LOWEMISSION

2021 ANNUAL REPORT

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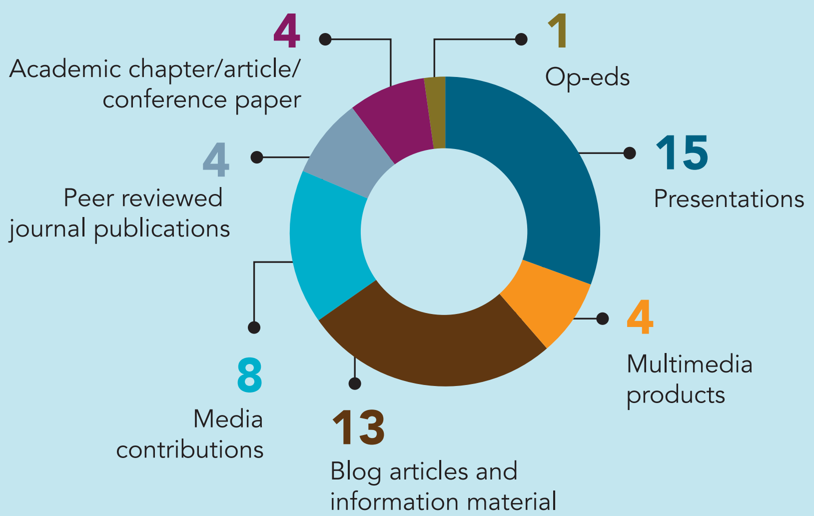

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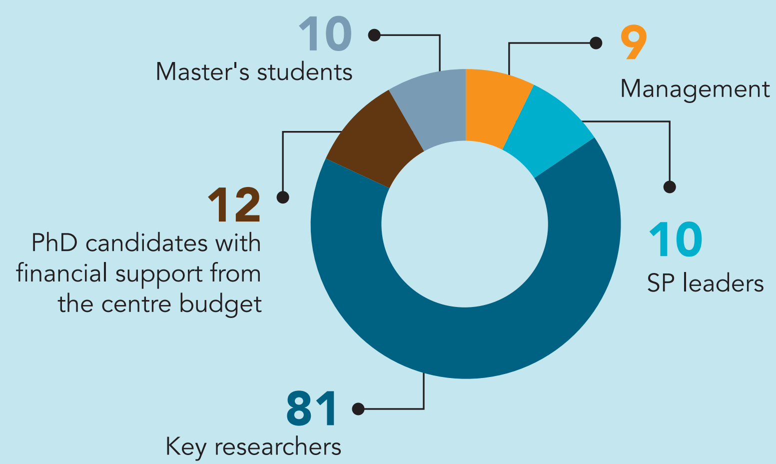

About *LowEmission*

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.

Photo: Kjetil Alsvik © Equinor/Sleipner


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2021 achievements

LowEmission has now been operating for two and a half years, with the pandemic causing disruptions around the world during most of that period. Thanks to the hard work and adaptability of our scientists and partner organisations, the pandemic has had no significant negative impacts on centre activities in 2021. All experimental work is on track, and no major health safety and environment incidents have been reported during the year. Digital tools have allowed us to continue our work despite disruptions, and certain aspects of this transformation may well remain in place even after the end of the pandemic – the use of webinars and the awareness that some meetings can more efficiently be done online, for example.

In total 12 PhD candidates have started working on their research projects, out of the 19 PhD/postdocs the Centre aims to educate. Some of these PhD candidates have written articles that are featured in this report, and all of them provide us with a description of their project on pages 66-69. In addition, 9 master's students have completed their *LowEmission*-related projects since the Centre was established – the objective for the duration of the Centre is to educate a total of 30 master's students.

Communication and dissemination activities are on track and will intensify as the centre produces more results. This year, the centre produced 4 peer-reviewed journal publications and 15 presentations. A summary of communication activities can be found on pages 71-72.

As the centre reaches its cruising altitude, one core objective will be to increase the involvement of industry partners and ensure their active participation in the subproject families. The more industry partners contribute to shaping and initiating case studies and spin-off initiatives, the greater the centre's technological payoff will be. *LowEmission* got lots of visibility at COP26 and Arendalsuka in 2021. The centre collaborated with other research centres (NorthWind, NCCS and NTRANS) to provide a factual foundation to the public debate about solving the climate challenge. The document resulting from this collaboration was well received by decision makers and will be built upon in 2022.

The consortium has grown in 2021, with the arrival of 3 new industry partners in addition to the existing 32. These new partners are OMV, Spirit Energy and DNO. Their participation is a clear indication of the industry's interest in supporting the development and implementation of low emission technology for the offshore oil and gas sector.

Message from the Chair

The latest IPCC report on the impacts of climate change was just published (Q1,22) and is clearly stating the need for immediate action to reduce the impact of global warming, and to adapt to its consequences. In 2021, the UN Secretary-General declared the situation a code red for humanity, and this year's report tells us what living in a code red world may look like.

Meanwhile, there is an ongoing conflict in Ukraine that has led to an energy shortage in Europe, and we may be facing an energy-versus-climate dilemma in the time to come. To me, this means that to ensure energy security as well as decarbonisation, we have to deploy all available tools – energy efficiency, renewables, and low-carbon energy solutions are all required.

The current decade is decisive for how we will tackle the biggest challenge of all time.

In Norway, the NCS is responsible for about a quater of the GHG emissions and we have an increased commitment (Stortingsmelding 36) to reduce these by 50% within 2030.

There is an increasing awareness and effort in the O&G industry to develop and deploy low-emission technologies, and most operators on the NCS are recognising the need to diversify the decarbonisation toolbox as the ambitions increases – 50% reduction towards 2030 and net-zero emission in 2050.

The *LowEmission* centre works with a portfolio of solutions to support these ambitions in a collaboration between academia, industry, and the authorities through the Research Council of Norway. It is important to work with solutions for both short, medium, and long-term emission reduction targets. Every asset is different and may need its own tailored set of solutions.

LowEmission is making new technologies and solutions available. Collaboration is key – both between different industry partners as well as public-private partnerships – to develop, deploy and implement available technologies for a healthier globe.

HEGE ROGNØ

Hege has more than 30 years of experience in the oil industry, both from field operations, business development and technology development. She has international experience (UK, Australia) and from 2009 to 2012 she headed Equinor's East Coast Canada office in St. John's. Since 2016, she has been heading Equinor's technology development within Low Carbon Oil&Gas Technologies including Low Carbon Power&Heat solutions for offshore/onshore applications.

Message from the Acting Director

It's been roughly two and a half years since *LowEmission* kicked off, and how much we have learned during this time! The nearly two years of operating during a pandemic have taught us new ways to collaborate and communicate, and interactions between industry partners, researchers and PhD candidates are continuously evolving.

I look back at 2021 as a successful year for *LowEmission* – we've gained new momentum in our research activities; results are being published and disseminated at an increased rate and our 12 PhD candidates are bringing new knowledge and competence to the consortium. Furthermore, innovation is being fostered through the different SPs, case studies and spin-off projects, to name a few. We intend to keep up this momentum moving forwards, and even to further accelerate it through our strong and growing partnership.

The importance of keeping up, and further increasing the momentum has only become clearer this past year as we see the push and need for rapid decarbonisation moving faster towards the top of the industrial and political agenda. The stronger ambitions set out for emission reductions on the Norwegian Continental Shelf in Proposition No 195 to the Storting (2020-2021) – an increase from 40% to 50% emission reduction towards 2030 – is a particularly important signal to the *LowEmission* partnership.

In this context, *LowEmission* contributes not only with research and development, but also with science-based communication in dialogue with different stakeholders, most notably at 'Arendalsuka' and COP26 this year. Together with the FMEs NCCS, NorthWind, and NTRANS, we developed a North Sea strategy document in both Norwegian and English – The North Sea as a springboard for the green transition.

Lastly, I would like to thank the whole *LowEmission* partnership for your strong efforts to accelerate development of low-emission solutions and to foster the next generation of experts to lead us through the energy transition.

STEFANIA OSK GARDARSDOTTIR

Stefania is a Research Manager at SINTEF Energy Research and holds a PhD in Energy Technology. Her field of expertise is CO_2 capture in power and industrial processes as well as 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 CCS chain. She co-leads the SINTEF Foundation's strategic focus area on hydrogen and is also the Acting Director and Centre Manager of the RCN and industry funded *LowEmission* Research Centre.

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 KPN, 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

Gender equality

Gender balance at *LowEmission* is good, whether we look at Centre management, the Board or the Technical committee. The Chair, Centre Director and Centre Manager are all women. The Centre follows SINTEF and NTNU's guidelines for recruitment.

Centre partners encourage 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 *subproject 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 now 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.

Turning the corner: emission cuts as a precondition to oil and gas activity

OG21 presented its new strategy titled "A New Chapter" at the *LowEmission* Consortium Days in November. As the title makes clear, the strategy constitutes a change of discourse for the Norwegian oil and gas industry, where decarbonisation takes the centre stage. We had a chat with OG21's Managing Director, Gunnar Lille.

OG21 (Oil and gas for the 21st century) is mandated by the Research Council of Norway to work for efficient, safe, and environment-friendly value creation from Norwegian oil and gas resources. The mandate specifies that OG21 shall inspire the industry to develop and use new and better knowledge and technology adapted to an evolving energy system, and to the climate targets.

NB: The interview was conducted before the invasion of Ukraine by Russia was launched.

LE: The new strategy seems to increase the focus on low emission technology. What is this telling us about the oil and gas industry's view of the energy transition?

GL: The biggest change is probably the fact that reduction of greenhouse gases has become a prerequisite to oil and gas activity. It's a precondition to continuing oil and gas exploitation, to keep getting support from the public at large and not least to secure capital. Reducing emissions has evolved from something that was "the right thing to do" to being good business. The priority for OG21 is still to ensure that the industry is competitive. Earlier, that mostly meant having low operating costs, but now it means in addition to reduce emissions to keep the public's support and secure capital.

LE: How does reducing emissions help secure capital?

GL: We've seen a bit change among institutional investors over the last few years. They are now more and more concerned about Environmental, social, and corporate governance management in the enterprises they invest in, and especially goals and plans for reducing CO_2 emissions. We see this also reflected through initiatives in the finance sector, like the UN Principles for Responsible investments, and in the EU Taxonomy system. All this will make access to capital easier and cheaper for the enterprises with the lower CO_2 emissions.

LE: The new OG21 strategy includes decarbonisation of petroleum value chains. Can you tell us more about that?

GL: This is the new part. Reducing emissions has become essential to competitiveness. As we speak, Norwegian natural gas is being exported to the EU and the UK through pipelines and generating record revenues – because the price of gas is so high due to a combination of reasons. Meanwhile, the EU sent clear signals through its Green Deal that it intends, over time, to phase natural gas out of its energy mix. So, in this case, decarbonising means securing a future market for our natural gas; whether through natural-gas-fired power plants that have CCS, or through hydrogen/ammonia production from natural gas (also with CCS).

LE: What is the role of research, development, and innovation in this context?

GL: It's absolutely crucial. Already 7-8 years ago, OG21 saw that low emission technology would become increasingly important. So, in our previous strategy (launched in 2016), we recommended the establishment of a low emission technology centre. The Ministry of Petroleum and Energy ended up heeding that recommendation and the *LowEmission* started its activities a few years later. The target, which is to cut emissions in half by 2030, will require loads of new technology. Electrification is the most crucial, but it involves significant costs, so reducing these costs through research is very important for us. Costs can be reduced by improving designs on things like subsea cables, for example, but also through system integration – connecting the energy system through hubs and creating an offshore grid. But lots of research challenges need to be ironed out before we get there.

LE: What's the biggest challenge, with regards to research?

OG21's Managing Director, Gunnar Lille, presented his organisation's new strategy at the LowEmission Consortium Days in November.

We need to attract bright, young people.

GL: It's to get the solutions quickly enough. If we are going to reach the emissions reduction targets, we need the solutions as soon as possible. Electrification is the most important measure for us to cut emissions, and we realise that it's a controversial topic given current energy prices. So we look simultaneously at other solutions like energy efficiency improvements, optimising reservoir drainage, optimising electricity production. Beyond 2030, we can imagine offshore energy hubs with efficient gas-fired power plants that are equipped with CCS and that deliver power to nearby platforms. And if there's a power surplus at any time, we can either send it to land or store it as hydrogen/ammonia. Once we get there, we've really come a long way in decarbonising the whole value chain.

The oil and gas industry needs to attract bright, young people, says OG21's Managing Director, Gunnar Lille. Here, PhD candidate Mohammad Ali Motamed is shown discussing with Thierry Boscal-de-Reals, R&D Project Manager at TotalEnergies, during the poster session at the LowEmission Consortium days.

LE: The new OG21 strategy has three main recommendations: 1) Pursue technology through the innovation system; 2) Technology leadership; and 3) Attract and develop talent. How does a centre like *LowEmission* contribute to those recommendations?

GL: The first recommendation is about the innovation system. The interaction between all the players who contribute to bring forth innovations – research institutions, oil and gas companies, investors, and the government. We believe the system works well, but it is quite segmented into sectors. We believe it could be improved by supplementing the sectorial approach with a more holistic view across sectors, or "missions" if you like.

The second recommendation is very important. Technology leadership means that people working in the industry need to get the right signals from their leaders. Sometimes trying new solutions means failing a couple of times at first, and tolerance for failure is much higher when people get a clear message from their leaders that solving this particular problem is a priority.

The third recommendation has to do with the industry's reputational challenge. The average age of our employees is high. We need to attract bright, young people. They want interesting tasks, and they want to work for companies that take the climate issue seriously. And on many levels, we do; companies like Equinor, Shell and Total are heavily involved in hydrogen and CCS. We need to show that we are working on solutions to provide cheap energy and reduce emissions along the whole value chain, including both production and end-use.

LE: The Norwegian government recently announced its plans for offshore wind. What does offshore wind development mean for OG21?

GL: It will provide more power, which will be much needed. And there are synergy effects that can be achieved. In our strategy, we provide an overview of the overlapping areas of expertise between the oil and gas industry and up and coming industries like offshore wind, CCS, hydrogen and seabed minerals. Much of the knowledge developed by oil and gas can be applied in those industries, and the opposite is also true. In the digital realm, a whole lot of progress can be made (and knowledge shared) in fields like cybersecurity, big data and machine learning. The more we integrate the energy system, the more importance this synergy will be getting.

The new OG21 strategy can be downloaded from the organisation's website: og21.no

Beyond the shelf: 3 ways *LowEmission* innovations will benefit industries beyond oil & gas

From 2019 to 2026, the *LowEmission* research centre will develop new technology and concepts for offshore energy systems and integration with renewable power production technologies. The overarching target is to reduce offshore greenhouse gas emissions from operations on the Norwegian Continental Shelf, but the centre's innovations will benefit industry far beyond oil and gas.

"Together with CCS and hydrogen/ammonia technologies, electrifying the shelf will be vital to reduce emissions in the years to come. But to get full value from the research centre, it's important that these innovations can be used in other contexts, especially ones that will eventually overtake the Norwegian oil and gas industry, says Stefania Osk Gardarsdottir, Acting Director of the *LowEmission* research centre.

THE ECONOMIC FUTURE OF THE NORTH SEA

LowEmission played a central role in the development of 'The North Sea as a platform for the green transition', a research-based report prepared by SINTEF and NTNU for distribution at Norway's Arendalsuka and Glasgow's COP26 in 2021.

"Norwegian industry has an edge because of its extensive knowledge about the North Sea and its experience carrying out projects in challenging offshore conditions. On top of that, a lot of the existing oil and gas infrastructure can be repurposed to play a role in the decarbonisation transition," said Stefania Gardarsdottir at the launch of the report.

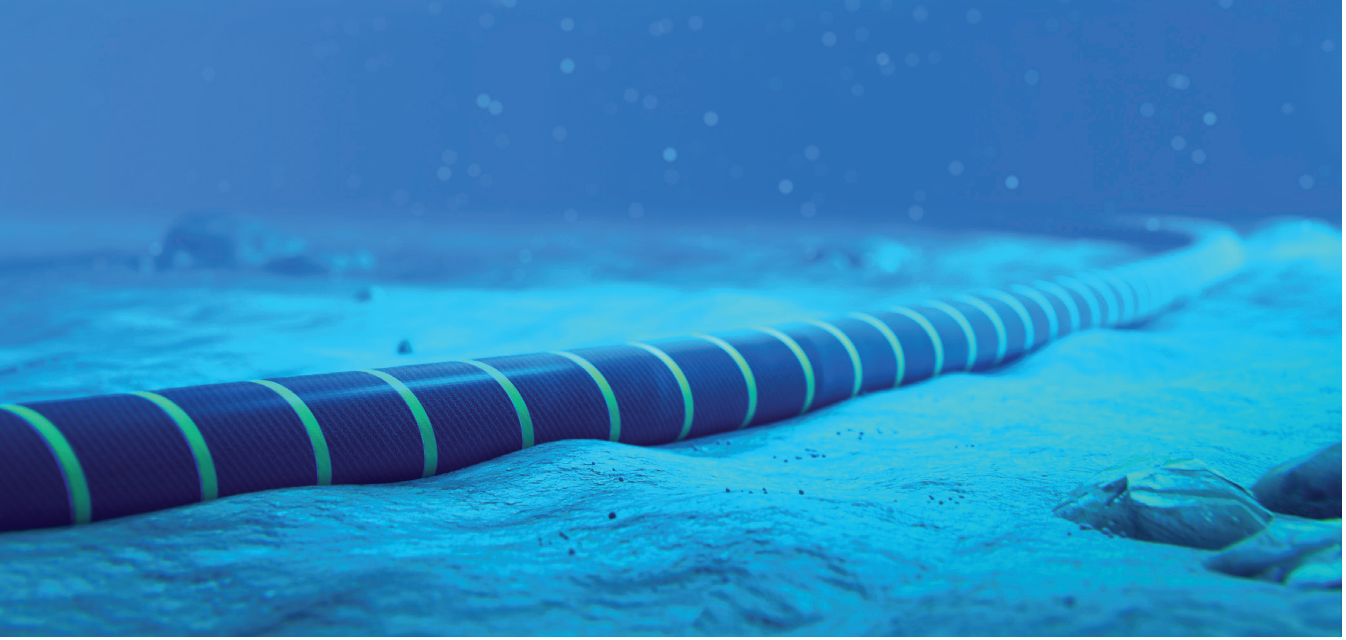
ELECTRIFICATION TECHNOLOGIES

Various research tasks on electrification will be of use to the emerging offshore wind industry, for example. System integration aspects and innovations with cable technologies are just two areas where industries that transport electricity will benefit.

LowEmission's concept as an innovation platform has already bore fruit in this area. Two of the centre's partners – Nexans and SINTEF Energy – came together to launch an IPN spin-off project with Statnett: Design, modelling and testing of HVDC cable insulation for future cable grids.

High voltage subsea cables are crucial to electrify oil platforms. *LowEmission* is trying to find new designs to reduce their costs and comply with the expected requirement to stop using the proven lead-based sheaths.

Wet-design high voltage power cables with no metallic protective barrier are lighter and



therefore easier and cheaper to install than traditional heavier cables. Since the wet design enables water to enter the cable over time, electrical stress, water soluble contaminants and a humidity level above 70% can result in the growth of so-called water trees.

LowEmission research into the formation of water trees will help drive forward this innovation, which will benefit industries beyond oil and gas. In particular, offshore wind farms will become more viable with cheaper, lighter cables to carry the generated power ashore.

FUEL CELLS & HYBRID PROPULSION TECHNOLOGIES

The development of fuel cells and hybrid propulsion systems for petroleum industry related logistics activities can also be utilised for other mobility applications especially in the maritime industry. Knowledge acquired through *LowEmission* work has synergies with the Green Platform project ZeroKyst, which focuses on the decarbonisation of the fisheries and aquaculture industries, as well as the FHF project "Elektrifisering av kystfiskeflåten ved bruk av batterier og brenselceller" (Electrification of the coastal fishing fleet through the use of batteries and fuel cells), which designed a 13 m long coastal fisher boat fuelled with hydrogen and ammonia[1].

Within the ZeroKyst project, NTNU and SINTEF will develop a cohesive plan for hydrogen supply and charging infrastructure along the Norwegian coast as part of the goal for new and existing vessels in the fisheries and aquaculture industry to become emission-free.

HYDROGEN AND AMMONIA FOR GAS TURBINES

Hydrogen and ammonia combustion research for gas turbines undertaken by *LowEmission* is also useful in other sectors where the fuel needs to be decarbonised, such as the process, metal, glass industries and the power industries. All the experimental and numerical tools developed for understanding and predicting how these fuels behave could be adapted in other types of burners, furnaces, and boilers. Spin-off proposals and other project proposals have been prepared based on the knowledge acquired by the research group. Some aspects are also relevant for maritime applications and the shipping industry – in fact that specific application, combustion in gas engines, is being investigated within *LowEmission*.

Several *LowEmission* partners including NTNU and SINTEF play a major role in the Norwegian CCS Research Centre, NCCS. An exchange of knowledge takes place between the two centres to share knowledge in the field of gas turbines.

1 https://www.fhf.no/prosjekter/prosjektbasen/901640/

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.

Wind energy for offshore installations: opportunities and challenges

HOW CONNECTING OFFSHORE WIND TO OIL AND GAS RIGS CAN HELP REDUCE THEIR GREENHOUSE GAS EMISSIONS

By Daniel Mota

Natural gas represented approximately 50% of the Norwegian production of oil equivalents in 2020. However, not all gas extracted from the Norwegian Continental Shelf is transported to land (see figure). Part of it is burnt in low-efficiency, single-cycle gas turbines for the generation of electricity and heat in the oil and gas fields of the Barents, North, and Norwegian Seas. Offshore gas turbines alone account for roughly 20% of the total greenhouse gas emissions of Norway. From a global perspective, it is beneficial to use a renewable offshore source of electrical energy and transport all the gas to the continent. A large land-based combined-cycle natural gas power plant has approximately twice the efficiency of a coal-fueled plant – in other words, the same electrical power for half the CO_2.

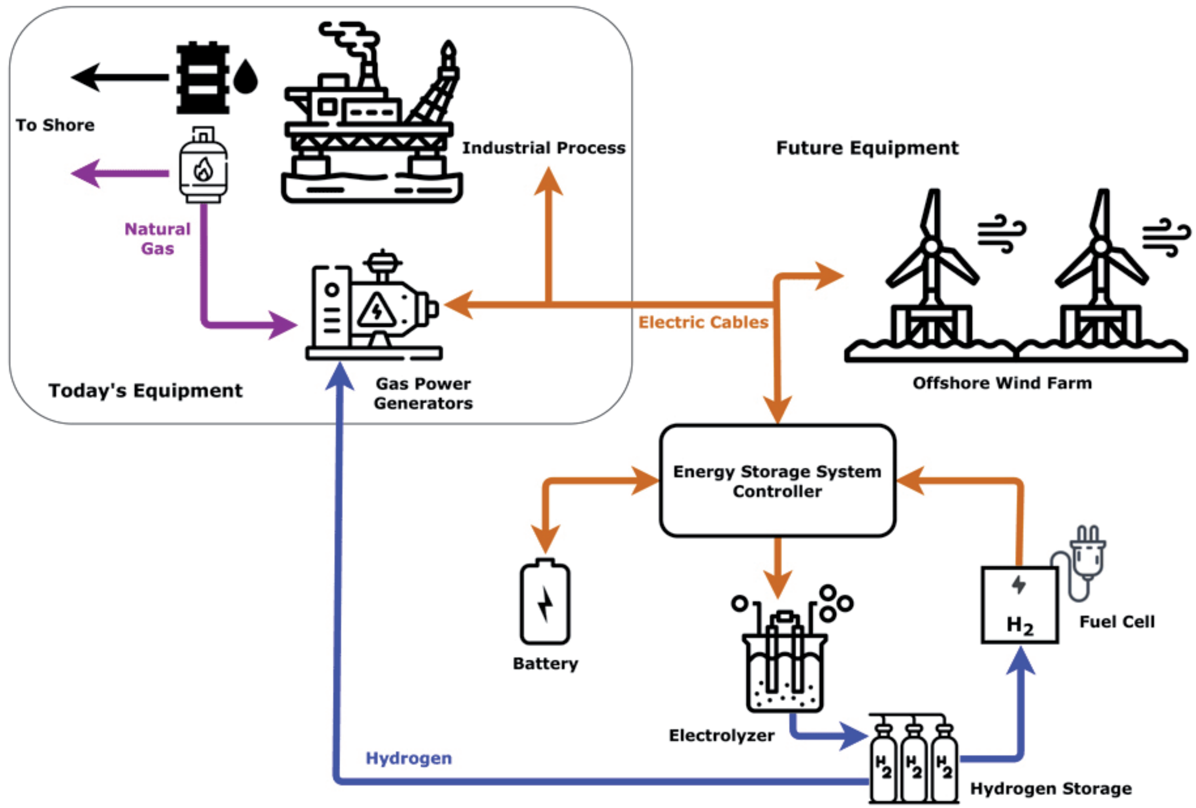
The oil and gas activities on the Norwegian Continental Shelf are extremely energy intensive. In 2008, a report estimated that 15 TWh of electrical energy was consumed on the active fields on the Barents, North, and Norwegian Seas. To put this figure into perspective, the hydropower plants owned by one of the largest Norwegian power utility companies can produce 17 TWh per year and can supply 2.2 million people, or 40% of the Norwegian population.

OPPORTUNITIES AND CHALLENGES OF OFFSHORE WIND

Offshore wind farms present an extraordinary opportunity for reducing the consumption of natural gas for electricity generation on the Norwegian Continental Shelf. By connecting a wind farm to the energy-intensive process of an oil and gas platform, a considerable part

JOURNEY TOWARDS A FOSSIL FUEL FREE SOCIETY

Natural gas and petroleum are the remains of accumulated dead organisms at the bottom of ancient seas. Coal deposits were once forests in a time when wood was not yet biodegradable. These abundant energy deposits captured from sunlight millions of years ago allowed humanity to thrive in the present. Nowadays, petroleum, natural gas and coal together represent 80% of the world's primary energy source. In other words, society would go to a halt if we suddenly stopped using fossil fuels. This dependency on fossil fuels warms the climate. This is why we need to reduce our carbon footprint and move towards a fossil fuel free society. Unfortunately, replacing 80% of the world's primary energy source will take decades. On our journey towards this goal, we must find and take the less polluting paths.



Integration of an offshore wind farm to an oil and gas platform.

Some of the icons in this figure are from www.flaticon.com of the gas that would otherwise get burnt in low-efficiency turbines can be directed to land. However, wind power generation comes with a series of technological challenges.

BALANCE OF POWER

Offshore platforms don't store electric energy directly. The energy required by the industrial process and the energy supplied by the generators walk a tight balance. The power demanded by each motor, pump and even light bulb has to be continuously provided by the electric generators. An unbalance of power directly affects the generator's speed; in other words, the system's electrical frequency. The governors of the turbines regulate the amount of natural gas burnt for meeting precisely the process demand. They continuously control gas valves (figurative gas pedals) for maintaining the rotating speed of the generators constant. However, wind is intermittent. There is no valve or pedal for increasing or decreasing wind speed. If wind is to replace natural gas, an energy storage system is necessary to maintain the electrical grid of the platform stable.

LONG TERM BALANCE OF POWER

On the scale of hours or days, average wind speeds vary considerably. A long-term energy storage device is therefore necessary to "save" fast winds for the times when they stop blowing.

In the figure, this is represented by the pairing of an electrolyzer and a fuel cell. The electrolyzer breaks water into hydrogen and oxygen using the excess wind energy. The fuel cell combines the stored hydrogen with oxygen, releasing water and electricity, when wind is low.

The turbines of oil and gas platform are usually "aeroderivatives". In short, they are aviation turbines that run on natural gas instead of jet fuel. This characteristic makes it possible to adapt the turbines for running on hydrogen produced by the electrolyzer. Strategies for sizing the storage system, as well as managing the production and use of hydrogen, are an active field of research.

SHORT TERM ENERGY BALANCE

Every spinning thing holds a form of energy called rotating kinetic energy. A large metal part, the rotor, spins quickly inside the electric generator. This rotor is electromagnetically coupled to the platform's electrical grid. It serves as an energy buffer and is vital for stabilizing the grid during the start-up or shutdown of the platform's large motors. The energy in the rotating parts of generators is physically available to the electrical grid – no controller or programming required.

Wind turbines, however, cannot spin at a constant speed. Because of that, they need special power electronic converters for operating. This removes their electromagnetic coupling with the grid. Therefore, whenever a gas turbine is replaced by a group of wind turbines, a part of this vital energy buffer that was directly connected to the grid disappears.

This problem can be solved by using a fast storage device. Such a device is represented by the battery in the figure. A power electronic converter is necessary for maintaining an energy buffer (the battery) and using it whenever necessary. For example, the energy in the battery has to be retrieved for supporting the start-up of a large compressor. Note that this has to be actively programmed in the controller of the energy storage system. This is known as "virtual inertia". This control strategy is investigated by numerous research groups worldwide and has not yet become a consolidated technology.

THE WAY FORWARD

Various challenges lie ahead, and many technological advances are necessary on our journey towards a fossil fuel free society. This journey is going to be long and it is imperative that we choose less polluting paths. One such choice is to reduce the consumption of natural gas for electricity generation on the Norwegian Continental Shelf.

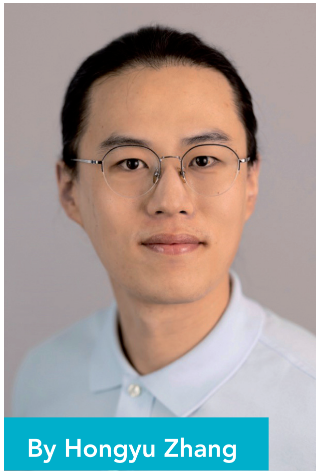
In this context, research initiatives like the *LowEmission* Research Centre are key. This initiative seeks to develop technologies and solutions needed to reduce offshore greenhouse gas emissions on the Norwegian Continental Shelf. A total of 19 PhD students and postdocs, plus 30 MSc candidates are expected to contribute to *LowEmission* from 2019 to 2026.

READ MORE ON THE TOPIC FROM THE SAME AUTHOR

- D Mota, E Tedeschi – On Adaptive Moving Average Algorithms for the Application of the Conservative Power Theory in Systems with Variable Frequency
- D Mota, E. Tedeschi – Understanding the Effects of Exponentially Decaying DC Currents on the Dual dq Control of Power Converters in Systems with High X/R
- E Alves, D Mota, E Tedeschi – Sizing of Hybrid Energy Storage Systems for Inertial and Primary Frequency Control

Offshore energy hubs: a useful tool to decarbonise the Norwegian continental shelf's energy system

Offshore energy hubs are poised to play an important role in the North Sea's green transition. These hubs will serve as connecting points and storage sites for the energy produced with offshore renewables. Building them optimally to get the best results at the lowest possible cost will require careful analysis.



By Hongyu Zhang

THE ROLE OF NATURAL GAS ON THE NORWEGIAN CONTINENTAL SHELF

Norway was the world's third-largest exporter of natural gas in 2019. Offshore oil and gas extraction was responsible for 26.6% (13.3 Mt CO_2 equivalent) of the total Norwegian greenhouse gases in 2020. Norway is stepping up its climate goal, with planned emissions reduction of 50% to 55% by 2030, compared to 1990 levels. The Norwegian Continental Shelf's (NCS) energy system will have to be decarbonised to be aligned with the goal. 84.6% of the total emissions from offshore oil and gas extraction is from gas turbines located on platforms. These turbines have a low efficiency – of around 33%. Replacing gas turbines with renewable energies will help platforms achieve zero emission for the extraction part of the oil and gas industry. North Sea offshore wind may play a central role in the shelf's energy system decarbonisation. Offshore Energy Hubs (OEHs) may help efficient offshore wind power generation and distribution.

An OEH is a physical energy connection point with energy storage, where multiple energy carriers can be converted, conditioned and stored – see Figure 1 for an illustration of an OEH. Offshore wind power has a variable output and may not meet the security of supply requirement of platforms. Energy storage can solve the problem, by compensating for wind power volatility – and helping it replace gas turbines fully. However, adding batteries to a platform can be impractical due to the weight and space limitations. OEHs can convert surplus wind power and store it in the form of hydrogen. Then OEHs can generate electricity with fuel cells and supply it to platforms when the wind isn't blowing.

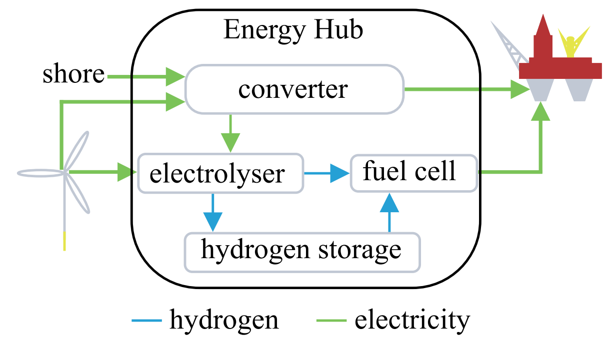


Figure 1: Conceptual illustration of OEHs

OEHs may fill a useful role in both the short- and long-term. In the short to mid-term, they can provide a carbon-free energy supply for offshore oil and gas extraction, maritime cargo transport, and offshore farming. In the longer term, the development of OEHs may also facilitate the transition to a decarbonised continental energy export. After the oil and gas fields have fallen into disuse, OEHs may produce and export green hydrogen and connect with a North Sea offshore grid.

PLANNING TO ACHIEVE BEST RESULTS

It is important to make investment planning in OEHs and other decarbonisation technologies (offshore wind, offshore solar, subsea cables, for example) to achieve a zero emission NCS energy system in a cost-efficient way. The investment planning can be formulated as an optimisation model. An optimisation model is a mathematical description of a system that aims to minimise or maximise an objective with some constraints. Optimisation is widely used in energy research.

It would be useful to analyse the value of OEHs from different aspects, such as emissions, energy losses and costs. An illustration of an investment planning problem for the NCS energy system is shown in Figure 2. The problem focuses on the decarbonisation of the offshore oil and gas platforms. All 66 operating fields in the North Sea part of the NCS are clustered into five groups. OEHs are invested in five candidate locations around the field clusters. By conducting sensitivity analysis on CO_2 tax, we aim to show the value of OEHs under different CO_2 tax levels.

In 2021, the CO_2 tax is about 55 €/tonne in Norway with an ambition to increase it to 200 €/tonne in 2030. Combined with the increase in the EU emissions trading system, the CO_2 price could be in the range of 250 – 300 €/tonne by 2030. Figure 3 shows the investments decisions.

We can see that the break-even price of OEHs is around the planned CO_2 price in 2030. In addition, the potential benefits of the OEHs may realise once they provide services to more sectors, such as exporting hydrogen for industries or transportation.

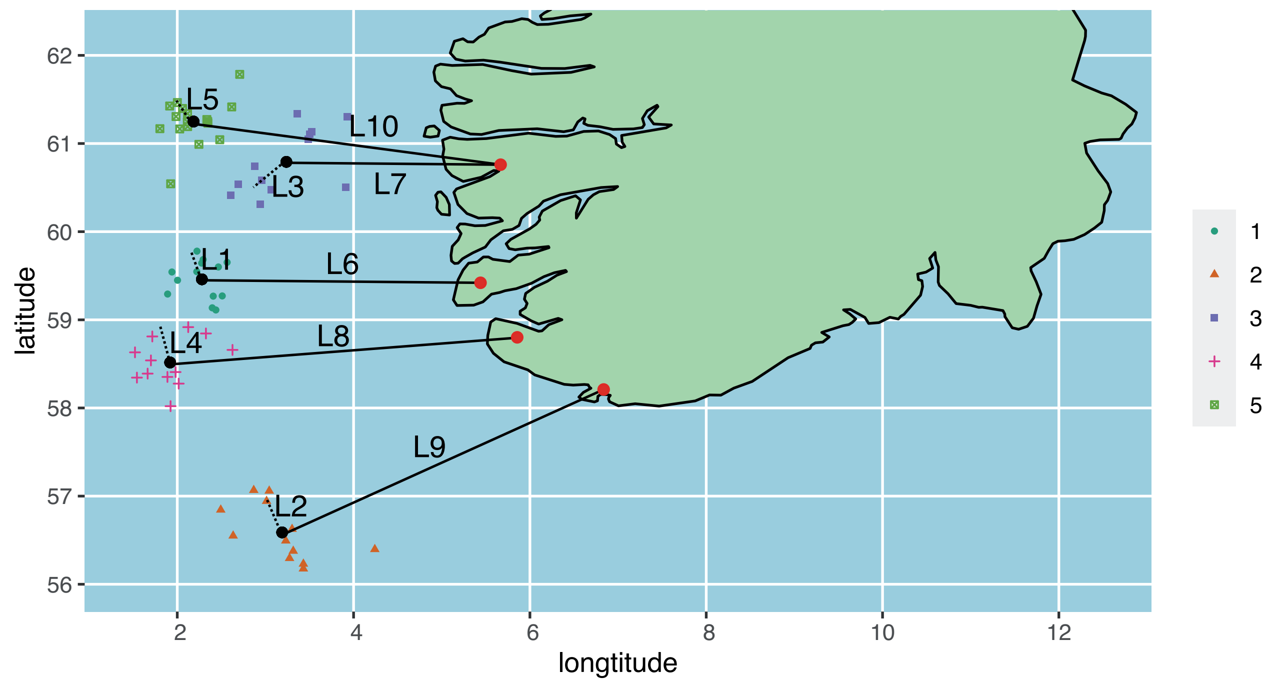


Figure 2: Illustration of the NCS energy system investment planning with OEH. L1 – L5 (dotted lines) represent HVAC cables, while L6 – L10 (solid lines) are HVDC cables. Black dots represent energy hubs, and the red dots represent the onshore buses they connect to. Points with different shapes and colours represent NCS oil and gas fields. The technologies considered include offshore wind, offshore solar, OEHs (electrolysers, hydrogen storage facilities and fuel cells), batteries, electric boilers and subsea cables.

Figure 4 shows the difference in emissions and costs in the cases with and without OEHs. OEHs have the potential to reduce CO_2 emissions by an extra 50%, while reducing the total costs by 5%. It is also worth noticing that a carbon budget may be necessary to enable a zero emission energy system in addition to the CO_2 tax.

From Figure 5, we find that as production from wind turbines replaces gas turbines, energy loss from gas turbines is reduced. However, due to the lack of energy storage, electricity generation shedding increases. We find that OEHs can effectively reduce electricity generation shedding, although there is an energy loss during conversion (from electricity to hydrogen, for example). Overall, energy loss is up to 10% lower in the case of OEHs.

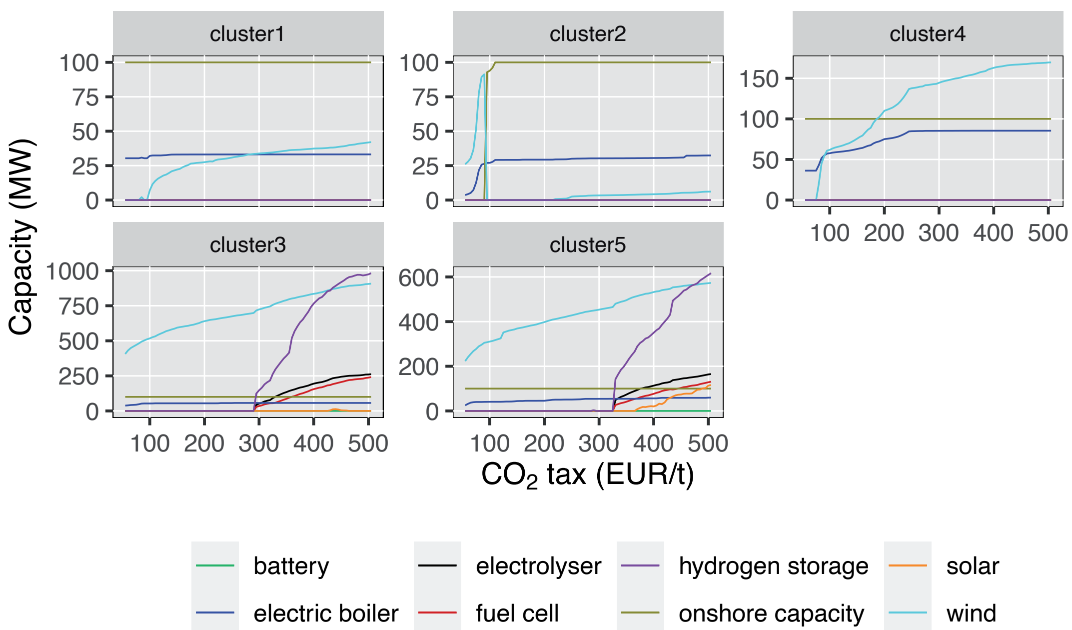


Figure 3: Capacities of technologies in each cluster. Hydrogen storage is measured in tonnes.

GENERATION SHEDDING

Generation shedding, in the context of electricity production, refers to the wasted part of the electricity generation, occurring when more power gets generated than necessary.

From a large-scale techno-economic analysis, we find that OEHs can reduce emissions and energy losses in a more cost-efficient way. OEHs may benefit Norway in both the short- and long-term, helping with both decarbonising the shelf and exporting clean energy. In addition, OEHs may also contribute to European climate targets. However, to make such analysis more accurate, collaboration between academia and industry is needed.

For the detailed modelling and the results on sensitivity analysis of CO_2 budget and the capacity of power from shore, we refer the readers to our paper to our paper "Modelling and analysis of offshore energy hubs".

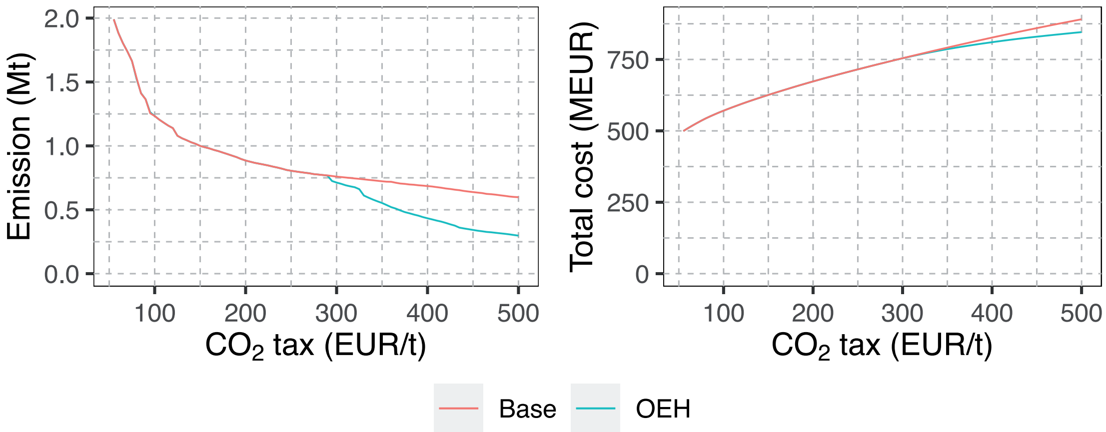


Figure 4: Emission and cost comparison (Base: the system without OEHs, OEH: the system with OEHs).

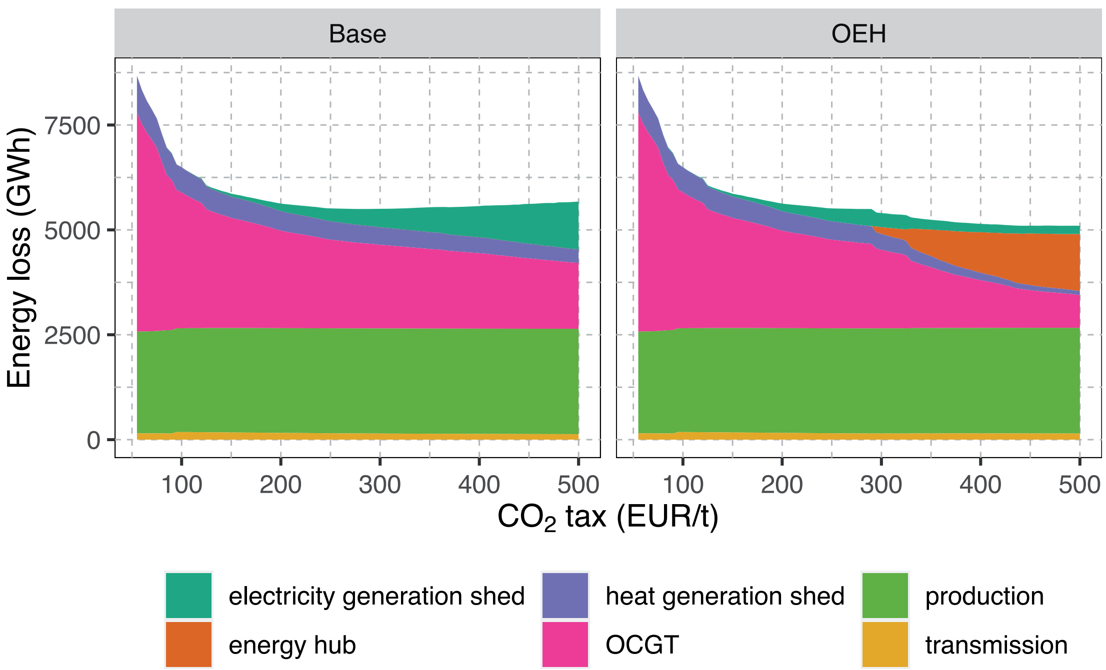
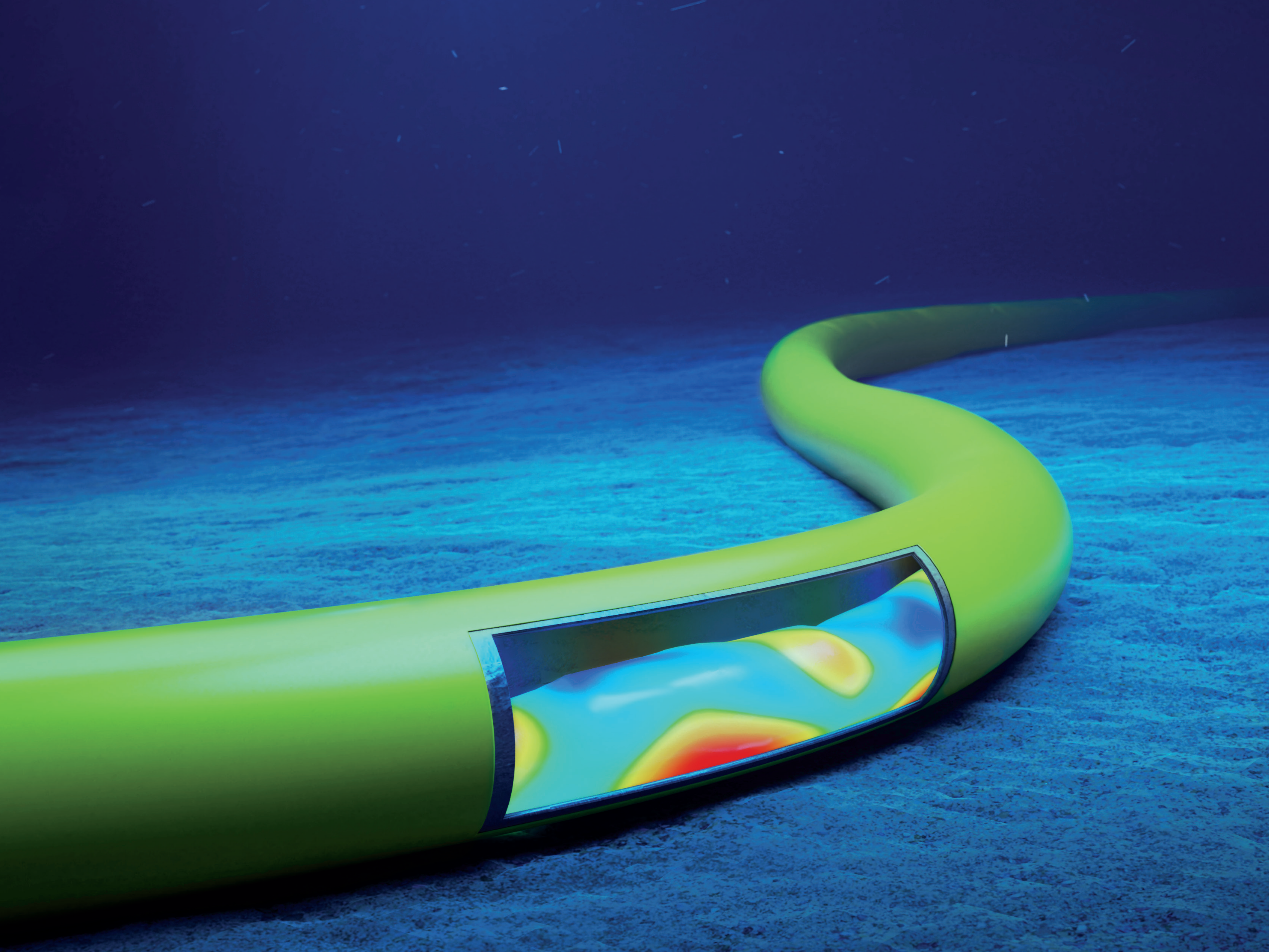


Figure 5: Energy loss (Base: the system without OEHs, OEH: the system with OEHs).



Environmental assessment of the cold flow technology

By Leila Eyni

A BIT OF BACKGROUND

The latest OG21 strategy document has outlined that after 2030, the production of Norwegian offshore oil and gas fields will increasingly be dominated by new fields. Due to fewer large oil and gas discoveries, attention has turned to smaller, less economically viable discoveries. Cost-efficient development of most of those resource would require tiebacks and utilisation of already established infrastructure. A tieback is a connection between a satellite field and the processing facility of another field. Future marginal subsea tieback developments may add up to 4 bnboe (billion nok barrel oil equivalent) from breakeven prices of 50-90 USD/bbl with current solutions. Besides reducing costs, a tieback will also have the potential to reduce CO_2 emissions and carbon footprint by extending the lifetime of production infrastructure and reducing the number of required facilities. Furthermore, a tieback will increase utilisation of a facility after plateau production of the main field. This, in turn, will lead to higher overall process efficiency.

However, transporting the produced reservoir streams over very long distances on irregular terrain and with cold ambient temperatures poses flow assurance challenges. Conditions of high pressure and low temperature can cause the formation of hydrate particles that can lead to increased pressure drop or plugging of flowlines. This can in turn hinder optimal extraction of hydrocarbons, or cause equipment malfunction.

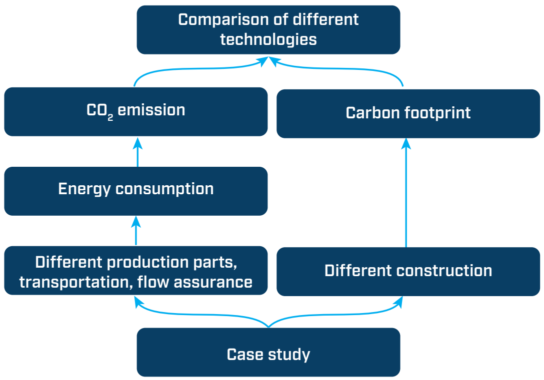
Traditional measures to address hydrate formation involve chemical-based technologies, costly thermal insulation, or energy intensive pipeline heating. All these alternatives implicate environmental hazards or rather high CO_2 emissions. This is contrary to *LowEmission*'s target, which aims at decreasing the offshore environmental footprint. The so-called Cold Flow technology is an upcoming alternative which offers both less costs, footprint and emissions during operation. The Cold Flow concept enables the flow of hydrocarbon production fluids at thermodynamic equilibrium in uninsulated pipelines, without the help of chemical modifiers, active or passive heating, or heat-retention schemes.

THE COLD FLOW TECHNOLOGY

In the Cold Flow concept, hydrate particles are induced in a controlled manner in a dedicated reactor-cooler unit. These so-called dry-hydrate particles will form a stable liquid slurry that can easily be transported and does not agglomerate and plug the pipe downstream of the cooler. It can be defined as a flow of non-adhesive and non-cohesive hydrate particles dispersed in the production fluids.

As part of my PhD research, we performed a case study to investigate the concept's limitations and to quantify the environmental performance of Cold Flow and compare with traditional field development options. The case was developed with input from industry partners and comprises of an oil field in the northern region that might be produced with a local dedicated FPSO (Floating production, storage and offloading unit) or a 100 km tieback solution to the closest suitable existing offshore processing facility. Cold Flow as well as different heating and insulation options were considered as hydrate prevention technologies for the tieback solution. Also, two different reservoir recovery methods were considered, namely gas injection and water injection. A realistic model of the subsea system and flowlines was created in the commercial dynamic flow simulator LedaFlow to study the fields flow performance and concept feasibility during the lifetime of the project.

Carbon footprint, energy consumption, and related CO_2 emissions were estimated and compared for all concepts. The carbon footprint estimates were based on the main components' weight and a carbon emission factor, assuming steel as main material. Details regarding the emission factor and estimating the weight of construction can be found in our previous works. The power consumption during operation was based on simplified models for the main processing units covering pumps, compressors, heating, etc. Results were translated into emissions assuming an emission factor of 5000 tonnes CO_2/MW*year when gas turbines are used for power generation. The detailed procedure of calculating the energy consumptions of the main contributors for each case is also presented in our paper to be published at the 41st International Conference on Ocean, Offshore and Arctic Engineering (OMAE 2022).



A quick glance at the procedure.

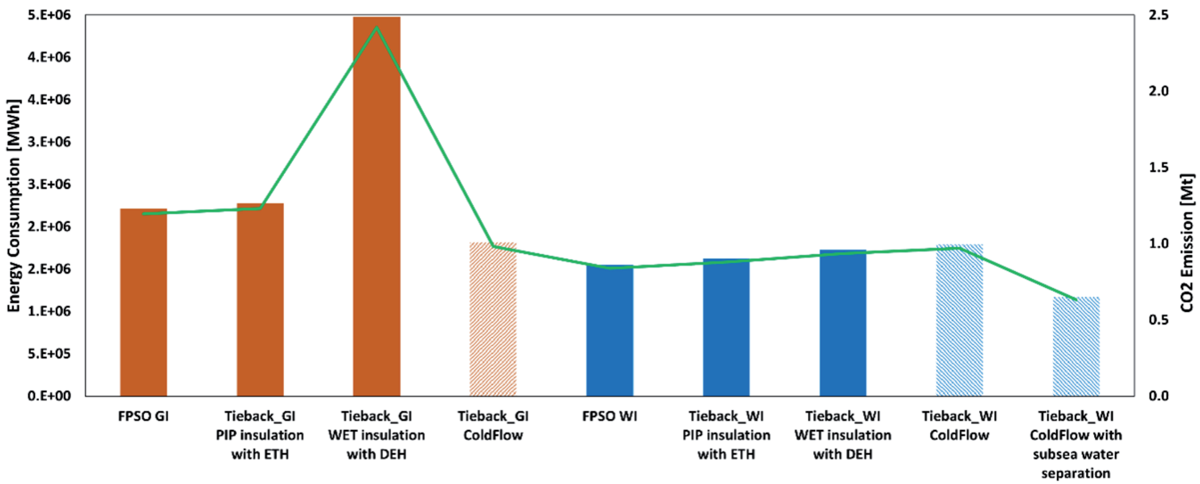


Figure 1. Comparison of CO_2 emission and energy consumption of all considered cases[1]. The line shows energy consumption. The blue column shows water injection (WI) cases, while the orange column shows gas injection (GI) cases. Bars with patterns indicate cold flow technology.

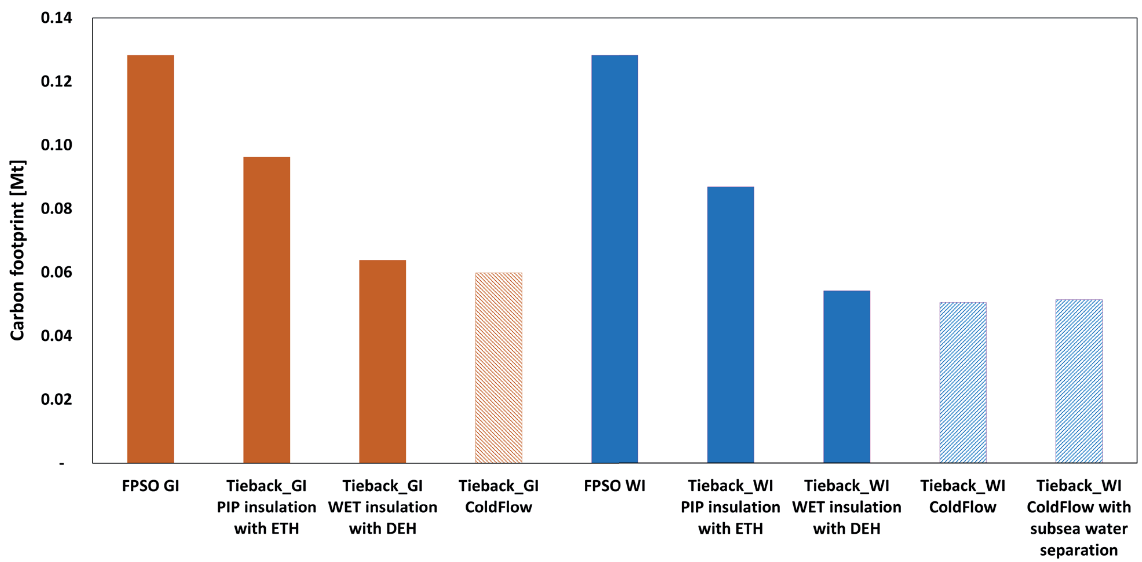


Figure 2. comparison of the carbon footprint of all considered cases[1]. The blue column shows water injection (WI) cases, while the orange column shows gas injection (GI) cases. Bars with patterns indicate cold flow technology.

1 PiP=Pipe in Pipe, ETH=Electrical Traced Heat, DEH=Direct Electrical Heat

RESULTS

Results show that in comparison with traditional alternatives, this technology could reduce energy demand by about 385,500 MWh and 370,600 MWh for gas and water injection, respectively. This corresponds to reduced lifetime CO_2 emissions of 22% and 30% for the gas and water injection scenarios when compared against a standalone FPSO development. These reductions are equivalent to around 0.3 $MtCO_2$ for both scenarios, which is a great achievement. Please see Figure 1 and Figure 2 .

This technology offers many other advantages. Cold Flow can be more cost-effective and simpler to maintain and implement in comparison with traditional approaches. All large and costly subsea power consumers along the flowline (for heating and boosting, for example) may be removed depending on the scenario. In addition, results indicate that the technology is not only relevant for liquid-dominated production (here water injection, which was the initial design case) but also for production with higher gas rates. This will extend the possible application area of the technology.

In summary, we can expect the Cold Flow technology to be an important option for many future field developments standing for a considerable part of the required emission reduction. In combination with a cost advantage, this will enable field developments that otherwise would have been discarded. For more details, we refer to our publications at OMAE 2022.

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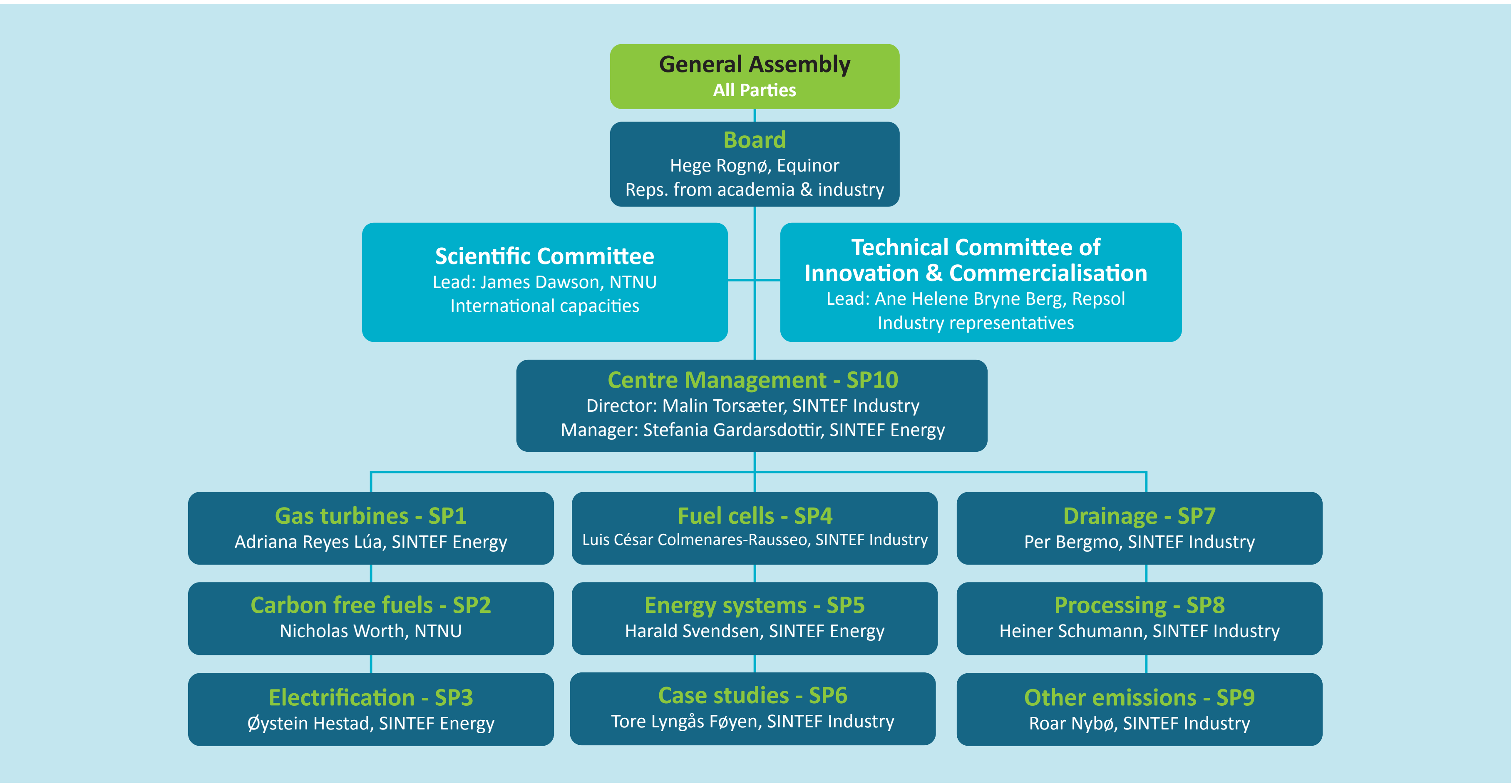
Eyni, L., Stanko, M., Schümann, H., 2021, Methods for Early-Phase Planning of Offshore Fields Considering Environmental Performance, http://dx.doi.org/10.2139/ssrn.3935491

Schümann, H., Eyni, L., Fattahi, M., 2021, DSP8_2021_3 Feasibility and environmental analysis for a 100 km tie-back solution with cold-flow, Project memo, *LowEmission* center, SINTEF

"Technical and environmental evaluation of a hydrate cold flow technique to produce an oil reservoir using a ling tie-back and comparison against traditional development concepts" as part of the 41st International Conference on Ocean, Offshore and Arctic Engineering (OMAE 2022) in Hamburg, Germany in June 2022.

Organisation

GOVERNANCE STRUCTURE



CENTRE MANAGEMENT TEAM 2021

Malin Torsæter
Centre Director
Research Manager
SINTEF Industry

Stefania O. Gardarsdottir
Centre Manager
Research Manager
SINTEF Energy Research

Jon Magne Johansen
Business Developer
Senior Business Developer
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Research Scientist
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Anders Ødegård
Centre Operations
Senior Project Manager
SINTEF Industry

Lars Magne Nonås
Centre Operations
Research Manager
SINTEF Ocean

James Dawson
Lead for Scientific Committee
Professor
NTNU

Ane H. Bryne Berg
Technical Committee of
Innovation & Commercialisation
Senior Manager New Projects
Repsol Norge AS

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
Lundin	Charlotte Berge
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	Gjertrud Halset
Wintershall Dea	Michael Charles
TotalEnergies	Thierry Boscals de Réals
Research Council of Norway (observer)	Andreas Quamme Nielsen

Operators

ConocoPhillips, equinor, Lundin Energy Norway, REPSOL, TotalEnergies, vår energi, wintershall dea, DNO, OMV, SPIRIT ENERGY

Service & vendors

ABB, aibel, AkerSolutions, altera INFRASTRUCTURE, BOREALIS, COGNITE, CoorsTek, CURISTEC, CYBERNETICA, KONGSTEIN, KONGSBERG, Nedstack PEM FUEL CELLS, Nexans, ODFJELL DRILLING, REINERTSEN NEW ENERGY, ReStone AS, RYSTAD ENERGY, ScanWell, Schlumberger, SERAM COATINGS, SIEMENS energy, T.EN TECHNIP ENERGIES, Thomassen Energy a Hanwha company

Research & development

SINTEF

NTNU

Public financing

The Research Council of Norway

Associated Research Entities

University of Strathclyde Glasgow

Carnegie Mellon University

TNO innovation for life

The Oil & Gas Technology Centre

Lund University

Sandia National Laboratories

DTU Technical University of Denmark

University of Cambridge

Cranfield University

Associated agencies

Norsk Industri

Norsk olje&gass

Petroleumstilsynet

Norwegian Energy Partners

Oljedirektoratet

Cooperation between partners

The subproject (SP) families have proven to be an integral part of stimulating collaboration between industry and R&D partners. The SP families consist of technical representatives from the industry partners, as well as researchers and PhD candidates working within the different SPs. The SP 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.

SCIENTIFIC COMMITTEE

International academic collaboration is important to ensure quality and excellence in LowEmission. The Scientific Committee will be comprised of a number of internationally recognised researchers. Its job is to support quality and excellence by assessing the output of the academic programme in terms of Research and dissemination, providing recommendations for improvement, and highlighting important areas that should be addressed if the resources are available. The Committee aims to meet every 2 years starting in the spring of 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. Mrs Ane Bryne Berg (Repsol Norge) was the leader of the TCIC for most of 2021.

WEBINAR SERIES

The *LowEmission* autumn webinar series was a success this year as well. In total, 9 webinars were held, attracting a total of just under 200 participants from the consortium.

The topics were as follows:

- Achieving Uptime Targets for Wind-Powered Subsea Boosting, 12/03, Aker Solutions Innovation Challenge
- Energy florom waves and tides, 30/09, TotalEnergies Innovation Challenge
- Towards estimation of long-term power demand for installation on the NCS, 07/10, SINTEF
- Offshore heat-to-power cycles – How are we solving design and operational challenges? 14/10, SINTEF
- NCS C+: The Norwegian Continental S, 21/10, SINTEF
- Electrical Power Components; Challenges due to load variations, power electronics and new materials, 28/10, SINTEF
- Hydrogen Fuel Cells – more than just H_2 + ½ O_2 → H_20, 04/11, SINTEF
- Reducing emissions by reducing water pollution, 11/11, SINTEF
- Feasibility and environmental analysis for a 100 km tie-back solution with cold-flow, 25/11, NTNU, SINTEF, EMPIG

CONSORTIUM DAYS

The annual *LowEmission* Consortium days were held on 17-18 November in Trondheim. This was the Centre's first major in-person event since the beginning of the pandemic. Keynote speakers for the conference were Gunnar Lille, managing director at OG21, who presented his organisation's new technology strategy for the Norwegian petroleum industry. Thierry Boscal-de-Reals, R&D Project Manager at TotalEnergies, presented the company's plan for the green transition. Lennart Näs, Senior Key Expert GT Operation and performance, had a presentation about decarbonised energy solutions.

The keynote speeches were followed by presentations from the leaders of all of the Centre's subprojects, as well as two knowledge-building spin-off projects. Then followed presentations by PhD candidates, a poster session with all PhD candidates in the Centre as well as two panel debates: the first about Efficiency and emission improvement, and the second about New installations. A third panel took place on the second day, titled "Mobile Units and Hybrid System".

Above: The annual LowEmission Consortium days were held on 17-18 November in Trondheim.

Above: Thierry Boscal-de-Reals, R&D Project Manager at TotalEnergies: "Oil will be key to finance TotalEnergies' green transition, but it will have to be low-cost and low-carbon."

Left: Marit Mazzetti, Senior Research Scientist at SINTEF, presents her knowledge-building projects for industry: Digital Twin for Optimal Design and Operation of Compact Combined Cycles in Offshore Oil and Gas Installations.

Right: Ane Bryne Berg (Repsol) representing the Technical committee of innovation & commercialisation, and Charlotte Berge (Lundin) representing the Board, had an interesting discussion about the challenge of taking things for the simulation/prototype stage to the real world.

Left: Francesco Finotti, Research Manager at SINTEF Energy, presents Carbon Links (LINCCS), a Green platform project that will link large-scale, cost-effective, permanent offshore CO_2 storage across the value chain. Øystein Hestad, also Research manager at SINTEF Energy, presented another Green platform project, called Ocean Grid. This project will develop new technology, knowledge and solutions to enable a profitable development of offshore wind on the Norwegian continental shelf. It will look particularly at the way offshore wind will be connected to the grid. Both projects will have significant research synergy with LowEmission.

RESEARCH AND RESULTS

SINTEF Research Scientist Katie McCay prepares a fuel cell stack for testing at the Norwegian Fuel Cell and Hydrogen Centre. The stack was provided by LowEmission partner Nedstack.

Photo: SINTEF

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 runs 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 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 turbine (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. This concept has been implemented before. However, the weight and footprint of a bottoming cycle system need to be minimal to enable widespread implementation. In SP1 we develop more compact and lightweight designs considering thermodynamic optimisation, possibly using other working fluids than steam (addressed in Task 1.3). Analysing their operation and proposing optimal operational strategies for the CCGTs is the goal of Task 1.1.

MAIN RESULTS IN 2021

- Further development of in-house framework for simultaneous optimisation of component specifications and process parameters for bottoming cycles. Model reformulation for improving robustness. Web interface (WEB-GUI) for thermodynamic simulation of bottoming cycles delivered this year.
- Simulation results for a simple steam power cycle and for a recuperated CO_2 cycle.
- Definition of standard configuration for a combined cycle to be used for coordinated work between Task 1.1 and Task 1.3.
- Creation of a new Dymola package "*LowEmission*_SP1" with a simple and self-explaining package structure to be used for the analysis of dynamic operation of steam bottoming cycles. The package includes gas turbine models, 1D dynamic process models of once-through steam generators (OTSG), a steam turbine model and a condenser model.
- Definition of the control problem for bottoming cycles for power production. Beginning of the work for implementation of control structures in Dymola.
- Participation in the 6th international seminar on ORC power systems, Munich-2021 “Improving the off-design efficiency of Organic Rankine bottoming cycles by variable area nozzle turbine technology" by PhD student Mohammad A. Motamed and supervisor Ass. Prof. Lars O. Nord. Full (peer-reviewed) paper published.

IMPACT AND INNOVATIONS

- Improvement of robustness of new methodology for simultaneous optimisation of component specifications and process parameters. This methodology was implemented in the web interface for analysing bottoming cycles.

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.

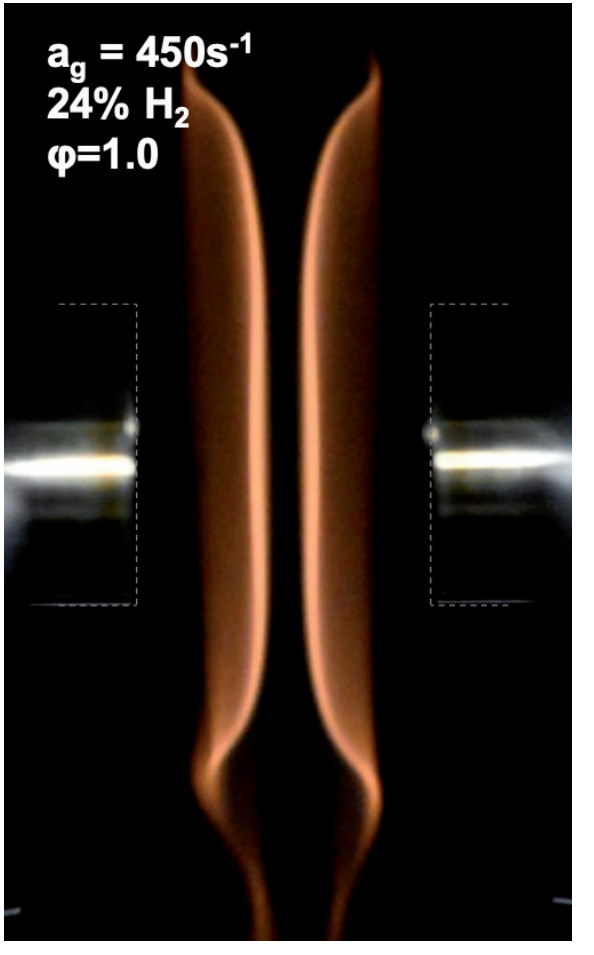
MAIN RESULTS IN 2021

- **WP1.1** Preliminary quantitative Raman/Rayleigh measurements have been made in NH_3 flames at TU Darmstadt, and extinction experiments on a laminar opposed jet burner are ongoing.
- **WP1.2** A new PhD candidate joined the project in September 2021 and started planning and design work for the experimental investigation of burner staging strategies in $NH_3/H_2/N_2$ flames at atmospheric pressure at NTNU.
- **WP1.3** An experimental campaign with $NH_2/H_2/N_2$ fuel blends at pressurised conditions up to 10 bar was conducted. 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.
- **WP2.1** SINTEF and Sandia National Laboratories have conducted the first Direct Numerical Simulations (DNS) of the non-reacting flow field in a simplified *Flamesheet-type* combustion system geometry.
- **WP 3.1** Detailed chemical modelling and simulations are being conducted, which will improve our understanding of ammonia injection and fueling on engine performance, emissions, ignition, and flame structure/speed. A PhD student is currently conducting a research visit to CERFACS, and preparation for modelling work is underway.

IMPACT AND INNOVATIONS

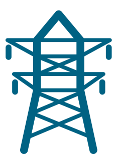
The research planned in SP2 encompasses technology development and gas turbine combustion chamber optimisation, and ICE novel fueling strategies, and it is therefore particularly well-suited to result in technical innovations.

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



ØYSTEIN HESTAD

Research Manager

SINTEF Energy Research

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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 gives lighter cables without the need for a metallic barrier to prevent water ingress, and reduced costs for 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

The gas turbines used for offshore power production today emit large quantities of greenhouse gases (GHG). Electrification from shore has the potential to drastically reduce these emissions. While the technology for electrification is already available, it is not often used as the price of electrification is high. The emphasis of SP3 is on reducing costs without sacrificing system reliability for the energy system and key 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 2021

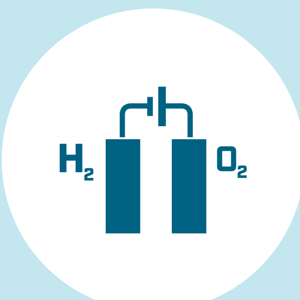
- Improved and documented the offshore grid layout optimisation model (PowerGIM).
- Completed analyses with the European power system expansion optimisation model EMPIRE.
- A new methodology for water tree analysis based on Scanning electron Microscopy (SEM) coupled with energy dispersive X-ray analysis (EDX) has been further developed. This will be an important tool in future research on water tree inception and growth, which is central in future development of wet-design cables.
- The first stage of a long running ageing experiment to investigate the impact of temperature cycling on degradation of wet design cables has been finalised. The results will be analysed in 2022.
- A test setup for investigating the effect of increased interfacial pressure along the interface in subsea connectors has been developed. This will be an important part of the infrastructure for the planned work in 2022 on subsea connectors.
- A framework for the simulation of offshore electrification and its global impact on CO_2 emissions has been established. The framework includes a description of the expected evolution of the European energy system and scenarios for the electrification of the NCS. It was developed based on up-to-date information and datasets, in order to ensure relevance of the case studies to be assessed in following task activities.

IMPACT AND INNOVATIONS

- The main goal of the material characterisation of aged wet-design cables (ongoing in 2022) is to link chemical and mechanical properties of the XLPE cable insulation with inception and growth of water trees. A methodology was established, including examinations of the surface of the spiralized slices soaked in de-ionized water by SEM combined with EDX. This methodology will now be put to use in the Green Platform Ocean Grid research project.
- The methodology developed to quantify and analyse GHG emissions gives a sound basis to measure the actual environmental impact of electrification.
- Analyses with EMPIRE show the importance, under the given assumptions, of onshore power to offshore installations. They also show the added benefits of building up the network in the Northern Sea to serve as both power supply and transmission hub.
- The work in SP3 has been important for two newly granted spin off projects (DeMoKab and GP Ocean Grid), in addition, two applications for competence building projects with support from the *LowEmission* consortium were submitted to the Research Council in February 2022.

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

The overall objective of SP4 is to investigate the use of fuel cell technologies on offshore installations, either to replace or hybridise with gas turbines for heat and power supply. By hybridisation, fuel cells may contribute with 5-10% reduction in CO_2-emissions. The research covers both low and high temperature technologies, respectively PEMFC and SOFC.

- PEMFC aims at finding the optimal design and operational strategies of large-scale PEMFC power plant under dynamic loads.
- Evaluate and optimise the inherent possibilities of SOFC technology integrated with the onsite energy system (intermittent renewable energy and gas turbines).
- Assess the materials and long-term stability of reversible proton ceramic fuel cells (PCFC) (i.e., H+-SOFC) for production of electricity and pressurized dry H_2.

MAIN RESULTS IN 2021

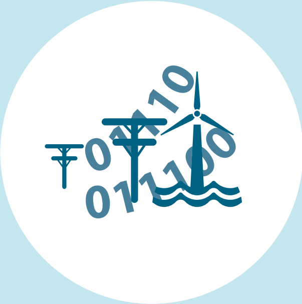
- Report providing an overview of fuel cell system performance under dynamic conditions including BoP. The report is based on an extensive literature review and technology survey to evaluate and compare PEMFC and SOFC/PCFC technologies with respect to system integration on offshore platforms using hydrogen, ammonia, or natural gas as the fuel.
- Testing of a PEMFC stack (8kW) provided by an industrial partner was successfully carried out under defined dynamic load profile and preliminary results show a good response under the given operating conditions.
- Report describing solid oxide fuel cell (SOFC) systems where various balance-of-plant components were described. Different options for how to combine these in a system for stationary applications were evaluated based on fuel (H_2 and NH_3) input and requirements for dynamic response and efficiency.
- A tubular proton ceramic electrochemical cell was tested for its performance and durability in reversible operation (H_2-production and power generation). The test-cell – developed primarily for electrolysis operation – displayed better electrode kinetics in electrolysis mode than in fuel cell mode. A long-term stability test of 520 hours was conducted. The cell displayed very stable and robust performance with degradation rates of 1-2%/khr and 6-8%/khr in electrolysis mode and fuel cell mode, respectively.

IMPACT AND INNOVATIONS

Collecting and summarising the offshore suitability of current available fuel cell technologies will enable further required, and more targeted investigations and developments to allow for real tests and implementation.

SP5

Energy systems – digital solutions



HARALD SVENDSEN

Research Scientist

SINTEF Energy Research

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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.

- Develop and apply tools for optimal low-emission energy system planning and operation

- Propose and assess power system control strategies for stable and efficient electrical systems with less gas turbines and more power electronics
- Prepare and submit 2 or more scientific papers
- Involve 3 PhD students into SP work, and define associated master projects
- Analyse data and develop data-driven methods to estimate future energy demand on the Norwegian continental shelf

MAIN RESULTS IN 2021

- The HyOpt investment planning model has been extended to include uncertainty. Documentation has been improved.
- The Oogeso model for operational optimisation/simulation has been updated. Open-source code has been tidied up and better documented.
- The "LEOGO" reference platform specification has been finalised (version 1.0), including a detailed dynamical electrical model for stability analyses. Analyses and comparisons of performance with different energy supply alternatives have been performed.
- Data-driven methods have been developed and tested with public data to estimate long-term energy demand on the NCS, with initial focus on water injection processes.
- The feasibility of integrating topside (SP8) and downhole (SP7) models for joint optimisation is ongoing.
- Several scientific publications have been submitted and accepted in journals and conferences by the three PhD candidates on topics related to controls and optimisation.

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. The Oogeso model is presently being integrated with industry software in a spin-off project.
- The detailed 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 an open model facilitates knowledge building and information sharing prior to case-specific analyses.

SP6

Case studies & innovation

TORE FØYEN

Research Scientist

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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 2021

- Conducted two "*LowEmission* Innovation Challenges" with industrial challenge from Aker Solution and TotalEnergies to get the industry perspective.
- *LowEmission* autumn technical webinar series.
- 5 case studies investigating the potential of new technology for emissions reduction.

IMPACT AND INNOVATIONS

Five case studies were initiated.

Heat & power generation

- Reduced-carbon operation of Elgin and Franklin O&G fields
- Subsea connectors and penetrators for high voltage renewable applications

System integration

- Energy storage for the deployment of Low Emission technologies

Reduced offshore energy consumption

- Energy recovery in electrified petroleum production plants
- Optimisation of low-emission platform

SP7

Energy efficient drainage

PER EIRIK S. BERGMO

Research Scientist

SINTEF Industry

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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. The work is performed in close cooperation with industry partners.

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. Focus in 2021 has been on:

- identifying potential technologies and strategies to reduce energy use in production
- assessing effect of technologies on field scale models, quantifying energy use and reduction potential
- further developing optimisation framework to enable maximised oil and gas recovery combined with reduced energy needs and costs.

MAIN RESULTS IN 2021

- A tool for setting up and quantifying energy consumption of water injection systems has been constructed.
- A simulation framework for quantifying effect of water shutoff technology on oil production and reduced energy consumption in field scale reservoir drainage has been developed.
- The effect of using DAR-technology for water shutoff on oil production and potential for reduced consumption was assessed for the modified Norne E-segment model.
- The effect of improved inflow performance on energy use and potential for reduction was evaluated on field scale generic models.
- A method for collaborative optimisation by shared objective function data was developed to speed up field scale joint optimisation of oil and gas production and CO_2 emissions.

IMPACT AND INNOVATIONS

Expected innovations are:

- Assessment methodology for energy consumption for relevant drainage strategies
- Methodology for co-optimisation of oil and gas production, energy use and costs
- Guidelines for selecting energy-efficient drainage strategies.

SP8

Energy-efficient processing

HEINER SCHÜMANN
Research Scientist
SINTEF Industry
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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 2021

- Generic field scenarios where studied and main energy consumers and losses identified.
- Optimising topside unit operation and applying energy recovery was demonstrated for a generic case. A theoretical potential of 30% emission reduction was identified.
- The environmental performance (footprint and emissions) was studied for a Cold-Flow solution as transport and flow assurance concept for future tie-back developments. When compared with traditional alternatives, a lifetime emission reduction of over 20% was achieved.

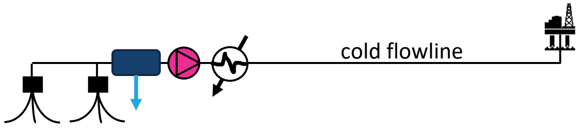

Figure 1: Cold-flow concept

- A joint PhD candidate was recruited together with SP7. The candidate will focus on developing an integrated optimisation framework considering both subsurface and topside modelling and the important interactions.

IMPACT AND INNOVATIONS

- Example studies demonstrating the potential of new technology will accelerate implementation of new solutions: This has been done for the Cold-Flow technology and topside energy recovery devices.
- A modelling framework for combined subsurface-topside optimisation was extended to correctly cover technical aspects of the processing system. This will lead to more accurate predictions.

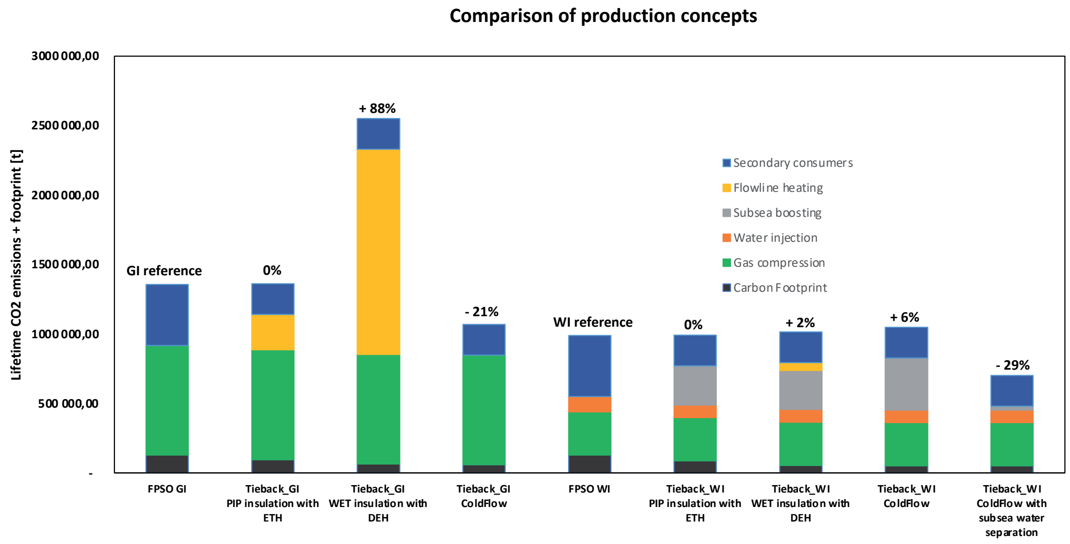

Figure 2: Lifetime emissions for different field development options. The Cold-Flow concept reduces lifetime emissions by more than 20% compared to the other options. Results are based on a field case with a 100 km tie-back solution.

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 2021

Offshore logistics

Collaborating with industry partners on MOLO, a planning software tool being developed by SINTEF Ocean, which helps offshore supply planners plan and analyse optimal routes for their vessels, reducing emissions from the vessel fleet while delivering to platforms and rigs. An early version has been in use at Equinor for the past couple of years and their experience has helped refine the software.

Discussions with other industry partners have outlined a potential for more operational decision support, taking into account uncertainties in demand and weather. We are pursuing this through 2022.

Hybrid propulsion

Today, battery packs reduce vessel emissions, and other technologies like ammonia fuel and fuel cells running on ammonia or hydrogen are steadily improving. However, the optimal design of these would depend on both the vessel design and how the vessel is typically used. We have addressed this in 2021 through integration of the ship-performance simulation tool Gymir with HyOpt, an optimisation model for energy systems. SP9 has worked on new scenario functionalities in Gymir to simulate offshore vessel operations. SP9 has also developed a framework for putting results from Gymir into HyOpt, allowing us to test how new vessel designs with emission friendly propulsion will perform in realistic operations.

A case study funded through SP6 analysed in 2021 the real-world performance of a platform supply vessel with a hybrid diesel generator and battery pack power system. The vessel was in regular supply operations in the North Sea. Through the use of HyOpt and Gymir, we were able to assess the emission reduction potential in the current design and the range of emission reductions possible through larger battery packs, reduced speed and access to offshore charging.

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, where methane is one of many compounds that crude oil consists of. Work in 2021 has refined calculations of the magnitude of the different ways in which these emissions take place.

Impact and innovations

The software in development in SP9 lays a foundation for more cooperation between actors in the offshore supply chains and will help make informed investment decisions when seeking to minimise emissions from the supply vessel fleet.

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.

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.

LOWEMISSION INNOVATION CHALLENGE

Two *LowEmission* Innovation Challenges were conducted in 2021: Aker Solutions' 'Achieving Uptime Targets for Wind-Powered Subsea Boosting' and Total Energies' 'Renewable Ocean Energies'. The idea of the Innovation Challenges is to give industry partners the spotlight. They are invited to present low-emission related challenges to the researchers and the whole Consortium. The Innovation challenges are intended to spur new ideas, inspire new activities within the Centre or even the development of new spin-off projects outside of the Centre. A concrete result is the newly awarded Green platform project LINCCS – Carbon Links, which was strongly rooted in Equinor's *LowEmission* Innovation Challenge presented in December 2020.

Featured innovations

Methodology to link chemical and mechanical properties of the XLPE cable insulation with inception and growth of water trees

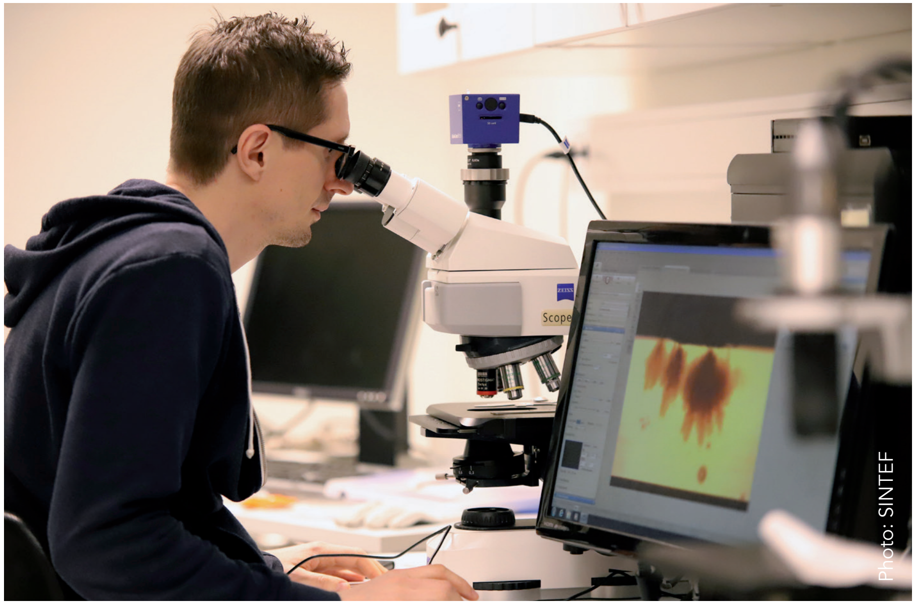
Key researcher:
Cédric Lesaint (SINTEF)

High voltage subsea cables are crucial to supply electrical energy to oil platforms – but also for other applications such as inter-array cables in floating wind farms. At *LowEmission*, new designs are evaluated to reduce their costs. The use of wet-design high voltage AC power cables is an attractive alternative. These cables are easier to implement and install than traditional subsea cables. Since they are lighter, much longer sections can be transported at once for installation, reducing the overall costs. However, over time, water molecules will enter the cable and cause a degradation of the cable insulation which can result in a reduction of its service lifetime.

The combination of electrical stress, water soluble contaminants and a humidity level above 70% can result in the growth of so-called water trees: dense networks of extremely small water-filled voids and channels. A particular concern is water trees appearing at the interface between the semi-conductive layers and the insulation. Results obtained at Low Emission show that the concentration of sodium and chlorine measured near the position of a water tree was twice as high as anywhere else

In modern cables, no contamination is normally observed at the interface between the XLPE insulation and screens. However, if the ions responsible for inception of the water trees at the interface are migrating from the screens, they could be revealed by a simple and new methodology consisting of examining the surface by scanning electron microscopy, combined with energy dispersive X-Ray.

Furthermore, an innovative use of focused ion-beam milling is promising to exclude contaminations at the surface, detecting ions tens of microns into the sample.



Cédric Lesaint, research scientist at SINTEF, examines a cross-section of subsea cable under a microscope.

Extended modelling framework for combined subsurface-topside optimisation

Key researchers: Handita Reksi Dwitantra Sutoyo (NTNU), Carl Fredrik Berg (NTNU) and Heiner Schümann (SINTEF)

Energy consumption in the petroleum production process can be divided into three main contributors, namely reservoir depletion techniques, transport techniques and processing and export of produced fluids. While the individual contribution of each part is field dependent, the general trend shows that energy intensity (and thus emission intensity) of a field typically increases rapidly with declining production rate. This is reflected in all aforementioned parts.

Still, todays planning and optimisation approaches typically address these areas independent of each other. The interdependencies, however, become more crucial when emission intensity is defined as an optimisation objective in addition to high recovery rate. As an example, the optimum depletion strategy might require changes in the topside pressure setpoints during the field's lifetime. The choice and configuration of processing systems must enable the depletion strategy. However, focusing on overall emission reduction might introduce limitations set by the processing equipment.

As part of a PhD project, an integrated modelling and optimisation framework considering subsurface and topside modelling is developed. This will enable correctly handling the interdependencies of topside and subsurface processes and predicting important feedbacks in terms of changed production (subsurface) or energy consumption. Combined optimisation of system design, unit operation and depletion strategy will be possible in one step.

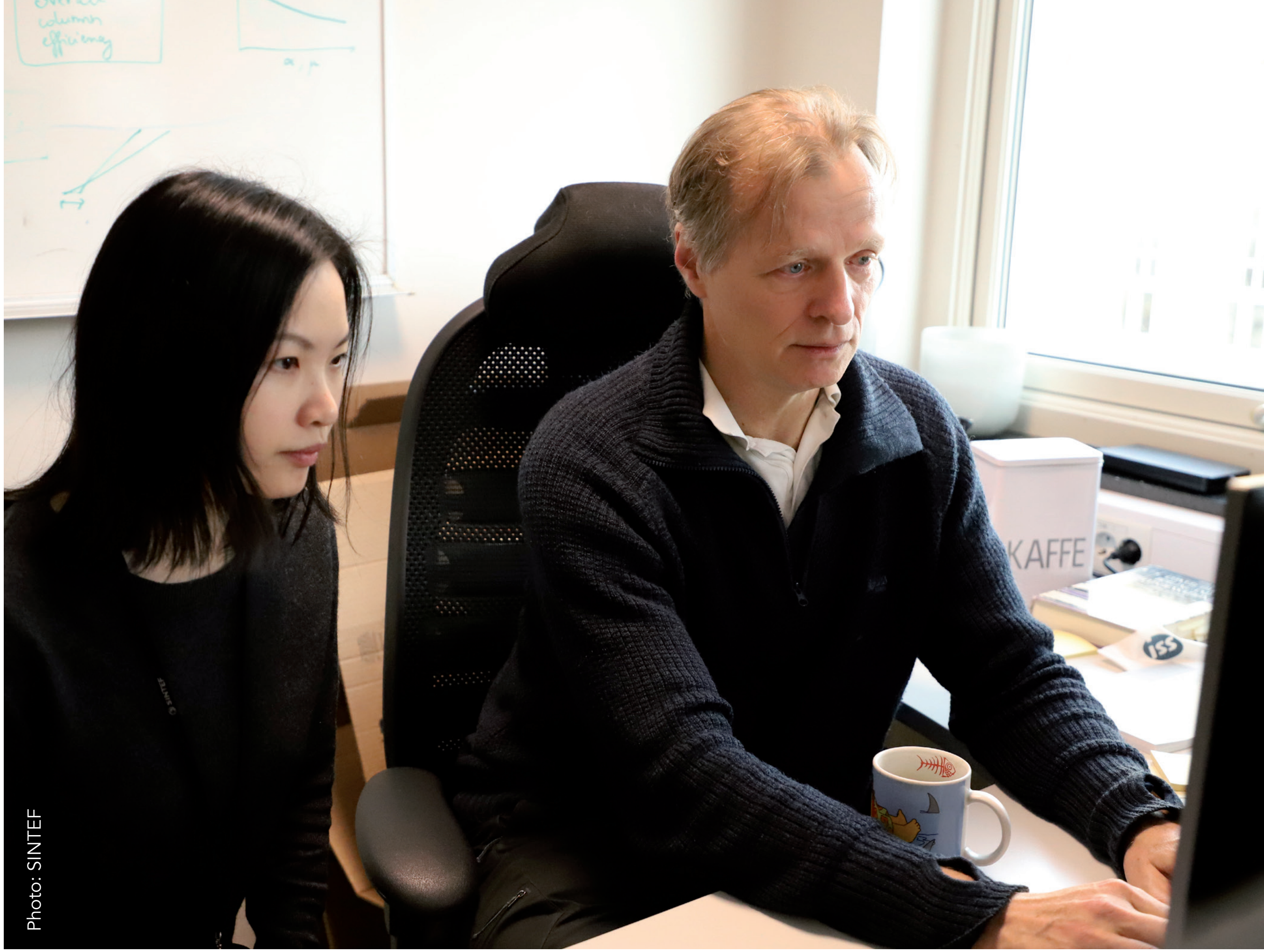
The code is written in Python and will be open source. Most recent activities focused on implementing more realistic models for processing equipment correctly relating energy consumption to unit performance.

Web interface for analysis of combined cycle systems

Key researchers: Geir Skaugen (SINTEF), Han Deng (SINTEF)

Gas turbines are the main source of electrical power, mechanical power and heat in offshore oil and gas installations. In onshore power plants, the exhaust gas from the gas turbines is usually used to run a bottoming cycle to produce additional electricity or steam. This solution can also be applied in offshore facilities to substantially reduce fuel requirements and the associated CO_2 emissions. However, the weight and footprint of a bottoming cycle system need to be minimal to ensure widespread implementation of these combined cycle systems.

Within the *LowEmission* Research Centre, we developed an interactive optimisation tool that can be used to find the potential for heat and power production from gas turbine exhaust. The model computes optimal process parameters for the bottoming cycle. This bottoming cycle analyser can be used to study the effect of different configurations of process requirements and system specifications on the combined cycle, by always maximising net power output after the process heat demand has been covered.



SINTEF research scientists Han Deng and Geir Skaugen looking at the web interface they developed to help the oil and gas industry determine how much power and heat can be produced from recovered exhaust heat through a bottoming cycle, on a given installation.

The user can analyse combined cycles with different models of gas turbines and bottoming cycles using either steam or supercritical CO_2, with relevant configurations. The tool produces a report and several thermodynamic diagrams that facilitate the understanding of the effect of varying system specifications.

Spin-off projects

***LowEmission* has contributed to the launch of several spin-off projects, solving specific challenges for the industry. The following were awarded funding in 2021.**

COLLABORATIVE AND KNOWLEDGE-BUILDING PROJECTS (KSP)

All KSPs are financed by Petromaks2 (Research Council of Norway) and *LowEmission*'s industry partners

CleanOFF Hub – Clean Offshore Heat and Power Hub

CleanOFF Hub is a KSP involving SINTEF Energy, NTNU and *LowEmission*'s industry partners. Its objective is 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.

INNOVATION PROJECTS FOR THE INDUSTRIAL SECTOR (IPN)

DeMoKab – Design, modelling and testing of HVDC cable insulation for future cable grids

DeMoKab is an IPN involving Nexans Norway, Statnett and SINTEF Energy. The project originates from the *LowEmission* centre, and aims to develop new knowledge and digital models to find out how the electrical insulation of HVDC cables is affected by temporary spikes in voltage due to various types of faults in future HVDC networks. Funding: The Research Council of Norway, Nexans Norway and Statnett.

GREEN PLATFORM

LINCCS – Carbon Links

LINCCS is a Green Platform project involving the following partners: SINTEF (Energy, AS and Ocean), Aker Solutions, Aize, Cognite, Equinor, Lundin, TotalEnergies, Wintershallm, Vår Energi and Wärtsilä. The project aims to connect cost-effective and permanent offshore CO_2 storage through the whole CCS value chain. Funding: Research Council of Norway and project partners.

Ocean Grid

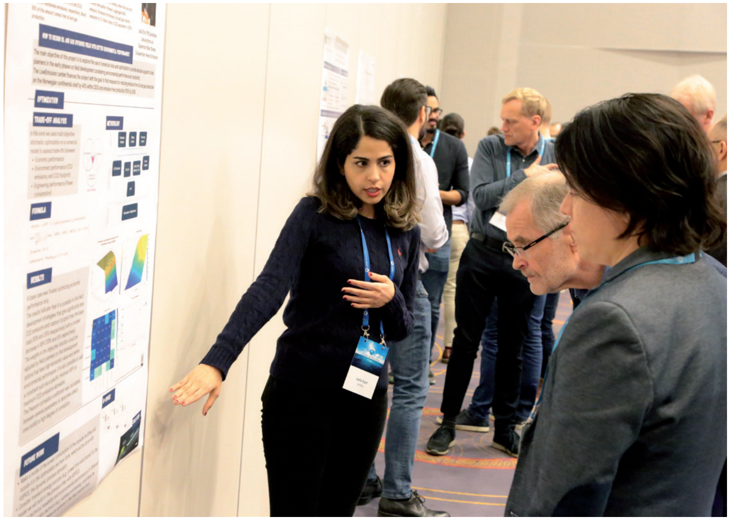
Ocean Grid is a Green Platform project involving the following partners: Equinor, Fred. Olsen Seawind, Hafslund Eco, Nexans, AkerSolutions, Aibel, SINTEF (Energy and Ocean), UiO, NTNU, Benestad, ABB, Hitachi Energy, Aker Offshore Wind, DNV, Deep Wind Offshore, Agder Energi and Statnett. The project aims at developing cost-competitive energy technologies for the international market through research-based innovations in order to realign the Norwegian offshore industry from Oil & Gas-based activities towards offshore wind energy and hydrogen. Funding: Research Council of Norway and project partners.

Education and recruitment

The *LowEmission* academic research program includes a total of 18 PhD students and one Postdoc. Hiring of new candidates continued in 2021, and 12 PhDs candidates are now actively engaged within the Centre. Most of them are about halfway through their project, busy with coursework and publishing results from their research. In addition, 5 MSc students and a number of summer students have completed their projects through *LowEmission* in 2021.

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 2021 Consortium days last November. A PhD poster session was well-attended, and two of the candidates presented their work on stage to a room full of *LowEmission* partners.



Left: PhD candidate Leila Eyni presents her poster titled "Energy Efficient Production" at the LowEmission Consortium days.

Photo: SINTEF

Right: PhD candidate I Gusti Agung Gede Angga presents his work on the reduction of emissions from hydrocarbon production through alternative and energy-efficient drainage strategies, at the LowEmission Consortium days.

OUR PHD CANDIDATES

Handita Reksi Dwitantra Sutoyo
Affiliation: NTNU-IGP
Nationality: Indonesian
Supervisors: Carl Fredrik Berg (NTNU-IGP), Heiner Schumann (SINTEF)
Period: 2021-2024
Thesis: Reduction of emission from hydrocarbon production through alternative and energy-efficient drainage strategies

The focus of this study is reducing emissions during hydrocarbon production. High energy consumption from topside processing of oil and gas leads to an increase in emissions. The research focuses on coupling subsurface drainage strategies with topside processing (e.g., water injection pumping, gas injection, gas compression, oil export pump, cooler). A series of optimization strategies can later be proposed in order to reduce the emission in a robust way.

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

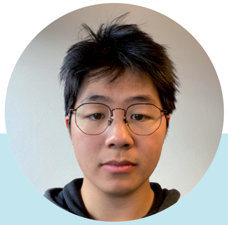
My project's main objective is to study, develop, evaluate and validate modelling approaches to compute energy efficiency and environmental performance of hydrocarbon production systems (subsea and in-well components), including guidelines and recommendations for implementation and operation of the technology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

International cooperation

LowEmission had several international cooperation activities during this past year. Here is a list of the most important ones:

- Academic cooperation with Politechnico de Torino, by way of supervising a master's student (the supervisor being NTNU Professor Lars Nord, associated with SP1). Equinor, a partner of *LowEmission*, was also involved.
- *LowEmission* PhD candidate Mohammad Ali Motamed is co-supervised by Professor Magnus Genrup, from Lund University, in Sweden.
- SINTEF and NTNU research scientists involved in SP2 cooperate with many international associated partners, among which TU Darmstad in Germany, Sandia National Laboratories in the US, TU Delft in the Netherlands, and CERFACS, in France, where one of the SP2 PhD candidates is doing a research visit.

The centre also has ambitions of contributing to the realisation of new EU projects that will be either completely or partly based on *LowEmission* results. This is particularly relevant in the context of our continued collaboration with other research centres, such as FME NCCS and other petrocentres, FMEs and SFIs. The centre also has an open dialogue with the Net Zero Technology Centre in Scotland, about possible international collaboration projects and general cooperation.

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.

Against the continued backdrop of the pandemic, digital communication continued to play a vital role for *LowEmission* in 2021. While this was once again effective, we were delighted to also support the in-person event Consortium Days.

STRATEGIC COMMUNICATION EFFORTS

Together with several FMEs, *LowEmission* took part in the important political events Arendalsuka in Norway and COP26 in Glasgow. *LowEmission* supported the conception and development of a North Sea strategy document in both Norwegian and English.

At COP26, *LowEmission* was discussed in a side event focused on the North Sea as a springboard for the future green economy. The event was live streamed.

During 2021, the Ministry of Petroleum and Energy sent out a consultation letter on its guide for land allocation, licensing process and applications for offshore wind power, and proposals for amendments to the Marine Energy Act and the Marine Energy Act regulations. *LowEmission* management supported FME NorthWind, NTNU and SINTEF in their formal response.

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 continuing this relevant relationship in future years. A summary of the science-based response was repurposed in a SINTEF news article.

LOWEMISSION WEBINARS

Internal communication to industry partners is an important task for the centre. During 2021, a total of 9 webinars were held for *LowEmission* partners on a variety of scientific topics. In total, just under 200 people attended the webinars. Due to the success of this webinar series, more webinars are planned for 2022.

Stefania Osk Gardarsdottir, Acting Director of LowEmission, holds a speech via videoconference at the United Nations Climate Summit COP26 in Glasgow. Also shown are Nils Røkke (SINTEF) and Asgeir Tomasgard (NTNU).

CONSORTIUM DAYS

Continuing the topic of internal communication, the communications team supported November's Consortium Days event in Trondheim, the first major in-person event since the beginning of the pandemic. Tasks included promotion before, during and after the event, including a summary article 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 & 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 was updated throughout the year with the latest news from the project.

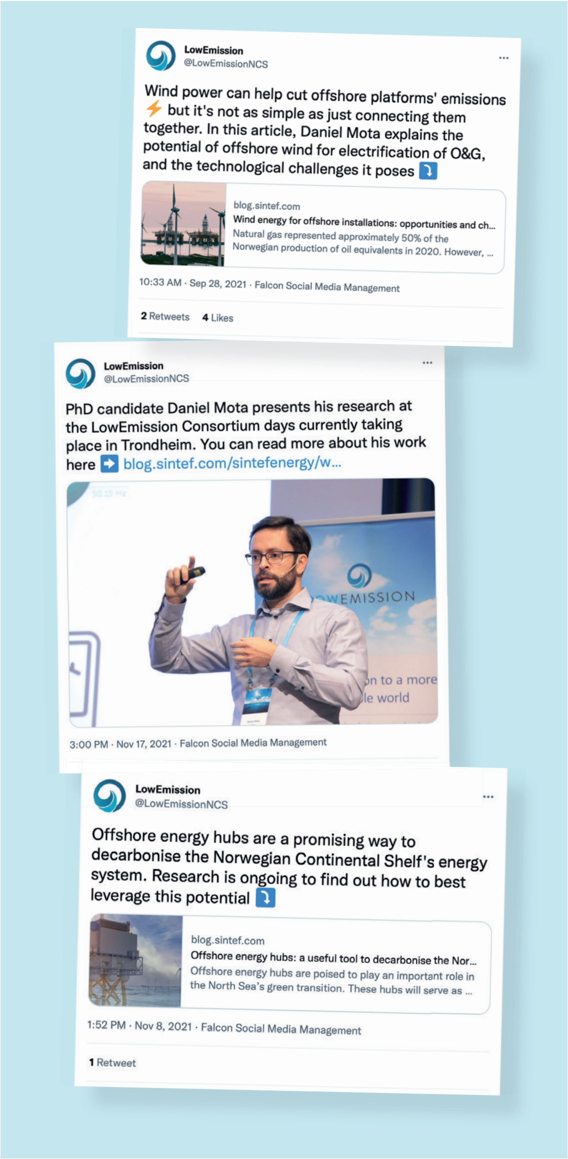
LowEmission participants are encouraged to create blog posts about their tasks throughout the year. Many blog posts summarise project results or scientific publications but are targeted at different groups such as private industry or government decision-makers. Other blogs are aimed at fellow researchers working in climate technologies and related fields. During 2021, six blogs were published across a variety of *LowEmission* topics.

SOCIAL MEDIA

The *LowEmission* communications team maintains a Twitter account – @LowEmissionNCS. At the end of 2021 it had 97 followers. The centre also newly created a LinkedIn page, which will be used during the course of the next year 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 will be distributed to all partners to gain input on their preferred communications methods and channels for future years.



Appendix

STATEMENT OF ACCOUNTS

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

Funding	Amount	In-kind	Sum
The Research Council	15 622		**15 622**
The Host Institution (SINTEF Energi)		640	**640**
Research Partners			
NTNU		3 515	**3 515**
SINTEF AS		523	**523**
SINTEF Ocean		214	**214**
Enterprise partners			
Operators	17 580		**17 580**
Vendors		3 016	**3 016**
Public partners			
Sum	**33 202**	**7 908**	**41 110**

Costs			
The Host Institution (SINTEF Energi)	12 136		**12 136**
Research Partners	25 958		**25 958**
Enterprise partners		3 016	**3 016**
Sum			**41 110**

PUBLICATIONS

PEER REVIEWED JOURNAL PUBLICATIONS

Search criteria: *From:* 2021 *To:* 2021 *sub-category:* Academic article *sub-category:* Academic literature review *sub-category:* Short communication *All publishing channels*

1. **Alves, Erick Fernando; Mota, Daniel dos Santos; Tedeschi, Elisabetta.** Sizing of Hybrid Energy Storage Systems for Inertial and Primary Frequency Control. *Frontiers in Energy Research* 2021 ;Volume 9.(649200). NTNU
2. **Mota, Daniel dos Santos; Tedeschi, Elisabetta.** On Adaptive Moving Average Algorithms for the Application of the Conservative Power Theory in Systems with Variable Frequency. *Energies* 2021 ;Volume 14.(4). NTNU
3. **Mota, Daniel; Tedeschi, Elisabetta.** Understanding the Effects of Exponentially Decaying DC Currents on the Dual dq Control of Power Converters in Systems with High X/R. *Compatibility in power electronics* 2021. NTNU

4. **Motamed, Mohammad Ali; Nord, Lars O.** Assessment of organic Rankine cycle part-Load performance as gas turbine bottoming cycle with variable area nozzle turbine technology. *Energies* 2021 ;Volume 14.(23). NTNU

PRESENTATIONS

Search criteria: *From:* 2021 *To:* 2021
Main category: Conference lecture and academic presentation *All publishing channels*

1. **Alves, Erick Fernando; Mota, Daniel dos Santos.** Sizing of Hybrid Energy Storage Systems for Inertial and Primary Frequency Control. NTNU PESC Colloquium; 2021-04-23. NTNU
2. **Bergmo, Per Eirik Strand.** Reducing emissions by reducing water production. *LowEmission* Webinars; 2021-11-11 - 2021-11-11. SINTEF
3. **Mota, Daniel.** Control Strategies for Stability Guarantee in Oil and Gas Platforms with Renewable Energy Integration. 2021 *LowEmission* Consortium Days; 2021-11-17 - 2021-11-18. NTNU
4. **Mota, Daniel.** Dual Sequence Controller with Delayed Signal Cancellation in the Rotating Reference Frame. Twenty-second IEEE Workshop on Control and Modeling for Power Electronics (COMPEL 2021); 2021-11-02 - 2021-11-05. NTNU
5. **Mota, Daniel.** *LowEmission* SP5 and OFFLEX partners - PhD Studies. *LowEmission* SP5 and OFFLEX partners; 2021-06-15 - 2021-06-15. NTNU
6. **Mota, Daniel dos Santos.** Understanding the Effects of Exponentially Decaying DC Currents on the Dual dq Control of Power Converters in Systems with High X/R. 2021 IEEE 15th International Conference on Compatibility, Power Electronics and Power Engineering (CPE-POWERENG); 2021-07-14 - 2021-07-16. NTNU
7. **Motamed, Mohammad Ali; Nord, Lars O.** Assessment of Alternative Concepts for Efficiency Enhancement of Gas Turbine Operation under Varying Loads. *LowEmission* Centre SP1 family meeting 2021; 2021-09-01 - 2021-09-01. NTNU
8. **Motamed, Mohammad Ali; Nord, Lars O.** Improving the Off-design Efficiency of Organic Rankine Bottoming Cycle by Variable Area Nozzle Turbine Technology. *LowEmission* Consortium Days 2021; 2021-11-17 - 2021-11-18. NTNU
9. **Motamed, Mohammad Ali; Nord, Lars O.** Improving the off-design efficiency of organic Rankine bottoming cycle by variable area nozzle turbine technology. 6th International Seminar on ORC Power Systems; 2021-10-11 - 2021-10-13. NTNU
10. **Reyes Lua, Adriana; Deng, Han; Skaugen, Geir; Motamed, Mohammad Ali; Mocholí Montañés, Rubén; Zotica, Cristina Florina.** Low Emission SP1 Updated Results 2021. Second Low Emission SP1 Family Meeting 2021; 2021-09-01 - 2021-09-01. ENERGISINT NTNU
11. **Reyes-Lúa, Adriana; Rohde, Daniel; Mocholí Montañés, Rubén; Skaugen, Geir.** SP1 2020 Results and Plans for 2021. First *LowEmission* SP1 Family Meeting 2021.; 2021-03-02. ENERGISINT
12. **Røkke, Nils Anders; Hustad, Johan Einar.** Nordsjøen som plattform for grønn omstilling. Nordsjøen som plattform for grønn omstilling; 2021-08-06 - 2021-08-06. ENERGISINT NTNU
13. **Røkke, Nils Anders; Tomasgard, Asgeir.** The North Sea as a springboard for the green transition Three recommendations. The North Sea as a springboard for the green transition Three recommendations; 2021-11-09 - 2021-11-09. ENERGISINT NTNU
14. **Svendsen, Harald Georg.** Wind power integration in offshore energy systems –operational optimisation. EERA DeepWind'2021 - Offshore Wind R&D Digital Conference; 2021-01-13 - 2021-01-15. ENERGISINT
15. **Zhang, Hongyu; Tomasgard, Asgeir; Knudsen, Brage Rugstad; Svendsen, Harald Georg; Bakker, Steffen J.** Decarbonised

offshore energy hubs: modelling, optimisation and sensitivity analysis. NORS Annual Conference 2021; 2021-11-17 - 2021-11-18. NTNU ENERGISINT

PART OF A BOOK/REPORT

Search criteria: *From:* 2021 *To:* 2021 *sub-category:* Academic chapter/article/ Conference paper *All publishing channels*

1. **Ditaranto, Mario; Saanum, Inge; Larfeldt, J.** Experimental study on high pressure combustion of decomposed ammonia: How can ammonia be best used in a gas turbine?. I: *Proceedings of the ASME Turbo Expo 2021: Turbomachinery Technical Conference and Exposition.* The American Society of Mechanical Engineers (ASME) 2021 ISBN 978-079188495-9. ENERGISINT
2. **Lesaint, Cedric Michel; Hvidsten, Sverre; Hestad, Øystein Leif Gurandsrud; Olsen, Elise; Bengtsson, Karl Magnus.** Microscopy Study of Inception Sites of Vented Water Trees in a HV XLPE Cable Aged in Salt Water. I: *2021 IEEE Electrical Insulation Conference - EIC.* IEEE 2021 ISBN 978-1-6654-1564-4. p. 218-221. ENERGISINT
3. **Mota, Daniel; Alves, Erick Fernando; Tedeschi, Elisabetta.** Dual Sequence Controller with Delayed Signal Cancellation in the Rotating Reference Frame. I: *2021 IEEE 22nd Workshop on Control and Modelling of Power Electronics (COMPEL).* IEEE conference proceedings 2021 ISBN 978-1-6654-3635-9. NTNU
4. **Motamed, Mohammad Ali; Nord, Lars O.** Improving the off-design efficiency of organic Rankine bottoming cycle by variable area nozzle turbine technology. I: *Proceedings of the 6th International Seminar on ORC Power Systems 11 – 13 October 2021.* Munich: Technical University of Munich 2021 ISBN 978-3-00-070686-8. NTNU

MULTIMEDIA PRODUCTS

Search criteria: *sub-category:* Multimedia product *All publishing channels*

1. **Røkke, Nils Anders.** Arendalsuka: Nordsjøen som plattform for grønn omstilling. SINTEF Energ 2021. ENERGISINT
2. **Røkke, Nils Anders.** Møt oss på Arendalsuka 16 august. SINTEF Energ 2021. ENERGISINT
3. **Røkke, Nils Anders; Hustad, Johan Einar.** North sea - three recommendations. SINTEF Energ 2021. ENERGISINT NTNU
4. **Røkke, Nils Anders; Hustad, Johan Einar.** 3 råd: Slik kan Nordsjøen bli en plattform for grønn omstilling. SINTEF Energ 2021. ENERGISINT NTNU

OP-EDS

Search criteria: *From:* 2021 *To:* 2021 *sub-category:* Feature article *sub-category:* Editorial *All publishing channels*

1. **Røkke, Nils Anders.** Innlegg: Slik kan vi gjøre norsk sokkel til Europas grønne muskel. *Dagens næringsliv* 2021. ENERGISINT

BLOG ARTICLES AND INFORMATION MATERIAL

Search criteria: *From:* 2021 *To:* 2021 *Main category:* Information material(s) *All publishing channels*

1. **Albert, Daniel.** *LowEmission* Consortium Days 2021. ENERGISINT
2. **Gardarsdottir, Stefania Osk; Sundseth, Kyrre.** Building a Hydrogen Future in Norway. SINTEF ENERGISINT
3. **Gribkovskaia, Victoria.** Forsyningsoperasjoner offshore med utslippsfritt drivstoff En tverrfaglig mulighetsstudie. OCEAN
4. **Gribkovskaia, Victoria; Andersen, Tina; Flatberg, Truls; Halvorsen-Weare, Elin Espeland; Nonås, Lars Magne; Sandvik, Endre.** Forsyningsoperasjoner offshore med utslippsfritt drivstoff. SINTEF OCEAN
5. **Gribkovskaia, Victoria; Andersen, Tina; Flatberg, Truls; Halvorsen-Weare, Elin Espeland; Nonås, Lars Magne; Sandvik, Endre.**

Offshore supply with emission-free fuels A cross-disciplinary feasibility study. OCEAN SINTEF

6. **Lesaint, Cedric Michel.** High voltage subsea cables: reducing costs by simplifying design. ENERGISINT
7. **Lesaint, Cedric Michel.** Høyspente sjøkabler: Reduserte kostnader med et enklere design. ENERGISINT
8. **Mota, Daniel dos Santos.** Wind energy for offshore installations: opportunities and challenges How connecting offshore wind to oil and gas rigs can help reduce their greenhouse gas emissions. NTNU
9. **Røkke, Nils Anders; Hustad, Johan Einar.** Arendalsuka 2021:Tre råd til politikere for grønn omstilling av Nordsjøen. ENERGISINT NTNU
10. **Røkke, Nils Anders; Tomasgard, Asgeir.** #COP26: The North Sea as a springboard for the green transition Three recommendations. ENERGISINT NTNU
11. **Røkke, Petter Egil; Hustad, Johan Einar.** Tre råd til politikere for grønn omstilling av Nordsjøen. ENERGISINT NTNU
12. **Talic, Belma.** Fuel cells for reducing emissions from the oil and gas industry. SINTEF
13. **Tande, John Olav Giæver; Kvamsdal, Trond.** Høringssvar om havvind fra SINTEF og NTNU Kunnskapsbasert utvikling, kvalitative konkurranser og raskt tempo. ENERGISINT NTNU

MEDIA CONTRIBUTIONS

Search criteria: *From:* 2021 *To:* 2021
Main category: Media contribution *sub-category:* Popular scientific article *sub-category:* Interview Journal *sub-category:* Article in business/trade/ industry journal *sub-category:* Sound material
All publishing channels

1. **Føyen, Tore Lyngås.** Løser samfunns-utfordringer i sommerjobben. https://www.sintef.no/ [Internet] 2021-09-08. SINTEF
2. **Gardarsdottir, Stefania Osk.** Norwegian project eyes reduction of ship CO_2 emissions with Carbon Capture and Storage. Safety4Sea [Business/trade/industry journal] 2021-05-14. ENERGISINT
3. **Gardarsdottir, Stefania Osk.** Skal forske på CO_2-fangst på skip. Metal supply [Business/trade/industry journal] 2021-05-26. ENERGISINT
4. **Mølnvik, Mona J.** – Vi må ha alt, og vi må ha det fort. Energi og klima [Business/trade/ industry journal] 2021-04-09. ENERGISINT
5. **Røkke, Nils Anders.** COP26 Event: Hvilken rolle har CCS i nullutslippssamfunnet 2050?. [Internet] 2021-11-03. ENERGISINT
6. **Røkke, Nils Anders; Hustad, Johan Einar.** Norge treng EU for grøn omstilling av Nordsjøen: - Feil, meiner Senterpartiet. [Newspaper] 2021-08-17. ENERGISINT NTNU
7. **Mota, Daniel.** Wind energy for offshore installations: opportunities and challenges. *SINTEF blogg* 2021. NTNU
8. **Zhang, Hongyu.** Offshore energy hubs: a useful tool to decarbonise the Norwegian continental shelf's energy system. #SINTEF-blog 2021. NTNU

PERSONELL

MANAGEMENT

Name	Position	Main research area	Institution
James Dawson	Professor	Fluid mechanics and combustion	NTNU
Stefania Gardarsdottir	Research Manager	Techno-economic process analysis	SINTEF
Jon Magne Johansen	Senior Business Developer	Business development	SINTEF
Ane H. Bryne Berg	Senior Manager	New Projects	Repsol Norge AS
Ragnhild Skorpa	Research Scientist	Well integrity	SINTEF
Malin Torsæter	Research Manager	Formation physics	SINTEF
Anders Ødegård	Senior Project Manager	Fuel cells and hydrogen	SINTEF
Lars Magne Nonås	Senior Research Scientist	Optimization of offshore logistics	SINTEF
Ann Karin Jullumstrø Aalberg	Project Coordinator	Accounting and central operations	SINTEF

SP LEADERS

Last name	Position	Main research area	Institution	SP
Adriana Reyes Lúa	Research Scientist	Process control, value chain analysis	SINTEF	1
Nicholas Worth	Associate Professor	Turbulence, combustion, experimental methods	NTNU	2
Øystein Hestad	Research Manager	Transmission technology	SINTEF	3
Luis Cesar Colmenares-Rausseo	Research Scientist	Low-temperature fuel cell and electrolysers	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
Malin Torsæter	Research Manager	Formation physics	SINTEF	10

KEY RESEARCHERS

Name	Institution	Main research area	SP
Brede Andre Larsen Hagen	SINTEF / NTNU	Heat exchanger optimization	1
Adriana Reyes Lúa	SINTEF	Thermal energy systems	1
Geir Skaugen	SINTEF	Thermal energy systems	1
Han Deng	SINTEF	Heat exchanger optimization	1
Rubén M. Montañés	SINTEF	Thermal energy systems	1
Cristina Zotica	SINTEF	Thermal energy systems	1
Andrea Gruber	SINTEF	DNS of reacting flows	2
James Dawson	NTNU	Experimental measurement of reacting flows	2
Jonas Moeck	NTNU	Theoretical/low-order numerical modelling	2
Mario Ditaranto	SINTEF	Experimental measurement of reacting flows	2
Nicholas Worth	NTNU	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
Amar Abideen	NTNU	High voltage insulation (PhD)	3
Cedric Lesaint	SINTEF	Transmission technology	3
Emre Kantar	SINTEF	Transmission technology	3
Frank Mauseth	NTNU	High voltage insulation	3
Gerardo A. Perez-Valdes	SINTEF	Operations research, optimisation, economics	3
Gunnar Berg	SINTEF	Transmission technology	3
Hans Helmer Sæternes	SINTEF	Transmission technology	3
Harald Svendsen	SINTEF	Grid planning	3
Julian Straus	SINTEF	Optimisation, process, energy system	3
Luca Riboldi	SINTEF	Energy supply, process, energy system	3
Marit Mazzetti	SINTEF	Energy supply, process, energy system	3
Sverre Hvidsten	SINTEF	Transmission technology	3
Torbjørn A. Ve	SINTEF	Transmission technology	3

Name	Institution	Main research area	SP
Øystein Hestad	SINTEF	Transmission technology	3
Luis Colmenares-Rausseo	SINTEF	Low temperature fuel cells PEMFC	4
Øyvind Lindgård	SINTEF	Low temperature fuel cells PEMFC	4
Katie McCay	SINTEF	Low temperature fuel cells PEMFC	4
Patrick Fortin	SINTEF	Low temperature fuel cells PEMFC	4
Yash Raka	SINTEF	Fuel cell Systems	4
Belma Talic	SINTEF	High temperature fuel cells SOFC	4
Einar Vøllestad	SINTEF	High temperature fuel cells SOFC	4
Jonathan Polfus	SINTEF	High temperature fuel cells SOFC	4
Wen Xing	SINTEF	High temperature fuel cells SOFC	4
Adriana Reyes Lua	SINTEF	Offshore energy system	5
Andrzej Holdyk	SINTEF	Electrical system modelling and stability	5
Til Kristian Vrana	SINTEF	Electrical system modelling and stability	5
Asgeir Tomasgaard	NTNU	Optimisation	5
Brage Knudsen	SINTEF	Control systems, gas	5
Leif Erik Andersson	SINTEF	Data-driven analysis	5
Daniel Mota	NTNU	Electrical system control and stability	5
Elisabetta	NTNU	Electrical system control and stability	5
Harald Svendsen	SINTEF	Energy systems, renewable integration	5
Hongyu Zhang	NTNU	Optimisation	5
Jan Ole Skogestad	SINTEF	Integrated modelling	5
Kiet Tuan Hoang	NTNU	Controls	5
Elisabetta Tedeschi	NTNU	Controls	5
Lars Imsland	NTNU	Controls	5
Michal Kaut	SINTEF	System optimisation	5
Roar Nybø	SINTEF	Integrated modelling	5

Name	Institution	Main research area	SP
Tore Føyen	SINTEF	Reservoir technology, drainage, IOR, EOR	6
Ragnhild Skropa	SINTEF	Well integrity	6
Stefania Gardarsdottir	SINTEF	Techno-economic process analysis	6
Alv-Arne Grimstad	SINTEF	Reservoir technology, drainage, IOR, EOR	7
Arne Marius Raaen	SINTEF	Rock physics, fracturing and inflow performance	7
Bjørnar Lund	SINTEF	Gas lift optimisation	7
Carl Fredrik Berg	NTNU	Reservoir technology, field scale optimisation	7
I Gusti Agung Gede Angga	NTNU	Reservoir and topside, field scale optimisation	7
Jan Ole Skogstad	SINTEF	Reservoir modelling and simulation	7
Per Bergmo	SINTEF	Reservoir technology, drainage, IOR, EOR	7
Albert Barrabino	SINTEF	Oil & gas processing, dynamic modelling	8
Heiner Schümann	SINTEF	Oil & gas processing, multiphase transport and subsea technology	8
Leila Eyni	NTNU	Oil & gas processing, subsea technology	8
Marita Wolden	SINTEF	Flow Assurance	8
Milan Stanko	NTNU	Oil & gas processing, subsea technology	8
Torleif Holt	SINTEF	Oil & gas processing, energy recovery	8
Dag Atle Nesheim	SINTEF	Offshore logistics, optimization, energy and transport	9
Daniel Franklin Krause	SINTEF	Methane emission measurements, energy and transport	9
Elin E. Halvorsen-Weare	SINTEF	Offshore logistics, optimization, energy and transport	9
Endre Sandvik	SINTEF	Offshore logistics, optimization, energy and transport	9
Lars Magne Nonås	SINTEF	Offshore logistics, optimization, energy and transport	9
Maria Føre	SINTEF	Methane emission measurements, energy and transport	9
Morten Hammer	SINTEF	Gas technology	9
Ole Meyer	SINTEF	Gas technology	9
Roar Nybø	SINTEF	Well drilling, modelling, machine learning	9
Thor Anders Aarhaug	SINTEF	Sustainable energy technology	9

Name	Institution	Main research area	SP
Truls Flatberg	SINTEF	Operations research, optimisation, economics	9
Victoria Gribkovskaia	SINTEF	Offshore logistics, optimization, energy and transport	9
Yauheni Kisialiou	SINTEF	Offshore logistics, optimization, energy and transport	9

PHD CANDIDATES WITH FINANCIAL SUPPORT FROM THE CENTRE BUDGET

Name	Nationality	Period	Sex M/F	Topic	SP
Amar Abideen	Saudi-Arabian	09/2020 - 08/2023	M	Wet Design of AC Power Cables for Future Offshore Power Grids	3
Mohammad Ali Motamed	Iranian	07/2020 - 06/2023	M	Assessment of alternative concepts for combined cycle gas turbine operation under varying loads	1
Martin Richter	German	09/2020 - 08/2023	M	The structure of ammonia/hydrogen/nitrogen flames	1
Jessica Gaucherand	French	10/2020 - 09/2023	F	Ammonia/Hydrogen for internal combustion engines	3
Leila Eyni	Iranian	08/2020 - 08/2023	F	Methods to Design and Manage Energy-Efficient Offshore Hydrocarbon Production Systems	8
I Gusti Agung Gede Angga	Indonesian	05/2020 - 04/2023	M	"Reduction of emissions from hydrocarbon production through alternative and energy-efficient drainage strategies"	7
Daniel Mota	Brazilian-Norwegian	02/2020 - 01/2022	M	Control strategies for stability guarantee in oil and gas platforms with significant renewable energy integration	5
Hongyu (Richard) Zhang	Chinese	09/2020 - 08/2022	M	Stochastic programming models for planning and design of hybrid offshore energy systems integrating renewables	5
Kiet Tuan Hoang	Norwegian	11/2020 - 10/2022	M	Model predictive control under uncertainty for offshore power systems integrating renewables	5
Andreas Ormevik	Norwegian	09/2020 - 08/2022	M	Logistics optimization of low-emission offshore vessels	9
Aksel Ånestad	Norwegian	09/2021-09/2024	M	The effect of staging on the stability and emissions performance of an industrially relevant swirl stabilised combustor	2
Handita Reksi Dwitantra Sutoyo	Indonesian	10/2021-10/2024	M	Combine optimization of topside and subsurface production strategies in order to reduce emissions from hydrocarbon production	7+8

MASTER'S STUDENTS

Name	Sex M/F	Topic	Task	Year
Jens Fredrik Lunde	M	Electric field distribution in layered polymeric HVDC insulation	3.2	2019-2020
Ingrid Wibe	F	Impact of offshore electrification in Norway to greenhouse gas emissions within the European energy system	3.3	2020-2021
Fadhil Berylian	M	Calculation and visualization of energy dissipation and energy balance in reservoir models	7,1	2020
Andreas Bakke Moan	M	A hybrid genetic approach to the operational supply vessel planning problem with speed optimization	9,1	2020
Pål Ødeskaug	M	A hybrid genetic approach to the operational supply vessel planning problem with speed optimization	9,1	2020
Trygve H. Stuen	M	Influence of Hydrogen Use As a Fuel on Aeroderivative Gas Turbine Performance	2.1	June 2021
Ali Hassan	M	Dynamic modelling of topside processing	8,1	2021-2022
Mostafa Fattahi	M	Environmental performance of ColdFlow tie-ins	8,1	2021
Mohammed Heidari	M	Virtual intertia	5,2	2021-06
Tord Solberg	M	Controls	5,1	2021-06

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