LOWEMISSION

2022 ANNUAL REPORT

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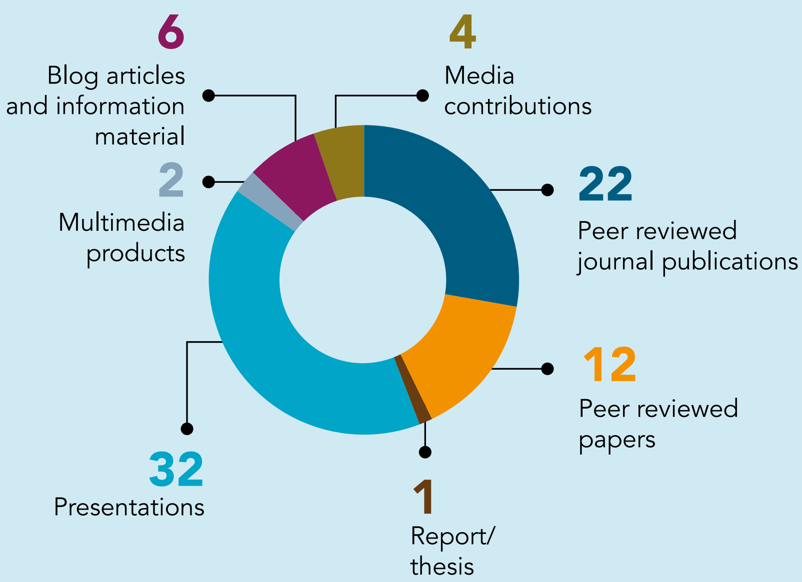
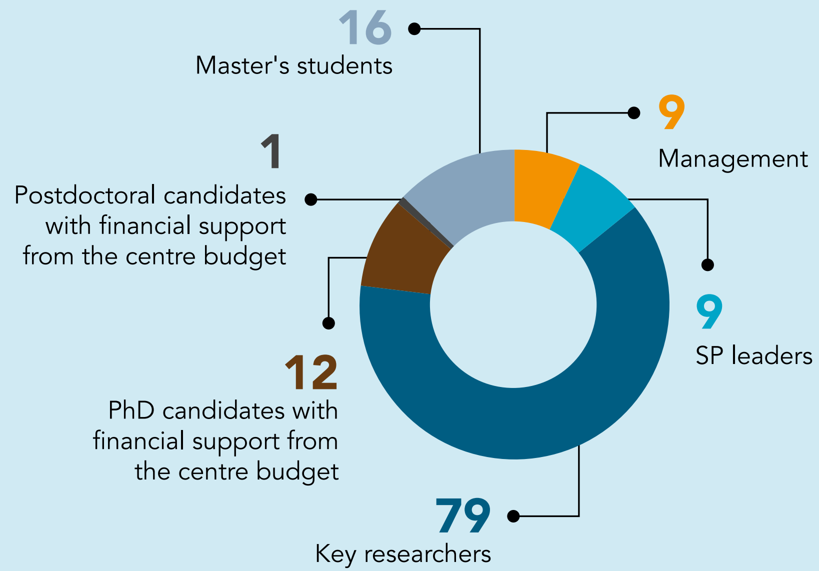


PEOPLE



About *LowEmission*

LowEmission is a research centre for low emission technology for petroleum activities on the Norwegian continental shelf (NCS). World-leading Norwegian and international industrial entities including vendors, operators and energy companies join forces with globally recognised research groups at SINTEF and NTNU, and other top-rated universities and research institutes. The 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 development and implementation of low-emission offshore technologies on the NCS. It will help Norwegian industry meet its 2030 goal of 50% reduction in greenhouse gas emissions – and move 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 the industry.

A large crane pieces together the tower of a floating wind turbine at the Hywind Tampen assembly site in Gulen, Norway.

2022 achievements

LowEmission has now been operating for three and a half year, with the pandemic causing disruptions around the world during most of that period. Then came Russia's invasion of Ukraine, followed by a global energy crisis.

As of the end of 2022, 11 PhD candidates have started their research projects at *LowEmission*. In addition, 16 MSc students have completed their projects since the Centre was established – the objective for the duration of the Centre is to educate a total of 30 master's students.

In this report, research results from some of the Centre's PhD candidates are featured, and descriptions of all the PhD and Postdoctoral candidate projects can be found on pages 64-68.

2022 saw an increased focus on innovation in the Centre activities, with a mapping of the Centre innovations being carried out in the spring. This mapping included considerations on "Success probability", "Emission reduction potential", "Category of innovation", "Technology Readiness Level (TRL)" and involvement/relevance to industry partners. So far, around 30 potential innovations have been identified in *LowEmission*,

a significant pool considering the short time the Centre has been in operation. The innovations are systematically documented and followed up through the Centre's research activities and potential spin-off activities.

LowEmission has dialogue with the two new Petroleum research centres; CSSR and NCS2030 which both started up in 2022, on common interests, synergies and forms for collaboration.

Communication and dissemination activities are on track and will intensify as the Centre produces more results. This year, the Centre produced 22 peer-reviewed journal publications and 32 presentations. A summary of communication activities can be found on pages 70-71.

As the Centre reaches its cruising altitude, one core objective will be to further increase the involvement of industry partners and ensure their active participation in the sub-project families. The more industry partners contribute to shaping and initiating case studies and spin-off initiatives, the greater the Centre's technological payoff and impact will be.

LowEmission received significant visibility at Arendalsuka in 2022. Together with FME HYDROGENi, NorthWind, NTRANS and NCCS, *LowEmission* contributed to the report Nordsjøen som løsning på klima og energikrisen (The North Sea as a solution to the climate and energy crisis)[1] and hosted an event where the report was presented during Arendalsuka. Building on from the 2021 iteration, *Nordsjøen som platform for grønn omstilling* (The North Sea as a platform for the green transition)[2], the document explained how the North Sea can be used as an important arena for the green shift by enabling CCS, floating offshore wind turbines, hydrogen production and energy islands. Together, the centres provided a factual foundation to the public debate about solving the climate challenge and invited to a debate with members of parliament, industry actors and NGOs. The document resulting from this collaboration was well received by decision makers.

1 SINTEF, NTNU. 2022. Nordsjøen som løsning på klima- og energikrisen
2 SINTEF, NTNU. 2021. Nordsjøen som platform for grønn omstilling

A talk with the Centre Director and Centre Chair

ESPEN ENGE

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

STEFANIA OSK GARDARDSDOTTIR

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 analysis 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.

With every year, the climate crisis is getting more acute. We have also experienced an energy crisis in Europe – accelerated by Russia's invasion of Ukraine. The importance of new innovations, technology and concepts for offshore energy systems and integration with renewable power production is even more pressing. Although 2022 has been a challenging year, it has also been a year of milestones. One such milestone is the start of operation of Hywind Tampen, the largest floating offshore wind farm. Offshore wind has an enormous potential for the electrification of oil and gas activities on the Norwegian Continental Shelf.

Are we on the track to reach the goal of zero emission activities on the Norwegian Continental Shelf by 2050, and why is LowEmission important is this respect?

ESPEN: Several reports have concluded that even more needs to be done faster to reach the 2030 and 2050 goals for the NCS. However, my perception is that the change initiatives and ambitions have really accelerated the last years. *LowEmission* has a quite unique setup, with close collaboration between the researchers, equipment vendors, engineering houses and the operating companies. This constellation has great potential to ensure that we select the best R&D projects and that we can reduce the time to piloting and implementation.

STEFANIA: It is clear that we need more of everything to have a chance to reach the net zero goal – more research and innovation, more piloting, demonstration and implementation of low-emission technologies. Several of the technologies we work with in *LowEmission* are in the early phases of development and it will be crucial to further this development towards implementation in collaboration with the industry to ensure the impact we need, namely, to drastically reduce emissions.

The Centre is now almost halfway through its lifetime. What role do you see for LowEmission moving forward, what can we do to accelerate and strengthen our contributions to emission reductions on the Norwegian Continental Shelf and what are the major challenges we have to tackle when it comes to R&D?

ESPEN: *LowEmission* has had a great start and following the midway evaluation we have actions established to further improve its impact. *LowEmission* should be looked at as an enabler which matures technology for others to implement. Communication, knowledge sharing, cooperation, high ambitions and willingness to take implementation risk is something which is required in the E&P industry as a whole to reach these goals. *LowEmission* needs to continue ensuring high quality and high impact R&D activities but add to this an increased focus on communication and cooperation such that the vendors and operators know when and how to engage early to help to accelerate promising technologies through piloting and final implementation.

STEFANIA: Looking back, I think we can be very proud of what the Centre has achieved in its first half. A foundation has been laid in cooperation with the whole partnership, the first PhD candidates are soon finishing their work and many of them will be finding their career paths continuing with one of the *LowEmission* partners. Moving forwards, the partnership will put stronger focus on innovation activities, pushing to shorten the time from development to piloting and implementation. A key to maximize the success and impact of the centres activities is cooperation, which also acts to bring down risks and costs, something which is often a hurdle for implementing new technologies.

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

Subobjectives 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 Norwegian Continental Shelf through industry-driven research and innovation, aiming to become an international knowledge Centre on offshore low-emission technologies. From the start, the Centre has had a focus 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 Sub-Project 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 Sub-Projects family meetings with industry partners, presenting in webinars and annual Consortium meetings, pitching 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 to always reflect the most promising emission reduction possibilities, *LowEmission* has executed yearly calls for case studies. This stimulates even stronger interactions between researchers and the industry in their Sub-Project families to come up with 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 DECAMMP, SeaConnect and Hy4GET which are all co-funded by the *LowEmission* partnership and the Research Council of Norway and were granted funding in 2022.

Moving into the second half of the Centre lifetime, increased efforts will be put into innovation activities to further stimulate and advance the Technology Readiness Level of technologies developed in the Centre and to spin off activities aiming for piloting and demonstration.

Gender equality

Gender balance in the Centre management, the Board and the Technical committee of *LowEmission* is good. 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. NTNU developed a plan for equal opportunities and recruitment of 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

The *LowEmission* centre, 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 so-called Sub-Project family. These are groups of industry contacts that have expertise linked to each subproject of the Centre. In this way, doctoral candidates are integrated into the activities of the Centre. They also get the chance to join events and meetings to which the Centre's scientists and industry experts participate.

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, creation of internships or linking each student to relevant industry contacts.

Message from 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 Technical Committee of Innovation and Commercialization (TCIC) is a body of the *LowEmission* Centre governance. The Technical Committee advises the Board on different aspects such as engaging in innovation activities, quality assurance on annual working plans and monitoring progress in all the Centre work packages, with inputs from the Sub-Project-families. The TCIC acts as a bridge between research and development and the industry needs.

In November 2022 Norway has further enhanced its GHG emissions reduction target for 2030 from 50% to 55% compared to the 1990 level. The DNV Energy Transition Norway 2022 indicates, based on forecast modelling, that *"GHG emissions (in Norway) will continue to decline over the entire forecast period. Emissions in 2021 were slightly lower than in 1990 and by 2030 will have declined 25% compared with 1990 levels. By 2050, we expect an emissions decline of 79% compared with 1990, to 10.8 million tCO2e, hence falling way short of both the 2030 (55% cut) and the 2050 net zero ambitions."*

In this context the deliverables from the *LowEmission* Centre are even more important. As it was described by the government appointed Energy Commission in their report that they submitted to the Ministry of Petroleum and Energy on 1 February 2023: "we need more of everything, faster".

During 2022, The TCIC did perform a review of the Annual Working Plans, Case studies and KSP spin-off projects but also decided to put a focus on innovation. The industry needs to see technology development reaching high technology readiness levels, and to take on-board the technology, and prepare for qualification and implementation. It means a closer involvement with the work performed by the researchers.

During November 2022, the TCIC held a workshop to reflect on potential improvements for better collaboration between the industry and the scientists as well as levers for accelerating technology qualification and commercialisation.

CEDRIC FAYEMENDY

Looking ahead – a positive momentum for low and zero emission solutions

BENEDICTE SOLAAS, director climate and the environment, Offshore Norge

The Norwegian oil and gas industry must reduce its emissions by 50 per cent in 2030 and further down towards zero in 2050. We had a talk with director for climate and the environment at Offshore Norge, Benedicte Solaas. Offshore Norge is an associated agency to *LowEmission*.

Offshore Norge is an employer and industry organization for companies with activites related with the Norwegian Continental Shelf (NCS).

The year 2022 proved to be a year of challenges, as the intensifying climate crisis was further compounded by a global energy crisis, which was further accelerated by Russia's invasion of Ukraine. Energy prices spiked to extreme levels. How will this affect the energy transition and the effort to reduce emissions?

There is no doubt that 2022 has been a challenging year. The war in Ukraine has of course significantly affected the situation for our industry. Norwegian oil and gas have always been important for Europe, but the Norwegian energy supply is now even more crucial, with Europe cutting back imports of Russian oil and gas. Our industry has responded quickly to this situation, ensuring high production from the Norwegian Continental Shelf (NCS). At the same time, the increased production has not come at the expense of the efforts to mitigate climate change. The industry continues to work systematically towards the 2030 targets of reducing emissions by 55 per cent on the NCS.

The global situation has led to challenges, like high electricity prices in Norway – and even higher ones in the EU. This led to some factories having to close down, which affect people's jobs. The EU and the European Commission have done a lot to speed up the energy transition, not least by allocating more funds. IEA actually expects that the energy transition in Europe will go faster because of the war in Ukraine, sparking momentum for low-carbon energy sources.

This of course puts a lot of pressure on Norway to remain competitive in the global arena, developing new technologies like offshore wind, carbon capture and storage (CCS) and hydrogen. This is true particularly with regards to offshore wind, where Europe have come a long way.

Despite the challenges we faced in 2022, I strongly believe that there will be a positive outcome, and that we see a positive momentum building.

Do we have to choose between either energy security or mitigating climate change?

I hope, and believe, that we don't have to choose between either energy security or mitigating climate change. At Offshore Norge, we are now working on our annual status report – tracking the efforts made by the Norwegian oil and gas industry to ensure that Norway and the world will reach emission targets. Although the situation undoubtedly is more challenging now because of the international situation, and we experience that some projects are no longer viable, the industry remains focused on reaching their climate ambitions.

Offshore Norge recently published a report that got a lot of attention in Norway – saying that electrification of Norwegian oil and gas production indeed will have an effect on global emissions. How important is the development of new low- and zero-emission solutions for oil and gas production, in order to meet ambitious targets to reduce greenhouse gas emissions?

Developing new low and zero emission solutions for oil and gas production is very important and should be a high-priority climate measure. Electrification of oil and gas operations enables significant reductions in CO_2 emissions. The most usual method is when the electricity comes from land through power cables. Moving forward, we see that it can be challenging to develop sufficient renewable electricity and grid infrastructure by 2030. However, electrification with power from shore is vital for industry to meet its climate targets, and it will be very difficult for Norway to reach its 2030-targets if we do not reduce emissions from the oil and gas industry. Of course, given that we are steering towards a power deficit and the high electricity prices, the industry faces a more challenging situation with regards to electrification.

What is the role of research and new innovations in this context?

The challenges I just mentioned reinforce the need for developing other low-carbon technologies. This means research and innovation is very important looking forward. One big challenge is uncertainty whether new solutions can be developed fast enough considering the ambitious 2030-targets, and at a reasonable price.

What is the biggest challenge, with regards to research?

We need to come up with more solutions and new technologies through research, and to continue developing new innovations. We must remember that we also have very ambitious climate targets after 2030. The ambitions for 2050 will require us to use the entire toolbox – and will undoubtably be the biggest challenge.

A talk with Torleif Husebø, head of process integrity at the Petroleum Safety Authority

TORLEIF HUSEBØ
Head of process integrity,
Petroleum Safety Authority

The Petroleum Safety Authority Norway (PSA) is a government supervisory and administrative agency with regulatory responsibility for safety, the working environment, emergency preparedness and security in the petroleum sector.

The Petroleum Safety Authority (PSA) is an associated agency to *LowEmission*. We had a talk with head of process integrity at PSA, Torleif Husebø, about research and innovation – and PSAs role when it comes to implementation of low emission technologies.

How does PSA work with operators and vendors on the NCS to support implementation of low-emission technologies in their operations?

The regulations for the petroleum activities offshore and on specific land-based facilities cover aspects related to loss of life, damage to the environment and loss off economical value. Hence, PSAs' work covers a broad context where low emission technologies represent a development that is important in order to meet the greenhouse-gas reduction targets in Norway.

In order to enable a positive development for safety, and to allow sound technological development, the rules are mainly written as goal-based requirements expressing a safety related target that shall be met, but not how. The 'how' part is to a large extent up to the industry, especially through developing and evolving industry standards. R&D plays an important role in developing both new technologies and operational practices. In combination with a structured technology qualification approach this enables the industry to implement low emission technology.

The greenhouse gas reduction targets set by the government and the industry are off course relevant for PSA in our work. We need to follow the technological development closely in order not to act as a hinderance for implementation of relevant technology, but also to influence the development such that it also contributes to a positive development for the aspects that PSA focus on. A specific example of PSA's work in the area of low emission is a study that we performed around optimizing the use of power from shore by investigating various concepts where power from shore is also used to supply emergency systems (fire water pumps and emergency generators). We also find that participating in R&D efforts like the *LowEmission* centre is a good way of both following the development, as well as influencing the stakeholders in the centre.

What is the role of research and new innovations in this context?

The need for improvement can stem from several motives. Being optimizing operations, improving safety or reduce greenhouse-gas emissions, research and development normally plays an important role in the process of bringing new and improved solutions to the marked. The CO_2 reduction targets for the Norwegian petroleum industry are ambitious, and new solutions must be added on top of the already known mechanisms in order to reduce emissions towards the target.

The industry acknowledges this, and we observe that they are very interested in supporting promising R&D initiatives.

There is no doubt about the fact that R&D plays an important role in the development of the petroleum industry, both in general and in regards to reducing greenhouse-gas emissions.

What do you see as the biggest challenge, with regards to research and innovation?

From our point of view we see some obstacles that could be a hinderance. In some cases, the necessity for new solutions is not aligned with potential customers (the industry) and the R&D community. It is hard to sell a solution that the market does not see the need for. Hence, a close dialogue between the R&D community and the industry is important such that the product meet the requirements in the market.

We also observe that for new technology a structured approach to qualify technology can be difficult to follow. This could result in hinderance in the implementation process.

For PSA – a safety and working environment regulator – the safety and working environment potential of new solutions are not identified in the development process. We acknowledge that safety and working environment often is not the motivating factor for R&D, but we expect that these factors also are considered in a continuous improvement context when relevant.

An Analysis of Wind Power Potential Based on Dynamic Process Modelling

BY LEILA EYNI
PhD candidate *LowEmission* (2020-2023)
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With the rapid development of offshore wind technology in Norway, is it feasible to use wind energy exclusively to supply power to offshore oil and gas installations?

According to our last study, the definitive answer to this question is NO; based on our results, we concluded that, under steady-state conditions, wind energy cannot be used solely to power the processing system, and another power source must be employed to compensate for intermittent wind power generation. However, another question arises: Is it worth utilizing wind energy for oil and gas platforms? Certainly, based on our findings, the integration of wind energy could reduce CO_2 emissions significantly. We studied this issue in our last journal article, which you can find summarized here.

Gas turbines that use natural gas or diesel to power compressors and pumps account for approximately 85% of CO_2 emissions in offshore oil and gas facilities. As a result, the oil and gas industry seek a suitable alternative to gas turbines in order to improve the environmental friendliness and sustainability of offshore platforms. However, gas turbines have the advantage to provide significant power (in the order of tenths of MW), in a stable manner with low footprint. It is therefore important that the alternative provides significant amounts of power in a stable manner. Our research examined how wind power can be used as an alternative since it has been exploited on a large scale in recent years and proved as competent source of energy.

Nevertheless, using wind power is challenging because offshore oil and gas installations require a fairly constant and reliable source of power, while wind power typically exhibits significant fluctuations. Therefore, the possibility of supplying the necessary power for the system through wind energy was investigated. First, a dynamic process simulation tool, K-Spice SimExplorer by Kongsberg, has been used to model the processing system (shown in Figure 1) and to calculate the overall power consumption trend for our case study. We considered three options. The first is producing and consuming wind power simultaneously with small backups of gas turbines. In the second option, wind power can be produced, stored in the subsurface for example, by generating hydrogen or ammonia during periods of high wind generation, and then consumed during periods of low wind generation. In the third option, gas turbines can be integrated with these two green energy sources to provide power when there are power deficits. For the last two options, a numerical optimization was formulated to determine the minimum size required for the energy storage system and the highest possible constant power that can be delivered. In the optimization, for the second option, it was assumed that the energy storage is completely charged at initial time. We have developed the formulation in such a way that it is possible to add any additional constraints or parameters to the optimization model.

For the first method, power consumption by the processing facility fluctuated according to the amount of wind power available, shown in Figure 2.

While theoretically it is possible to reduce production to adapt to wind power constraints, such a sudden change from maximal to minimal power may not be technologically feasible. It usually takes some time for the processing system to adapt to new operating conditions and settings. Very often the wind power was either

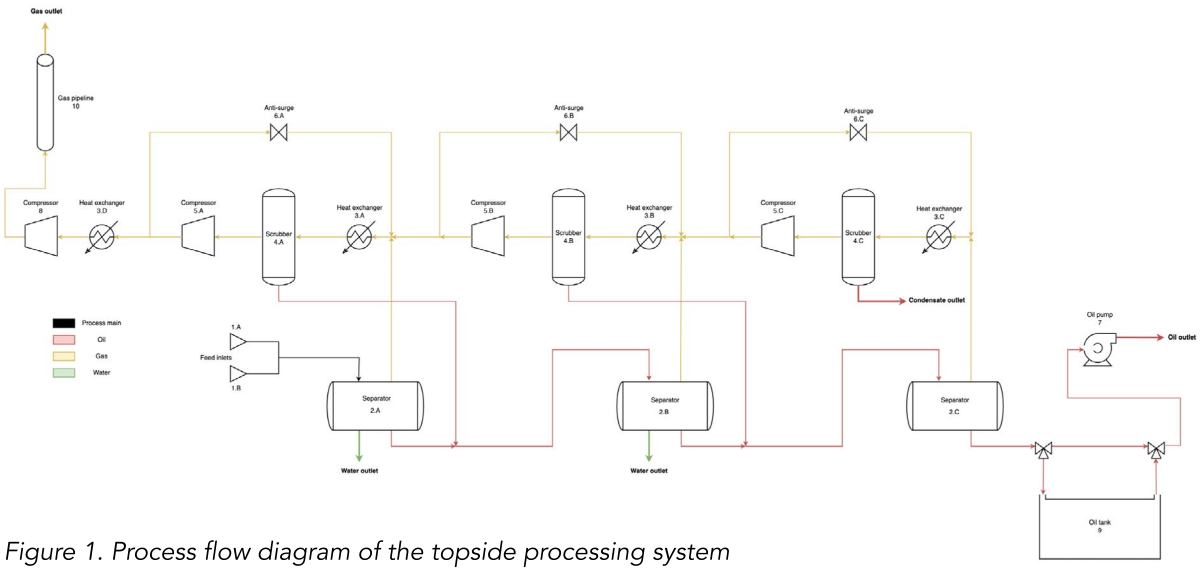

Figure 1. Process flow diagram of the topside processing system

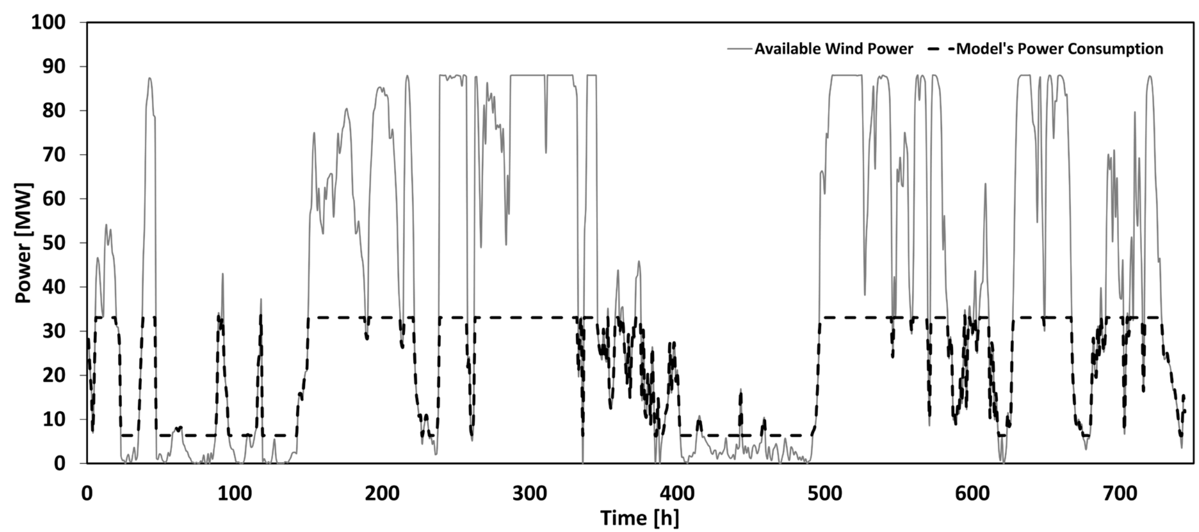

Figure 2. The model's power consumption time series data together with the available wind power

higher or lower than the required processing power. Therefore, a stable and constant power supply for the processing system needs to be ensured through an auxiliary system (energy storage). Figure 3 shows that by utilizing energy storage methods, wind energy can be continuously used for the entire month, providing a reliable and constant source of power for the case study. The amount of energy storage required in this case was of 3,500 MWh. However, it is highly dependent on the energy conversion efficiencies assumed (from wind power to storage, and from storage to processing facilities). Moreover, it allows wind energy to be utilized to its full potential.

By integrating gas turbines into the previous method, even higher power can be provided with a lower amount of energy storage, as shown in Figure 4. The required storage capacity required for this case was of 1,800 MWh.

Table 1 summarizes all the assumptions and findings from the different sections of the study. Comparing hydrogen and ammonia storage volumes with conventional oil and gas reservoirs, the required average underground storage volume is not unreasonable for option 2 and 3 although its feasibility should be further investigated. Storage and gas turbines for the system require space and are associated with

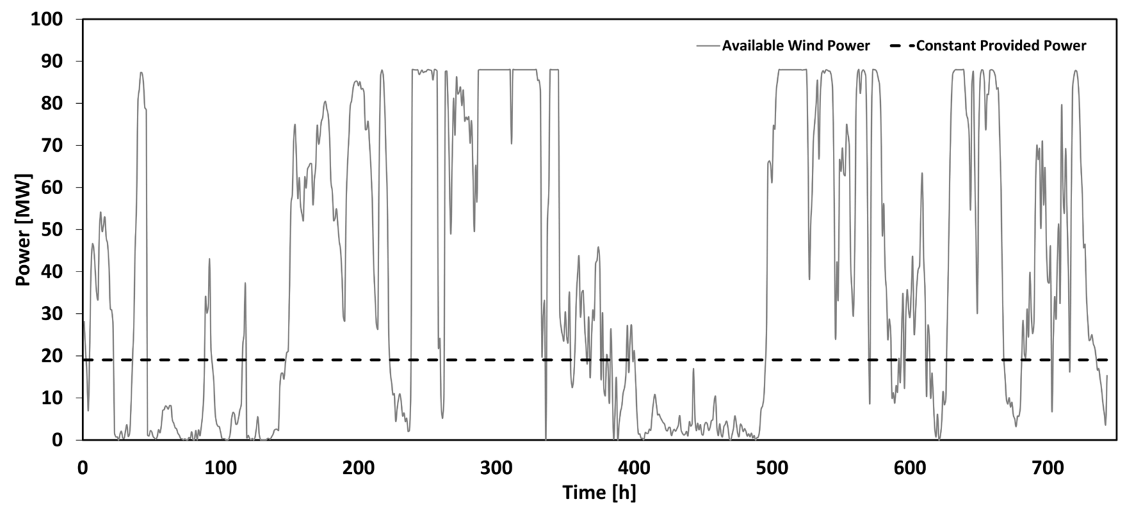

Figure 3. Constant power supply from wind power and energy storage methods

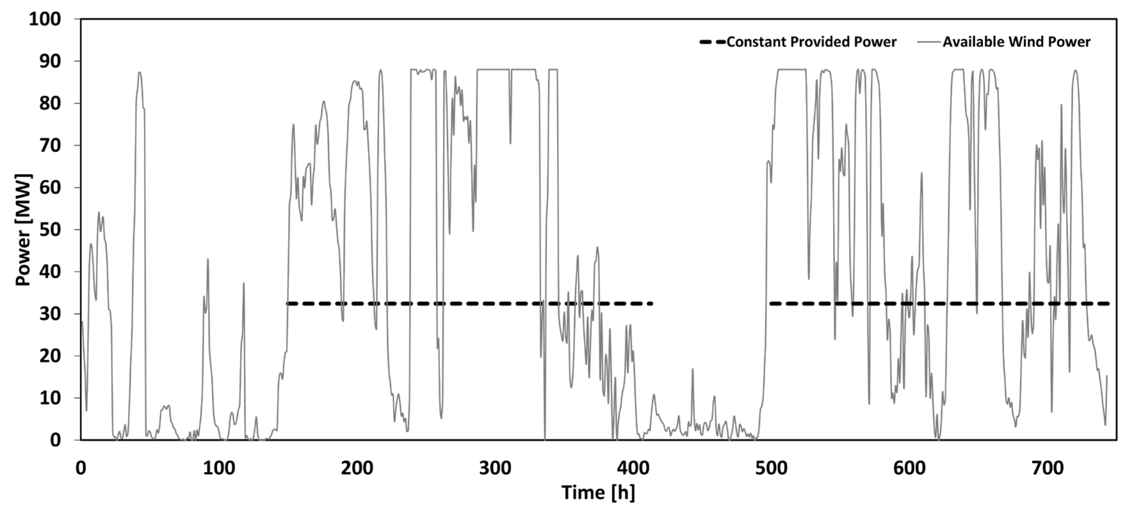

Figure 4. Constant power supply from wind power, energy storage and gas turbines

financial burdens in case they are required. CO_2 emissions are reduced by all methods, but at different rates. If the required energy storage capacity is too high, expensive and economically unfeasible, it may be more practical to rely more on gas turbines, even though emitting more CO_2. Other factors should be considered as well, such as the maximum energy storage requirement, the feasibility of providing a gas turbine, the required amount of production, and the maximum emissions permitted. Therefore, a comprehensive feasibility study is necessary to determine the optimum method for a particular case study.

This study is only the beginning of an optimization investigation into offshore wind energy's potential for powering offshore oil and gas installations. Several operational and economic considerations need to be taken into account when designing a workable technical solution to integrate offshore wind farms with offshore platforms. We invite you to read our paper, and we would also appreciate your comments and suggestions for future work.

Read more from the same author on this topic:

Eyni, L., Stanko, M., Schümann, H., & Qureshi, A. H. (2022). Dynamic Process Modeling of Topside Systems for Evaluating Power Consumption and Possibilities of Using Wind Power. *Energies*, 15(24), 9482.

Eyni, L., Stanko, M., Schümann, H. (2023). Maintaining constant export oil and gas rates in offshore installations powered by fluctuating wind energy. 42 International Conference on Ocean, Offshore and Arctic Engineering (OMAE).

	Method 1	**Method 2**	**Method 3**
Energy storage requirement	NO	YES	YES
Gas turbines requirement	YES	NO	YES
Initial storage requirement	NO	YES	NO
Wind penetration [%]	74	100	68
Provided power [MW]	[6.37:33.06]	19	32.4
Maximal required energy storage [MWh]	0	3500	1850
Required hydrogen storage [MWh]	0	5540	2950
Required ammonia storage [MWh]	0	4630	2450
Emissions of CO_2	YES	NO	YES
Emission intensity reduction [$\frac{t_{CO_2}}{t}$]	0.058	0.067	0.045
Accumulated production [t]	3.76×10^5	3.99×10^5	4.75×10^5

Table 1. Key results of the methods[3]

3 An indication of wind penetration is the ratio between the time when a wind farm produces energy and the total time of production.

Featured partners

LENNART NAES
Engineer, Siemens Energy

**FEATURED *LOWEMISSION* PARTNER:
LENNART NAES, SIEMENS ENERGY**

Siemens Energy is one of *LowEmission*' s more than 30 partners. We asked Lennart Naes who is an engineer at Siemens Energy three questions about NCS and collaboration in *LowEmission*.

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

A large number of technical challenges must be resolved and confirmed to land and introduce a zero-carbon energy system with the same reliability, safety and stability as today. There is no silver bullet which we can have all our focus on. We can though conclude that green/blue fuels will inevitable have to be one of the corner stones to reach a full 100 % CO_2-free energy mixture. It is therefore most important to fully understand all aspects of new fuels, from combustion to transportation.

What does Siemens Energy hope to get out of LowEmission?

Siemens Energy is committed to the transition to net-zero and since this is a huge task, better understanding will be required in so many areas. *LowEmission* is a unique constellation and we are confident in that we will together make important achievements along the path to decarbonization.

What motivates the industry to reduce emissions on the NCS?

Zero-carbon footprint will have a high market value and be key for successful branding and to attract top talents. The industries on the NCS can see a reduction of the CO_2-emissions from the production, especially when brought to zero, as an enabler for end customers to realize 100 % CO_2-free products, e.g. "blue" plastics or electricity. To bring the actual production to zero could therefore be one way to increase revenue per unit and also as an important measure that goes hand in hand with other initiatives.

BJØRN SANDEN
Technical Director for Submarine & Land Systems, Nexans

FEATURED *LOWEMISSION* PARTNER: BJØRN SANDEN, NEXANS

Bjørn Sanden is the Technical Director for Submarine & Land Systems in Nexans. Nexans is a leader in the design and manufacturing of cable systems and services, with approximately 25 000 people in 42 countries. Nexans is a partner in *LowEmission*.

In your view, what is the most important research challenge regarding emissions reductions on the NCS?

First of all, the the most important of all is reflected in the overall goal of the *LowEmission* centre to contribute to reduction of the offshore greenhouse gas emissions on the NCS by 50% by 2030. To enable this to happen new technology is needed, but equally important is develop cost efficient solutions that the industry and society can adopt on sound financial principles.

What does Nexans hope to get out of LowEmission?

Nexans as a company is committed to contribute to carbon neutrality and the goals of *LowEmission* centre resonates well with our own commitment. Specifically on technology, Nexans hope that the work in the centre contributes to technology developments within our area that can contribute to the overall ambition for the centre.

What motivates the industry to reduce emissions on the NCS?

Both on individual and corporate level we all feel strongly for the future of our planet and with this a common commitment to reduce the greenhouse gas emissions.

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

Reducing emissions in oil and gas: how other technologies than electrification can contribute


Photo: Thor Nielsen

STEFANIA GARDARSDOTTIR, Centre Director
RAGNHILD SKORPA, Centre Manager

Electrification of oil and gas is the most straightforward way to reduce emissions in oil and gas exploitation, but other technologies can also make a big difference.

Norway has committed to ambitious greenhouse gas reduction targets over the coming decades. Reducing emissions linked to oil and gas exploitation on the Norwegian continental shelf (NCS) is crucial to reaching those goals. Oil and gas exploitation accounts for 27 percent of Norwegian greenhouse gas emissions and are the second largest source of such emissions in the country, after the transportation sector.

LowEmission is a Research centre for petroleum (PETROSENTER) where the industry and the research community work together on long term projects to develop as many emissions reduction solutions as possible. The ambition for the centre is to produce technologies that will help cut the emissions on the shelf in half by 2030. This will constitute a major step on the road to achieving zero-emission production by 2050.

To reduce emissions by 50 percent by 2030, we depend completely on low-hanging fruit solutions such as electrification, offshore wind and energy efficiency, combined with gas-based solutions (like hydrogen, ammonia and CCS) that will play an even bigger role after 2030. In short, we depend on a portfolio of different solutions, and in some cases tailor-made solutions for each field.

WE MUST REDUCE THE COST OF ELECTRIFICATION

Running an oil platform is an energy-intensive process, and estimations show that full electrification of the NCS will require 15 TWh – which corresponds to about 10 percent of Norway's total energy use in 2021. Electrification is one of the largest research focuses of *LowEmission* and other research efforts SINTEF is involved in, such as NorthWind and Ocean Grid.

At *LowEmission*, we look for solutions that can reduce the costs without negatively affecting the energy system's reliability. A stable and predictable delivery of power is a fundamental requirement relied upon by Norwegian industry. With a partial electrification of the NCS, the reliability of supply would have to be equally satisfactory both on land and on offshore platforms.

To ensure enough power can be delivered, we will need to install high tension subsea power cables in combination with converter stations to enable long-distance AC transmission. To this end, we are researching new cables, without protective metal sheaths and therefore lighter, cheaper to manufacture and less expensive to install.

THE POWER SYSTEM MUST BE BUILT STEP-BY-STEP, BUT IN A CO-ORDINATED WAY

Electrifying the NCS should be carried out by stages, to reduce costs. The most important detail to keep in mind is that the various projects in the North Sea are built in such a way that allows them to be connected to each other. Given a partial electrification of the NCS and development of offshore wind, the North Sea network can enable the offshore "energy hubs" that will provide power to the platforms to become net exporters of power, instead of net importers. The hubs can then be built upon to create large energy islands, each connected to up to 30 GW of installed offshore wind capacity. These energy islands can offer large cost savings, while enabling the transport of wind energy via carriers such as hydrogen, and they can send power back to the shore, in the long term.

Connecting energy hubs and energy islands to international hubs, in a multinational offshore power grid, would allow for even more offshore wind development. To get there, we need a close collaboration between the countries bordering the North Sea, where each participant takes a share of the risks and rewards. Our analyses performed using the EMPIRE model of the European power market show that the offshore wind potential gets best utilised if it's connected to a network of subsea cables linking Norway with hubs in the North Sea and other European countries.

ENERGY EFFICIENT DRAINAGE AND PROCESSING

Emissions can also be significantly reduced by making the core operations of oil and gas platform more energy efficient, by optimising drainage and processing. Currently, the power generated by gas turbines goes towards injection (about 30%), gas compression (about 40%) and other operations like transport and auxiliary loads (about 30%).

So, about a third of the power from the turbine goes directly to pump water or gas up and down from the reservoir, to ensure proper pressure support and drainage. Gas compression, as well as transporting the pumped flow to the platforms, are also energy-intensive processes.

The need for pressure support increases with the age of a field, along with the share of water and gas that are pumped up. This in turn increases the CO_2 footprint of the field (because more water and gas are pumped, to extract the same amount of resource. The worst offenders when it comes to emissions are therefore the oldest fields – they are also the fields where it is most difficult to reduce emissions, since the infrastructure has a short remaining life span, which makes improvements costly while giving little time to benefit from them. Through energy efficiency measures alone, the total emissions on the NCS could be reduced by up to 20 percent.

LowEmission also works on increasing the energy efficiency of the drainage process. We do this by calculating the amount of energy used in the flow processes. This allows us to see which parts of the processes have the biggest potential for energy savings – while keeping production at a stable, high level. Our measurements have given us an optimisation framework for both energy use and costs.

Optimising processes both in-well and topside involves identifying the areas where energy gets wasted, and establishing the potential for energy savings in transport and processing systems (for example), through recovering pressure and heat losses in various processes.

Another important aspect of our research is to examine processes on the platforms and under the seabed as a whole. By modelling these processes in an integrated manner, we discover larger potentials for emissions reduction than if we studied them separately. Different drainage strategies will impact the energy use topside in different ways – and the limitation of process equipment must also be taken into account.

Inversely, the reservoir itself will respond to any change in the inlet pressure from a platform, or the injection pressure; this too must be taken into account when optimising top-side. Flexible processes (injection, production and transport) can help enable the integration of renewable energy sources like wind power, when used together with other measure such as energy storage. To find the best strategy, we must understand the interplay between reservoir, transport and processing, including the technical and physical limitations and time constraints.

GAS TURBINES CAN BE IMPROVED OR REPLACED

The turbines powering the oil production on offshore platforms need to provide power continuously, and their energy source today is natural gas. A gas turbine typically has an efficiency rate of 25 to 40 percent. This means that not all the energy released by combusting the gas gets converted to electricity. Over half of it dissipates as heat. Some of this excess heat gets used for processes on the platform.

Since over 80 percent of the CO_2 emissions from oil and gas comes from gas turbines, the potential for improvements on this front is significant. These improvements range from making the turbines more efficient, to recovering their excess heat and introducing better designs; they can even include entirely new combustion technologies using carbon-free fuels.

Reducing emissions from gas turbines can be done by recovering the excess heat from their flue gas to produce electricity – through a process called bottoming cycle. This technology is already tried and tested, but it requires the installation of additional equipment on platforms that have limited extra space and load capacity. We are therefore working on developing compact and lightweight designs, that include for example the use of other liquids than water to run the turbines.

Both hydrogen and ammonia are viable options to decarbonise the gas turbines entirely. This requires improving existing combustion technology and developing entirely new solutions. Hydrogen can be produced both through electrolysis and with natural gas (in the latter case, with carbon capture and storage, to eliminate those emissions). On the platforms, existing pipe infrastructure can be used to blend hydrogen with the natural gas, which can be an effective emissions reduction solution if hydrogen is produced at times when there is a surplus of power. Hydrogen and ammonia can be used not only in oil production, but also in shipping, and to store surplus energy generated by wind power. Using these fuels in this manner would establish a whole value chain.

How weather conditions greatly influence emissions from offshore logistics

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The overall fleet of platform supply vessels (PSVs) contributes to approximately 1.5% of Norway's total annual CO_2 emissions. Weather impact affects the PSVs route planning and the performed voyages in terms of increased fuel consumption and hence, CO_2 emissions. By thoroughly assessing the weather impact when planning routes for platform supply vessels, it is possible to reduce emissions from PSV operations by 15-20% and create more robust schedules performing better in a larger range of unpredictable operational conditions.

OFFSHORE LOGISTICS PLANNING: ROUTING AND SCHEDULING

Figure 1 shows a simplified planning scheme used to represent how a fleet of three PSVs vessels continuously operate on three different routes in a weekly, cyclic sailing plan in order to meet cargo demands at a set of eight different offshore installations.

In a real-life setting, this weekly schedule can rarely be performed due to sudden changes in requested orders from the offshore installations.

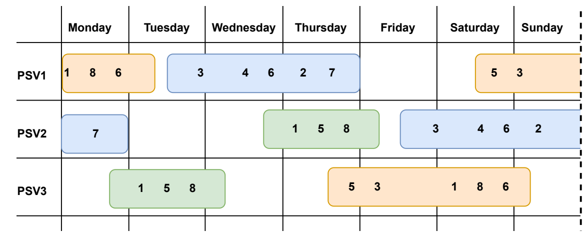
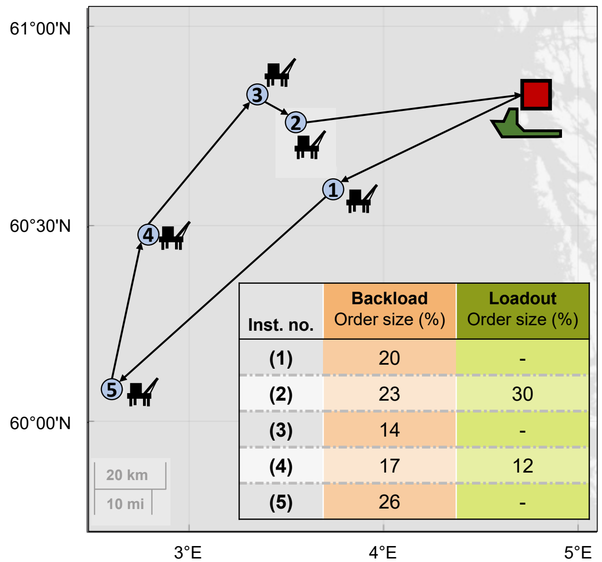


Figure 1 - A simplified planning scheme for PSV schedules in offshore logistics

Hence, the vessels need to be rescheduled, and key questions in this operational planning problem can be formulated as:

> *Which PSVs should service which installations, in which sequence, in order to make operations as fuel-efficient as possible while still meeting the requested demands?*

The illustration in Figure 2 provides a simple numerical example with a single PSV and five installations with demands as specified, highlighting the key features of the planning problem stated above.



Inst. no.	Backload Order size (%)	Loadout Order size (%)
(1)	20	-
(2)	23	30
(3)	14	-
(4)	17	12
(5)	26	-

Figure 2 - A small example of operational planning

It can easily be proven that the visiting sequence 1-5-4-3-2 (as shown) gives the optimal route (shortest distance sailed).

This route should be performed within a period of 48 hours, in order to be repeatable in a weekly schedule. When considering also time required for cargo handling, the remaining time available for completing the route yields a required average sailing speed of 11 knots.

WEATHER DEPENDENCY SIGNIFICANTLY COMPLICATES THE PLANNING PROCESS

If no considerations are made regarding the weather conditions during the period of performing the planned route, sailing every leg of the route at 11 knots will indeed be the least fuel-consuming alternative. However, we all know that there is no such thing as a day with completely calm seas in the North Sea. Once we account for the impact weather conditions have on the operation of PSVs, the least fuel-consuming schedule for a given route can only be found through a *speed optimization* process where speed can vary on every leg. The key feature of the weather-dependent speed optimization, is that the fuel consumption curves for the vessels *vary with time*. Hence, the most fuel-efficient speed also changes with time, and speed selections for one leg will affect the fuel consumption curves on all later legs on the same voyage.

Let's assume a weather forecast over the next 48 hours as shown in Figure 3. When considering the impact of weather conditions to the fuel consumption at a sufficiently high level of detail, the optimal speed selections for the six legs of the route displayed in Figure 2 are found to be 9, 11, 13, 12, 7 and 12 knots respectively – the average speed for the entire route remains at 11 knots, but these speed selections yields a 15%

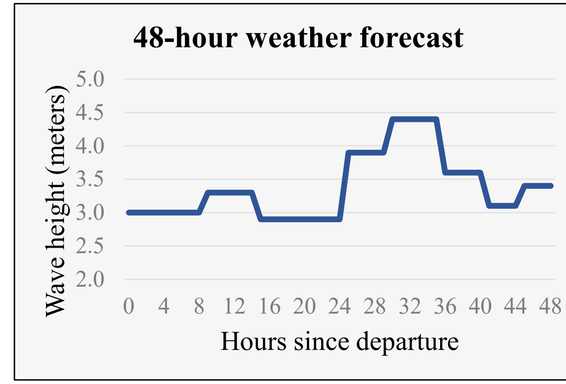


Figure 3 - A 48-hour weather forecast representative for the winter months

reduction of fuel consumption, compared to maintaining a constant speed on the entire route.

UNDERSTANDING THE TRUE WEATHER IMPACT ON THE PSVs IS OF GREAT IMPORTANCE

There are numerous ways of evaluating weather impact to vessels, and in order to fully utilize the potential of weather-dependent speed optimization, precise models for calculating fuel consumption in a wide range of sea states are required. In my most recent work, I emphasize the importance of addressing several characteristics of a given sea state, and find that

- Wave *heights* is the single most influential parameter that affects the PSV operations.
- At the same time, waves of a certain height can be very different in terms of energy density, which is dependent of the wave *period*.
- Lastly, the impact of wave *direction* has been assessed and found to have a large influence on the experienced weather impact to PSV operations. Figure 4 shows how the maximum attainable speed for a PSV that can sail in 15 knots in calm water is reduced for waves of different significant wave heights (Hs). As seen, only small reductions of maximum attainable speed are seen in following seas.

A SUMMARY OF KEY FINDINGS – HOW LARGE SAVINGS CAN BE ACHIEVED?

Perhaps more precise than talking about emission reductions, is to discuss the magnitude of *additional* emissions that can be avoided by thoroughly assessing the weather impact when planning routes for platform supply vessels. In my computational experiments, I have evaluated 25 sailing routes to and from installations serviced from Mongstad supply base for a set of ten different weather forecasts. The main results can be summarized as follows:

- On average, additional CO_2 emissions of 5-6 % are observed when wave heights are used as the only parameter to quantify weather impact. If no weather impact considerations are made, additional emissions can be as high as 15-20%.
- The worse weather conditions, the greater is the importance of accounting for weather.
- PSVs routes and schedules created in a weather-dependent routing framework are significantly more robust to sudden changes in weather or available sailing time on routes.

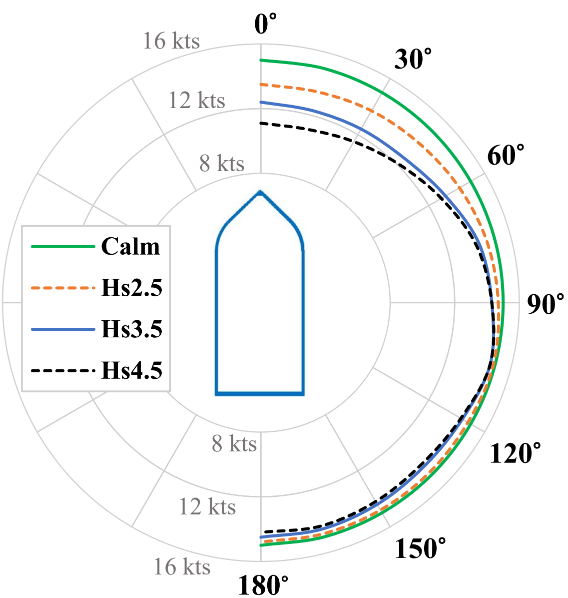
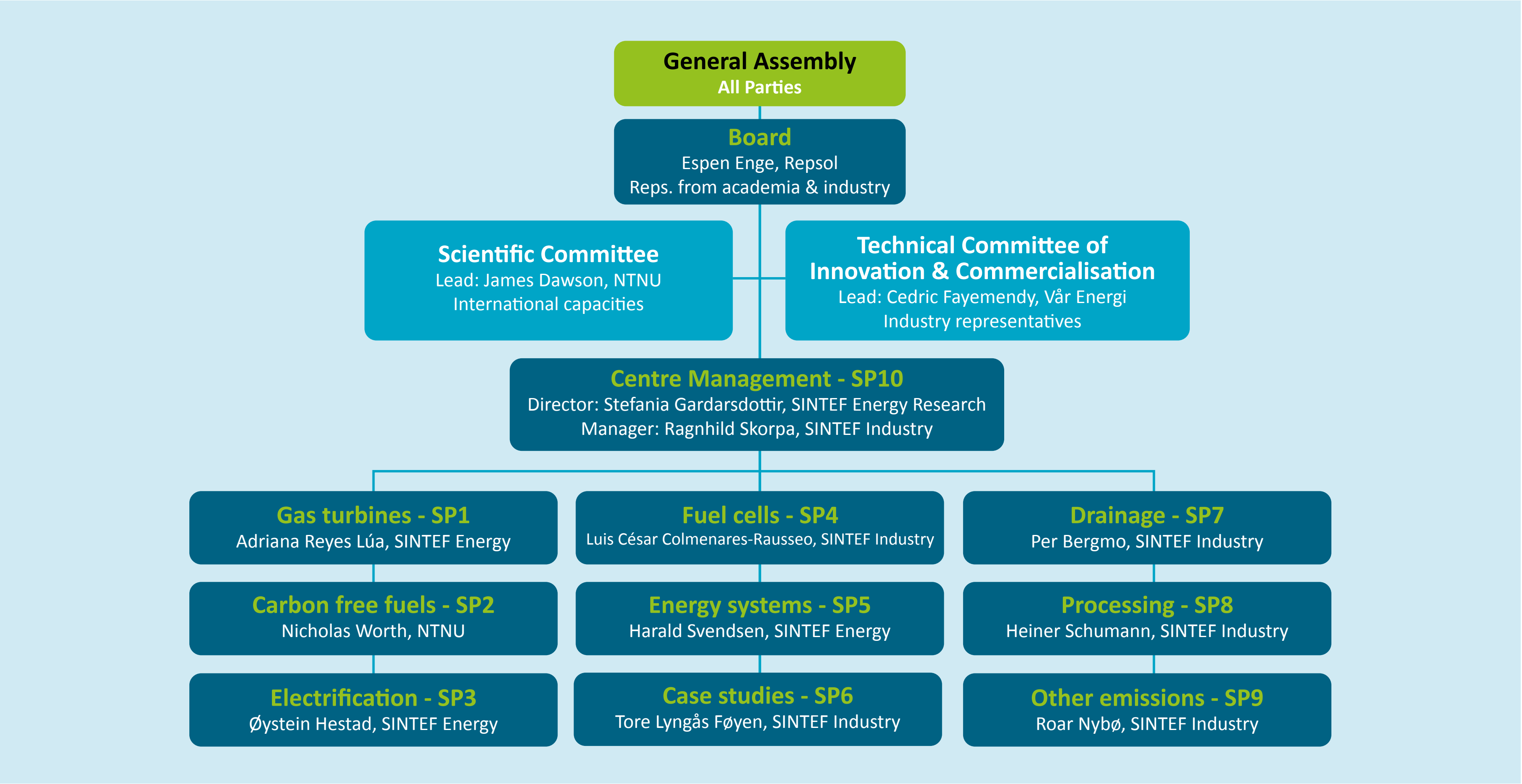


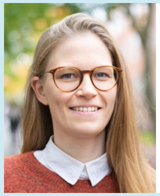
Figure 4 - Maximum attainable speed for a PSVs in waves of different heights and directions

Organisation

GOVERNANCE STRUCTURE



CENTRE MANAGEMENT TEAM 2022



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Vår Energi

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SINTEF Ocean

James Dawson
Lead for Scientific Committee
Professor
NTNU

Helen Berntsen Auflem
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SINTEF Energy Research

BOARD

The board of *LowEmission* 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 industry with representatives from SINTEF, NTNU and industry.

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

PARTNERS

Operators

Service & vendors

Research & development

SINTEF

NTNU

Public financing

The Research Council of Norway

Associated Research Entities

Berkeley University of California

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

Petroleumstilsynet

Norwegian Energy Partners

Oljedirektoratet

COOPERATION BETWEEN PARTNERS

An important arena for industry engagement are so-called Sub-Project families, where each of the Centre´s nine sub-projects have established a group of technical experts from the industry partners who directly contribute with their expertise. The Sub-Project families discuss matters such as strategies, operational plans for the coming year, communication and dissemination activities and research results, as well as performing quality assurance of results and publications.

Interactions between the SP-families and other governance bodies in the Centre, the Board and the Technical Committee are also vital. Larger event 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 five internationally recognised researchers in a variety of different topics relevant to the centre. 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 center with recommendations for improvement and highlight emerging topics that should be considered by the center. The SC meets on a yearly basis at the beginning of the academic year (August) starting in 2022.

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 study 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

The *LowEmission* webinar series was a success this year as well. Two webinar series were held in 2022, one in the spring and one in the autumn, with a total of 21 presentations. In the spring series we got to hear from our 12 PhD students, and in the autumn, we got 8 selected presentations form the *LowEmission* subprojects. Attendance has been steady between 20 – 40 participants in each webinar. This year the *LowEmission* webinars were also opened for the public. The events have been announced on LinkedIn and published on the *LowEmission* website.

The topics in the spring series were as follows:

- Blow-Out Behaviour of Ammonia/Hydrogen/Nitrogen-Air Flames, Martin Richter, PhD candidate, NTNU
- Power hardware-in-the-loop: matching real life full-scale and laboratory downscaled power electronic converters, Daniel Mota, PhD candidate, NTNU
- Weather-dependent offshore logistics planning, Andreas Ormevik, PhD candidate, NTNU
- Effects of well placement on CO_2 emissions from waterflooding operation, Gusti Agung Gede, PhD candidate, NTNU
- Optimization of power consumption for emissions reduction in oil and gas processing plant, Handita Reksi Dwitantra Sutoyo, PhD candidate, NTNU

- Emission reduction in offshore gas turbine power cycles by low footprint solutions, Mohammad Ali Motamed, PhD candidate, NTNU
- Combustion of ammonia/hydrogen blends in staged gas turbines, Aksel Ånestad, PhD candidate, NTNU
- Modelling of ammonia combustion, Jessica Gaucherand, PhD candidate, NTNU
- Optimal operation of offshore hybrid power systems, Kiet Tuan Hoang, PhD candidate, NTNU
- Analysis of degraded aluminium conductor screen of service aged XLPE cable, Amar Abideen, PhD candidate, NTNU
- Investment planning of the North Sea energy system under uncertainty, Hongyu Zhang, PhD candidate, NTNU
- Topside Model considering Periodic Power Supply from Renewable Energy Sources, Leila Eyni, PhD candidate, NTNU

The topics in the autumn series were as follows:

- *LowEmission* centre – where are we now and the way ahead, Stefania Gardarsdottir, Centre Director *LowEmission*, SINTEF Energy
- Electrical ageing and temperature cycling of XLPE insulation saturated with water, Torbjørn Andersen Ve, Research Scientist, SINTEF Energy Research
- Nature of methane emissions from offshore platforms and the frequency of site-wide measurements that are needed, Daniel Krause, Sr. Engineer, SINTEF Ocean
- Operation and Control of Offshore Combined Cycles, Cristina Zotică, Researcher, SINTEF Energy Research
- Introduction to Virtual FCS library a multi-scale cyber-physical platform for designing and optimising fuel cell battery hybrid systems, Yash Raka, Research Scientist, SINTEF Industry
- An open source framework for Integrated Production Modelling (IPM) – collaboration of *LowEmission* and the DigiWell project, Thiago Silva and Paul Roger Leinan, Researchers, SINTEF Industri
- Reservoir response to variation in injection and production at different timescales, Per Bergmo, Research Scientist, SINTEF Industry.
- High-resolution numerical modelling of flame stabilization in a geometrically simplified Flamesheet burner for hydrogen-fired gas turbines, Andrea Gruber, Senior Research Scientist, SINTEF Energy Reseach

CONSORTIUM DAYS

The annual *LowEmission* Consortium days were held on 23-24 November in Trondheim. It was an occasion for researchers and industry representatives to exchange ideas and learn about the latest technological developments. The event gathered around 100 participants.

Keynote speakers for the conference were Hege Rognø, Head of Equinor's technology development within Low Carbon Oil and Gas Technologies, who said that the "code red" signals from the UN are clear. More needs to happen, faster, to reach 50% emissions reduction by 2030. Gunnar Lille, managing director at OG21, talked about the changes in the energy context due to the war in Ukraine, and how these changes impact the energy transition plans. Linda Karlsen, VP Performance, Aker Solutions, presented her organisation's plans to make renewables and transitional energy solutions their biggest business in 2030. *LowEmission* Centre Director Stefania Gardardsdottir presented a summary of the Centre's activity over the past year.

Two panel debates took place. The first one, moderated by Centre Chair Espen Enge (Repsol), was about using innovation to accelerate the implementation of new solutions. Astri Kvassnes (Restone), Torleif Husebø (Petroleum Safety Authority Norway), Eli Grong Aursand (SINTEF TTO and Venture) and Andrea Schmueli (SINTEF) participated in the panel discussion.

In the second panel debate, participants discussed the fact that lots of emissions reduction technologies are ready to go but are not being implemented due to barriers. Such barriers

can be competition between companies and knowledge gaps from one sector to the other. The conclusion was that collaboration must increase between companies, whether they are vendors or operators, to rapidly implement the decarbonisation solutions that are ready. This panel was moderated by Kristin Jordal (SINTEF), and the participants were Jill Leikvoll (Aker Solutions), Lennart Näs (Siemens Energy), Asmund Maeland (ABB), Gunnar Lille (OG21) and Kristin Skavang (Aibel).

A number of technical and scientific presentations were also given, both by PhD candidates, the industry and participants in case studies and spin-off projects of *LowEmission*.

The closing address was given by Simen Moxnes, Senior Advisor New Energy Systems at Equinor. In his speech, he outlined how the North Sea can remain a European energy centre after the energy transition.

RESEARCH AND RESULTS

SP1

Efficiency enhancement of gas turbines

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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 2022

- Robustifying underlying models both for speed-up, heat source flexibility, and stability of geometry describing heat recovery steam generators for offshore bottoming cycles.
- Development of models for printed circuit heat exchangers for improved performance.
- Updated simulation results for a simple steam power cycle and for a recuperated CO_2 cycle.
- Definition of the control problem for bottoming cycles for power production. Implementation of advanced control structures for steam bottoming cycles for power production in Dymola.
- Simulation results of dynamic model of a steam bottoming cycle for power production and a combined cycle with two gas turbines and a steam bottoming cycle for power production.
- Three peer-reviewed publications:
  - M. A. Motamed, and L. O. Nord (2022) "Part-load efficiency boost in offshore organic Rankine cycles with a cooling water flow rate control strategy". Energy. vol. 257. ddoi: 10.1016/j.energy.2022.124713
  - C. Zotică, R. M. Montañés, A. Reyes-Lúa, and S. Skogestad, (2022) "Control of steam bottoming cycles using nonlinear input and output transformations for feedforward disturbance rejection," *IFAC-PapersOnLine*, vol. 55, no. 7, pp. 969–974, doi: 10.1016/j.ifacol.2022.07.570.
  - M. A. Motamed, and L. O. Nord (2022) "Development of a simulation tool for design and off-design performance assessment of offshore combined heat and power cycles". Proceedings of the 63rd International Conference of Scandinavian Simulation Society, SIMS 2022, Trondheim, Norway, September 20-21, 2022. doi: 10.3384/ecp192001
- Three oral presentations in international conferences:
  - SIMS 2022: 63rd International Conference of Scandinavian Simulation Society (Trondheim, Norway, Sep. 20-21) Oral presentation: "Development of a simulation tool for design and off-design performance assessment of offshore combined heat and power cycles".
  - DYCOPS 2022: 13th IFAC Symposium on Dynamics and Control of Process Systems, including Biosystems (Busan, Korea/Hybrid, June 14-17) Oral presentation: "Control of steam bottoming cycles using nonlinear input and output transformations".
  - NPCW - Nordic Process Control Workshop. (Luleå, Sweden, 17-18 March). Oral presentation: "Static input transformations for disturbance rejection, decoupling and linearization - with application to temperature control for steam generators".
- Lead in Case Study (2022-2023) "Advanced power fluctuation control for combined wind, gas and steam turbine systems", in which the dynamic CCGT model developed in SP1 is used using data. Cooperation with SP5.
- One successful KSP spin-off application (DECAMMP). Together with SP2. Project to start in 2023.

IMPACT AND INNOVATIONS

- Development of a simulation tool for design and off-design performance assessment of offshore combined heat and power cycles.
- Definition of control problem and dynamic simulation results for compact offshore steam bottoming cycles for power production using advanced control structures implemented in a detailed dynamic model.
- Advancement in understanding of bottoming cycles using CO_2 as working fluid and its potential for weight, size, and performance improvement.

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 2022

- **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. Novel extinction strain rate measurements were reported in the Proceedings of the Combustion Institute journal.
- **WP1.2** Novel confinement effects in a single flame were reported in the ASME Journal of Engineering for Gas Turbines and Power. Additionally, a simplified axially staged burner was used to investigate burner staging strategies at atmospheric pressure during CH_4, NH_3/H_2, or H_2 fuelling, demonstrating the flexibility of this configuration. A draft paper was submitted to the ASME 2023 Turbo Expo.
- **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. Preliminary results indicate that the favourable pressure scaling effect plateaus beyond 5 bar, but more work is needed to assess the role of the flame structure in this scaling. Corresponding results in a DLE gas turbine burner were published as a conference paper at the 2022 ASME Turbo Expo.
- **WP1.3** Additional funding was awarded for the study of non-premixed NH_3/CH_4 flames under pressurised conditions. The results provided an assessment about the rate of decarbonisation that could be achieved, and the corresponding NOx emissions, which are highly relevant for the Elgin and Franklin O&G fields.
- **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 draft paper was submitted to the ASME 2023 Turbo Expo.
- **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. Further studies using DNS will be conducted in collaboration with CERFACS to better understand thermo-diffusive instabilities. Papers have been prepared for the European Combustion Meeting (Rouen, France, 2023), and the 63rd International Conference of Scandinavian Simulation Society (Trondheim, Norway).

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 novel results in WP1.3 demonstrating the favourable scaling of emissions with pressure indicate the potential feasibility of ammonia blended fuels in practical devices, with the potential for rapid deployment.

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.

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:

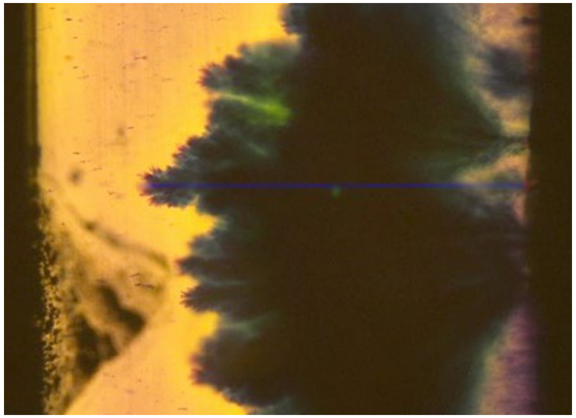
- Identify/develop cost-efficient, reliable power components for offshore/subsea power distribution
- Test components/insulation systems based on models of typical load patterns
- Develop models for estimation of global GHG emission reduction due to electrification

MAIN RESULTS IN 2022

- EMPIRE, the Energy system model previously used in *LowEmission* Center, has been re-coded in the programming language Julia, a more efficient, data-focused, and modern software which will provide better performance on larger cases in the future experimental simulations in the centre.
- *Subsea Connectors:* Experimental setup for testing cable samples with slip-on terminations was prepared, and preliminary experiments were finalized. Material characterization and numerical simulations were conducted, which are essential foundations for further work within the centre and in the spin-off project KSP SeaConnect.
- The aging setup for MVAC cables to investigate SIED mechanisms (water treeing mechanism in cables with aluminium conductor) is running.
- Investigation of the SIED mechanism revealed what we believe to be a link between the increased adhesion between the conductor screen and the conductor due to the formation of a corrosion layer on the conductor surface with the formation of SIED structures in the conductor screen. This hypothesis will be further investigated in 2023.
- The first phase of the study on the effect of temperature cycling on water treeing in XLPE was finalized and presented at ICD 2022. Results show that thermal cycling with rapid cooling will significantly increase water treeing in cables with ionic contaminants. For offshore wind farm cables, which are subjected to large and frequent temperature variations, it is therefore of great importance to continue to increase the cleanliness of such cable insulation systems and identify and remove severe sources for water treeing.
- Preliminary assessments were conducted on the global balance of CO_2 emissions resulting from offshore electrification.

IMPACT AND INNOVATIONS

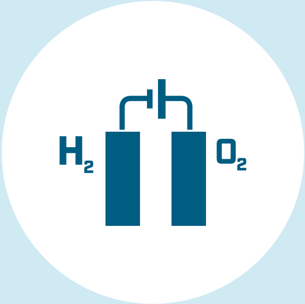
- HV wet design cables: The proposed new hypothesis for the main cause of the Stress-Induced Electrochemical Degradation (SIED) mechanism for water tree degradation of sub-sea cables is to be tested in 2023. Important work on a methodology for investigating the root cause of water treeing will be used and further refined in the 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.
- HV Subsea connectors: Novel approach of applying additional external radial pressure on the field grading cone to facilitate a controlled but significantly increased interfacial pressure investigated, setup in the lab finalized, will be further developed in the spin-off project SeaConnect.
- Implementation of methodologies to measure the environmental impact of offshore electrification



Example of a long water tree observed after ageing (757 μm) growing from a sodium chloride inclusion positioned at the lower semiconductor

SP4

Fuel cells for zero emission heat and power



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This subproject investigates the use of fuel cell technology, considering the varying requirements of heat and power, hydrogen management and integration into the offshore energy system. Specific research includes 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 planned.

MAIN OBJECTIVE

SP4 aims at investigating the use of fuel cell technologies in the offshore energy system. For instance, by hybridisation, fuel cells may contribute to CO_2-emissions reduction by a 5-10%. 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.

MAIN RESULTS IN 2022

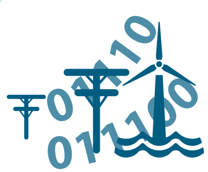
- By using a PEMFC stack (8kW) provided by an industrial partner, four different maritime load profiles were identified and performed on the fuel cell for periods of 24 hours. It was determined that the type of dynamic cycle has some impact on the amount of reversible degradation seen in the fuel cell, with cycles that are more dynamic in nature causing more degradation due to poor water balance and catalyst surface oxidation. However longer cycling times (>1000 h) need to be implemented before significant irreversible degradation is seen.
- Ammonia is classified as a sticky impurity, meaning it can be adsorbed onto the walls of tubing as well as the catalyst material or membrane. The dynamic nature of adsorption and desorption processes with NH_3 concentrations below 1 ppm in the tubing of a test station was investigated as a prerequisite to perform accurate and reproduceable sub-ppm level NH_3 impurity single cell tests. The effect of temperature, humidity, surface area, and NH_3 concentration in combination with pressure, gas flow rate, tube material needs to be considered for a better understanding the effect of NH3 on PEMFC performance.
- An optimized steam/air electrode for reversible operation of a PCFC has been developed, resulting in a 50% reduction in electrode resistance. A long-term durability test (>1750 h) of a single cell in pressurized operation was performed, investigating the impact of process parameters, and cycling interval for reversible operation. It is remarkable the durability and low degradation rate of the cell when operated in reversible mode, being the overall degradation rate below 2%/khr in both modes of operation, although the largest degradation rate is observed during the fuel cell operation.

IMPACT AND INNOVATIONS

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 fuel cell technology would support innovative solutions for production of electricity and pressurization of dry H_2 offshore.

SP5

Energy systems – digital solutions



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This subproject develops generic methods, models and digital tools for analysis and optimisation of integrated offshore energy systems with renewable energy supply, to enable cost-effective designs and reliable and stable energy systems with low or zero CO_2 emissions. Integration of various low emission technologies is in focus. 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.

- Improve Hyopt and Oogeso optimisation models to better support investment and operational planning decisions
- Propose and assess power system control strategies for stable and efficient electrical systems with less gas turbines and more power electronics
- Improve integrated physics-based modelling and data-driven analysis methods to evaluate energy demand and emissions
- Prepare and submit 3 or more scientific papers

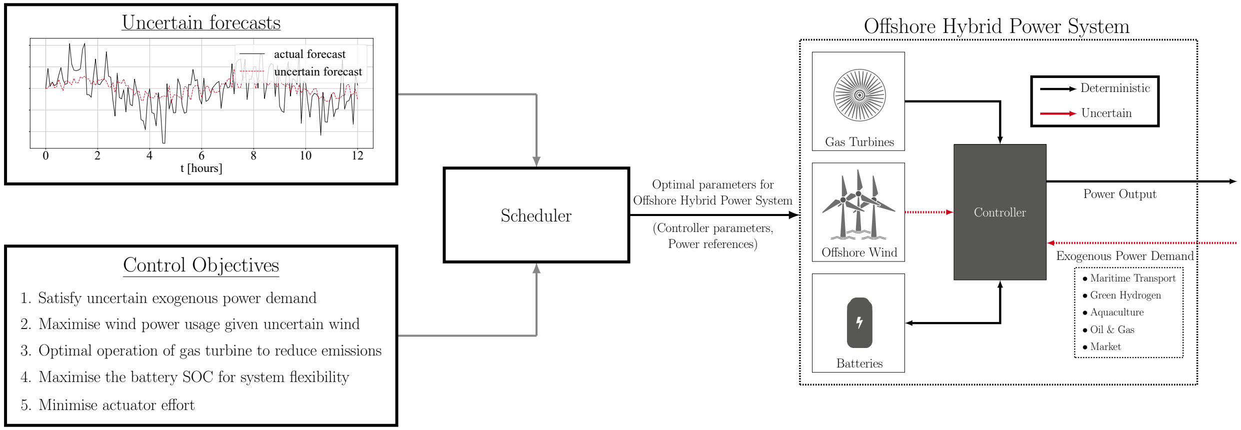
MAIN RESULTS IN 2022

- Strategic uncertainty included in the HyOpt investment planning model and demonstrated in a test case. Investigated potential for code restructuring to reduce computation times.
- The LEOGO reference platform specification has been updated based on industry input and published as an open dataset (version 2.0) and journal paper.
- Further advanced data-driven methods to estimate long-term energy demand on the NCS, with initial focus on water injection processes.
- Offshore energy hubs
- Good progress on phd topic decarbonisation of offshore energy systems (H Zhang)
- Good progress on phd topic model predictive control for hybrid systems (K Hoang)
- Good progress on phd topic electrical control/ stability for offshore energy systems (D Mota)
- Productive research visits by PhD students to Berkeley, US (Kiet Hoang) and Carnegie Mellon University, US (Hongyu Zhang)
- Scientific paper publications well beyond target, including an Energy journal publication on offshore energy hubs, an IET Energy Systems Integration publication, and several conference publications in conference proceedings.

IMPACT AND INNOVATIONS

- The Oogeso and HyOpt software models for energy system optimisation in operation and investment planning can be used by operators and suppliers for decision support or to identify needs. Both models are available as open-source.
- The electrical modelling lays the foundation for detailed investigations addressing power system stability with the integration of different kinds of low emission technology (e.g. wind power, fuel cells, variable loads). The use of the LEOGO open model facilitates knowledge building and information sharing prior to case-specific analyses.
- Coupling of reservoir and topside models to perform detailed analyses of the impact of variable water injection rates

Kiet Hoang phd work:



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. Studies on the economic aspects of technology development through advanced techno-economic analyses are also performed.

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 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 2022

Seven new case studies were initiated through an industry lead nomination prosses. The seven case studies will be completed in April 2023 and presented in webinar series in May-June. The seven case studies are listed below.

Application of heat pumps for better heat integration of process streams
Evaluating the use of HTHPs as an alternative for direct electric heating in case of electrification of offshore oil and gas production unit.

Emission reduction potential of Cold Flow demonstrated for a real field case
Demonstrate the emission advantage or possible energy saving as well as the technical limitations of Cold Flow, which enables flow of hydrocarbon production fluids at thermodynamic equilibrium in uninsulated pipelines, without the help of chemical modifiers.

Options for sequestering CO_2 from offshore installations
Investigate and compare the cost, footprint and energy use associated with different local and small-scale CO_2 capture and storage solutions.

Advanced power fluctuation control for combined wind, gas and steam turbine systems
Assess how advanced process control can guarantee reliable offshore power generation in a system with a combined cycle and wind power

Ekofisk - Impact of wind turbines on gas turbine operation and power system stability
Quantify the impact of offshore wind turbines connected to the Ekofisk power system on gas turbine operation and power system stability, and to propose and assess possible measures to decrease undesired implications.

Electrification of the NCS with offshore wind and power to shore
Assess how best to reduce NCS CO_2 power generation emissions by electrification from offshore wind energy with net power to shore.

Use of low- and zero-emission technologies and alternative energy carriers in supply vessel fleets
Accelerate the transition towards sustainable zero-emission offshore logistics by 2050 through an integrated application of zero-emission fuels, energy-saving technologies and energy-efficient operations.

IMPACT AND INNOVATIONS

Three new Knowledge-building Project for Industry with *LowEmission* partners and research was granted in June. All three project proposals were based on findings from previous case studies. Demonstrating how the subtask contributes to identifying key barriers to implementing *LowEmission* technologies and how they can be overcome by focus and target R&D.

The three projects are:
- DECAAMP, led by SP1 manager Adrina Reyes Lua
- Sea Connect, led by SP3 research led by Emre Kantar
- Hy4GET, led by SP6 manager Tore Føyen

SP7

Energy efficient drainage

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This subproject analyses the energy use for different reservoir drainage strategies. Potential reductions in energy use will be identified, both for implementation on short time scales in mature fields, and on longer time scales for new field developments.

MAIN OBJECTIVE

Assess and quantify energy use coupled to sub-surface 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 technologies on field scale models, quantifying energy use and reduction potential.
- Further developing optimisation frameworks to enable maximised oil and gas recovery combined with reduced energy needs and costs.

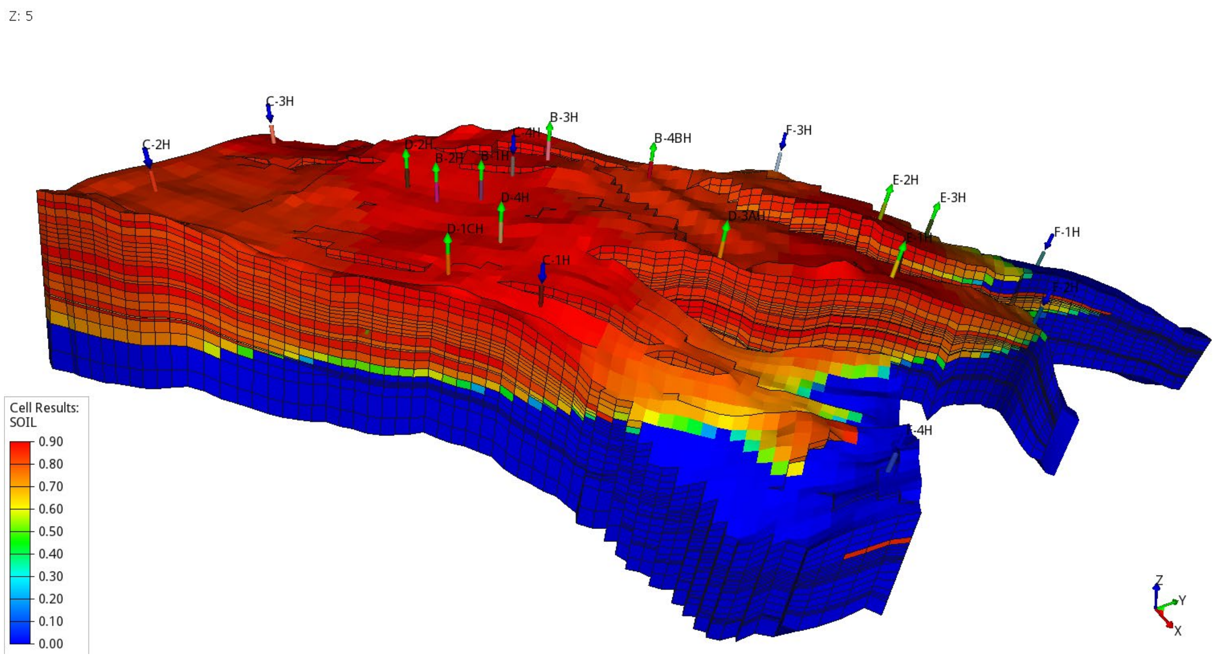
MAIN RESULTS IN 2022

- The tool for calculation and visualisation of energy dissipation in the subsurface developed in 2020 has been revisited and updated. Optimising the code resulted in a speedup of 100 for the most time-consuming part of the code, making the tool more applicable for field scale use.

- Effect of changing production tubing size for increasing water cut production has been studied using the multiphase simulator LedaFlow. Varying the production tubing did not significantly change the flow regimes to give less pressure drop in the wells.
- The simulation of using water shutoff technology on the modified Norne field model to reduce energy consumption was finalised. Large reduction in energy used for water injection and production can be achieved, but with a penalty in reduced oil production.
- The work on an integrated topside-subsurface model together with SP8 is continuing. A summer student made the first prototype of a fully coupled model. The work is done in collaboration with the DigiWell project (KSP-project).
- A case study investigating different options for sequestering CO_2 captured from offshore gas turbines was started. The study considers injection of carbonated water in an oil field or aquifer as well as transport by ship or pipeline to existing or nearby storage sites.
- Four conference contributions and two journal papers were produced.

IMPACT AND INNOVATIONS

- Potential for reduction of energy use and CO_2 emissions have been shown by use of water shutoff technology on generic field scale models.
- Methodology for co-optimisation of oil and gas production, energy use, emission and costs have been applied to several drainage strategies.
- Tool for analysing energy dissipation in the subsurface has been constructed.



Initial oil saturation in the modified Norne field model used in SP7 for field scale assessment of drainage strategies to reduce energy consumption. The model has 7 water injection wells and 11 oil production wells.

SP8

Energy-efficient processing

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This subproject demonstrates new technologies (and improves existing ones) for subsea, in-well and topside processing with minimal energy use.

MAIN OBJECTIVE

The main objective of SP8 is twofold: to demonstrate and optimise the use of new technologies for subsea, in-well and topside processing with minimal energy consumption for new and existing field developments on the NCS; and to support industrial uptake of the innovations. This will be achieved by:

- Demonstrating energy wastage and identifying the potential for efficiency improvements.
- Testing new technologies and concepts to accelerate their implementation.
- Demonstrating "non-intrusive" process optimisation solutions for existing fields.
- Studying measures necessary to meet challenges arising from future energy supply solutions (examples of such challenges: unsteady energy supply, little excess heat).

MAIN RESULTS IN 2022

- A literature study on early water removal technology was performed describing several solutions for subsea and in-well separation. The study will be background for further research on optimum field design and energy efficient transport methods. Early water

removal will lead to reduced energy demand for transporting. In addition, the need for water injection as pressure support is reduced by lowering the backpressure in wells.
- The work on topside energy recovery and more efficient pumping systems was finalized. An investment-benefit study for the use of plunger pumps replacing centrifugal pumps was performed. Energy savings of several MW are possible. An upgrade before production start is most beneficial. Still, also a late life upgrade after plateau production has passed can be profitable.
- A case study was started investigating the feasibility and energy saving potential of using heat pumps for integrated heat management on an electrified FPSO. In particular for electrified fields, the absence of available waste heat from gas turbines will require alternative efficient heating methods. The study is performed in close collaboration with Altera Infrastructure.
- A case study demonstrating the energy saving potential of the cold flow technology was started. Cold Flow is a 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
- Solutions for flexible production as measure for balancing variable power supply from offshore wind turbines was studied. It was found that the utilization of an oil tank as well as the variable pressure in gas export pipes can be used to secure constant export rates even at variable production rates.
- Two conference contributions and two journal publications were produced in 2022:
  - Holt, Torleif, and Heiner Schümann. "Energy Efficient Operation of Petroleum Production Plants." Paper presented at the SPE Norway Subsurface Conference, Bergen, Norway, April 2022. doi: https://doi.org/10.2118/209539-MS
  - Leila Eyni, Milan Stanko, Heiner Schümann, Methods for early-phase planning of offshore fields considering environmental performance, Energy, Volume 256, 2022, https://doi.org/10.1016/j.energy.2022.124495.
  - Eyni, L, Fattahi, M, Schümann, H, Lund, F, Stanko, M, & Strømmegjerde, L. "Technical and Environmental Evaluation of a Hydrate Cold Flow Technique to Produce an Oil Reservoir Using a Long Tie-Back and Comparison Against Traditional Development Concepts." Proceedings of the ASME 2022 41st International Conference on Ocean, Offshore and Arctic Engineering. Volume 3: Materials Technology; Pipelines, Risers, and Subsea Systems. Hamburg, Germany. June 5–10, 2022. V003T04A019. ASME. https://doi.org/10.1115/OMAE2022-79513
  - Eyni, L.; Stanko, M.; Schümann, H.; Qureshi, A.H. Dynamic Process Modeling of Topside Systems for Evaluating Power Consumption and Possibilities of Using Wind Power. Energies 2022, 15, 9482. https://doi.org/10.3390/en15249482

IMPACT AND INNOVATIONS

- The energy saving potential of several MW as well as costs and cost benefits for more efficient pump systems based on plunger pumps was shown
- 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 is shown 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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This subproject seeks to reduce emissions from mobile units through logistics optimisation and zero-emission vessels, and to reduce methane and other emissions.

MAIN OBJECTIVE

SP9 has two objectives: to reduce emissions from offshore mobile units by optimising logistics and ensuring the use of low-emission vessels; and to reduce methane and non-methane volatile organic compounds (NMVOC) emissions from crude oil tankers and installations.

MAIN RESULTS IN 2022

Offshore logistics

2022 has seen SP9 further pursuing software development for operational vessel planning. More efficient planning leads to a more efficient vessel utilization and thus reduced emissions which is a goal for operators' in-house planners. A detailed description of a realistic PSV operational planning problem has been formulated. As part of a prototype for the LOGOps planning tool, work was started on a simulator that takes such a scenario as input and simulates the outcome of plans based on expected weather conditions.

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.

Hybrid propulsion

In 2022 this task worked primarily on initiating work on ammonia as a fuel in hybrid energy systems for mobile offshore units. The first half of the year was used on reviewing the current status through a study of relevant research literature and associated data with a primary focus on offshore supply vessels. This work was summarised in a memo that provides an overview of the literature study.

This work was further used as a basis for collecting available cost and technical data for the various variants for using ammonia as a fuel (both in fuel cell systems and for direct combustion). The data gathered will be used for technoeconomic studies in 2023 using the HyOpt optimization model.

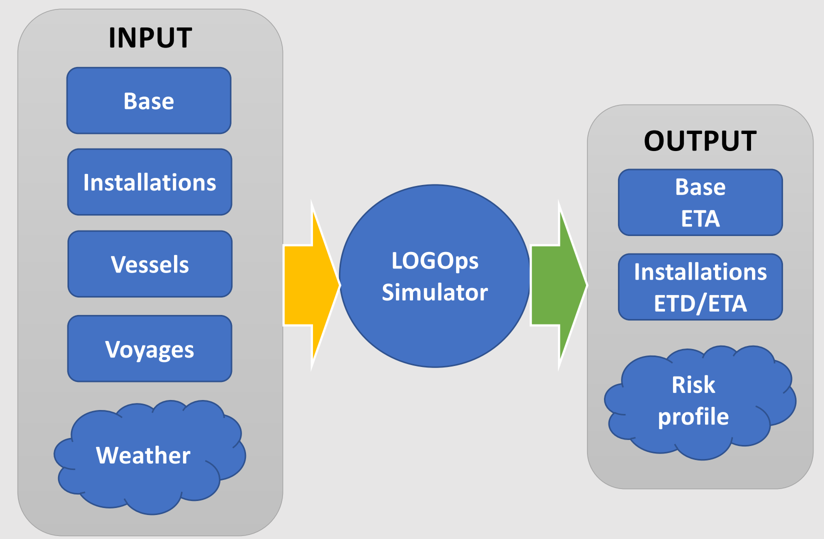
Methane emissions

Methane is a powerful greenhouse gas and one of the many sources of its emissions is the loading, transport and unloading of crude oil. In 2022 we studied under what conditions free gas is released in pipes on the ship during loading.

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 2022 we have spread awareness about these issues in the industry and continue to work with industry to evaluate and demonstrate new monitoring schemes.

IMPACT AND INNOVATIONS

The software in development in SP9 lays a foundation for more cooperation between actors in the offshore supply chains. Together with our work on energy systems for mobile units, the work will help make informed investment decisions when seeking to minimise emissions from the supply vessel fleet.



OPERATIONAL ROUTING AND SCHEDULING OF OFFSHORE SUPPLY VESSELS

Innovations

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

MAPPING OF *LOWEMISSION* INNOVATIONS

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 new application of existing knowledge or commercialisation of R&D results.

This definition has provided a basis for mapping of innovations in the Centre, carried out during first half of 2022. This mapping includes considerations on "Success probability", "Emission reduction potential", "Category of innovation", "Technology Readiness Level (TRL)" and involvement/relevance to industry partners.

So far, around 30 potential innovations have been identified in *LowEmission*. The innovations are systematically documented and followed up through the Centre research activities and potential spin-off activities.

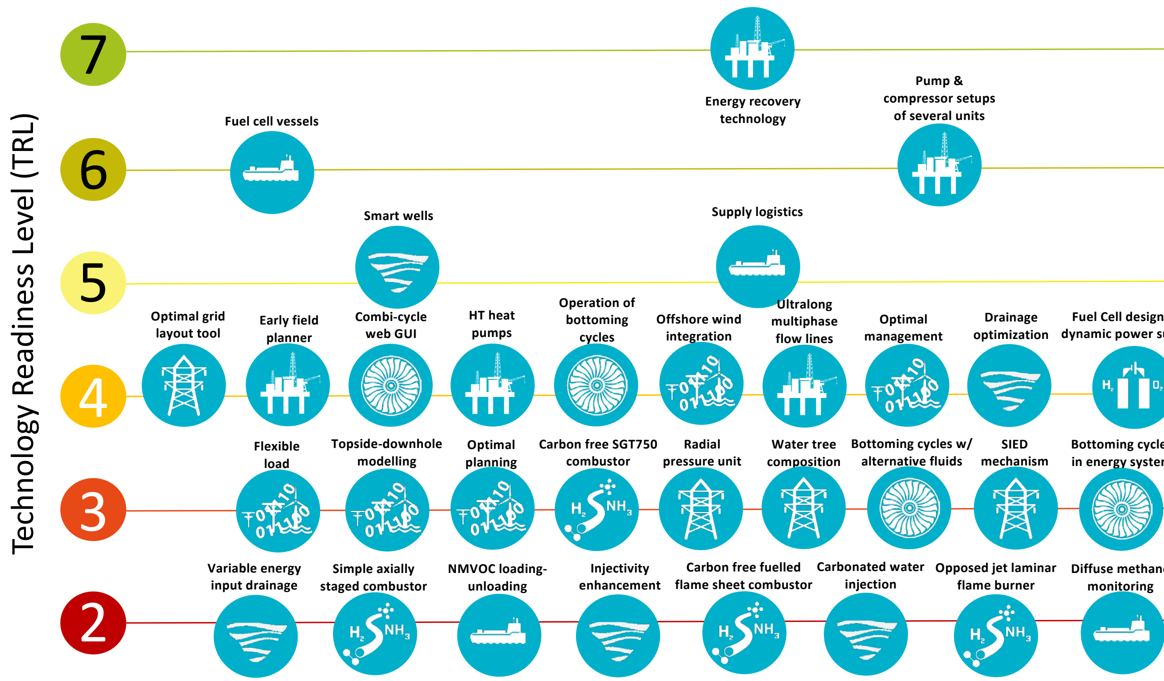


Figure 10. Identified potential Innovations in LowEmisison

Featured innovations

TESTING OF CARBON FREE FUELS FOR FUTURE GAS TURBINE COMBUSTION SYSTEMS

Key researchers: Nicholas Worth (NTNU), Andrea Gruber (SINTEF), Mario Ditaranto (SINTEF), James Dawson (NTNU), Terese Løvås (NTNU), Jonas Moeck (NTNU).

Carbon free fuel blends are being tested in geometry which is highly relevant for the Siemens Energy SGT750 and Thomassen Energy Flamesheet gas turbine combustion systems. This testing will help us to understand the combustion performance of novel fuel blends involving ammonia and hydrogen on these devices, including the emissions performance, as well as flame stabilisation, dynamic stability and resistence to flashback and blow-off. These fundamental research findings will be essential in future innovative design modifications to the combustor geometry permitting them to burn carbon free fuels. While the work undertaken in research centre is relatively low TRL (typically 1-3), future practical implementation by GT manufacturers would be expected to take this to much higher levels, before eventually reaching the commercialization stage.

Furthermore, as part of the fundamental research work undertaken in SP2, a number of innovative lab scale burners have been developed. A new opposed jet burner allows the investigation of fundamental flame properties for novel carbon free fuel blends. The burner consists of two opposed laminar jets, which are used to stabilise a counterflow flame, with optical access for advanced measurement diagnostics. The setup will allow such measurements to be performed more easily in future, improving our understanding of new carbon free fuel blends. Additionally, a new simple axially staged burner allows key features of a can combustor with radial downstream fuel injection to be tested on a simple generic geometric design, allowing the emissions performance and stability to be assessed with different fuel splits and fuel blends.

INTEGRATED TOPSIDE-DOWNHOLE MODELLING

Key researchers: Roar Nybø (SINTEF), Harald Svendsen (SINTEF), Per Eirik S. Bergmo (SINTEF), Heiner Schümann (SINTEF), Jan Ole Skogestad (SINTEF), Alf Arne Grimstad (SINTEF), Roar Nybø (SINTEF), I Gusti Agung Gede Angga (NTNU).

In the digitalization of oil and gas, collaboration across disciplines may create new opportunities for optimization and emission reductions. A prominent example is "Integrated Asset Modelling" (IAM) which is an industry term referring to computer models that represent the subsurface reservoir and the surface infrastructure as one integrated system. The IAM approach allows a more holistic approach to field management, with better utilization of existing data streams, to optimize production over the lifetime of the field.

Gathering both researchers from subsurface and surface discipline, the *LowEmission* center is uniquely well suited to explore this approach for reduction of CO_2 emissions. Sub-projects SP5, 7 and 8 have investigated emissions associated with water injection pumps. CO_2-emissions could be reduced if the pumps were ramped up and down in sync with the availability of green energy, whether from wind power or green fuels in the gas turbines. Rather than surface control treating the subsurface as a "black box" with a fixed requirement for injection rates, we ask what's possible when you open up the silos and optimize for CO_2-reduction. We find that, depending on both surface and subsurface conditions, it can be perfectly admissible to vary or reduce the injection rate. An IAM approach also calls into question emissions from backup power that ensure constant injection rates. Broadening the scope from traditional IAM to the field's energy grid, we could regulate the pumps as load balancing of the grid, similar to the "smart grid" approach onshore.

SUPPLY LOGISTICS PLANNING TOOLS

Key researchers: Victoria Gribkovskaia (SINTEF), Elin Espeland Halvorsen-Weare (SINTEF), Yauheni Kisialiou (SINTEF), Lars Magne Nonås (SINTEF).

Offshore supply logistics is one of the key elements in the upstream oil and gas value chain. Highly specialised offshore supply vessels (OSVs) are in daily operations between onshore bases and installations and rigs offshore. Scheduling and routing of these vessels are highly complex planning tasks with a multitude of time-critical constraints. SINTEF Ocean developed an optimisation-based planning tool for decision support on fleet size and schedules for OSVs operating from the same base called MOLO (Maritime Offshore Logistics Optimisation).

The tool can provide the user with optimised weekly schedules and a selection of vessels best suited for performing the supply tasks. The user can also assess plans developed manually or effects of changes introduces to them with the help of the tool. All operators under the *LowEmission* centre are given open access to the tool and are encouraged to test it and suggest new functionalities. Currently, SINTEF Ocean is working on developing a more operational planning tool LogOps aimed at providing decision support for day-to-day OSV operations that take into account unplanned demand fluctuations, and effects of weather on vessel's performance.

Spin-off projects

LowEmission has contributed to the launch of several spin-off projects, solving specific challenges for the industry. In total, six 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 spin-offs such as Innovation Projects for the Industry (IPN) and Green Platform projects.

NEW KSP SPIN-OFF PROJECTS GRANTED FUNDING IN 2022:

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: Tore Lyngås Føyen, SINTEF Industry

SeaConnect – High Voltage Subsea Connections for Resilient Renewable Offshore Grids

- Objective: to significantly increase the breakdown 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. reactor 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

ONGOING KSP SPIN-OFF PROJECTS

CleanOFF Hub – Clean Offshore Heat and Power Hub

- Objective: to develop innovative and cost-effective 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: Marit J. Mazzetti, 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

LowEmission PhD candidate Amar Abideen prepares a segment of subsea cable for laboratory aging at SINTEF Energy Lab, in Trondheim

The *LowEmission* academic research program includes a total of 18 PhD students and one Postdoc. As of the end of 2022, 11 PhD candidates have started their research projects at *LowEmission*, and 16 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, important to the nation, 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 tightly 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 2022 Consortium days last November. Six 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 PHD CANDIDATES

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.

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

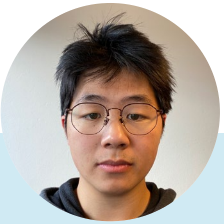
My project's main objective is to study, develop, evaluate and validate modelling approaches to compute energy efficiency and environmental performance of hydrocarbon production systems (subsea and in-well components), including guidelines and recommendations for implementation and operation of the technology 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.

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.

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 ammonia-hydrogen-nitrogen flames.



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.

Jessica Gaucherand
Affiliation: NTNU
Nationality: French
Supervisor: Prof. Terese Løvås (NTNU)
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.

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.

Daniel dos Santos Mota
Affiliation: NTNU
Nationality: Brazilian-Norwegian
Supervisor: Prof. Elisabetta Tedeschi (NTNU)
Period: 2020-2023
Thesis: Control strategies for stability guarantee in oil and gas platforms with significant renewable energy integration

I will propose control strategies for guaranteeing the stability of the electrical grid of oil and gas platforms with significant renewable energy integration. Gas turbines on the Norwegian Continental Shelf, usually running at low efficiency levels with spare capacity, account for roughly 20% of the total greenhouse gas emissions of Norway. Offshore wind represents an opportunity for reducing such emissions. In the next two years, I will investigate and propose strategies for overcoming technological challenges ahead of partially replacing gas-powered generators by offshore wind. These strategies are also applicable to island communities relying on fossil fuels as a primary energy source.

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.

Wonsik Song
Affiliation: Norwegian University of Science and Technology (NTNU)
Nationality: Republic of Korea
Supervisor: Dr. Andrea Gruber (NTNU and SINTEF Energy Research) and Nils Erland L. Haugen (Luleå University of Technology and SINTEF Energy Research)
Period: August 1, 2022 – July 31, 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 NOx 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.

International cooperation

Collaboration with international academic and R&D institutes in *LowEmission* has been a focus since its inception and includes for example 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; *LowEmission* acting as host to exchange students; knowledge exchange and idea generation for research tasks. These collaborations result in high quality publications, potential recruitments and idea generation for new research activities.

- *LowEmission* PhD candidate Mohammad Ali Motamed receives guidance from Professor Magnus Genrup at Lund University in Sweeden.
- Through international cooperation in *LowEmission*, four of the PhD candidates are on research visits at internationally recognized research institutions both in Europe; Jessica Gaucherand at CERFACS in France and Martin Richter at TU Darmstad in Germany and in North America; Kiet Tuan Hoang at Berkeley University of California and Hongyu Zhang at Carnegie Mellon University, Pittsburgh.
- Researchers from SINTEF and NTNU in SP2 collaborate with several international associated partners, including TU Darmstad in Germany, Sandia National Laboratories in the USA, TU Delft in the Netherlands and CERFACS in France.
- A researcher from SINTEF in SP8 is hosting an exchange student from Politecnico di Torino who wrote his master's thesis during the visit and is currently working on joint publication of his results with SINTEF researchers.
- Cooperation and dialogue have been established with Memorial University of Newfoundland, Canada, in connection with a KSP application for water injection.
- Collaboration and dialogue have been established with Johnson Matthey, a supplier company from the UK in connection with an approved KSP project (KSP DECAMMP) on the use of ammonia and hydrogen in gas turbines offshore.

Communications

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 FMEs, *LowEmission* took part in the important political event Arendalsuka in August 2022. *LowEmission* supported the conception and development of a North Sea strategy document in both Norwegian and English.

The report was presented at Arendalsuka. It contends that green transition solutions in the North Sea can alleviate problems such as the high energy prices experienced in Norway and the uncertain European energy supply in the context of the Ukraine war. Following the presentation, a debate focused on three recommendations by SINTEF and NTNU to better leverage the potential of the North Sea for solving the climate and energy crises:

1) Norway should create a roadmap and action plan to realise the North Sea's future energy system together with other North Sea countries
2) Norway needs to increase Research and Innovation cooperation with other European countries, to ensure value creation
3) Norway has to ensure the whole process is knowledge-based and inclusive

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 2023, and possibly COP28 as well.

On 14-15 March, *LowEmission* was one of the five research centres led by SINTEF invited to present at a communications conference organised by SINTEF Energy Research, entitled Skal fakta ha makta? (Should facts have power?).

LOWEMISSION WEBINARS

Internal communication to industry partners is an important task for the centre. During 2022 two webinar series were held, with a total of 21 presentations. The webinars were held for *LowEmission* partners as well as for the public. Attendance has been steady between 20 – 40 participants in each webinar session. The events have been announced on LinkedIn and published on the *LowEmission* website.

CONSORTIUM DAYS

The communications team supported November's Consortium Days event in Trondheim. The event gathered around 100 participants. Tasks included promotion before, during and after the event, including a summary article on the SINTEF blogg, and social media posts. Professional photographs were taken of presenters and participants, which will prove valuable for future communications work and media coverage.

WEBSITE, BLOGS, PODCASTS & NEWSLETTERS

The website www.lowemission.no is the communications hub for the research centre and is the first port-of-call for those interested in finding out more. It has been updated throughout the year with the latest news from the project and other relevant news, as well as information about upcoming events.

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 2022, 6 blogs were published across a variety of *LowEmission* topics.

LowEmission Centre Director Stefania Gardarsdottir were, together with NorthWind Centre Director John Tande, guest of a Smart Forklart episode. Gardarsdottir and Tande discussed solutions for reducing greenhouse gas emissions related to oil and gas exploitation on the Norwegian continental shelf. In the podcast, John Olav and Stefania discuss the immense potential of offshore wind to provide the required renewable energy to oil and gas installations.

SOCIAL MEDIA

The *LowEmission* communications team maintains a Twitter account – @LowEmissionNCS. At the end of 2022 it had 145 followers. The centre also has a LinkedIn page, with 258 followers. The LinkedIn page is used to share articles, updates and results. Posts were also regularly shared on SINTEF Twitter and LinkedIn pages. All project partners are encouraged to share news and blogs via their own social media channels to amplify reach.

LOOKING FORWARD

Now we are a few years into *LowEmission*, it's time to take stock of the communications measures so far and look to future requirements. In early 2022, a communications survey was distributed to all partners to gain input on their preferred communications methods and channels for future years. We are now analysing the results and will use this valuable input in further communications work.

As part of our commitment to keeping our clients and partners informed, we invite you to follow our LinkedIn page. By following our LinkedIn page, you can stay up to date on the latest industry news, trends, and insights. We have a lot of interesting blog articles in the pipeline for 2023, that we are looking forward to sharing. Our page features regular blog posts and articles written by our team of experts, providing you with valuable information on a variety of topics. You'll also have access to information about upcoming events and workshops.

Feel free to follow us on LinkedIn

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	14 915		**14 915**
The Host Institution (SINTEF Energi)		665	**665**
Research Partners			
NTNU		3 454	**3 454**
SINTEF AS		510	**510**
SINTEF Ocean		366	**366**
Enterprise partners			
Operators	19 871		**19 871**
Vendors		2 713	**2 713**
Public partners			
Sum	**34 786**	**7 708**	**42 494**
Costs			
The Host Institution (SINTEF Energi)	12 354		**12 354**
Research Partners	27 427		**27 427**
Enterprise partners		2 713	**2 713**
Sum			**42 494**

PUBLICATIONS

PEER REVIEWED JOURNAL PUBLICATIONS

Search criteria: *From*: 2022 *To*: 2022 *sub-category*: Academic article *sub-category:* Academic literature review *sub-category:* Academic chapter/article/ conference article *All publishing channels*

1. **Abideen, Amar; Mauseth, Frank; Hestad, Øystein Leif Gurandsrud; Faremo, Hallvard.** Review of Water Treeing in Polymeric Insulated Cables. Proceedings of the Nordic Insulation Symposium 2022 ;Volum 27.(1) NTNU ENERGISINT
2. **Angga, I Gusti Agung Gede; Bellout, Mathias; Bergmo, Per Eirik Strand; Slotte, Per Arne; Berg, Carl Fredrik.** Collaborative optimization by shared objective function data. Array 2022 ;Volum 16. s. 1-16. NTNU SINTEF
3. **Angga, I Gusti Agung Gede; Bellout, Mathias; Kristoffersen, Brage Strand; Bergmo, Per Eirik Strand; Slotte, Per Arne; Berg, Carl Fredrik.** Effect of CO_2 tax on energy use in oil production: waterflooding optimization under different emission costs. SN Applied Sciences 2022 ;Volum 4. s. - NTNU SINTEF

4. **Angga, I Gusti Agung Gede; Sutoyo, Handita Reksi Dwitantra; Bellout, Mathias; Bergmo, Per Eirik Strand; Slotte, Per Arne; Berg, Carl Fredrik.** Effects of Well Placement on CO_2 Emissions from Waterflooding Operation. I: SPE Norway Subsurface Conference 2022. Society of Petroleum Engineers 2022 ISBN 978-1-61399-857-1. s. - SINTEF NTNU
5. **Bergmo, Per Eirik Strand; Grimstad, Alv-Arne.** Water Shutoff Technologies for Reduced Energy Consumption. SPE Norway Subsurface Conference 2022 s. - SINTEF
6. **Ditaranto, Mario; Saanum, Inge; Larfeldt, Jenny.** Experimental Study on Combustion of Methane / Ammonia Blends for Gas Turbine Application. I: ASME Turbo Expo 2022: Turbomachinery Technical Conference and Exposition - Volume 3B: Combustion, Fuels, and Emissions. The American Society of Mechanical Engineers (ASME) 2022 ISBN 978-0-7918-8600-7. ENERGISINT
7. **Eyni, Leila; Stanko Wolf, Milan Edvard; Schümann, Heiner.** Methods for early-phase planning of offshore fields considering environmental performance. Energy 2022 ;Volum 256. s. 1-13. SINTEF NTNU
8. **Hoang, Kiet Tuan; Knudsen, Brage Rugstad; Imsland, Lars Struen.** Hierarchical nonlinear model predictive control of offshore hybrid power systems. IFAC-PapersOnLine 2022 ;Volum 55.(7) s. 470-476. ENERGISINT NTNU
9. **Holt, Torleif; Schümann, Heiner.** Energy Efficient Operation of Petroleum Production Plants. I: SPE Norway Subsurface Conference 2022. Society of Petroleum Engineers 2022 ISBN 978-1-61399-857-1. SINTEF
10. **Bergmo, Per Eirik Strand; Holt, Torleif; Skogestad, Jan Ole.** Dynamic Reservoir Behaviour and Production Due to Periodic Supply of Wind Power. ASME 2022 41st International Conference on Ocean, Offshore and Arctic Engineering 2022 ;Volum 10. SINTEF
11. **Mota, Daniel; Alves, Erick Fernando; Sanchez Acevedo, Santiago; Svendsen, Harald Georg; Tedeschi, Elisabetta.** Offshore Wind Farms and Isolated Oil and Gas Platforms: Perspectives and Possibilities. I: Proceedings of ASME 2022 41st International Conference on Ocean, Offshore & Arctic Engineering Volume 10 : Petroleum technology. The American Society of Mechanical Engineers (ASME) 2022 ISBN 978-0-7918-8595-6. NTNU ENERGISINT
12. **Motamed, Mohammad Ali; Nord, Lars O.** Development of a simulation tool for design and off-design performance assessment of offshore combined heat and power cycles. I: Proceedings of the 63rd International Conference of Scandinavian Simulation Society, SIMS 2022, Trondheim, Norway, September 20-21, 2022. Linköping University Electronic Press 2022 ISBN 978-91-7929-545-5. s. 1-8. NTNU
13. **Motamed, Mohammad Ali; Nord, Lars O.** Part-load efficiency boost in offshore organic Rankine cycles with a cooling water flow rate control strategy. Energy 2022 ;Volum 257. s. - NTNU
14. **Richter, Martin; Schulthesis, R.; Dawson, James; Gruber, Andrea; Barlow, R.S.; Dreizler, A.; Geyer, D.** Extinction strain rates of premixed ammonia/hydrogen/nitrogen-air counterflow flames. Proceedings of the Combustion Institute 2022 s. - ENERGISINT NTNU
15. **Svendsen, Harald Georg; Holdyk, Andrzej; Vrana, Til Kristian; Mosgren, Idun Runde; Wiik, Jan.** Operational Planning and Power Management System for Offshore Platform With Wind Energy Supply – Impacts on CO_2 Reduction and Power Quality. I: Proceedings of ASME 2022 41st International Conference on Ocean, Offshore & Arctic Engineering Volume 10 : Petroleum technology. The American Society of Mechanical Engineers (ASME) 2022 ISBN 978-0-7918-8595-6. ENERGISINT
16. **Svendsen, Harald Georg; Vrana, Til Kristian; Holdyk, Andrzej; Schümann, Heiner.** The Low Emission Oil and Gas Open reference

platform—An off-grid energy system for renewable integration studies. IET Energy Systems Integration 2022 s. 1-14 SINTEF ENERGISINT

17. **Ve, Torbjørn; Lesaint, Cedric Michel; Sæternes, Hans Helmer; Hvidsten, Sverre; Mermigkas, Athanasios; Bærug, Håvard; Hestad, Øystein Leif Gurandsrud; Mauseth, Frank; Abideen, Amar.** Electrical Ageing and Temperature Cycling of XLPE Insulation Saturated with Water. I: 2022 IEEE 4th International Conference on Dielectrics - ICD. IEEE (Institute of Electrical and Electronics Engineers) 2022 ISBN 978-1-6654-1833-1. s. 737-741. ENERGISINT NTNU
18. **Vrana, Til Kristian; Riboldi, Luca; Voldsund, Mari; Svendsen, Harald Georg; Mo, Olve.** Offshore wind power for supplying local off-grid electricity demand. I: 11th International Conference on Renewable Power Generation - Meeting net zero carbon - RPG 2022. Institution of Engineering and Technology (IET) 2022 ISBN 978-1-83953-789-9. ENERGISINT
19. **Zhang, Hongyu; Tomasgard, Asgeir; Knudsen, Brage Rugstad; Grossmann, Ignacio E.** Offshore Energy Hubs in the Decarbonisation of the Norwegian Continental Shelf. I: Proceedings of ASME 2022 41st International Conference on Ocean, Offshore & Arctic Engineering Volume 10 : Petroleum technology. The American Society of Mechanical Engineers (ASME) 2022 ISBN 978-0-7918-8595-6. NTNU ENERGISINT
20. **Zhang, Hongyu; Tomasgard, Asgeir; Knudsen, Brage Rugstad; Svendsen, Harald Georg; Bakker, Steffen J.; Grossmann, Ignacio E.** Modelling and analysis of offshore energy hubs. Energy 2022 ;Volum 261. s. 1-19 ENERGISINT NTNU
21. **Zotica, Cristina Florina; Mocholí Montañés, Rubén; Reyes Lua, Adriana; Skogestad, Sigurd.** Control of steam bottoming cycles using nonlinear input and output transformations for feedforward disturbance rejection. IFAC-PapersOnLine 2022 ;Volum 55.(7) s. 969-974. ENERGISINT NTNU
22. **Ånestad, Aksel; Ahn, Byeonguk; Nygård, Håkon Tormodsen; Worth, Nicholas.** The Effect of Rectangular Confinement Aspect Ratio On the Flame Transfer Function of a Turbulent Swirling Flame. Journal of Engineering For Gas Turbines and Power 2022 ;Volum 145.(5) s. - NTNU

PEER REVIEWED PAPERS

Search criteria: *From* 2022 *To*: 2022. *Sub-category*: academic article. *Sub-category*: academic review article. *Sub-category*: academic chapter/article/conference article. *All publishing channels.*

1. **Banet, Catherine.** Energy Planning Legal Requirements and Offshore Wind in Norway. I: *A Force of Energy - Essays in Energy Law in Honour of Professor Martha Roggenkamp*. Groningen: University of Groningen Press 2022 ISBN 9789403429533. s. 191-203. UiO
2. **Deveci, Muhammet; Pamučar, Dragan; Cali, Umit; Kantar, Emre; Kölle, Konstanze; Tande, John Olav Giæver.** Hybrid q-Rung Orthopair Fuzzy Sets Based CoCoSo Model for Floating Offshore Wind Farm Site Selection in Norway. *CSEE Journal of Power and Energy Systems (JPES)* 2022 ;Volum 8.(5) s. 1261-1280. NTNU ENERGISINT
3. **Høyer-Hansen, Martin; Hellesø, Svein Magne; Solheim, Kristian Thinn; Mehammer, Eirill Bachmann; Eberg, Espen; Pedersen, Per Atle.** Optimisation of power cable ampacity in offshore wind farm applications. *Journal of Physics: Conference Series (JPCS)* 2022 ;Volum 2362. ENERGISINT
4. **Kölle, Konstanze; Göcmen, Tuhfe; Eguinoa, Irene; Alcayaga Roman, Leonardo Andres;**

Aparicio-Sanchez, Maria; Feng, Ju; Meyers, Johan; Pettas, Vasilis; Sood, Ishaan. FarmConners market showcase results: wind farm flow control considering electricity prices. *Wind Energy Science* 2022 ;Volum 7.(6) s. 2181-2200. ENERGISINT

5. **Kölle, Konstanze; Göcmen, Tuhfe; Garcia Rosa, Paula Bastos; Petrovic, Vlaho; Eguinoa, Irene; Vrana, Til Kristian; Long, Qian; Pettas, Vasilis; Anand, Abhinav; Bartlas, Thanasis K.; Cutululis, Nicolaos A.; Manjock, Andreas; Tande, John Olav Giæver; Ruisi, Renzo; Bossanyi, Ervin.** Towards integrated wind farm control: Interfacing farm flow and power plant controls. *Advanced Control for Applications* 2022 ;Volum 4.(2). ENERGISINT
6. **Korpås, Magnus; Holttinen, Hannele; Helisto, Niina; Kiviluoma, Juha; Girard, Robin; Koivisto, Matti; Frew, Bethany; Dobschinski, Jan; Smith, J. Charles; Vrana, Til Kristian; Flynn, Damian; Orths, Antje; Soder, Lennart.** Addressing Market Issues in Electrical Power Systems with Large Shares of Variable Renewable Energy. I: *2022 18th International Conference on the European Energy Market - EEM*. Institute of Electrical and Electronics Engineers (IEEE) 2022 ISBN 978-1-6654-0896-7. NTNU ENERGISINT
7. **MacKinnon, Danny; Afewerki, Samson; Karlsen, Asbjørn.** Technology legitimation and strategic coupling: A cross-national study of floating wind power in Norway and Scotland. *Geoforum* 2022 ;Volum 135. s. 1-11 OCEAN NTNU
8. **Merz, Karl Otto.** Towards a particle-flow framework for uncertainty quantification, with applications in wind plant system dynamics and control. *Journal of Physics: Conference Series (JPCS)* 2022 ;Volum 2362. ENERGISINT
9. **Tabib, Mandar; Tsiolakis, Vasileios; Pawar, Suraj; Ahmed, Shady E.; Rasheed, Adil; Kvamsdal, Trond; San, Omer.** Hybrid deep-learning POD-based parametric reduced order model for flow around wind-turbine blade. *Journal of Physics: Conference Series (JPCS)* 2022 ;Volum 2362. s. - NTNU SINTEF
10. **Vardaroglu, Mustafa; Gao, Zhen; Avossa, Alberto Maria; Ricciardelli, Francesco.** Validation of a TLP wind turbine numerical model against model-scale tests under regular and irregular waves. *Ocean Engineering* 2022 ;Volum 256. s. - NTNU
11. **Wu, Mengning; Gao, Zhen; Zhao, Yuna.** Assessment of allowable sea states for offshore wind turbine blade installation using time-domain numerical models and considering weather forecast uncertainty. *Ocean Engineering* 2022 ;Volum 260. s. - NTNU
12. **Zhang, Wanwan; Vatn, Jørn; Rasheed, Adil.** A review of failure prognostics for predictive maintenance of offshore wind turbines. *Journal of Physics: Conference Series (JPCS)* 2022 ;Volum 2362. s. - NTNU

REPORT/THESIS

1. **Gardarsdottir, Stefania Osk.** *LowEmission* Annual Report 2021. Trondheim: Prosjektet *LowEmission* 2022 82 s. ENERGISINT

PRESENTATIONS

1. **Angga, I Gusti Agung Gede; Bellout, Mathias; Bergmo, Per Eirik Strand; Slotte, Per Arne; Berg, Carl Fredrik.** Collaborative optimization by shared objective function data. Geilo Winter School; 2022-01-24 - 2022-01-28. SINTEF NTNU
2. **Deng, Han; Skaugen, Geir.** Combined heat and power cycles from Gas turbine exhaust - Potential analyses through the WEB-GUI. *LowEmission* Research Center - webinar; 2022-01-21. ENERGISINT
3. **Eyni, Leila.** Dynamic process modeling of topside systems for evaluating power consumption and possibilities of using wind

power. *LowEmission* PhD webinar series (spring 2022); 2022-06-23 - 2022-06-23 NTNU

4. **Eyni, Leila; Fattahi, Mostafa; Schümann, Heiner; Lund, Fredrik; Stanko, Milan; Strømmegjerde, Lars.** Technical and environmental evaluation of a hydrate cold flow technique to produce an oil reservoir using a long tie-back and comparison against traditional development concepts. ASME 2022 41st International Conference on Ocean, Offshore and Arctic Engineering OMAE2022; 2022-06-05 - 2022-06-10. SINTEF NTNU
5. **Gardarsdottir, Stefania Osk.** Emission reduction on the NCS – why and how?. Kommunikasjonskonferansen 2022; 2022-03-15 - 2022-03-15. ENERGISINT
6. **Gardarsdottir, Stefania Osk.** *LowEmission* – Research Centre for a Low-Emission Petroleum Industry on the Norwegian Continental Shelf. OED besøk på SINTEF; 2022-08-24 - 2022-08-24 ENERGISINT
7. **Gardarsdottir, Stefania Osk.** *LowEmission* Research Centre – R&D for reducing emissions on the Norwegian Continental Shelf. CSSR Kick-Off Science day; 2022-09-08 - 2022-09-08. ENERGISINT
8. **Gardarsdottir, Stefania Osk; Hustad, Johan Einar.** Nordsjøen som plattform for grønn omstilling. Energikommisjonen; 2022-06-17 - 2022-06-17. ENERGISINT NTNU
9. **Gardarsdottir, Stefania Osk; Røkke, Nils Anders; Hustad, Johan Einar.** Nordsjøen som løsning på klima- og energikrisen. Arendals-uka 2022; 2022-08-15 - 2022-08-19 ENERGISINT NTNU
10. **Gribkovskaia, Victoria; Nonås, Lars Magne; Sandvik, Endre.** Teknologi for fremtidig lavutslippsaktiviteter på norsk sokkel. Felt-utviklingskonferansen; 2022-02-15 - 2022-03-29. OCEAN
11. **Krause, Daniel Franklin; Tobiesen, Finn Andrew.** Better technology for methane emissions mapping & abatement. Developing autonomous drones for quantifying offshore fugitive methane emissions. NOROG partner meeting; 2022-04-25 - 2022-04-25 OCEAN SINTEF
12. **Krause, Daniel Franklin.** *LowEmission* Webinars - Nature of methane emissions from offshore platforms and the frequency of site-wide measurements that are needed. *LowEmission* webinar series; 2022-11-02 - 2022-11-02. OCEAN
13. **Leinan, Paul Roger; Silva, Thiago Lima.** *LowEmission* Webinars - An open source framework for Integrated Production Modelling (IPM) – collaboration of *LowEmission* and the DigiWell project. *LowEmission* webinar series; 2022-11-30 - 2022-11-30. SINTEF
14. **Mota, Daniel.** Coordination of Power Reserves in an O&G Platform Connected to a Wind Farm and Equipped with Energy Storage. *LowEmission* Consortium Days 2022; 2022-11-23 - 2022-11-24. NTNU
15. **Mota, Daniel.** Coordination of Power Reserves in O&G Platforms with Wind Energy. *LowEmission* Consortium Days 2022; 2022-11-23 - 2022-11-24. NTNU
16. **Mota, Daniel.** Offshore Wind Farms and Isolated Oil and Gas Platforms: Perspectives and Possibilities. ASME 2022 41st International Conference on Ocean, Offshore and Arctic Engineering; 2022-06-05 - 2022-06-10. NTNU
17. **Motamed, Mohammad Ali; Nord, Lars O.** Decarbonized gas turbines: Steady-state and transient simulation tools. *LowEmission* Consortium Days 2022; 2022-11-23 - 2022-11-24. NTNU
18. **Qiu, Kang; Andersson, Leif Erik; Zotica, Cristina; Reyes-Lúa, Adriana; Mocholí Montañés, Rubén; Chabaud, Valentin Bruno; Vrana, Til Kristian.** Model predictive control of compact combined cycles in off-shore power plants integrating a wind farm. *LowEmission* Consortium Days 2022; 2022-11-23 - 2022-11-24. ENERGISINT
19. **Reyes Lua, Adriana; Skaugen, Geir; Deng, Han; Motamed, Mohammad Ali; Mocholí**

Montañés, Rubén; Zotica, Cristina Florina. *LowEmission* SP1 Updated Results 2022. *LowEmission* SP1 Family Meeting. *LowEmission* SP1 Updated Results 2022. *LowEmission* SP1 Family Meeting; 2022-06-29 - 2022-06-29. ENERGISINT NTNU

20. **Schümann, Heiner; Bergmo, Per Eirik Strand; Holt, Torleif; Skorpa, Ragnhild; Gardarsdottir, Stefania Osk; Eyni, Leila; Stanko Wolf, Milan Edvard.** *LowEmission* centre - Energy efficient production methods for offshore oil and gas production. The November Conference - Brazil and Norway; 2022-11-07 - 2022-11-09. NTNU SINTEF ENERGISINT
21. **Skorpa, Ragnhild; Gardarsdottir, Stefania Osk.** *LowEmission* Research Centre. Joining Forces; 2022-04-05 - 2022-04-06 SINTEF ENERGISINT
22. **Vrana, Til Kristian; Riboldi, Luca; Voldsund, Mari; Svendsen, Harald Georg; Mo, Olve.** Offshore Wind Power for supplying Local Off-Grid Electricity Demand. Renewable Power Generation - RPG 2022 - Meeting net zero carbon conference; 2022-09-22 - 2022-09-23 ENERGISINT
23. **Zhang, Hongyu.** Modelling and analysis of offshore energy hubs. NTNU Energy Systems Seminar; 2022-03-25 - 2022-03-25. NTNU
24. **Zhang, Hongyu.** Offshore energy hubs in the decarbonisation of the Norwegian Continental Shelf. The *LowEmission* Centre Spring 2022 Webinar Series; 2022-06-23 - 2022-06-23. NTNU
25. **Zhang, Hongyu; Mazzi, Nicolò; McKinnon, Ken; Nava, Rodrigo Garcia; Tomasgard, Asgeir.** A stabilised Benders decomposition with adaptive oracles applied to investment planning of multi-region power systems with short-term and long-term uncertainty. INFORMS Annual Meeting 2022; 2022-10-16 - 2022-10-19. NTNU
26. **Zhang, Hongyu; McKinnon, Ken; Nava, Rodrigo Garcia; Mazzi, Nicolò; Tomasgard, Asgeir.** Stabilised Benders decomposition with adaptive oracles. TACEMM winter school/workshop 2022; 2022-02-28 - 2022-03-04. SINTEF NTNU
27. **Zhang, Hongyu; Tomasgard, Asgeir; Knudsen, Brage Rugstad; Grossmann, Ignacio E.** Offshore energy hubs in the decarbonisation of the Norwegian Continental Shelf. ASME 41st International Conference on Ocean, Offshore & Arctic Engineering (OMAE 2022); 2022-06-05 - 2022-06-10. NTNU ENERGISINT
28. **Zhang, Hongyu; Tomasgard, Asgeir; Knudsen, Brage Rugstad; Grossmann, Ignacio E.** The Impact of Decarbonising Offshore Fields on Investment Planning of the North Sea Energy System. 43rd IAEE International Conference; 2022-07-31 - 2022-08-04. NTNU ENERGISINT
29. **Zhang, Hongyu; Tomasgard, Asgeir; McKinnon, Ken; Mazzi, Nicolò; Nava, Rodrigo Garcia.** Investment planning of multi-region power systems with uncertainty using stabilised Benders decomposition with adaptive oracles. European Conference on Stochastic Optimization & Computational Management Science Conference 2022 (ECSO-CMS 2022); 2022-06-29 - 2022-07-01 NTNU
30. **Zotica, Cristina Florina; Mocholí Montañés, Rubén; Reyes Lua, Adriana; Skogestad, Sigurd.** Control of steam bottoming cycles using nonlinear input and output transformations for feedforward disturbance rejection. 13th IFAC Symposium on Dynamics and Control of Process Systems, including Biosystems (DYCOPS); 2022-06-14 - 2022-06-17. ENERGISINT NTNU
31. **Zotica, Cristina Florina; Mocholí Montañés, Rubén; Reyes Lua, Adriana; Skogestad, Sigurd.** Static input transformations for disturbance rejection, decoupling and linearization - with application to temperature control for steam generators. Nordic Process Control Workshop; 2022-03-17 - 2022-03-18 ENERGISINT NTNU
32. **Ånestad, Aksel; Ahn, Byeonguk; Nygård, Håkon Tormodsen; Worth, Nicholas.**

The effect of rectangular confinement aspect ratio on the flame transfer function of a turbulent swirling flame. ASME Turbo Expo 2022, Turbomachinery Technical Conference and Exposition; 2022-06-13 - 2022-06-17 NTNU

MULTIMEDIA PRODUCTS

1. **Gardarsdottir, Stefania Osk.** intervju ifm Arendalsuka. SINTEF Energi 2022 ENERGISINT
2. **Tande, John Olav Giæver; Gardarsdottir, Stefania Osk.** Hvordan kan vi kutte utslippene på norsk sokkel? (Video). SINTEF 2022 ENERGISINT

BLOG ARTICLES AND INFORMATION MATERIAL

1. **Eyni, Leila.** Environmental Assessment of the Cold Flow Technology. NTNU
2. **Gardarsdottir, Stefania Osk.** Beyond the shelf: 3 ways *LowEmission* innovations will benefit industries beyond oil & gas. ENERGISINT
3. **Gardarsdottir, Stefania Osk.** *LowEmission* - Technological developments for reducing emissions on the Norwegian continental shelf. ENERGISINT
4. **Gardarsdottir, Stefania Osk.** *LowEmission* - Teknologiutvikling for lavere utslipp for norsk sokkel. ENERGISINT
5. **Gardarsdottir, Stefania Osk; Skorpa, Ragnhild.** Det er ikke bare elektrifisering som vil bidra til å kutte utslipp på norsk sokkel. SINTEF ENERGISINT
6. **Mølnvik, Mona J.; Røkke, Nils Anders; Tande, John Olav Giæver; Gardarsdottir, Stefania Osk.** Nordsjøen som løsning på klima- og energikrisen. ENERGISINT

MEDIA CONTRIBUTIONS

1. **Gardarsdottir, Stefania Osk.** Er hydrogen hypen som alltid kommer om 10 år?. Fornybaren Energi Norge 2022. ENERGISINT
2. **Gardarsdottir, Stefania Osk; Tande, John Olav Giæver.** Hvordan kan vi kutte i utslippene på norsk sokkel? Podcast. SINTEF Smart forklart 2022. ENERGISINT
3. **Gardarsdottir, Stefania Osk; Tande, John Olav Giæver.** Smart forklart: Hvordan kan vi kutte utslippene på norsk sokkel?. SINTEF 2022. ENERGISINT
4. **Zhang, Hongyu.** Accelerating Transition at NTNU Energy Transition Conference 2022. Trondheim [Internett] 2022-03-30 NTNU

PERSONELL

MANAGEMENT

Name	Main research area	Institution
James Dawson	Fluid mechanics and combustion	NTNU
Stefania Gardarsdottir	Techno-economic process analysis	SINTEF
Jon Magne Johansen	Business development	SINTEF
Cedric Fayemendy	Reservoir technology and innovation strategies	Vår Energi
Ragnhild Skorpa	Well integrity	SINTEF
Anders Ødegård	Fuel cells and hydrogen	SINTEF
Lars Magne Nonås	Optimization of offshore logistics	SINTEF
Helene Berntsen Auflem	Central operations and innovation strategies	SINTEF
Ann Karin Jullumstrø Aalberg	Accounting and central operations	SINTEF

SP LEADERS

Name	Position	Main Research Area	Institution	SP
Adriana Reyes-Lúa	Research Scientist	Process control, value chain analysis	SINTEF	1
Nicholas Worth	Assosiate Professor	Turbulence, combustion, experimental methods	NTNU	2
Øystein Hestad	Research Manager	Transmission technology	SINTEF	3
Luis Colmenares-Rausseo	Senior Research	Low-temperature fuel cell and electrolysis	SINTEF	4
Harald Svendsen	Research Scientist	Energy systems, renewable integration	SINTEF	5
Tore Lyngås Føyen	Research Scientist	Reservoir technology, drainage, IOR, EOR	SINTEF	6
Per Eirik Bergmo	Research Scientist	Reservoir technology, drainage	SINTEF	7
Heiner Schümann	Research Scientist	Process modelling and concept testing	SINTEF	8
Roar Nybø	Senior Business Developer	Well drilling, machine learning	SINTEF	9

KEY RESEARCHERS

Name	Institution	Main research area	SP
Geir Skaugen	SINTEF Energy	Thermodynamic optimization, compact bottoming cyc	1
Han Deng	SINTEF Energy	Thermodynamic optimization, compact bottoming cyc	1
Rubén M. Montañés	SINTEF Energy	Thermal energy systems, process modelling and con	1
Adriana Reyes Lúa	SINTEF Energy	Thermal energy systems, process modelling and con	1
Cristina Zotica	SINTEF Energy	Thermal energy systems, process modelling and con	1
Lars O. Nord	NTNU	Thermal energy systems, gas turbines, process mod	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
Marit Mazzetti	SINTEF Energi	Energy supply, 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
Frank Mauseth	NTNU Dept. of El. Power Eng.	High voltage insulation	3
Luis Cesar Colmenares-Rausseo	SINTEF Industry	Low temperature fuel cells PEMFC	4

Name	Institution	Main research area	SP
Fortin Patrick	SINTEF Industry	Low temperature fuel cells PEMFC	4
Lindgård Øyvind	SINTEF Industry	Low temperature fuel cells PEMFC	4
Katie McCay	SINTEF Industry	Low temperature fuel cells PEMFC	4
Ødegård Anders	SINTEF Industry	Low temperature fuel cells PEMFC	4
Yash Raka	SINTEF Industry	Low temperature fuel cells PEMFC	4
Talic Belma	SINTEF Industry	High temperature fuel cells SOFC	4
Vøllestad Einar	SINTEF Industry	High temperature fuel cells SOFC	4
Stefania Gardarsdottir	SINTEF Energy		4
Andrzej Holdyk	SINTEF Energy	Power system modelling	5
Brage Knudsen	SINTEF Energy	Energy system	5
Daniel Mota	NTNU	Power system and control	5
Michal Kaut	SINTEF Industry	Energy system planning	5
Roar Nybø	SINTEF Industry	Integrated topside-downhole modelling	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
Hongyu Zhang	NTNU	Energy system planning	5
Kiet Tuan Hoang	NTNU	Model-predictive control	5
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

Name	Institution	Main research area	SP
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 subse	8
Andrea Alvarado Shmueli	SINTEF Industry	oil & gas processing, flow assurance	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
Harald Svendsen	SINTEF Energy	Energy system	8
Lars Magne Nonås	SINTEF Ocean	offshore logistics	9
Victoria Gribkovskaia	SINTEF Ocean	offshore logistics	9
Truls Flatberg	SINTEF Industri	fuels cells, hydrogen	9
Anders Ødegård	SINTEF Industri	fuels cells, hydrogen	9
Maria Føre	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
Anne Steenstrup-Duch	SINTEF Energi	Dissemination/Communication of results	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	2
Amar Abideen	Saudi-Arabia	2020-2024	M	Wet Design of AC Power Cables for Future Offshore Power Grids	3
Andreas Breivik Ormevik	Norway	2020-2024	M	Emission Reduction in the Upstream Offshore Supply Chain on the Norwegian Continental Shelf	9
Daniel Mota	Norway	2020-2023	M	Cooperative control strategies for stability in oil and gas platforms	5
Handita Reksi Dwitantra Sutoyo	Indonesia	2021-2022	M	Combine optimization of topside and subsurface production strategies in order to reduce emissions from hydrocarbon production	7+8
Hongyu Zhang	China	2020-2024	M	Long-term investment planning of decarbonized offshore energy infrastructure	5
I Gusti Agung Gede Angga	Indonesia	2020-2023	M	Reduction of emissions from hydrocarbon production through alternative and energy-efficient drainage strategies	7
Jessica Gaucherand	French	2020-2023	F	Ammonia/Hydrogen for internal combustion engines	2
Kiet Hoang	Norwegian	2020-2024	M	Stochastic model predictive control	5
Leila Eyni	Iran	2020-2023	F	Production systems	8
Martin Richter	German	2020-2023	M	The structure of ammonia/hydrogen/nitrogen flames	2
Mohammad Ali Motamed	Iran	2020-2023	M	Assessment of alternative concepts for combined cycle gas turbine operation under varying loads	1

POSTDOCTORAL CANDIDATES WITH FINANCIAL SUPPORT FROM THE CENTRE BUDGET

Name	Nationality	Period	Sex M/F	Topic	Task
Wonsik Song	South Korea	2022-2025	M	Fundamental combustion characteristics of ammonia-based fuels	SP2, WP2.1

MASTER'S STUDENTS

Name	Sex M/F	Topic	Year
Guido Aldas	M	Integrated production modelling	2023
Shayan Kianijo	M	Integrated production modelling	2023
Sondre Wennberg	M	Emission reductions in Arctic Energy Systems analysis using Oogeso	2022
Ali Hassan	M	Dynamic modelling of topside processing	2022
Adel Ramadan	M	Energy optimization of offshore gas installation	2021
Anders Helgeland Vandvik	M	Operational planning	2021
Ingrid Wibe	F	Impact of offshore electrification in Norway to greenhouse gas emissions within the European energy system	2021
Karl Petter Ulsrud	M	The time-dependent vessel routing problem with speed optimization	2021
Mohammed Heidari	M	Virtual intertia	2021
Mostafa Fattahi	M	Environmental performance of ColdFlow tie-ins	2021
Tord Solberg	M	Controls	2021
Trygve Stuen	M	Influence of Hydrogen Use as a Fuel on Aeroderivative Gas Turbine Performance.	2021
Andreas Bakke Moan	M	A hybrid genetic approach to the operational supply vessel planning problem with speed optimization	2020
Fadhil Berylian	M	Calculation and Visualization of Energy Dissipation and Energy Balance in Reservoir Models	2020
Jens Fredrik Lunde	M	Electric field distribution in layered polymeric HVDC insulation	2020
Pål Ødeskaug	M	Operational Supply Vessel Planning Problem with Speed Optimization	2020

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

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