of the cable conductor. The case study will investigate this "Stress-induced electrochemical degradation" (SIED) experimentally. The goal is to arrive at good combinations of materials, that can prevent this problem.

Wind power integration and operational planning of offshore power systems

This case study develops improved wind farm power curves and apply these in simulations to assess operational planning for oil and gas clusters supplied by wind power. The case study improves the realism of the power curves by taking into account effects such as the wake effect, wind direction, turbine spacing and a wide range of wind conditions. The case study will produce realistic power time series with time resolutions down to 1 minute or less and simulate power dispatch planning and energy system operation for a cluster of oil and gas platforms powered by a wind farm.

Powering clusters of oil and gas platforms through large offshore wind farms

The cost of power cables could be reduced if offshore wind farms and oil and gas platforms shared a connection to shore. The wind farm connection to shore may be omitted entirely if it serves clusters of platforms. This case study will examine the cost differences between individual and shared connections, the dimensioning and placement of components in each scenario and optimal power sharing schemes for operational scenarios.

Energy storage and power management solutions for reducing part load operation of gas turbines

Most installations operate with redundant gas turbines to handle sudden or unexpected peak loads. The turbines are running inefficiently with loads as low as 40%, which increases the CO_2 emitted per kW produced. This case study investigates if an energy storage solution could manage peak loads long enough for a spare gas turbine to be started, reducing the number of turbines in operation and reducing CO_2 emissions.

The study also investigates opportunities for flexible demand, which can reduce the total power consumption until a spare turbine is started.

Energy efficiency of oil production and effects of intermittent reservoir fluid flow

Renewable energy such as wind and solar are intermittent and periodic in nature. But does power demand from installations have to be constant? What would be the effect of reducing or even stopping the major mass flows on an installation in periods of reduced power supply? We are interested in how variations in water injection and export of oil and gas would affect reservoir behaviour. This is not easy to model, as it hinges on upscaling transient effects at pore-level scales to reservoir-level scale. This case study is performing core flooding tests under micro-CT x-ray imaging. The goal is to collect data that can indicate how redistribution of fluid saturations at pore level transform to saturation changes on centimetre-scale. This will lay the foundation for new drainage strategies with a potentially large impact on energy efficiency and low-emission operations.

Development of an autonomous platform to conduct site-level measurements of methane at offshore platforms

Methane can be released from a number of sources on a platform, such as flaring, produced water, cold vented and fugitive emissions. Measurements and estimates for each source can be summed up, but will the sum equal the actual emissions from the installation as a whole? Will it do so at all times? Are there sources of emissions we have not accounted for? Without site-level measurements, we don't know. The Oil and Gas Methane Partnership 2.0 (OGMP 2.0) is a multi-stakeholder partnership to improve accuracy and transparency of reporting methane emissions. Members are required to perform such an independent site-level measurement, which has created a demand for a cost-efficient way to carry this out. To demonstrate such a solution, this case study is flying a drone downwind of Neptune Energy's Gjøa platform. The drone is equipped with a methane sensor and through data analysis of measurements throughout its specially designed flight pattern, we can determine the total methane emissions from the platform and compare these with Neptune's source-level estimates. Through this pilot, the case study seeks to create a standard approach for emission quantification and pave the way for campaigns with autonomous drones, where an onsite drone operator is not needed.

PSV energy-saving measures and retrofit potential quantified

Low- and zero-emission vessels are on the drawing board, but how can we save energy and reduce emissions from the *existing* platform supply vessel (PSV) fleet? With a lifetime of 20-25 years, these vessels will be around for a long time. This case study seeks out the measures which can be implemented quickly on today's vessels. This is done through a systematic and holistic analysis of factors such as for instance propeller design, air lubrication and bulbous bow design. The analysis involves both hydrodynamic analysis and studying actual speed and loading condition through in-service ship data. For any given fleet in its area of operations, the method can be applied to define a list of applicable measures with a timeline for implementation. A combined

emission reduction potential, of both technical and operational measures, will be quantified.

IMPACT AND INNOVATIONS

Two Collaborative and Knowledge-building spin-off projects from the LowEmission centre were granted by the Norwegian Research Council in 2023. One of these, ZeroLog - Towards sustainable zero-emission offshore logistics, was granted as a Collaborative and Knowledge-building Project under the Petromaks 2 program. The ZeroLog proposal was built on the results and industry dialog through the case studies in the 2020-2022 period relating to offshore vessels and fleets, as well as work carried out in SP9.

The other one, SafeAm - Increased safety of ammonia handling for maritime operations, was granted under the EnergiX program. The SafeAm proposal spun out of industry and R&D dialogue in SP1 and SP2 in the Centre as well as with other ongoing R&D projects from SINTEF and NTNU.

Marta Bucelli presenting KSP SafeAm at LowEmission Consortium Days.

SP7

Energy efficient drainage

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This subproject analyses the use of energy for different reservoir drainage strategies. Potential reductions in energy use by considering alternative drainage strategies will be identified, both for implementation in mature fields, and for new field developments. The aim is to achieve a reduction in energy use and associated emissions without jeopardising recovery.

MAIN OBJECTIVE

Assess and quantify energy use coupled to subsurface flow processes for relevant drainage strategies and identify potential for energy reduction while maintaining focus on maximising oil and gas recovery.

This will be achieved by:

- Identifying potential technologies and strategies to reduce energy use in hydrocarbon production.
- Assessing effect of applying technologies on field scale models, quantifying energy use and emission reduction potential.
- Further developing optimisation frameworks to enable maximised oil and gas recovery

combined with reduced energy needs and costs.
- In addition, investigate strategies for integrating renewable energy sources where the effect of energy supply variability and need for energy storage is minimised.

MAIN RESULTS IN 2023

- Effect on oil and gas production from varying energy consumption in the top side facilities was investigated at different time scales on the Norne full field simulation model. Results were presented at the 24th World Petroleum Congress.
- Joint optimisation of well placement and well control for energy efficient water flooding of oil fields was demonstrated on synthetic field scale models. This was performed using the LowEmission module in the open-source optimisation framework FieldOpt.
- Mobility control by deep placement of gel using time delayed gelling has been investigated to assess how this type of technology can affect the drainage process.
- The effect of using water inflow control devices in the production wells to limit water production was investigated on the Volve model. Results show that limiting the water production reduces the need for energy intensive water injection with a relatively small effect on oil production.
- Techno-economic evaluation of alternative solutions to deposit CO_2 captured from gas turbine power plants on offshore petroleum production platforms was presented at the TCCS-12 conference in Trondheim. A positive NPV can be achieved for the case where captured CO_2 is dissolved in water and injected into the oil field.
- The new PhD student, Phoo Pwint Nandar, started in August. She will continue work on optimisation and will work towards energy efficiency and variable energy use in the subsurface drainage process.

IMPACT AND INNOVATIONS

- A potential for small scale CCS offshore with EOR by carbonated water has been demonstrated on synthetic field scale reservoir models.
- Optimization framework for joint optimisation of oil and gas production and CO_2 emissions has been developed for water flooded oil reservoirs.
- Tool for analysing energy dissipation in the subsurface has been updated.

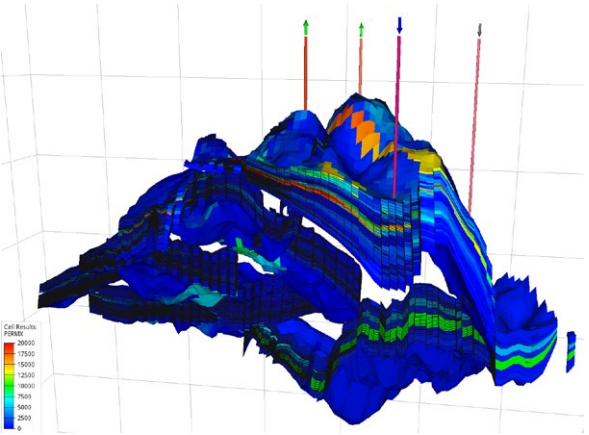

Illustration of high permeable zones leading to early water breakthrough and high water production in the Volve field.

SP8

Energy-efficient processing

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This subproject identifies and demonstrates in-well, subsea and topside solutions for transport and processing with minimal energy use. Solutions address both existing and new installations.

MAIN OBJECTIVE

The main objective of SP8 is to optimize existing processes and demonstrate the potential of new technologies for subsea, in-well and topside processing with minimal energy consumption for new and existing field developments on the NCS. This will be achieved by:

- Demonstrating energy wastage and identifying optimal process configurations for most efficient processing.
- Studying the potential of energy recovery solutions.
- Finding concepts for efficient long distance multiphase transport
- Study most energy efficient well design.
- Propose solutions simplifying the integration of renewable energy supply.

MAIN RESULTS IN 2023

- The effect of different well trajectories and well diameters on the pressure drop was studied. It was demonstrated that well design optimized for plateau production can lead to increased pressure drop in the late production years with changed productivity. This may cause increased need for energy efficient lifting and pressure support.
- An open source framework for coupled modelling of reservoir and flow network (originally created in the DigiWell project) was extended by a simple topside model. In addition a user guide was written explaining installation steps and several test cases. The framework will be used in future studies in LowEmission.
- A case study was completed demonstrating the feasibility, energy saving potential and limitations of the Cold Flow technology for developing long tie-backs without energy intensive heating, insulation or chemical injection as prevention measure for hydrate and wax blocking of pipes. Several industry partners are involved in the study, such as Equinor, Repsol, Total Energies, AkerBP, Aker Solutions. The identified energy saving potential was considerable, with more than 20%. To make the concept feasible for a wide range of production scenarios, relevant combinations with other technologies were identified.
- The feasibility of heat-pumps on an electrified FPSO was studied in a case study.
- Flexible production is one solution to face variable power supply from offshore wind. In this context, it was studied if export rates can be maintained constant even if production rates are unsteady. The application of oil storage tanks and active control of the pressure in export gas pipes was investigated. [Eyni et al., Maintaining constant export oil and gas rates in offshore installations powered by fluctuating wind energy, Proceedings of the ASME 2023 42nd International Conference on Ocean, Offshore and Arctic Engineering OMAE2023, https://doi.org/10.1115/OMAE2023-102454]
- An optimization workflow was tested for finding most efficient configurations and control of pump and compressor setups. For the test case increasing the frequency of setpoint adaptations considerably improved efficiency down to weekly changes. More frequent setpoint changes had minor effect. [Sutoyo et al., 2023, Energy efficiency of oil and gas production plant operations, Geoenergy Science and Engineering 226, https://doi.org/10.1016/j.geoen.2023.211759]

IMPACT AND INNOVATIONS

- The developed framework for optimizing design and operation of pump skids may be introduced in the work flow when designing future processing systems.
- The potential and technical feasibility of heat pumps is demonstrated in a case study. Energy consumption related to heating operations in electrified production platforms/ships can be reduced considerably.
- Field design and operation, as well as limitations of the cold flow technology for long tie-backs was demonstrated in a case study. This will help to consider the technology as real candidate for future low emission tie-back developments and accelerate technology uptake.

SP9

Other emissions

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MAIN OBJECTIVE

SP9 has two objectives: firstly, to reduce emissions from offshore mobile units by optimising logistics, exploring more efficient vessel operations, and the use of low-emission vessels; secondly, to reduce methane and non-methane volatile organic compounds (VOC) emissions from crude oil tankers and installations.

MAIN RESULTS IN 2023

Offshore logistics

In 2023 the research team has continued to pursue development and testing of the decision-support tool for operational offshore supply vessel planning, LogOps. More efficient planning leads to a more efficient vessel utilization and thus reduced emissions which is a goal for operators' in-house planners. New industry partners have been involved in the dialog and contributed with their problem understanding, and input to the tools. Understanding existing routines and tools available to the in-house planners is of utmost importance for potential introduction of the research results into the planning processes. This will be followed up in 2024.

Complementary to the logistical vessel planning is development of the GYMIR 3D vessel simulation software. The integration of these software suites allows us to study the impact different vessel designs, energy systems and propulsion systems may have on logistical efficiency and jointly optimize these. In 2023 GYMIR has been extended with a post-processing option that allows the user to visualise and compare performed simulations.

Hybrid propulsion

In 2023 this task continued the work on ammonia as a fuel for offshore supply vessels. Based on the HyOpt model (https://gitlab.sintef.no/open-hyopt) a general analysis framework was set up to study different power supply variants. The options include polymer electrolyte membrane (PEM) fuel cells with cracking, solid oxide ammonia fuel cells and direct combustion of ammonia (using hydrogen as a pilot fuel) – all in combination with batteries. Economic and environmental data can be obtained based on various operational speeds. Further work in 2024 will focus on similar analyses for mobile rigs.

Methane emissions

Methane is a powerful greenhouse gas and one of the many sources of its emissions is the loading, transport and unloading of crude oil. When loading crude oil on a ship, a significant mass of light hydrocarbons (VOC) is emitted out of the cargo tanks and flowing either to the atmosphere or to a vapour recovery unit (VRU). In 2023, an overview of measures was considered, to some degree tested and applied in order to reduce this VOC emission and examples of emission reduction is given. CFD simulations have continued in 2023 to study the liquid and the gas phases in a cargo tank.

The monitoring of methane is important for reducing emissions, but platform-wide measurement is not routinely in place and there exist misunderstandings about the magnitudes of the different sources of emissions. In 2023, the research team conducted a case study under SP6 to confirm the viability of a proposed fully autonomous drone system to quantify cold-vented and fugitive methane emissions from offshore platforms.

IMPACT AND INNOVATIONS

The development of decision-support tools in SP9 has been selected by the Centre as one of the ideas for the Innovation Sprint, with the aim of a broader outreach to interested industry partner and a detailed plan for possible commercialisation. Extended dialog between researchers and industry representatives through the activities under SP9 related to offshore logistics and vessel operations has led to a spin-off project that received support in 2023 through the Research Council of Norway's Petromaks 2 program as a Collaborative and Knowledge-building project. KSP project ZeroLog: Towards sustainable and zero-emission offshore logistics has as its goal to provide decision makers in the oil&gas industry with a unified framework for assessment of ship technologies for fleet renewal and planning of energy-efficient fleet operations to realize sustainable offshore logistics towards the 2030 and 2050 goals.

Innovations

LowEmission aims to be a platform for competence building and sharing and promoting innovation and value creation for industry. The partnerships between industry end-users, vendors and research institutions are a driving force for this, stimulating the innovation process and shortening the path from research to commercial products.

LOWEMISSION INNOVATION SPRINTS

In 2023, part of lifting our ambitions to move innovations from LowEmission forward towards application was to start the LowEmission Innovation Sprints Pilot. This pilot is a programme that aims to give selected, motivated innovation teams from the consortium knowledge, tools, and resources to dive into the potential of their innovations. The sprint was conducted in collaboration with Entreprenerdy over 9 sessions, where the participants learned the SEAM method through case-based learning.

OUR CASES STUDIES:

Offshore logistics optimisation – Viktoria Gribkovskaia, Roar Nybø, Yauheni Kisialiou, Elin Espeland Halvorsen-Weare, Lars Magne Nonås

Assessment tool for energy dissipation in the subsurface – Per Bergmo, Ole-Andre Roil, Carl Fredrik, Alv Arne, Benjamin Udo Emmel

Transformer tank design resistant to internal faults – Øystein Hestad, Espen Eberg, Amir Hayati-Soloot, Edel Sheridan, Håvard Bærug

An innovation can be a product, a technology, a component, a process or a sub-process, a model or sub-model, a concept, an experimental rig or a service that is new or significantly improved with respect to properties, technical specifications or ease of use. An innovation can also be a new application of existing knowledge or commercialisation of R&D results.

Victoria presenting the innovation sprint at LowEmission Consortium Days in Trondheim 2023.

Interview with Anders Haugland, Entreprenerdy – on innovation and how LowEmission has worked with the innovation sprint

Anders Haugland
Entreprenerdy

In 2023, LowEmission have had a specific focus on innovation. An innovation sprint was conducted in collaboration with the innovation consultancy company Entreprenerdy, where three innovation teams participated. This pilot programme aims to equip selected, motivated innovation teams from the consortium with the knowledge, tools and resources to explore the potential of their innovations.

We had a talk with Anders Haugland from Entrepenerdy, who's been working with LowEmission on the innovation sprint.

Anders holds a PhD from NTNU in thermodynamics and worked in various positions at SINTEF Energy Research until mid-2006. Since then, he has mostly been building companies and initiatives in the innovation ecosystem and supported technology-based startups. One of these companies is Entreprenerdy, which delivers the methodical platform and digital tools for the innovation sprint. Anders is presently the chairman of the board of Sustainable Energy Catapult Centre (operating under the governmental enterprise SIVA) and working for Gas Technology department at SINTEF Energy Research as a Special Adviser/Business Developer. Anders is also presently involved in commercializing results from his own PhD in the aquaculture space.

Entreprenerdy is a Norwegian tech startup based on the experience of two serial entrepreneurs and the findings of the founder's PhD thesis within entrepreneurial support systems. The methodology and tools are used by thousands of cases every year in a wide variety of themes, case maturity and geographies.

Why should a research centre like LowEmission focus on innovations from the centre?

I believe there are several aspects to consider. The world faces immense challenges, and science must serve as both the fundament and backbone for humanity's progress in finding solutions. I think the most robust research efforts in today's R&D landscape are conducted in these centres. Regarding innovations in the LowEmisssion research centre, the aim is to have a significant impact on the transmission period toward 2050, helping the world achieve net zero as effectively and safely as possible.

We need to do everything we can to support these innovations, and that has been the driving force behind the Innovation Sprints. However, not all innovations are immediately applicable. Hence, the innovation sprint mantra is "Finding the best next step for impact". A best next step for impact could involve investing more in research to better understand our findings, engaging more with industry to align our next efforts, or scaling a solution to an industrially relevant level – one that can have commercial value.

What should the role of the industry partners in the centre be in an innovation process/ innovation sprint, in your opinion?

Industry partners play a vital role as they can provide information about unsolved challenges and the value a solution to these challenges could represent. They help direct scientific efforts in the most relevant way and obviously take active part in implementing new solutions. The industrial networks, both thematic and commercial, represent a multitude of possibilities for new projects, addressing challenging phases of existing projects, and pursuing future opportunities. It's no wonder that we aim to activate more dialogue and collaboration with these industrial partners.

Can the innovation sprint be useful, also for those technologies that are not quite "ready for market"?

Absolutely! The innovation sprint marks the beginning of an iterative innovation journey (I call it that instead of an innovation marathon), where the whole idea is to better understand and identify your best next step for impact. The road ahead for many innovations will be long, but by addressing it systematically, you can be sure that the alternative route is even longer. Even if the best next step for impact involves more research, the input from a sprint will improve your chances of securing funding – simply by compelling you to address entrepreneurial and commercial aspects. If you are curious – please reach out to the centre management. You do not need an innovation sprint to get help.

Spin-off projects

LowEmission has contributed to the launch of several spin-off projects, solving specific challenges for the industry. In total, eight Knowledge-building Projects for the Industry (KSP) co-financed by the Research Council of Norway and the LowEmission partnership have been granted funding so far. In addition, LowEmission has stimulated to several other spinoffs such as Innovation Projects for the Industry (IPN), Green Platform projects and a DEMO project.

NEW KSP SPIN-OFF PROJECTS GRANTED FUNDING IN 2023:

ZeroLog – Towards Sustainable and Zero-emission Offshore Logistics

- Objective: Provide decisionmakers with a unified framework for assessment of ship technologies for fleet renewal and planning of energy-efficient fleet operations to realize sustainable offshore logistics.
- Project partners: SINTEF, NTNU, SNF, Equinor, Repsol, AkerBP, ConocoPhillips, Vår Energi, Sval Energi, DNO, OMV, Wintershall Dea, Simon Møkster Shipping, Corvus Energy, Sirius Design & Integration, EndVision
- Funding: Petromax 2 (Research Council of Norway), LowEmission operator companies
- Duration: 2023-2027
- Project Manager: Victoria Gribkovskaia, SINTEF Ocean

SafeAm – Increased safety of ammonia handling for maritime operations

- Objective: Accelerate implementation of new value chains for NH3 as a zero-emission fuel and energy carrier by improving safety systems design and procedures for handling of LNH3 spills on and into water
- Project partners: SINTEF, NTNU, USN, Equinor, Repsol, AkerBP, ConocoPhillips, TotalEnergies, Vår Energi, Sval Energi, DNO, OMV, Wintershall Dea, Yara CleanAmmonia, Wärtsilä, DNV, Kystverket, Sjøfartsdirektoratet, Havindustritilsynet, Amon
- Funding: EnergiX (Research Council of Norway), LowEmission operator companies, Wärtsilä, Yara Clean Ammonia
- Duration: 2023-2027
- Project Manager: Marta Bucelli, SINTEF Energy Research

ONGOING KSP SPIN-OFF PROJECTS

Hy4GET – Large-Scale Offshore Hydrogen Storage for Green Energy Transition

- Objective: to assess the geological conditions on the Norwegian continental shelf for hydrogen storage in salt caverns, address current methods for risk assessment of offshore hydrogen installations and evaluate the economic feasibility of large-scale hydrogen storage in different usage situations and scenarios.
- Project partners: SINTEF Industry, University of Bergen, LowEmission industry partners
- Funding: EnergiX (Research Council of Norway), LowEmission industry partners.
- Duration: 2023-2027
- Project manager: Benjamin Emmel, SINTEF Industry

SeaConnect – High Voltage Subsea Connections for Resilient Renewable Offshore Grids

- Objective: to significantly increase the break-down strength and lifetime of cable connectors and terminations by essentially controlling and

increasing the interfacial pressure between the components using a new design principle and tailor-made materials.
- Project partners: SINTEF Energy, NTNU, LowEmission industry partners, University of Strathclyde, Benestad Solutions, NKT, Systèmes et Connectique du Mans
- Funding: EnergiX (Research Council of Norway), LowEmission industry partners, Benestad Solutions, NKT, Systèmes et Connectique du Mans
- Duration: 2023-2027
- Project manager: Emre Kantar, SINTEF Energy

DECAMMP – Decomposed Ammonia for Carbon-Free Power Generation
- Objective: to develop a feasible conceptual design for the critical components (incl. re-actor and catalyst), processes, and operational strategies required to enable the use of NH_3/H_2 blends for carbon-free offshore power generation.
- Project partners: SINTEF Energy, SINTEF Industry, NTNU, LowEmission industry partners, Johnson-Matthey
- Funding: Petromaks2 (Research Council of Norway), LowEmission industry partners, Johnson-Matthey
- Duration: 2023-2027
- Project manager: Adriana Reyes Lùa, SINTEF Energy.

CleanOFF Hub – Clean Offshore Heat and Power Hub
- Objective: to develop innovative and costeffective concepts for offshore energy hubs that will deliver low-emission heat and power to existing or planned offshore oil and gas clusters.
- Project partners: SINTEF Energy, SINTEF Industry, NTNU, LowEmission industry partners
- Funding: Petromaks2 (Research Council of Norway), LowEmission industry partners
- Duration: 2021-2025
- Project manager: Luca Riboldi, SINTEF Energy

Digital Twin - Digital Twin for Optimal Design and Operation of Compact Combined Cycles in Offshore Oil and Gas Installations
- Objective: The main objective of DIGITAL TWIN is to develop modelling software necessary to design a digital twin for an offshore bottoming cycle with respect to optimizing its operational efficiency and reliability
- Project partners: SINTEF Energy, NTNU, University of Oslo, LowEmission industry partners
- Funding: Petromaks2 (Research Council of Norway), LowEmission industry partners
- Duration: 2021-2024
- Project manager: Leif E. Andersson, SINTEF Energy

OffFlex - Offshore energy system optimisation considering load and storage flexibility
- Objective: identify the potential, barriers, and benefits of using energy demand flexibility for energy balancing in oil and gas platforms with up to 100% wind energy supply
- Project partners: SINTEF Industry, SINTEF Energy, University of Oslo, LowEmission industry partners
- Funding: Petromaks2 (Research Council of Norway), LowEmission industry partners
- Duration: 2021-2023
- Project manager: Harald G. Svendsen, SINTEF Energy

Education and recruitment

The LowEmission academic research programme consists of a total of 16 PhD candidates and two Postdocs. As of the end of 2023, 13 PhD candidates and 1 Postdoc had started their research projects at LowEmission, and 17 MSc students have completed their projects since the Centre was established.

The academic research program holds an essential position in LowEmission. Giving highly motivated candidates the possibility to acquire a research scientist education is, in itself, an investment in the future, and important to Norway, industry, and academia. But beyond these advantages, the work performed by the candidates is also an essential part of realising the LowEmission objectives. Closely intertwined in the subproject families, candidates are working closely with our industry partners, producing highly relevant results. Their contributions are made through high-impact journal publications, at international conferences, in webinars and blog articles.

LowEmission PhD candidates got a chance to showcase their work at the 2023 consortium days last November. Four of the candidates presented their work on stage to a room full of LowEmission partners, followed by a well-attended PhD poster session, with contributions both from the PhD students in LowEmission, and affiliated KSP projects.

OUR CURRENT PHD CANDIDATES AND POSTDOC RESEARCHERS

Aksel Ånestad
Affilitation: NTNU
Nationality: Norwegian
Supervisors: Associate Professor Nicholas Worth (NTNU) and Professor James Dawson (NTNU)
Period: 2021-2024
Thesis: The effect of staging on the stability and emissions performance of an industrially relevant swirl stabilised combustor.

My work explores strategies to limit the NO_x emissions from gas turbines burning mixtures of ammonia and hydrogen. One way to reduce emissions while promoting efficient operation is to implement different types of staged combustion, for example by shooting fuel and air through jets into the combustion chamber to create a secondary flame. This project will implement and experimentally investigate these strategies in a scaled down Siemens SGT750 combustor. Results from this project may be used to retrofit existing gas turbines to burn carbon-free fuels safely and efficiently, enabling industrial scale green power production with minimal economic investments.

Amar Abideen
Affiliation: NTNU
Nationality: Saudi Arabian
Supervisors: Associate Prof. Frank Mauseth (NTNU) and Dr Øystein Hestad (SINTEF)
Period: 2020-2024
Thesis: Wet cable design for subsea applications
This work concerns transmission technologies in subsea.

The aim of this project is to examine and determine the critical aging mechanisms for wet design AC power cables with an emphasis on water treeing (WT) in XLPE cables. Results from this work can contribute to facilitating the electrification of offshore installations, which can lead to more efficient transmission and indirectly reduce the CO_2 emissions. The work started in 2020 with an initial experiment on aged cables to investigate WT structures and inception locations to identify factors that influence the inception of WTs.

Andreas Breivik Ormevik
Affiliation: NTNU
Nationality: Norwegian
Supervisors: Prof. Kjetil Fagerholt (NTNU) and Prof. Frank Meisel (Kiel Univ.)
Period: 2020-2024
Thesis: Emission reduction in the upstream offshore supply chain on the Norwegian Continental Shelf.

In my project, I will develop decision support models for optimising the performance of the upstream supply chain on the Norwegian Continental Shelf, aiming to evaluate the potential for reductions in greenhouse gas emissions from different supply chain stages. Large reductions both in terms of costs and emissions from the daily operations can be obtained through alternative policies for offshore logistics planning. My research work will start by investigating the impact of weather conditions on planning problems for platform supply vessels (through 2021), and I will continue by looking at the effects of restructuring the supply chain.

Hongyu Zhang
Affiliation: NTNU
Nationality: Chinese
Supervisors: Prof. Asgeir Tomasgard (NTNU), Prof. Ignacio Grossmann (Carnegie Mellon Univ.) and Dr Brage Rugstad Knudsen (SINTEF)
Period: 2020-2023
Thesis: Norwegian offshore energy system decarbonisation

My project is about the optimisation of Norwegian low-emission hybrid offshore energy systems investment planning and operation. Approximately a quarter of the current total Norwegian greenhouse gases is emitted from the Norwegian continental shelf, 84.6% of which is caused by platform located gas-fired generation. Therefore, it is of great importance to integrate more renewable technologies (e.g. offshore wind) to supply clean power to platforms to achieve low-emission offshore energy systems. I will develop a large-scale stochastic optimisation model and corresponding computational methods that provide cost-optimal, reliable, and secure low-emission hybrid offshore energy systems design and operational strategies.

I Gusti Agung Gede Angga
Affiliation: NTNU
Nationality: Indonesian
Supervisor: Associate Prof. Carl Fredrik Berg (NTNU)
Period: 2020-2023
Thesis: Reduction of emissions from hydrocarbon production through alternative and energy-efficient drainage strategies

My project aims to develop or improve methodologies for reducing CO_2 emissions associated with reservoir recovery techniques. It is important because the subsurface fluid flow processes have great influences on energy use in petroleum production. The main challenge is how to ensure high recovery while keeping emissions low. At first, I will develop models for accounting for energy use, emissions, and costs in offshore hydrocarbon production. After that, I will perform optimisations of the drainage strategy considering both economic and CO_2 emission aspects.

Jiyong Alex Shin
Occupation: PhD candidate
Affiliation: NTNU
Nationality: Korean
Supervisor: Jonas Moeck
Period: 2023 – 2026
Thesis: Combustion instability in future hydrogen combustors for power generation applications

My work is investigating the instability of hydrogen combustion inside the gas turbine systems. The 'FlameSheet' is a versatile gas turbine combustor that can accommodate various fuel types. Pressure and heat release fluctuations are the primary factors of combustion instability, which can potentially damage the combustor. To prevent this phenomenon, I am analyzing the flow of hydrogen-air fuel and resonance frequencies of 'FlameSheet' combustor model which is simulated in OpenFOAM. Subsequently, I will conduct experimental work to verify simulation result, and investigate combustion instability with other carbon-free fuel types. This research project will enhance the safety and efficiency of utilizing hydrogen fuel in gas turbine systems.

Kiet Tuan Hoang
Affiliation: NTNU
Nationality: Norwegian
Supervisors: Prof. Lars Struen Imsland (NTNU), Dr Brage Rugstad Knudsen (SINTEF)
Period: 2020-2024
Thesis: Stochastic nonlinear model predictive control of offshore hybrid power systems

I will establish the foundation for integrating alternative renewable offshore power systems such as offshore wind into existing offshore power systems using control and systems theory. This is important, because the total emission offshore accounts for approximately 25% of the total Norwegian greenhouse gas emissions. The vision is that the technology from this project will lay the foundation and facilitate increased share of renewable energy in offshore energy systems and reduce total greenhouse gas emissions. The focus of my work is on stochastic model predictive control, a technique that can be used to control the interactions between the different power systems in an optimal manner, even in the presence of uncertainties in for example weather predictions.

Leila Eyni
Affiliation: NTNU
Nationality: Iranian
Supervisors: Associate Prof. Milan Stanko (NTNU) and Dr. Heiner Schümann (SINTEF)
Period: 2020-2023
Thesis: Energy-efficient processing

My project's main objective is to study, develop, evaluate and validate modelling approaches to compute energy efficiency and environmental performance of hydrocarbon production systems (subsea and in-well components), including guidelines and recommendations for implementation and operation of the technology in the Norwegian Continental Shelf. For this purpose, I shall determine and evaluate modelling approaches to compute and assess key performance indicators such as energy efficiency, greenhouse gas emissions, CO_2 footprint,energy usage, thermodynamic properties (e.g. exergy), and economic indicators.

Martin Richter
Affiliation: NTNU
Nationality: German
Supervisors: Prof. James R. Dawson (NTNU), Andreas Dreizler (TU Darmstadt), and Prof. Dirk Geyer (TU Darmstadt)
Period: 2020-2023
Thesis: Investigation of the flame structure of ammonia-hydrogen-nitrogen flames

The main objective of my project is to provide experimental insights to the combustion of ammonia-hydrogen-nitrogen fuel blends by using advanced laser diagnostics. These blends can be obtained by partial cracking of ammonia into hydrogen and nitrogen. During combustion of ammonia hydrogen-nitrogen blends, no carbon dioxide is formed and in the right blend composition, the combustion properties are close to those of natural gas, which makes these blends applicable in gas turbines. Besides a variety of laser diagnostics, we will apply the combined Raman/ Rayleigh-spectroscopy to get deeper insights into the reaction processes in ammoniahydrogen-nitrogen flames.

Mohammad Ali Motamed
Affiliation: NTNU
Nationality: Iranian
Supervisor: Associate Prof. Lars O. Nord (NTNU)
Period: 2020-2023
Thesis: Lifetime efficiency improvement of gas turbine power generation offshore

I will design a gas turbine power generation system that could handle load changes efficiently offshore. This will reduce CO_2 emission and fuel consumption. This is important because gas turbines are expected to work mostly at inefficient part loads due to availability patterns of renewable energies. The design will be compatible with modern carbon capture and storage systems and hydrogen-base fuels requirements. I will develop a design methodology for future intermittent load gas turbines offshore. Then I will develop an inhouse modelling software for power generation offshore and assess the potential solutions through it.

Phoo Pwint Nandar
Occupation: PhD candidate
Affiliation: NTNU
Nationality: Burmese (Myanmar)
Supervisor: Carl Fredrik Berg, Per Eirik Bergmo
Period: 2023 – 2026
Thesis: Integrating the variable power supply from renewable sources into the optimization of subsurface drainage strategies

The main focus of my project is to efficiently include the power supply from wind turbines in the production optimization framework. If we are to rely completely on renewable energy in oil production, the intermittent nature of wind power will result in highly fluctuating water injection rates where the stable injection is favorable for pressure maintenance. I will investigate and develop a model for using subsurface energy storage as part of a sub-surface injection-production process as a starting point. From which, I will imply the different top-side conditions, the correlation between the external controls such as variable power cost, gas/oil price and optimal drainage strategies for the low emissions in the extended workflow.

Wonsik Song [postdoc]
Affiliation: NTNU
Nationality: Korean
Supervisor: Dr. Andrea Gruber (NTNU and SINTEF) and Nils Erland L. Haugen (Luleå University of Technology and SINTEF)
Period: 2022–2025

Even with the introduction of electric vehicles to light-duty engines which accounts for ~45% of CO_2 emissions in the transportation sector, internal combustion engines (ICE) will remain particularly for heavy-duty engines due to the battery weight and charging time. Considering the contribution of CO_2 emission from trucks ~30% and ships ~11%, it is of great importance to minimize emission problems in heavy-duty engines. My project is to improve the ignition of ammonia aimed at the development of low-emission and ultimately net-zero carbon emission combustion technology in internal combustion engines through high-fidelity computational fluid dynamics (CFD) simulations. For the ignition of ammonia at a wide range of operating conditions, we borrow a small amount of diesel fuel, triggering chemical reactions. Our target is then to find the optimal combination of ammonia/diesel ratio that guarantees successful ignition while emitting the lowest CO_2 and NO_x emissions. Starting from the fundamental understanding of ignition in the presence of turbulence at a gas phase, we will extend our understanding to a multi-phase involving more complexity and reality in the future.

OUR PHD GRADUATES

Daniel dos Santos Mota
Period: 2020 – 2023
Thesis: Control and Stability of Isolated Grids with Synchronous and Non-Synchronous Generation

This work explores the challenges and opportunities associated with integrating offshore wind turbines and energy storage systems into geographically compact power-intensive isolated electric grids. It proposes a set of control structures for new energy storage systems and existing synchronous generators for mitigating the negative effects of wind intermittency. In summary, it sheds light on the complex dynamics and interactions that arise when non-synchronous converter-interfaced renewable energy sources are connected to existing isolated electric grids previously dominated by traditional synchronous generation.

Jessica Gaucherand
Period: 2020-2023
Thesis: Numerical study of zero carbon fuel in combustion engines

In my project, I study the potential of using ammonia as a fuel for internal combustion engines. Ammonia is a carbon free fuel that is of interest to decarbonise engines. The goal of my project is to investigate burning ammonia with hydrogen and air in a compression ignition engine. I will be using numerical tools to investigate ammonia's combustion properties. This will allow an efficient combustion in the engine with the lowest amount of emissions such as nitrogen oxides.

International cooperation

Collaboration with international academic and R&D institutes has been a focus of LowEmission since its inception and includes Lund University (Sweden), TU Darmstad (Germany), CERFACS (France), Sandia National Laboratories (USA), Carnegie University (USA), DTU (Denmark), Universidade Federal de Minas Gerais (Brazil), Strathclyde University (UK), UC Berkeley (USA) and Politecnico di Torino (Italy).

These collaborations take place in various forms such as: co-supervision of PhD candidates, hosting candidates from LowEmission on research visits abroad and providing access to unique research infrastructure, and knowledge exchange and idea generation for research tasks. These collaborations result in high quality publications, potential recruitments, and idea generation for new research activities.

Through international cooperation in LowEmission, several of the PhD candidates have been on research visits at internationally recognised research institutions in Europe and the US during 2023:

- PhD graduate Jessica Gaucherand has visited CERFACS in France, where she has worked with Professor Thierry Poinsot, who is a world-leading expert in the field of turbulent combustion.
- PhD candidate Martin Löw has been working at TU Darmstadt in Germany, under the supervision of Professor Andreas Dreizler, who is a world-leading expert in the field of Raman/Rayleigh/LIF laser diagnostics.
- PostDoc Wonsik Song is currently on a yearlong research stay at Sandia National Lab in Livermore, California, where he is working with Dr.Jaqueline H. Chen.
- PhD candidate Kiet Tuan Hoang has been on a six-month research stay at Berkeley University of California in cooperation with Professor Ali Meshbah.
- PhD candidate Hongyu Zhang has been on a six-month long research stay at Carnegie Mellon University, Pittsburgh in cooperation with Professor IE Grossman.

Researchers from SINTEF and NTNU in SP2 collaborate with several international associated partners, including Thomassen Energy in the Netherlands and Siemens Energy in Sweden, to achieve a simplified structure/architecture in the combustion chambers of gas turbines.

Communication

To achieve LowEmission's goals of developing cleaner offshore energy systems and integrating with renewable power production technologies, gaining industrial and political willingness as well as public acceptance are important steps. If LowEmission is to reach its vision of becoming a platform for innovation, sharing new knowledge gained within the Centre will be an important success factor.

Communication efforts in the centre range from strategic, political communication to direct communication with industry professionals.

STRATEGIC COMMUNICATION EFFORTS

Together with several Centres for Environment-friendly Research (FMEs), LowEmission took part in the national political event Arendalsuka in August 2023. LowEmission participated at several events during Arendalsuka, and also hosted a event called *Hvordan kutte utslipp på norsk sokkel i en strømpriskrise?* (How to reduce emissions on the Norwegian Continental Shelf in an electricity price crisis).

The event was hosted in collaboration with Offshore Norge, SINTEF Energi, FME NorthWind, FME HYDROGENi and FME NCCS. The event served as a platform for in-depth discussions on emission reduction strategies on the Norwegian Continental Shelf, bringing together experts, researchers, and policymakers to explore sustainable alternatives. LowEmission received significant visibility at Arendalsuka, and Centre Director Stefania Gardarsdottir participated in several events.

The Research Council of Norway has expressed its wish for FMEs and other research centres to work together and share learning, so we look forward to further develop a relevant cooperation with other FMEs towards Arendalsuka 2024.

CONSORTIUM DAYS

The communications team supported the LowEmission consortium days 2023 event in Trondheim on 11 November. The event gathered over 100 participants. Tasks included promotion before, during and after the event, including a summary article on LowEmissions website, which was shared on LinkedIn. Professional photographs were taken of presenters and participants, which will prove valuable for future communications work and media coverage.

WEBSITE, BLOGS, PODCASTS & NEWSLETTERS

During summer 2023, LowEmission got a new website. The new LowEmission website is more user-friendly and better suited for sharing news from the Centre. We made sure that the new website retained the URL, www.lowemission.no, to ensure that it would be easy to find. The website is the communications hub for the Centre and is the first port-of-call for those interested in finding out more.

LowEmission researchers are encouraged to write blog posts about their work throughout the year. Many blog posts summarise project results or scientific publications but are targeted at different groups such as private industry or government decision-makers. Other blogs are aimed at fellow researchers working in climate technologies and related fields. During 2023, six blogs were published across a variety of LowEmission topics.

In 2023, LowEmission actively engaged with our stakeholders through the distribution of three comprehensive newsletters (October, December and May). As part of our commitment to effective communication, we introduced a novel initiative by launching an internal newsletter tailored for our centre's partners. This allowed us to showcase the diverse and impactful activities undertaken by each SP. The inception of the internal newsletter was a direct response to the board's request for an internal newsletter pilot, marking a step towards enhancing collaboration and sharing insights with our industry and R&D partners.

SOCIAL MEDIA

The LowEmission communications team maintains a LinkedIn page, with 405 followers, up from 258 followers the year before. The LinkedIn page is used to share articles, blogs, news and results from the Centre. Posts were also regularly reshared via the SINTEF Twitter and LinkedIn pages. All project partners are encouraged to share news and blogs via their own social media channels to amplify reach.

Following the rebranding of Twitter to X, the decision by the company to deprioritise core tasks such as content moderation, the exodus of millions of its users and the departure from the platform of key advertisers, the communications team has decided that it had lost its usefulness for the purposes of communicating Centre results and activities. The Centre's X-account (@LowEmissionNCS) will therefore no longer be updated.

Appendix

STATEMENT OF ACCOUNTS

(All figures in 1000 NOK) As an option the funding and cost for each partner may be presented and also how funding and cost is allocated to the subprojects in the centre.

Funding	Amount	In-kind	Sum
The Research Council	15 930		**15 930**
The Host Institution (SINTEF Energi AS)		762	**762**
Research Partners			
NTNU		2 432	**2 432**
SINTEF AS		535	**535**
SINTEF Ocean		469	**469**
Enterprise partners			
Operators	21 649		**21 649**
Vendors		4 265	**4 265**
Public Partners			
Sum	**37 579**	**8 463**	**46 042**

Costs			
The Host Institution (SINTEF Energi AS)	14 142		**14 142**
Research Partners	27 635		**27 635**
Enterprise partners		4 265	**4 265**
Sum			**46 042**

PUBLICATIONS

Peer reviewed publications
Search criteria: From: 2023 To: 2023. Sub-category: Academic article sub-category: Academic review article. Sub-category: Academic chapter/article/ conference article. All publishing channels.

1. **Angga, I Gusti Agung Gede; Bergmo, Per Eirik Strand; Berg, Carl Fredrik**. Joint well-placement and well-control optimization for energy-efficient water flooding of oil fields. Geoenergy Science and Engineering 2023 ;Volum 230. s. SINTEF NTNU
2. **Belay, Mohammed Ayalew; Blakseth, Sindre Stenen; Rasheed, Adil; Salvo Rossi, Pierluigi.** Unsupervised Anomaly Detection for IoT-Based Multivariate Time Series: Existing Solutions, Performance Analysis and Future Directions. Sensors 2023 ;Volum 23.(5) s. ENERGISINT NTNU
3. **Blakseth, Sindre Stenen; Andersson, Leif Erik; Mocholí Montañés, Rubén; Mazzetti, Marit Jagtoyen.** Hybrid Dynamic Surrogate Modelling for a Once-Through Steam Generator. Computer-aided chemical engineering 2023; Volum 52. s. 831-836. ENERGISINT NTNU
4. **Coulon, Victor; Gaucherand, Jessica; Xing, Victor; Laera, Davide; Lapeyre, Corentin;**

Poinsot, Thierry. Direct numerical simulations of methane, ammonia-hydrogen and hydrogen turbulent premixed flames. Combustion and Flame 2023 ;Volum 256. s. 112933-. NTNU

5. **Ditaranto, Mario; Füri, Marc; Solvang, Sindre Ertzgaard; Saanum, Inge.** Experimental and Numerical Results of a Non-DLE Aeroderivative GT Combustion System Burning Methane-Ammonia Blends at Intermediate Pressures. I: ASME Turbo Expo 2023: Turbomachinery Technical Conference and Exposition - Volume 3B: Combustion, Fuels, and Emissions. The American Society of Mechanical Engineers (ASME) 2023 ISBN 978-0-7918-8696-0. ENERGISINT NTNU
6. **Gaucherand, Jessica; Laera, Davide; Netzer, Corinna; Poinsot, Thierry.** Intrinsic instabilities of hydrogen and hydrogen/ammonia premixed flames: Influence of equivalence ratio, fuel composition and pressure. Combustion and Flame 2023 ;Volum 256. s. – NTNU
7. **Gaucherand, Jessica; Pedersen, Eilif; Netzer, Corinna; Løvås, Terese.** Modelling of a Solenoid Injector for Internal Combustion Engines and Simulation Using the Bond Graph Methodology. SAE technical paper series 2023. NTNU
8. **Gruber, Andrea; Heggset, Tarjei; Meyer, Ole; Altenburg, Luuk; Tummers, Mark; Klein, Sikke; Koomen, Joris; Stuttaford, Peter.** Numerical and Experimental Investigation of a Geometrically Simplified, Two-Dimensional FlameSheet™ Hydrogen Burner. I: ASME Turbo Expo 2023: Turbomachinery Technical Conference and Exposition - Volume 3B: Combustion, Fuels, and Emissions. The American Society of Mechanical Engineers (ASME) 2023 ISBN 978-0-7918-8696-0. NTNU ENERGISINT
9. **Hoang, Kiet Tuan; Boersma, Sjoerd; Mesbah, Ali; Imsland, Lars Struen.** Heteroscedastic Bayesian Optimisation for Active Power Control of Wind Farms. I: 22nd IFAC World Congress. Elsevier 2023 ISBN 9781510850712. s. 7650-7655. NTNU
10. **Hoang, Kiet Tuan; Knudsen, Brage Rugstad; Imsland, Lars Struen.** Reference optimisation of uncertain offshore hybrid power systems with multi-stage nonlinear model predictive control. I: 2023 American Control Conference (ACC 2023). IEEE (Institute of Electrical and Electronics Engineers) 2023 ISBN 979-8-3503-2806-6. s. 1251-1257. NTNU ENERGISINT
11. **Hoang, Kiet Tuan; Thilker, Christian Ankerstjerne; Knudsen, Brage Rugstad; Imsland, Lars Struen.** Probabilistic forecasting-based stochastic nonlinear model predictive control for power systems with intermittent renewables and energy storage. IEEE Transactions on Power Systems 2023 s. - ENERGISINT NTNU
12. **Kantar, Emre; Hvidsten, Sverre; Aakervik, Jørund.** Effect of Radial Pressure and Lubricant Types on Partial Discharge Inception in a Slip/On Medium Voltage XLPE Cable Termination. I: Jicable'23 - 11th International Conference on Power Insulated Cables, Lyon - France 18-22 June 2023 : proceedings. : SEE 2023 ISBN 9782959042409. ENERGISINT
13. **Lesaint, Cedric Michel; Liland, Knut Brede; Mermigkas, Athanasios; Klusmeier, Katharina Kuhlefelt; Kantar, Emre; Hvidsten, Sverre; Hestad, Øystein Leif Gurandsrud.** Formation of micro-cracks at the surface of a high voltage cable screen induced by aluminum corrosion. I: Jicable'23 - 11th International Conference on Power Insulated Cables, Lyon - France 18-22 June 2023: proceedings. : SEE 2023 ISBN 9782959042409. ENERGISINT
14. **Mota, Daniel dos Santos; Alves, Erick Fernando; D'Arco, Salvatore; Sanchez Acevedo, Santiago; Tedeschi, Elisabetta.** Coordination of Frequency Reserves in an Isolated Industrial Grid Equipped With Energy Storage and Dominated by Constant Power Loads. IEEE Transactions on Power Systems 2023 s. 1-15. NTNU ENERGISINT
15. **Mota, Daniel dos Santos; Banda, Joseph Kiran; Adeyemo, Ayotunde Adekunle; Tedeschi, Elisabetta.** Harmonic-Invariant Scaling Method for Power Electronic Converters in Power Hardware-in-the-Loop Test Beds. IEEE Open Journal of Industry Applications (OJIA) 2023 ;Volum 4. s. 139-148. NTNU
16. **Ormevik, Andreas Breivik; Fagerholt, Kjetil; Meisel, Frank.** Collaboration in supply logistics for offshore oil and gas logistics. Operations Research Proceedings 2023 s. 170-184. NTNU
17. **Ormevik, Andreas Breivik; Fagerholt, Kjetil; Meisel, Frank; Sandvik, Endre.** A high-fidelity approach to modeling weather-dependent fuel consumption on ship routes with speed optimization. Maritime Transport Research 2023 ;Volum 5. s. - NTNU OCEAN.
18. **Qiu, Kang; Andersson, Leif Erik; Zotica, Cristina; Reyes-Lúa, Adriana; Mocholí Montañés, Rubén; Verheyleweghen, Adriaen; Chabaud, Valentin Bruno; Vrana, Til Kristian.** Model

predictive control of compact combined cycles in offshore power plants integrating a wind farm. Computer-aided chemical engineering 2023 ;Volum 52. s. 1545-1550. ENERGISINT

19. **Sutoyo, Handita Reksi Dwitantra; Angga, I Gusti Agung Gede; Schümann, Heiner; Berg, Carl Fredrik.** Energy efficiency of oil and gas production plant operations. Geoenergy Science and Engineering 2023 ;Volum 226. s. - NTNU SINTEF
20. **Ånestad, Aksel; Sampath, Ramgopal; Moeck, Jonas; Gruber, Andrea; Worth, Nicholas Alexander.** The Structure and Stability of Premixed CH_4, H_2, and NH_3/H_2 Flames in an Axially Staged Can Combustor. Journal of Engineering For Gas Turbines and Power 2023 ;Volum 146.(5) s. 051002. ENERGISINT NTNU

Report/thesis

1. **Gardarsdottir, Stefania Osk.** LowEmission Annual report 2022. Trondheim: SINTEF Energi AS 2023 86 s.- ENERGISINT
2. **Gaucherand, Jessica.** Direct Numerical Simulation of premixed ammonia/hydrogen flames: the effects of thermodiffusive instabilities. Trondheim: NTNU 2023 (ISBN 978-82-326-7453-4) 181 s. Doctoral theses at NTNU(2023:377). NTNU
3. **Mota, Daniel dos Santos.** Control and Stability of Isolated Grids with Synchronous and Non-Synchronous Generation. Trondheim: Norwegian University of Science and Technology 2023 (ISBN 978-82-326-7603-3) 206 s.- NTNU
4. **Perez-Valdes, Gerardo Alfredo.** EMPIRE Dataset Update. Trondheim: SINTEF AS 2023 4 s.- SINTEF

Presentations

1. **Andersson, Leif Erik; Mocholí Montañés, Rubén; Windfeldt, Magnus Kyrre.** Dynamic modelling of combined cycle - Oseberg case. Digital Twin 1st Webinar; 2023-01-26 - 2023-01-26. ENERGISINT
2. **Angga, I Gusti Agung Gede; Bergmo, Per Eirik Strand; Berg, Carl Fredrik.** Effect of CO_2 tax on energy use in oil production: waterflooding optimization under different emission costs. IX Oil and Gas Production Optimization Workshop: The Digital Transformation for Sustainable Production; 2023-03-02 - 2023-03-03. SINTEF NTNU
3. **Bergmo, Per Eirik Strand; Holt, Torleif.** Case study: Offshore CCS – carbonated water injection. Low Emission Webinars; 2023-10-19 - 2023-10-19. SINTEF
4. **Bergmo, Per Eirik Strand; Holt, Torleif.** Small scale offshore CCS. TCCS-12; 2023-06-19 - 2023-06-21. SINTEF
5. **Bergmo, Per Eirik Strand; Schümann, Heiner; Holt, Torleif.** Reservoir Response to Variation in Injection and Production at Different Timescales. 24th World Petroleum Congress 2023; 2023-09-17 - 2023-09-21. SINTEF
6. **Eyni, Leila; Stanko, Milan; Schümann, Heiner.** Maintaining constant export oil and gas rates in offshore installations powered by fluctuating wind energy. ASME 2023 42nd International Conference on Ocean, Offshore and Arctic Engineering OMAE2023; 2023-06-11 - 2023-06-16. SINTEF NTNU
7. **Gardarsdottir, Stefania Osk.** LowEmission senteret - Teknologi for reduksjon av klimagassutslipp. OG21 Forum 2023 - På lag med Europa: Teknologi som sikrer norske energileveranser gjennom det grønne skiftet; 2023-11-16 - 2023-11-16. ENERGISINT
8. **Gardarsdottir, Stefania Osk.** Veien mot nullutslippssamfunnet. Innovasjonsdagen 2023; 2023-02-01 - 2023-02-01. ENERGISINT
9. **Gribkovskaia, Victoria.** Innovation sprint - Offshore logistics optimisation. LowEmission Consortium Days 2023; 2023-10-25 - 2023-10-26. OCEAN
10. **Gribkovskaia, Victoria; Nonås, Lars Magne.** Offshore logistics optimisation roadmap. LowEmission Consortium Days 2023; 2023-10-25 - 2023-10-26. OCEAN
11. **Hoang, Kiet Tuan; Thilker, Christian Ankerstjerne; Knudsen, Brage Rugstad; Boersma, Sjoerd; Mesbah, Ali; Imsland, Lars Struen.** Integrating wind in offshore power systems - control, forecasting, and learning. LowEmission Consortium Day; 2023-10-25 - 2023-10-26. ENERGISINT NTNU
12. **Hoang, Kiet Tuan; Thilker, Christian Ankerstjerne; Knudsen, Brage Rugstad; Imsland, Lars Struen.** Forecasting and control in presence of uncertain intermittent renewables. LowEmission Consortium Day; 2023-10-25 - 2023-10-26. NTNU ENERGISINT
13. **Hoang, Kiet Tuan; Thilker, Christian Ankerstjerne; Knudsen, Brage Rugstad; Imsland, Lars Struen.** Stochastic predictive control for power systems with intermittent renewables - A data-driven stochastic differential equations approach. LowEmission Webinars; 2023-11-07 - 2023-11-07 NTNU ENERGISINT
14. **Kantar, Emre; Hvidsten, Sverre; Aakervik, Jørund.** Effect of Radial Pressure and Lubricant

Types on Partial Discharge Inception in a Slip-On Medium Voltage XLPE Cable Termination. Jicable'23; 2023-06-18 - 2023-06-22 ENERGISINT

15. **Lesaint, Cedric Michel; Liland, Knut Brede; Mermigkas, Athanasios; Klusmeier, Katharina Kuhlefelt; Kantar, Emre; Hvidsten, Sverre; Hestad, Øystein Leif Gurandsrud.** Formation of micro-cracks at the surface of a high voltage cable screen induced by aluminum corrosion. Jicable'23; 2023-06-18 - 2023-06-22. ENERGISINT
16. **Mota, Daniel dos Santos; Banda, Joseph Kiran; Adeyemo, Ayotunde Adekunle; Tedeschi, Elisabetta.** Harmonic-Invariant Scaling Method for Power Electronic Converters in Power Hardware-in-the-Loop Test Beds. IEEE Energy Conversion and Expo; 2023-10-29 - 2023-11-02. NTNU
17. **Ormevik, Andreas Breivik.** Reducing emissions from offshore logistics. LowEmission Consortium Days 2023; 2023-10-25 - 2023-10-26 NTNU
18. **Qiu, Kang; Andersson, Leif Erik; Zotica, Cristina; Reyes-Lúa, Adriana; Mocholí Montañés, Rubén; Verheyleweghen, Adriaen; Chabaud, Valentin Bruno; Vrana, Til Kristian.** Model predictive control of compact combined cycles in offshore power plants integrating a wind farm. 33rd European Symposium on Computer Aided Process Engineering; 2023-06-18 - 2023-06-21. NTNU ENERGISINT
19. **Zhang, Hongyu.** Investment planning under uncertainty of energy systems: modelling and algorithms. Department of Integrated Systems Engineering seminar; 2023-05-15 - 2023-05-15. NTNU
20. **Zhang, Hongyu.** Investment planning under uncertainty of energy systems: modelling and algorithms. Computational Optimisation Group Seminar; 2023-03-24 - 2023-03-24. NTNU
21. **Zhang, Hongyu.** Investment planning under uncertainty of energy systems: modelling and algorithms. NTNU Energy Systems Seminar; 2023-03-31 - 2023-03-31. NTNU
22. **Zhang, Hongyu.** Investment planning under uncertainty of energy systems: modelling and algorithms. Edinburgh Research Group in Optimisation Seminar; 2023-03-29 - 2023-03-29. NTNU
23. **Zhang, Hongyu.** Oil and gas infrastructure in the European energy transition. LowEmission research centre webinar series; 2023-10-17 - 2023-10-17. NTNU
24. **Zhang, Hongyu.** The European energy transition. NorRen summer school 2023; 2023-08-21 - 2023-08-25. NTNU
25. **Zhang, Hongyu; Grossmann, Ignacio E.; Knudsen, Brage Rugstad; McKinnon, Ken; Nava, Rodrigo Garcia; Tomasgard, Asgeir.** Integrated investment, retrofit and abandonment planning of energy systems with short-term and long-term uncertainty using enhanced Benders decomposition. 2023 XVI International Conference Stochastic Programming; 2023-07-24 - 2023-07-28. NTNU
26. **Ånestad, Aksel; Sampath, Ramgopal; Gruber, Andrea; Moeck, Jonas; Worth, Nicholas Alexander.** The Structure and Stability of Premixed CH_4, H_2, and NH_3/H_2 Flames in an Axially Staged Can Combustor. ASME Turbo Expo 2023: Turbo-machinery Technical Conference and Exposition; 2023-06-26 - 2023-06-30. NTNU ENERGISINT
27. **Ånestad, Aksel; Sampath, Ramgopal; Moeck, Jonas; Gruber, Andrea; Worth, Nicholas Alexander.** The Structure of CH_4, H_2 and NH_3/H_2 Flames in an Axially Staged Can Combustor. ASME Turbo Expo 2023; 2023-06-26 - 2023-06-30. NTNU

Multimedia products

1. **Gardarsdottir, Stefania Osk; Tande, John Olav Giæver**. Arendalsuka: Hvordan kutte utslipp på norsk sokkel i en strømpriskrise?. SINTEF 2023 ENERGISINT.

Blog articles and information material

1. **Eyni, Leila.** Powering the Future: Integrating Offshore Wind Energy on Oil and Gas Installations. NTNU
2. **Gardarsdottir, Stefania Osk.** Five ways to reduce emissions from the Norwegian Continental Shelf. ENERGISINT
3. **Abideen, Amar; Hestad, Øystein Leif Gurandsrud.** The Key to Cable Longevity: Understanding water treeing in power cables. ENERGISINT
4. **Ormevik, Andreas Breivik.** How weather conditions greatly influence emissions from offshore logistics. NTNU
5. **Reyes-Lúa, Adriana; Ditaranto, Mario.** Decomposed ammonia – a new and powerful alternative for cutting emissions offshore. ENERGISINT

PERSONELL

Management

Name	Position	Institution
Stefania Gardarsdottir	Centre Director	SINTEF
Ragnhild Skorpa	Centre Manager	SINTEF
Lars Magne Nonås	Centre Operations	SINTEF
Helene Berntsen Auflem	Centre Coordinator	SINTEF
Jon Magne Johansen	Business Developer	SINTEF
James Dawson	Lead Academic Programme	NTNU
Ann Karin Jullumstrø Aalberg	Accounting and Centre Operations	SINTEF
Cedric Fayemendy	Leader of TCIC	Vår Energi

SP leaders

Name	Position	Main research area	Institution	SP
Adriana Reyes Lúa	Research Scientist	Process control, value chain analysis	SINTEF	1
Nicholas Worth	Associate Professor	Turbulence, combustion, experimental methods	NTNU	2
Øystein Hestad	Research Manager	Transmission technology	SINTEF	3
Katie McCay	Research Scientist	Low Temperature Fuel Cells and Electrolysers	SINTEF	4
Harald Svendsen	Research Scientist	Energy systems, renewable integration	SINTEF	5
Roar Nybø	Senior Business Developer	Well drilling, machine learning	SINTEF	6
Per Eirik Bergmo	Research Scientist	Reservoir technology, drainage	SINTEF	7
Heiner Schümann	Research Scientist	Process modelling and concept testing	SINTEF	8
Victoria Gribkovskaia	Research Scientist	Maritime Logistics, Operations Research	SINTEF	9

Key researchers

Name	Institution	Main research area	SP
Geir Skaugen	SINTEF Energy	Thermodynamic optimization, compact bottoming cycle design	1
Jonas Bueie	SINTEF Energy	Thermodynamic optimization, compact bottoming cycle design	1
Håvard Falch	SINTEF Energy	Thermodynamic optimization, compact bottoming cycle design	1
Rubén M. Montañés	SINTEF Energy	Thermal energy systems, process modelling and control	1
Adriana Reyes Lúa	SINTEF Energy	Process modelling and control	1
Kang Qiu	SINTEF Energy	Process optimization and control	1
Lars O. Nord	NTNU	Thermal energy systems, gas turbines, process modelling	1
Andrea Gruber	SINTEF Energy Research	DNS of reacting flows	2
Mario Ditaranto	SINTEF Energy Research	Experimental measurement of reacting flows	2
Rob Barlow	Sandia National Labs	Experimental measurement of reacting flows	2
Terese Løvås	NTNU	Numerical modelling and chemical kinetics	2
Jonas Moeck	NTNU	Theoretical/Low order numerical modelling	2
Nicholas Worth	NTNU	Experimental measurement of reacting flows	2
James Dawson	NTNU	Experimental measurement of reacting flows	2
Gerardo A. Perez-Valdes	SINTEF Industri	Operations Reaseach, Optimisation, Economics	3
Harald Svensen	SINTEF Energi	Grid Planning	3
Luca Riboldi	SINTEF Energi	Energy supply, Process, Energy system	3
Julian Straus	SINTEF Energi	Optimisation, Process, Energy system	3
Sverre Hvidsten	SINTEF Energi	Transmission technology	3
Torbjørn A. Ve	SINTEF Energi	Transmission technology	3
Cedric Lesaint	SINTEF Energi	Transmission technology	3
Emre Kantar	SINTEF Energi	Transmission technology	3
Hans Helmer Sæternes	SINTEF Energi	Transmission Technology	3
Øystein Hestad	SINTEF Energi	Transmission technology	3

Name	Institution	Main research area	SP
Frank Mauseth	NTNU Dept. of El. Power Eng.	High voltage insulation	3
Luis Cesar Colmenares-Rausseo	SINTEF Industry	Low temperature fuel cells PEMFC	4
Katie McCay	SINTEF Industry	Low temperature fuel cells PEMFC	4
Ødegård Anders	SINTEF Industry	fuel cell, hydrogen	4
Yash Raka	SINTEF Industry	fuel cell, hydrogen	4
Mari Juel	SINTEF Industry	fuel cell, hydrogen	4
Benjamin Synnevåg	SINTEF Industry	fuel cell, hydrogen	4
Vøllestad Einar	SINTEF Industry	High temperature fuel cells SOFC	4
Stefania Gardarsdottir	SINTEF Energy		4
Harald Svendsen	SINTEF Energy	Energy system	5
Andrzej Holdyk	SINTEF Energy	Power system modelling	5
Hallvar Haugdal	SINTEF Energy	Power system modelling	5
Thomas Treider	SINTEF Energy	Power system modelling	5
Valentin Chabaud	SINEF Energy	Wind power integration	5
Brage Knudsen	SINTEF Energy	Energy system	5
Michal Kaut	SINTEF Industry	Energy system planning	5
Jan Ole Skogestad	SINTEF Industry	Integrated topside-downhole modelling	5
Til Kristian Vrana	SINTEF Energy	Power system modelling	5
Leif Erik Andersson	SINTEF Energy	Data driven energy demand estimation	5
Asgeir Tomasgard	NTNU	Energy system planning	5
Elisabetta Tedeschi	NTNU	Power system and control	5
Lars Struen Imsland	NTNU	Model-predictive control	5
Daniel Mota	NTNU	Power system and control	5
Hongyu Zhang	NTNU	Energy system planning	5

Name	Institution	Main research area	SP
Kiet Tuan Hoang	NTNU	Model-predictive control	5
Roar Nybø	SINTEF Industry	Integrated topside-downhole modelling	6
Ragnhild Skropa	SINTEF Industry		6
Tore Føyen	SINTEF Industry	reservoir technology, drainage, IOR, EOR	6
Alv-Arne Grimstad	SINTEF Industry	reservoir technology, drainage, IOR, EOR	7
Per Bergmo	SINTEF Industry	reservoir technology, drainage, IOR, EOR	7
Jan Ole Skogstad	SINTEF Industry	reservoir modelling and simulation	7
Bjørnar Lund	SINTEF Industry	gas lift optimisation	7
Arne Marius Raaen	SINTEF Industry	rock physics, fracturing and inflow performance	7
Ole Andre Roli	SINTEF Industry	reservoir technology, computer programming	7
Carl Fredrik Berg	NTNU	reservoir technology, field scale optimisation	7
I Gusti Agung Gede Angga	NTNU	reservoir and topside, field scale optimisation	7
Torleif Holt	SINTEF Industry	oil & gas processing, energy recovery	7
Torleif Holt	SINTEF Industry	oil & gas processing, energy recovery	8
Heiner Schümann	SINTEF Industry	oil & gas processing, Multiphase transport and subsea technology	8
Torgeir Ustad	SINTEF Industry	multiphase flow modelling	8
Paul Roger Leinan	SINTEF Industry	Flow Assurance, modelling	8
Diana Gonzalez	SINTEF Industry	oil & gas processing, flow assurance	8
Milan Stanko	NTNU	oil & gas processing, subsea technology	8
Carl Fredrik Berg	NTNU	reservoir modelling	8
Lars Magne Nonås	SINTEF Ocean	offshore logistics	9
Victoria Gribkovskaia	SINTEF Ocean	offshore logistics	9
Yauheni Kisialiou	SINTEF Ocean	offshore logistics	9
Elin Espeland Halvorsen-Weare	SINTEF Ocean	offshore logistics	9

Name	Institution	Main research area	SP
Endre Sandvik	SINTEF Ocean	vessel performance	9
Truls Flatberg	SINTEF Industri	fuels cells, hydrogen	9
Anders Ødegård	SINTEF Industri	fuels cells, hydrogen	9
Maria Føre	SINTEF Ocean	methane	9
Ole Oldervik	SINTEF Ocean	methane	9
Thor Anders Aarhaug	SINTEF Industri	methane	9
Paal Skjetne	SINTEF Industri	methane	9
Daniel Krause	SINTEF Ocean	methane	9
Rune Aarlien	SINTEF Energi	Dissemination/Communication of results	10
Daniel Albert	SINTEF Energi	Dissemination/Communication of results	10
Astrid B Lundquist	SINTEF Energi	Dissemination/Communication of results	10
Mari Greta Bårdsen	SINTEF Energi	Dissemination/Communication of results	10
Anne Steenstrup-Duch	SINTEF Energi	Dissemination/Communication of results	10
Anka Aalberg	SINTEF Energi	Project management	10
Stefania O Gardarsdottir	SINTEF Energi	Project management	10
Jon Magne Johansen	SINTEF Energi	Project management	10
Stefan Götz	SINTEF Energi	Project management	10
Ragnhild Skropa	SINTEF Industry	Project management	10

Phd candidates with financial support from the centre budget

Name	Nationality	Period	Sex M/F	Topic	SP
Aksel Ånestad	Norway	2021-2024	M	The effect of staging on the stability and emissions performance of an industrially relevant swirl stabilised combustor	SP2
Amar Abideen	Saudi-Araboa	2020-2024	M	Wet Design of AC Power Cables for Future Offshore Power Grids	SP3
Andreas Breivik Ormevik	Norway	2020-2024	M	Emission Reduction in the Upstream Offshore Supply Chain on the Norwegian Continental Shelf	SP9
Daniel Mota	Norway	2020-2023	M	Cooperative control strategies for stability in oil and gas platforms	SP5
Handita Reksi Dwitantra Sutoyo	Indonesia	2021-2022	M	Combine optimization of topside and subsurface production strategies in order to reduce emissions from hydrocarbon production	SP7/ SP8
Hongyu Zhang	China	2020-2024	M	Long-term investment planning of decarbonized offshore energy infrastructure	SP5
I Gusti Agung Gede Angga	Indonesia	2020-2023	M	Reduction of emissions from hydrocarbon production through alternative and energy-efficient drainage strategies	SP7
Jessica Gaucherand	French	2020-2023	F	Ammonia/Hydrogen for internal combustion engines	SP2
Kiet Hoang	Norwegian	2020-2024	M	Stochastic model predictive control	SP5
Leila Eyni	Iran	2020-2023	F	Production systems	SP8
Martin Richter	German	2020-2023	M	The structure of ammonia/hydrogen/nitrogen flames	SP2
Mohammad Ali Motamed	Iran	2020-2023	M	Assessment of alternative concepts for combined cycle gas turbine operation under varying loads	SP1
Phoo Pwint Nandar	Myanmar	2023-2026	F	Methods for reduced emissions from offshore energy systems and integration with renewable energy	SP7
Jiyong (Alex) Shin	South Korean	2023-2026	M	Thermoacoustic stability of carbon-free combustors	SP2

LowEmission (the Research Centre for Low-Emission Technology for Petroleum Activities on the Norwegian Continental Shelf)
is a Centre for Petroleum Activities (PETROSENTER)
Project number: 296207

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