Annual report

2023

HighEFF

Centre for an Energy Efficient and
Competitive Industry for the Future

Contents

By numbers ... 3
The smart economics of energy efficiency ... 4
About HighEFF ... 5
Selected highlights from 2023 ... 6
The Added Value Created by Joining FME HighEFF ... 13
Message from the Chair ... 14
Message from the Centre Director ... 15
Our contribution to a more sustainable world ... 16
Industrial off-gas: An untapped resource ... 18
Vision and goals ... 20
Gender equality ... 21
How we work together ... 22
Cooperation with other FMEs ... 28
International cooperation ... 30
Organisation ... 31
Partners ... 32
Innovations ... 34
Research and results ... 39
Research Infrastructure ... 60
Education, researcher training and recruitment ... 62
Communications ... 63
Appendix ... 66

Cover image: *NTNU postdoc Mihir Mouchum Hazarika at work at HighEFFLab's MultiTest-Rack*

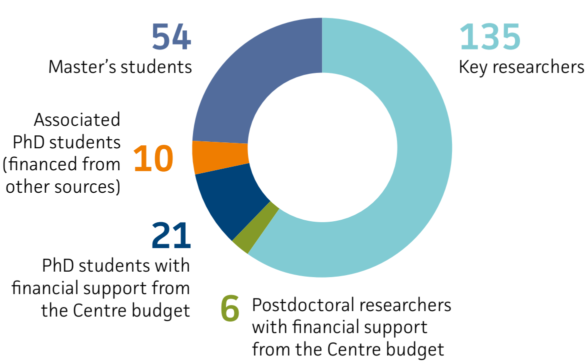
By numbers

37 PARTNERS

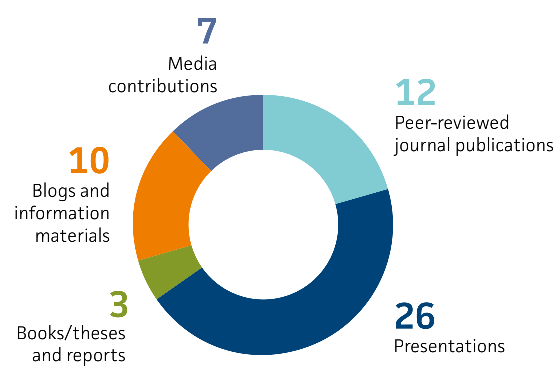
8 YEARS

400 MNOK

People



Communication and dissemination



The smart economics of energy efficiency

The logic behind energy efficiency is compelling and straightforward. Achieving the same outcomes with less energy is not only beneficial for reducing emissions but also makes sound economic sense. In contrast to some climate solutions that necessitate increased industrialisation or extensive land use, measures to improve energy efficiency are widely accepted and uncontroversial.

At the UN Climate Summit COP28 in Dubai in December, European Commission President Ursula von der Leyen announced the Global Pledge on Renewables and Energy Efficiency. This initiative, launched in partnership with the COP28 Presidency and 118 countries, sets ambitious global targets. By 2030, it aims to triple the installed capacity of renewable energy to at least 11 terawatts and double the rate of global energy efficiency improvements to approximately 4% annually. Another COP28 announcement was the Global Cooling Pledge, setting ambitious targets for the reduction of cooling-related emissions.

Norway is signatory to both of those pledges, and the work undertaken by HighEFF is integral to Norway's journey in meeting these commitments. If you would like to read more about the recent trends in energy efficiency, and action highlights for the next decade, check out the International Energy Agency's document Energy Efficiency: The Decade for Action.

2023: A year of achievements

2023 saw five more HighEFF PhDs (including 2 associated PhDs) defending their theses. These new experts are already bringing their fresh perspectives and skills to both the industrial and academic realms, tackling the challenges of energy efficiency. Progress has continued on Centre innovations – you can see examples of these innovations on pages 34-37.

Three Novel Emerging and Innovative Concepts were awarded funding. These are exciting projects directed at high-value innovative concepts that can make a difference both in the short and long term (see pages 55-57 for details - in the RA5 results section).

The way forward

As HighEFF enters its final year, our priority will be to ensure our results and innovations have the maximum effect in improving industrial energy efficiency. We will work towards that goal through our dissemination efforts, our contribution to HighEFF spin-off projects, our final conference on 8 May, and our final report.

Line Rydså leads HighEFF's Research Area 5: Society.

About HighEFF

HighEFF is a collaboration project between many national and international universities, research institutes and industry partners. In total, there are more than 40 partners from three continents. The industry partners represent all the largest industry sectors in Norway: Metal producing industries, oil, gas and energy companies, chemical industry and the food industry. HighEFF is led by SINTEF and NTNU.

Selected highlights from 2023

Novel Emerging and Innovative Concepts – NEIC

To further emphasise innovation and make room for new ideas, the Centre has been yearly funding Novel Emerging Concepts (NEC). As of 2022, HighEFF expanded this programme to also cover innovation, under the name Novel Emerging and Innovation Concepts (NEIC). These are projects directed at high-value innovative concepts that can make a difference both in the short and long term. This activity goes beyond what is already planned or ongoing at the Centre, and is funded through previously unallocated funds. Selected projects must contribute directly to reaching the main goals of HighEFF.

A total of 6 funding applications were received this year, leading to three of them being awarded funding. Applications were evaluated by Nancy Jorunn Holt (Hydro), Arve Solheim (ENOVA), Petter Nekså (SINTEF), Jens Olgard Dalseth Røyrvik (NTNU), Camilla Claussen (SINTEF), and Arne Petter Ratvik (SINTEF). The following projects were awarded funding this year:

- Enhanced capability of natural refrigerant-based heat pumps and refrigeration units through innovative Additive Manufacturing (PrintUP)
- Reduction of CO_2 emissions from industrial processes through integration of high-efficiency H_2O/CO_2 electrolysis (HighEFFEC)
- Biochar from Seaweed for Metal Production (BioChar-project, round 2)

For more details about these projects, consult the results section of “Society (RA5)”, on pages 55-57.

Results adopted by the industry

Thermal energy storage – REMA 1000 and Cartesian

Technology for thermal energy storage using Phase Change Materials (PCM) was developed within HighEFF as part of a dedicated doctoral study. Norsk Kylling, through its owner and user partner REMA 1000, showed interest in this technology for their new factory in Orkanger. The technology's maturity level was advanced from TRL 3 to 5, making it ready for piloting. In 2023, a pilot project with Rema 1000 began to test the technology in one of their grocery stores. The readily prototyped TES will be installed and tested during the summer of 2024. To further develop and commercialise this technology, startup Cartesian AS was established through SINTEF TTO, focusing on compact and modular thermal energy storage solutions.

PIA for reuse of excess heat in aluminium production

HighEFF's Pot Gas Recycling (PGR) idea, now applied in the aluminium industry, focuses on utilising surplus heat from gases emitted by aluminium electrolysis cells. It also explores enhancing CO_2 concentration for economically viable carbon capture and storage. REEL Norway, supported by the Research Council of Norway, developed a pilot plant called Pot Integrated Abart (PIA) at Alcoa Mosjøen. Building on PGR's work, PIA shows promising results in surplus heat utilisation, potentially aiding climate-neutral aluminium production.

Excess heat utilisation at Felleskjøpet Skansen

Based on a novel concept for a High Temperature Heat Pump developed at HighEFF, Aneo Industry, with support from Enova, installed a pilot heat pump at

Felleskjøpet Skansen in Trondheim. The heat pump operates in a cascade cycle to produce high-pressure steam. In the initial stage, it uses ammonia to generate low pressure steam at around 85-90°C. This steam then serves as a heat source for the top cycle, where steam is used as a refrigerant in a multistage steam cycle.

HighEFF partner Epcon has delivered the steam top cycle, with multistage steam compression (TRL 7-8). The ammonia cycle is delivered by GEA (TRL 8-9). The heat pump has a capacity of 1.2 MW and is expected to deliver 3.6 GWh/y of steam, saving about 2.4 GWh/y of electricity.

PhDs completed in 2023

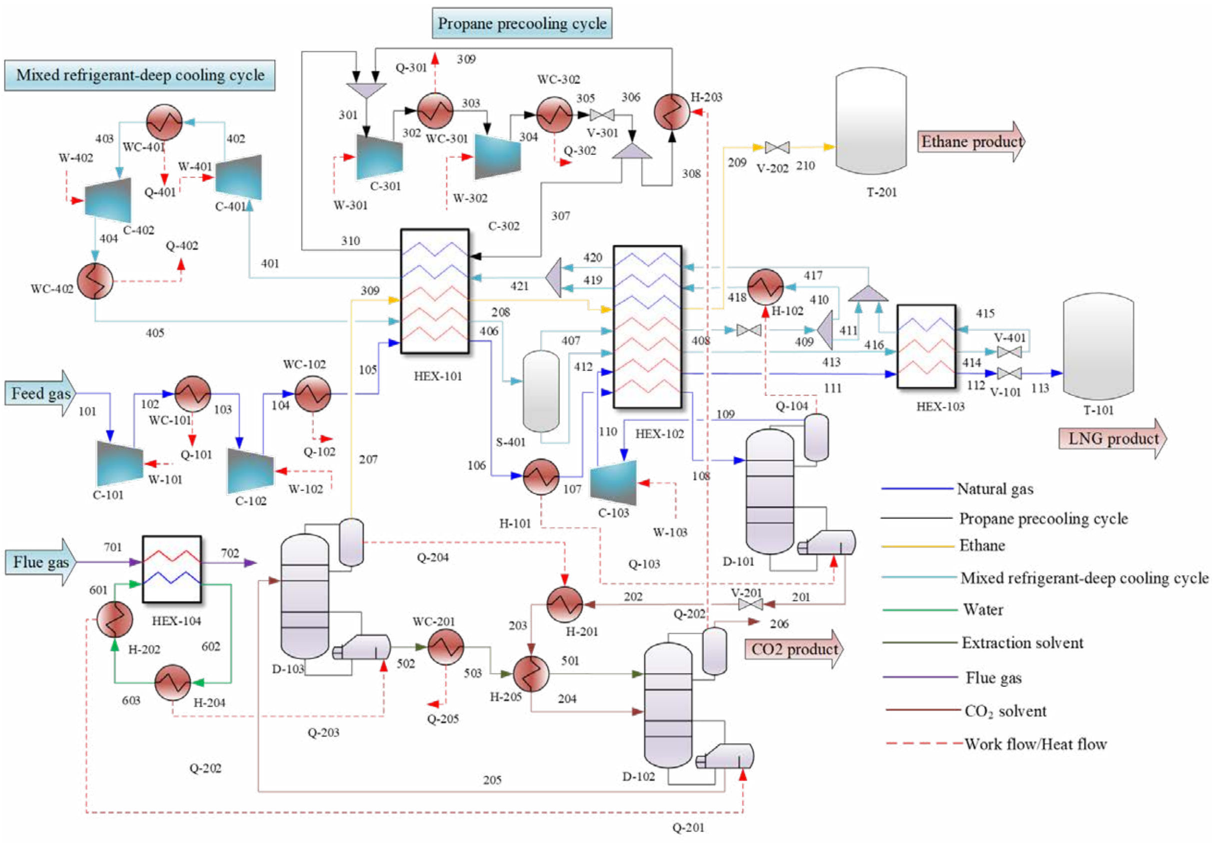
Flue gas recirculation for the silicon process
Vegar Andersen, PhD, NTNU

Metallurgical-grade silicon (MG-Si) is an essential material for the modern world. Either as a raw material for electronic grade silicon, photovoltaics, silicones or for alloying other materials such as aluminium. Producing MG-Si by carbothermal reduction generates emissions of CO_2, as well as other environmentally harmful emissions, such as NOX and SOX. A possible abatement strategy for reducing the environmental footprint of Silicon production is carbon capture. However, the low concentration of CO_2 in the process flue gas is a challenge for the cost and scale of any potential capture process. Flue gas recirculation (FGR) is a way optimising the flue-gas composition for future carbon capture by increasing the CO_2 concentration in flue gas without increasing the flue gas temperature. Through modelling, small-scale experiments and pilot scale furnace experiments FGR has been investigated. This research has shown that there is a significant cost reduction potential for carbon capture by implementing FGR in the silicon process. Investigation into process gas combustion also showed a potential for NOX emissions reduction, both for furnace flue gas and in the furnace tapping gas.

Liquefaction of natural gas with high ethane content – Integrated ethane recovery and carbon capture

Ting He, PhD, NTNU

For natural gas with high ethane content, such as shale gas and oil associated gas, separation and purification of ethane can improve the economic benefits. Ethane recovery and cryogenic CO_2 removal from natural gas has the potential to be integrated with natural gas liquefaction for reduction in thermal energy consumption and capital investment. Although there are some publications related to natural gas liquefaction processes integrated with NGL recovery or CO_2 removal, they mainly focus on conventional natural gas, which are not applicable to natural gas with high ethane content. To fill this gap, this study carried out a study on the liquefaction processes of natural gas that is rich in ethane to realize energy-efficient integrated ethane recovery and CO_2 removal.



Development of an ammonia-water absorption-compression heat pump at high temperature operation

Marcel Ulrich Ahrens, PhD, NTNU

Decarbonisation of the industrial sector is one of the most important measures for tackling global warming. Integrating high temperature heat pumps (HTHPs) for waste heat recovery and supply temperatures of more than 100°C is a sustainable solution for many industrial high-temperature applications. The absorption-compression heat pump (ACHP) is using a zeotropic ammonia-water mixture as working fluid and combines the technologies of an absorption and vapour compression heat pump with the ability of achieving high supply temperatures above 120°C with large temperature lifts (> 60 *K*) and non-isothermal heat transfer (*T glide* > 30 *K*).

The working principle and characteristics of different ACHP cycles were discussed and an overview of the current state-of-the-art was elaborated. Based on existing challenges for the realisation of ACHP systems with the desired application at high-temperature operation, research focus areas were identified: 1. The design and operation of the absorber and desorber; 2. The establishment of efficient liquid-vapour mixing and distribution; 3. The compressor design with respect to discharge temperature and lubrication and 4. The selection and cavitation protection of the solution pump. It was concluded that oil-free operation of the ACHP system can lead to improved efficiency and reduced costs by saving on the required oil management and thus further improve the competitiveness of ACHP systems for the usage in industrial high-temperature applications.

The outcome of the conducted research work is the ACHP prototype located in the NTNU laboratory with a maximum heat capacity of up to 200 kW and a maximum operating pressure and temperature of 40 bar and 190°C, respectively. Together with the pressurised water heat source and sink circuits, the established test facility allows the investigation of different component sections and application cases with heat sink outlet temperatures up to 140°C. The ACHP prototype is an important tool for the validation of numerical models, testing new elements and optimisation of the control strategy.

Optimal operation and control of thermal energy systems

Cristina Zotica, PhD, NTNU

The thesis has several objectives within the topic of optimal operation and control of thermal energy systems, including heat-to-power cycles, thermal energy storage systems, district heating networks with variable heat supply and heat exchangers. This thesis provides an understanding of the operation and control problem for heat-to-power cycles from a plantwide control perspective, including a steady-state and dynamic analysis (Figure 1). Furthermore, it provides a systematic theory for many nonlinear model-based calculation blocks used in the process control industry for nonlinear feedforward control, linearisation or decoupling (Figure 2). Finally, it studies how to handle constraints on manipulated variables used for inventory control to balance supply and demand using simple control elements such as PI-controllers, split range control and selectors (Figure 3).

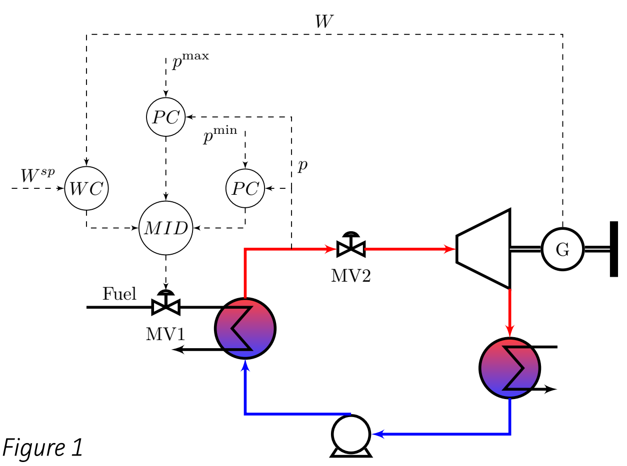


Figure 1

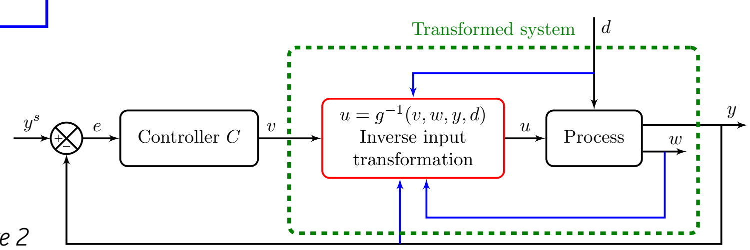


Figure 2

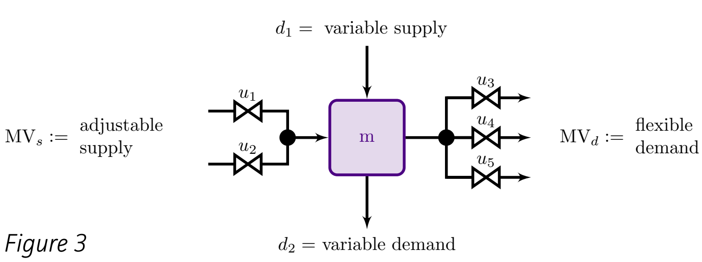


Figure 3

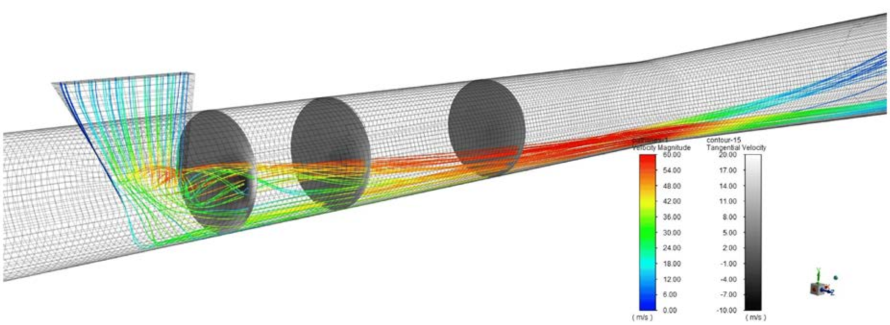
CFD modelling for improved components in CO_2 and ammonia vapour compression

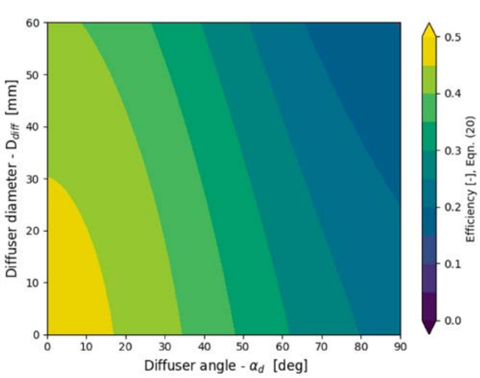
Knut Emil Ringstad, PhD, NTNU

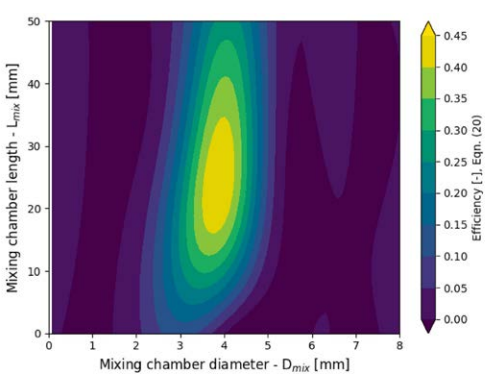
The Refrigeration and heat-pumping (HVAC) industry is rapidly growing while simultaneously transitioning to more environmentally friendly solutions. Switching the refrigerants to natural, environmentally friendly refrigerants, like CO_2, can significantly help to reduce emissions from this sector. The energy efficiency of CO_2-based heat pumps and refrigeration systems can be significantly improved when supported by a component called an ejector. Ejectors are used for expansion work recovery to enhance efficiency. However, ejector design is complex due to interdependent parameters and flow complexity, necessitating advanced models and tools.

The focus of this research was towards improving CO_2 ejector models for robust design optimisation and a better understanding of system operation. In this work, advanced Computational Fluid Dynamics (CFD) models were developed and compared to new experimental measurements. To aid in the design of new ejectors, an automated CFD tool was developed and combined with machine learning to look for design improvements. The algorithm was able to map ejector performance for off-design conditions, explore and optimise ejector designs, and predict local flow structures. Additionally, a numerical investigation of a novel swirl bypass concept for performance improvements of ejectors at of-design conditions is conducted.

The research has demonstrated the application of advanced CFD modeling for CO_2 ejectors, explored new design concepts, and worked on advanced machine learning based methods for improved energy efficiency of environmentally friendly refrigeration and heat-pumping solutions.







Research scientist Magnus Kyrkjebø Vinnes at work at the HighEFFLab heat exchanger test facility.

The Added Value Created by Joining FME HighEFF

Joining an FME can provide value to industrial partners on many levels.

- Top level research with significant budget and duration, directed towards industry needs
- First-rate recruitment opportunities from strong master's, PhD and post-doctoral programmes
- First access to detailed results for business development
- Improved economic and environmental sustainability through significant energy savings
- Cross-pollination effects through a varied network of engaged partners

Message from the Chair

The focus on all aspects of energy has increased during the last years. The invasion of Ukraine and Russia's reduced gas export to Europe, the transition to a more electrified society, the preservation of nature vs more renewable energy give us an energy trilemma that is very difficult to solve. However, energy efficiency in all its shades is the least controversial solution and is what HighEFF is all about.

In Norway, the awareness of energy having varying qualities, such as power and thermal, is raised both among the industry and the public. In addition, we see an increased number of new industries requiring significant electrical power and existing ones switching from fossil fuel to electrical power. This puts a large strain on the both the grid and the available power production capacity. HighEFF has produced technologies and methods for a more energy efficient society, and several of these are already implemented.

HighEFF has been an active player in the public debate on energy efficiency in addition to publishing a significant number of scientific articles.

HighEFF is now in the final harvesting phase. Technologies for increased energy efficiency, value creation and competitiveness, while decreasing GHG emissions in a broad span of industrial processes, are developed and being made ready for implementation. High expertise is required for implementation of these technologies and 25 PhDs /postdocs have been educated through HighEFF and will contribute to this. I am very happy to see that several of the PhDs /postdocs have taken jobs in both startups and in industry in Norway.

We are just in the beginning of the energy transition and I hope to see the good work and collaboration achieved within HighEFF be continued in the proposed *cEFF ("Norwegian research **c**entre for industrial energy **EFF**iciency").*

Arne Ulrik Bindingsbø is Chairman of the HighEFF Board. His current position is Leading Researcher, Energy efficiency and CO_2 reducing technologies, Research & Technology, at Equinor. Arne Ulrik earned a PhD in Materials Science from NTH in 1992. He has more than 30 years of R&D experience from the Oil & Gas sector. His focus area is to develop and execute R&D projects within the field of Energy Efficiency and Low Carbon Technologies. As these topics consist of many technical disciplines, Bindingsbø is very focused on collaborative innovation to obtain R&D projects that result in industrial implementation. Since 2014, he has held a position as Adjunct Professor at the Department of Marine Technology, NTNU.

Message from the Centre Director

As we are approaching the end of the contract period for FME HighEFF, which is now in 2024, we see more and more results from the educational activities and R&D being relevant towards innovations that will have an impact for increased industrial energy efficiency.

This includes modelling approaches for developing more integrated and efficient cycles and processes, components such as high temperature heat pumps, thermal energy storage units and heat exchangers as well as the actual candidates educated within HighEFF now working for user partners of the Centre. Dedicated activities for mapping the realised and potential impact of the innovative technologies and solutions from HighEFF will result in an overview of the target achievement compared to the original objectives of 30% reduced specific energy consumption, 10% reduced GHG emissions and increased value creation. This work will continue in 2024 and be presented at the final consortium meeting in May 2024. The knowledge developed within HighEFF also results in several spin-off projects. In June 2023, we saw the establishment of Cartesian AS, a startup company delivering solutions for thermal energy storage based on Phase Change Materials. Energy storage has been a dedicated R&D topic throughout HighEFF and has contributed towards the development of knowledge forming the basis for Cartesian AS.

Left: Arne Ulrik Bindingsbø, Chair of the HighEFF Board, and Petter E. Røkke, Centre director.

Petter E. Røkke is the Centre Director of HighEFF. His current position is Research Director for the Thermal Energy department at SINTEF Energy Research. Petter earned a PhD in Mechanical Engineering from NTNU in 2006. During his career at SINTEF, he has been active within the fields of CCS (CO_2 capture and storage), Bioenergy, and Industrial Energy Efficiency. Since 2011, he has been within the management group of SINTEF Energy Research, first as Research director for the Electric Power Technology department and since November 2012 for the Thermal energy department. He was chairman of the board for FME CenBio and is currently member of the board for FME Bio4Fuels.

Strategically, we hosted the energy efficiency conference in Trondheim 3 May with participation from industrial partners within and outside of the HighEFF partnership, authorities and research scientists to address the challenges related to the implementation of technologies and solutions for reduced energy consumption in the industry. This was also followed up with an event we hosted during Arendalsuka in August. Communication of results and innovations from HighEFF and how these can contribute towards the fulfilment of Norway's commitments in the COP28 agreement will continue in 2024.

During 2023, the HighEFF team also developed and submitted a proposal for a continuation of HighEFF, named cEFF ("Norwegian research entre for industrial energy EFFiciency"), including most of the partners in HighEFF. The final decision for this will take place in April 2024 (as far as we know), and we're keeping the fingers crossed for a continued collaboration that we have established during HighEFF – and by that contributing towards a more sustainable Norwegian industry in the future!

Our contribution to a more sustainable world

By increasing energy efficiency, value creation and competitiveness, while decreasing greenhouse gas emissions in a broad span of industrial processes, HighEFF contributes towards all 17 UN sustainable Development goals (SDGs). We have chosen to highlight four SDGs we consider most relevant to our activities, and where we hope to achieve significant impact through our research.

7 AFFORDABLE AND CLEAN ENERGY

Reaching climate goals requires access to clean, affordable energy. Two of the sub-goals for SDG 7 are to increase international collaboration on research related to clean energy and to double the world's energy efficiency by 2030. HighEFF, through its international consortium and focus on energy efficiency, is in line with these goals.

12 RESPONSIBLE CONSUMPTION AND PRODUCTION

We must use the world's limited resources more responsibly and efficiently, in terms of both production and consumption. Enabling a 20-30% reduction in specific energy use in industrial processes means industrial actors will be able to produce the same amount of goods with 20-30% less energy.

9 INDUSTRY, INNOVATION AND INFRASTRUCTURE

The SDGs are all dependent on cutting edge industrial innovation – one of the prime objectives of HighEFF. Together with industrial partners from a wide range of sectors, our research breeds new knowledge and innovation on components and processes to make industrial processes more energy efficient. This not only helps mitigate global warming but also brings down costs.

13 CLIMATE ACTION

The climate is changing at dramatic speeds, and we need to mitigate and adapt quickly. As a Research Centre for Environment Friendly Energy (FME), the most important job of HighEFF's research is to contribute to reaching SDG number 13. HighEFF aims through its research at enabling a 10% reduction in greenhouse gas emissions from industrial processes by 2024 and enabling a 20-30% reduction in specific energy use.

Industrial off-gas: An untapped resource

Ida Kero

Industrial off-gas can be a resource, but regulatory uncertainties are often in the way of fully leveraging it.

Re-using gases like CO_2 from industrial off-gas is desirable but will require large investments. The economic risk is increased by the fact that the rules for how you pay for emissions are changing continuously. In this respect, the European Union's regulations on emission allowance allocation and -price are particularly important. However, there are also other, less well-known regulations which will be equally important.

The potential of industrial off-gas

At the FME HighEFF research centre, we have mapped up how you can make use of off-gases from metallurgical smelting furnaces. We have seen that there are many different ways to use off-gases in general, but also that an off-gas with high levels of carbon monoxide (CO) is different from one that primarily consists of carbon dioxide (CO_2). A CO-rich gas can both be easier to use and be used for more purposes.

This mapping has indicated several important areas for research and technology development. We also see that, for the industry, it is quite difficult to choose between the different, already existing solutions. In order to make solid business cases to decide how to best make use of a CO-rich off-gas, the industry must know which regulatory frameworks to consider – not just now but also in the future.

This work is motivated by international climate agreements, which stipulate that the world must limit global warming to a maximum of 2 degrees Celsius. European directives pushing the green transition are being implemented, not least as a consequence of the European Green Deal. The regulations within the EU will strongly affect what is permitted also here in Norway. Several important regulations which affect the framework for Norwegian industries are also currently undergoing alterations, updates or are about to be phased in or out.

Emissions regulations affect off-gas reuse

Important European regulations are, for example, the Emission Trade System (ETS). Within the ETS, the allocation of free emission allowances is particularly important for the metal producing industry. The free allowances are intended to protect vulnerable industries against so-called carbon leakage. Carbon leakage is when production is moved from one country with strict emission regulations to another country which either completely lacks such regulations or where the regulations are not as strict. Europe is currently preparing for the phasing in of a new protective mechanism called CBAM (Carbon Border Adjustment Mechanism). CBAM will take over the function of the free allowances which will successively be phased out. This will be extremely influential for deciding which measures are economically viable in the future and which to steer away from.

Carbon monoxide is toxic, but combustible; it can be burned into CO_2. It is, for example, possible to burn the gas in turbines to produce electricity. Apart from combustion though, the CO can be used as a chemical. If CO is combined with hydrogen, the resulting gas mixture is called synthesis gas or syngas for short. Syngas is the feed stock for many processes which, among other things, produce chemicals, fuels, and polymers (e.g. plastic materials).

If we can replace fossil natural gas by CO-rich off-gas as feedstock for such processes, we will be able to reduce the total emissions. However, implementing such a replacement requires significant investments, which are more likely to happen if plant owners perceive them to be economically sensible over time. Current regulations encourage reuse of excess heat from the combustion of CO but provide little to no incentive for plant owners to invest in even more climate-efficient options. Tweaking regulations to e.g. stimulate production of high-quality energy products (such as electricity or syngas production) may well be a path worthy of exploration for policymakers.

That being said, even the best regulatory frameworks will be increasing the risk of investments if they are not perceived to be stable and reliable over time. Policymakers must therefore strike a balance between improving regulations and keeping them stable and predictable.

Vision and goals

Vision

Energy preservation and security is a global challenge. There is a global shortage of energy supply, and the way we use and produce energy today is causing greenhouse gas emissions contributing to climate change.

Norway and the EU have ambitious targets towards energy and climate. At the same time, there will be an increased demand for energy in the years to come. There is a clear need for reduction in industrial emissions and more effective industrial energy systems. If an industrial plant becomes more energy efficient, there will be more available energy for other purposes. Norway also depends on being more energy efficient to maintain a competitive industry in the future, both nationally and internationally. As part of solving this problem, FME HighEFF was established in 2016.

Goals

HighEFF spearheads the development and commissioning of emerging, energy-efficient and cross-sectorial technologies for the industry, and aims to:

- Enable reductions of 20-30% in specific energy use and 10% in emissions through implementation of the developed technologies and solutions for the HighEFF industry partners, thereby supporting the ambitious targets set by the EU and national authorities.
- Allow value creation for Norwegian industry by developing 15 to 20 new innovative solutions for energy and cost-efficient plants, energy recovery and use of surplus heat.
- Develop methods and tools for analysis, design and optimisation of energy efficient systems.
- Build an internationally leading Centre for strategic research within industrial energy efficiency.
- Generate 6 KPN, 8 IPN, 6 DEMOS and 4 EU spin-off projects.
- Enable competence building by educating 22 PhD/Postdoc candidates, 50 MSc candidates, and training/ recruiting 30 experts in industrial energy efficiency.
- Disseminate and communicate project results: 150 journal articles and conference papers.

Postdoc Shuai Ren, Professor Armin Hafner and PhD candidate Khalid Hamid (all from NTNU) in discussion at the NH_3/H_2O hybrid heat pump (Osenbrück 4.0) facility, a part of HighEFFLab.

Gender equality

HighEFF maintains a list of people involved in centre activities. Our list for 2023 shows a total of 160 men and 69 women. For the Research and innovation partners taken together, the numbers are 98 men and 36 women.

The Centre's six Research areas are led by 2 women and 4 men. Of the 26 recruited PhD candidates, 8 are women and 18 are men. When new positions are advertised, women are prioritised over men when qualifications are the same.

How we work together

The vision of HighEFF strongly relies on creating good arenas for cooperation between industry, academia and research partners. Our vision is founded on the words of Professor Arne Bredesen, who stated that excellent research is best produced through three means: knowledge, friendship and teamwork. HighEFF builds upon this vision through common goals, joint research and teamwork.

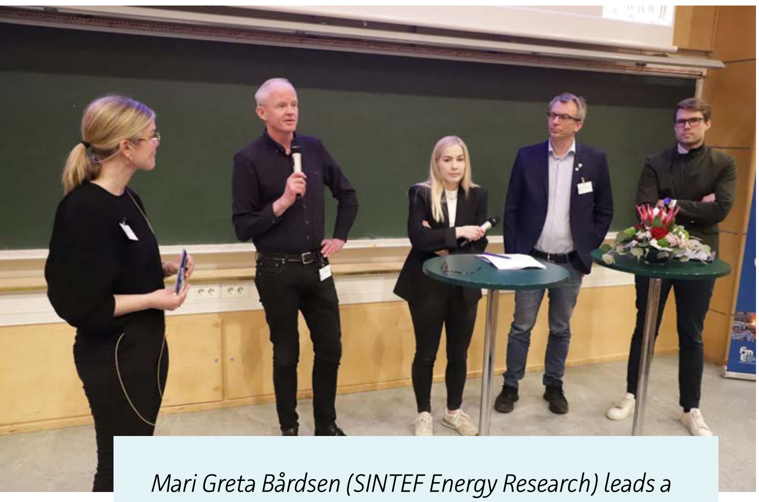
To ensure that all suggestions and input to research tasks are taken into consideration, the Scientific Coordinator has the overall overview of the Centre's progress. In addition to all the meetings for specific sectors, research areas, topics, activities, or tasks, 2023 saw the following larger meeting spaces and workshops open for all partners.

Annual Consortium meeting

The Annual Consortium meeting was held on 3-4 May. The first day was a conference open to the public, with discussions around the theme: "Energy efficiency: How the industry can unlock 20 TWh of conflict-free energy".

The Conference began with speeches by Centre director Petter Røkke; Toril Svaan, representing the Ministry of Petroleum and Energy; and Alexandra Bech Gjørv, CEO of SINTEF. The floor was then given to two members of the Norwegian Energy Commission, who presented a summary of the Commission's conclusions. Arve Ulriksen (Mo Industripark) and Liv Monica Stubholt (Selmer) held a lively presentation during which they underlined, among other things, the importance of leveraging excess heat as a resource.

Arve Ulriksen (Mo Industripark) and Liv Monica Stubholt (Selmer) summarise the conclusions of the Norwegian Energy Commission's final report, on day one of HighEFF's Annual Consortium meeting.



Mari Greta Bårdsen (SINTEF Energy Research) leads a political debate with participants Lars Haltbrekken (SV), Mari Holm Lønseth (H), Terje Settenøy (FrP) and Per Olav Hopsø (Ap).

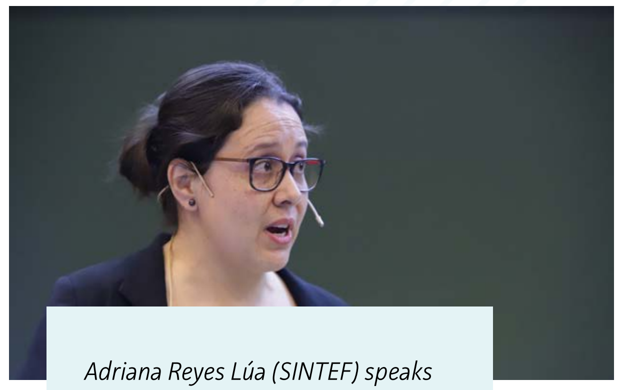
Annika Bremvåg (NTNU) leads a discussion with representatives from new industries: Bjørn Rønning (ICT Norway – data centres), Arne Fredrik Lånke (Elinor – batteries), Odd Arne Lorentsen (Gen2 Energy – hydrogen), Toini Løvseth (Renewables Norway – renewable energy production), Samuel Senanu (SINTEF).

A highlight of the day was a political debate featuring elected representatives from across the entire spectrum of Norwegian politics. Participants in the debate largely agreed on the fact that the regulatory framework needs to be adjusted to allow for more rapid progress in the field of energy efficiency. They also agreed that measures should be put in place to simplify collaboration between industries – especially industries that have no history of collaboration with each other. If they mostly agreed on the broad strokes, there were differences of opinion regarding exactly how the authorities should encourage a faster transition towards better energy efficiency.

Next were the “Industry and science” sessions, each with a short scientific presentation and multiple contributions from industry. For example, SINTEF senior researcher Hanne Kauko spoke about the industry as a flexibility provider; that is, how industry can help reduce the pressure on the power grid through energy sharing and energy storage. This was followed by a discussion with representatives from Rema 1000 and Tine, focusing on the progress they achieved in energy efficiency through their participation in the Centre.

One of the sessions focused on new industries, with representatives from Elinor Batteries, ICT-Norway, Gen2 Energy, and Renewables Norway. New industries will require more power, which makes energy efficiency even more relevant. In addition, these industries have potential when it comes to sharing surplus heat, if the right decisions are taken early on to make such a collaboration possible.

Also very valuable to both industry and scientists are the possibilities such a gathering provides for informal exchanges between people working in different fields. The best ideas sometimes arise during such conversations.



Adriana Reyes Lúa (SINTEF) speaks of low-carbon options for power generation for offshore applications.

Overall, the conference programme was well-received by participants, who commented that it was engaging and informative. Day two of the Annual Consortium meeting was dedicated to presentations by some of the Centre's PhDs, and to updates from the Centre's various Research Areas.

Frida Sæther (SINTEF) presents a top-down perspective on energy efficiency potential in the food and chemical sector.

David Pérez Piñeiro, one of HighEFF's PhD students, speaks about his work in energy management with peak demand tariffs via convex optimisation.

Cross-sector workshop 2023

Members of the HighEFF consortium gathered in Trondheim on 18 October for their annual Cross-Sector Workshop.

The event, which drew both researchers and industrial partners, highlighted the Centre's recent advancements and provided an engaging platform for in-depth dialogues on challenges in the realm of energy efficiency. Through a series of presentations, attendees were brought up to date with the ongoing research within HighEFF.

Central to the discussions were developments in high-temperature heat pumps designed for heat production from electricity and innovative concepts for power production from low-temperature surplus heat. The importance of thermal energy storage in increasing flexibility and reducing peak load was also emphasised.

Moreover, participants had the opportunity to delve into the design tools developed for heat exchangers, aiming to enhance the effectiveness of direct heat utilisation. This is indicative of the Centre's approach to not only boost energy efficiency but also capitalise on surplus heat.

Notably, the workshop touched upon the transition to greener production methods, with green aluminium production processes taking the limelight. Such advancements underline the significant strides being made by the consortium in steering Norwegian industry towards a decarbonised future.

One of the standout sessions revolved around the intriguing perspective of sustainability as a managerial technology.

HighEFF's 2023 Cross-Sector Workshop took place on 18 October.

Webinars

HighEFF organised a total of 17 webinars during the course of 2023. These were well attended live, and were also recorded to allow project partners who could not attend to view them later. Webinar topics were varied, but all related to increasing industrial energy efficiency.

- Biochar from seaweed for metal production
- Experimental analysis of the HighEFFLab Nh_3-H_2O combined absorption-compression heat pump (CACHP) test rig
- SkaleUP – Industrial HTHP for simultaneous cooling and heating
- Use of excess heat in the green transition
- Thermochemical storage: Opportunities and challenges to enable decarbonisation
- State of charge of PCM-based thermal batteries
- SiO reactivity and energy consumption during Si/FeSi production
- Integrated CO_2 heat pumping systems for hotels
- Regulatory implications for uses of CO-rich off-gas from ferromanganese production
- Geothermal power production in Norway?
- CFD-model based design for improved components in CO_2 refrigeration systems
- Energy efficiency in the dairy industry: Rørosmeieriet
- Potential for surplus-heat-to-power conversion in current and future aluminium production process with off-gas recycling
- Highlights from SFI Metal Production
- Industrial energy transition
- FME cEFF – Norwegian research Centre for industrial energy EFFiciency
- Nothing is possible

In addition to the webinars mentioned above, HighEFF also participated in a lunch webinar organised by NITO – The Norwegian engineer and technology union. The webinar featured a presentation outlining the exciting case of the collaboration between Sauda Energi and Eramet Norway, in which the two organisations are looking to leverage the excess heat generated in the ferromanganese production process. Centre director Petter Røkke was among the participants.

Spin-off projects

HighEFF contributed to the launch of several spin-off projects, solving specific challenges for the industry. The following projects were awarded funding or kicked off in 2023.

- BioCarb Upgrade (KSP) – Sustainable biocarbon value chains for the metallurgical industries
- ADVENCCS (KSP) – Integrating CO_2 capture and energy recovery in the ferroalloy industry
- InterLES (IPN) – Next generation smart hot water tanks with integrated latent energy storage
- COMPETES (IPN) – Competitive & environment-friendly thermal energy storage technology
- ZeSiM (KSP) – Zero Emission Silicon and Manganese Production through electrowinning.
- INDIGO (FORREGION) – Strengthened regional industrial innovation system for the green transition
- BioMet (KSP) – Transfer of research to industrial use

In addition, a project financed by Equinor was launched. **Integrated sector-coupled energy system** aims at increasing profitability in renewable electricity production, by introducing thermal flexibility through power-to-heat (heat pumps/electric boilers) combined with thermal storage in industry or business.

Photo: Cartesian / Kristoffer Wittrup

The Cartesian team: Håkon Selvnes, Chief Project Officer; Asle Jostein Hovda, Chairman of the Board; Mathias Kristensen, Engineer; Frode Iglebæk, CEO; Arne Fredrik Lånke, Board member; Alexis Sevault, CTO.

Spin-off company: CARTESIAN

CARTESIAN is a prime example of HighEFF research being put to use for practical applications. Stemming from a decade of developmental work by SINTEF and NTNU – much of which happened within HighEFF – CARTESIAN offers modular energy storage solutions for large-scale heating and cooling systems. The technology will enable large industrial and commercial facilities to use their energy more efficiently. Work on the technology within the company is spearheaded by Alexis Sevault and Håkon Selvnes, both of whom have extensive experience from their tenure with HighEFF.

HighEFF director Petter Røkke leads a meeting of the Centre management group.

Cooperation with other FMEs

Energy efficiency is central to the work of many other FMEs (Centres for Environment-friendly Energy Research), and we have a close collaboration with other centres on relevant topics.

- FME ZEN: Meetings were held to discuss concrete applications for heat pump solutions in buildings. Thermal energy storage, as a concept, is being tested at ZEBlab and is closely linked to ZEN's activities. The spin-off startup Cartesian AS is working on thermal energy storage that are relevant both for industry and buildings.
- SFI Metal Production: This Centre has ceased its activities in 2023, but its topic (energy-intensive industry, metal production) is very relevant for HighEFF, and close links were maintained between both Centres, not least by having Metal Production's leader as a Research Area leader within HighEFF.
- FME NCCS: Collaboration on the development and establishment of a KSP project focusing on CO_2 capture with integrated energy recovery in ferroalloy processes.

- FME CINELDI: This Centre focuses on the power grid of tomorrow, and has collaborated with HighEFF on the topic of flexibility in the energy system. In that context, HighEFF is focused mostly on heat as an energy carrier, while CINELDI looks at electricity.

- FME NTRANS: This Centre examines the energy system's role in the transition to a zero-emission society. HighEFF collaborated with this Centre in organising a series of workshops in 2022. In 2023, work was done to plan a common event (including other FMEs as well) held at the NTNU Energy transition week in March of 2024.

- Petrocentre LowEmission: This Centre works on emissions cuts in oil and gas production on the Norwegian continental shelf – and several of its sub-projects are dedicated to energy efficiency improvements. Equinor's role in both HighEFF and LowEmission ensures complementarity of both Centres' work.

The Centres listed above have overlaps with HighEFF, both in terms of the research community involved, and the user partners participating. Fundamental knowledge and research within the themes explored by HighEFF are also relevant for other Centres, other sectors and other applications than those being specifically worked on within HighEFF. User partners from the different Centres help ensure that efforts are not duplicated between the Centres, and that there is instead a complementarity between their areas of focus.

International cooperation

HighEFF has several international partners, including universities, research institutions, vendors and end-user partners. Many of the Norwegian companies involved also have considerable international activities. This ensures the necessary interaction and input required to focus activities on the challenges faced by industry and the energy system in the transition to a low-carbon society.

In the academic field, the Centre established double PhDs and MSc studies, where NTNU and an international university both have students within related topics in order to ensure a close exchange and development of knowledge. Many of the students also have shorter or longer research exchange periods at a partner university. The Scientific Committee monitors the academic production in order to benchmark the activity from an international perspective, as well as giving advice for further scientific focus and direction.

In addition to bilateral cooperation between academic partners, HighEFF also implemented dedicated cooperation between academic and industry partners.

International projects

The following projects are spin-offs of HighEFF, resulting in whole or in part from work done within the Centre.

R3VOLUTION (EU Horizon Europe): Efficient use and reuse of wastewater in industrial processes. HighEFF partner SINTEF Energy Research will perform waste heat recovery assessments of the project’s industrial demo sites and implement waste heat recovery at Felix Schoeller’s paper mill in Weissenborn, Germany.

H2Glass (EU Horizon Europe): Using hydrogen for process heat in glass production.

SuMaFood (Era-Net BlueBio Cofund): Sustainable preservation of marine biomass for an improved food processing value chain. Drying technology from SINTEF's HighEFFLab will be used.

Friendship (EU Horizon 2020): Integration of steam producing heat pumps to solar heat production.

TRINEFLEX (EU Horizon Europe): HighEFF partner SINTEF's part of this project involves demonstrating the potential of photovoltaic thermal hybrid solar collector technology in combination with a high temperature heat pump to reduce energy consumption in post-combustion carbon capture.

Decagone (Horizon Europe): Demonstrator of industrial carbon-free power generation from ORC-based waste-heat to energy systems.

FLXenabler (GEOTHERMICA, RCN): Flexible heat and cooling systems integrated with geothermal energy storage for decarbonised integrated energy systems.

Flex4Fact (Horizon Europe): End-to-end ecosystem based on a modular and multi-level architecture to enable flexible manufacturing in industries.

Organisation

FME HighEFF is hosted by SINTEF Energy Research. The Centre Director is Petter E. Røkke. The General Assembly (GA) where all industry partners, research partners and the Executive Board Chair are represented, makes all decisions that involve major changes to the consortium. Nancy Jorunn Holt (Hydro Aluminium) was appointed as the GA Chair at the first GA meeting in June 2017. She was succeded by Trond Eirik Jentoftsen at the beginning of 2024. The GA meets at least once a year.

Executive Board

Arne Ulrik Bindingsbø (Equinor Energy) was appointed Chair of the Executive Board at the first GA meeting in June 2017. In addition to Arne Ulrik Bindingsbø, current members of the EB are Anders Westin (Hydro Aluminium), Aasgeir Valderhaug (Elkem/Norwegian Ferroalloy Producers Research Association), Øystein Fjørtoft (REMA 1000 Norge), Anders Sørhuus (REEL Norway), Mona Mølnvik (SINTEF Energy Research), Nina Dahl (SINTEF Industry), Terese Løvås (NTNU), and Roger Lian (NTNU Samfunnsforskning). The EB usually holds four meetings a year.

Scientific Committee

The HighEFF Scientific Committee is composed of three national and three international experts. The mandate of the Scientific Committee is to provide advice on the relevance and quality of the scientific activities for the Centre as a whole, as well as the individual Research Areas. In addition, they highlight scientific trends, challenges and opportunities, and comment on how HighEFF performs relative to state-of-the-art (whether HighEFF research is world class or not). They provide strategic advice on scientific focus and priorities based on the performance of the various Research Areas and Work Packages. Robert C. ("Bob") Armstrong, Director at MIT Energy Initiative, volunteered to act as Chair of the Scientific Committee. The other members are Ignacio E. Grossmann (Former Director CAPD at CMU), Megan Jobson (Professor at Univ. of Manchester), Tor Grande (Vice Rector at NTNU), Jack A. Ødegård (Vice President Research at SINTEF Industry) and Kristin Jordal (Research Manager at SINTEF Energy Research).

Centre Management Team

The Centre Management Team (CMT) consists of the Centre Director Petter E. Røkke (SINTEF Energy Research), Centre Coordinator Ragnhild Sæterli (SINTEF Energy Research), the Scientific Leader Truls Gundersen (NTNU), Scientific Coordinator Petter Nekså (SINTEF Energy Research), and the six RA leaders. The RA leaders are Egil Skybakmoen (SINTEF Industry), Armin Hafner (NTNU), Trond Andresen (SINTEF Energy Research), Aud N. Wærnes (SINTEF Industry), Line Rydså (SINTEF Energy Research) and Brage R. Knudsen (SINTEF Energy Research). The CMT handles the strategic and executive centre management, including issues relating to coordination between work packages, and centre performance. CMT arrange regular meetings as needed for coordinating the activities of the Centre. The Centre management reports to EB on scientific, technical, and financial matters as well as actual progress.

Partners

Research & Education Institutes

SINTEF

Nord University

The University of Manchester

Norwegian University of Science and Technology - NTNU

KTH Royal Institute of Technologoy

AIT Austrian Institute of Technology GmbH

NTNU Samfunnsforskning AS

Carnegie Mellon University

Doshisha University

Shanghai Jiao Tong University

MIT Massachusetts Institute of Technology

User Industry

Equinor Energy

Hydro Aluminium

Rema 1000

Eramet Norway

Norsk Alcoa

Elkem

Mo Industripark AS

Gassco

Orkla

Glencore Nikkelverk ASA

TINE SA

Wacker Chemicals Norway AS

Finnfjord

Borregaard

Gether AS

Pelagia

Vendors & Technology providers

Alfa Laval Corp AB

Officine Mario Dorin

Cadio AS

Parat Halvorsen AS

EPCON Evaporation Technology AS

MYCOM

REEL International

Hybrid Energy AS

Enablers

ENOVA

Innovation Norway

Innovations

HighEFF adopted the following criteria and definitions of what constitutes an innovation.

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. The innovation should be adopted by somebody or be ready for utilisation provided that it is made probable that the innovation will be utilised within a limited timeframe.

When an HighEFF innovation is recorded, the probability of success and impact is evaluated simultaneously. If both criteria are high, the development of this innovation will continue with considerable effort.

New ideas for innovations are discussed by the Centre Management Team regularly, and the status of new and existing innovations is maintained. HighEFF has made many of these innovations visible through one pagers published on the HighEFF website

Biochar from Seaweed

Dried seaweed on the left, biochar from seaweed on the right.

Biochar from Seaweed for Metal production

Increasing biocarbon usage is a way for the metal industry to reduce their emissions, but a survey by the Process21 group highlighted that the supply of biocarbon from wood is insufficient to the needs of the process industry. New sources must therefore be explored. The NEIC project Biochar from Seaweed for Metal Production aims at investigating the utilisation potential of seaweed cultivated along the coastline of Norway by answering research questions relating to 1) the production of biochar from seaweed with suitable quality for the metal industry, 2) using surplus heat for the biochar production and 3) the presence of critical elements in the seaweed. The project is executed in cooperation with SINTEF Industry, SINTEF Ocean, SINTEF Energy, Elkem and Eramet.

Biochar from Seaweed: other uses

In addition to exploring the use of biochar from seaweed and kelp for metal production, HighEFF also investigates the potential extraction of critical materials (like lithium, magnesium, zinc) from the waste streams of seaweed processing. Calcination of this biochar has significantly reduced ash content, making it potentially valuable for the metal industry. Planned activities include testing its chemical properties, such as CO_2 and SiO reactivity, by creating pellets composed of seaweed biochar, charcoal, and a bio-binder.

Research scientist Stein Rørvik and Senior Research Scientist Samuel Senanu at work in SINTEF's CT lab, examining X-ray images of seaweed.

New heat exchanger prototype

A prototype for a new heat exchanger concept based on HighEFF research has been built. The heat exchanger aims to recover up to 400 MW of low- to medium-temperature heat from the exhaust gas of aluminium electrolysis processes. Current heat exchangers are oversized. The 2023 prototype is more compact, should require less maintenance, and is expected to have a longer lifespan. It is the result of a collaboration between HighEFF, SFI Metal Production, and the HighEFF partners Hydro, Alcoa and Reel. A test campaign in an industrial environment, connected to off-gas from one electrolysis cell at Alcoa Mosjøen is planned to start from March 2024.

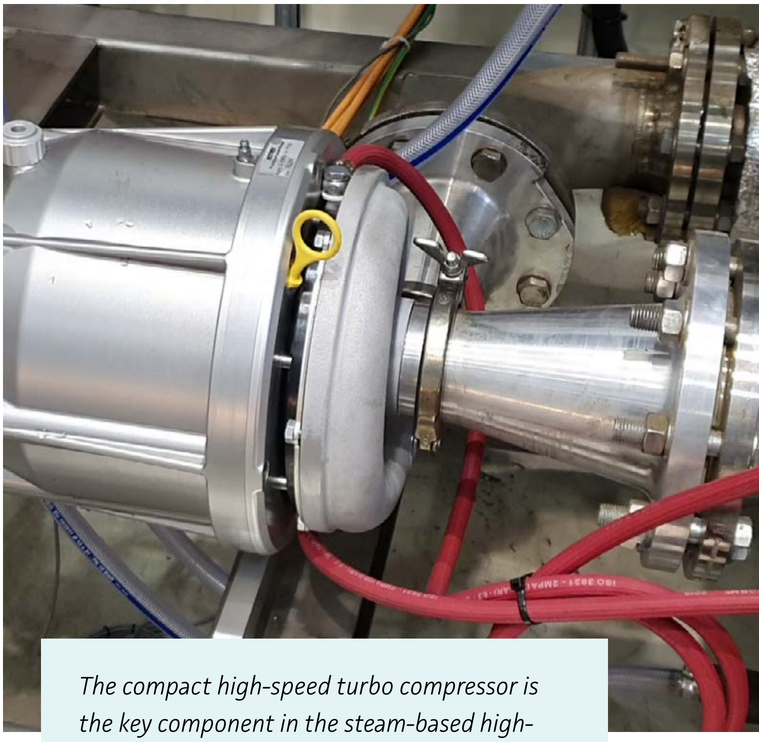
Photo: Magnus Kyrre Windfeldt

The heat exchanger prototype before installation.

High-temperature heat pumps

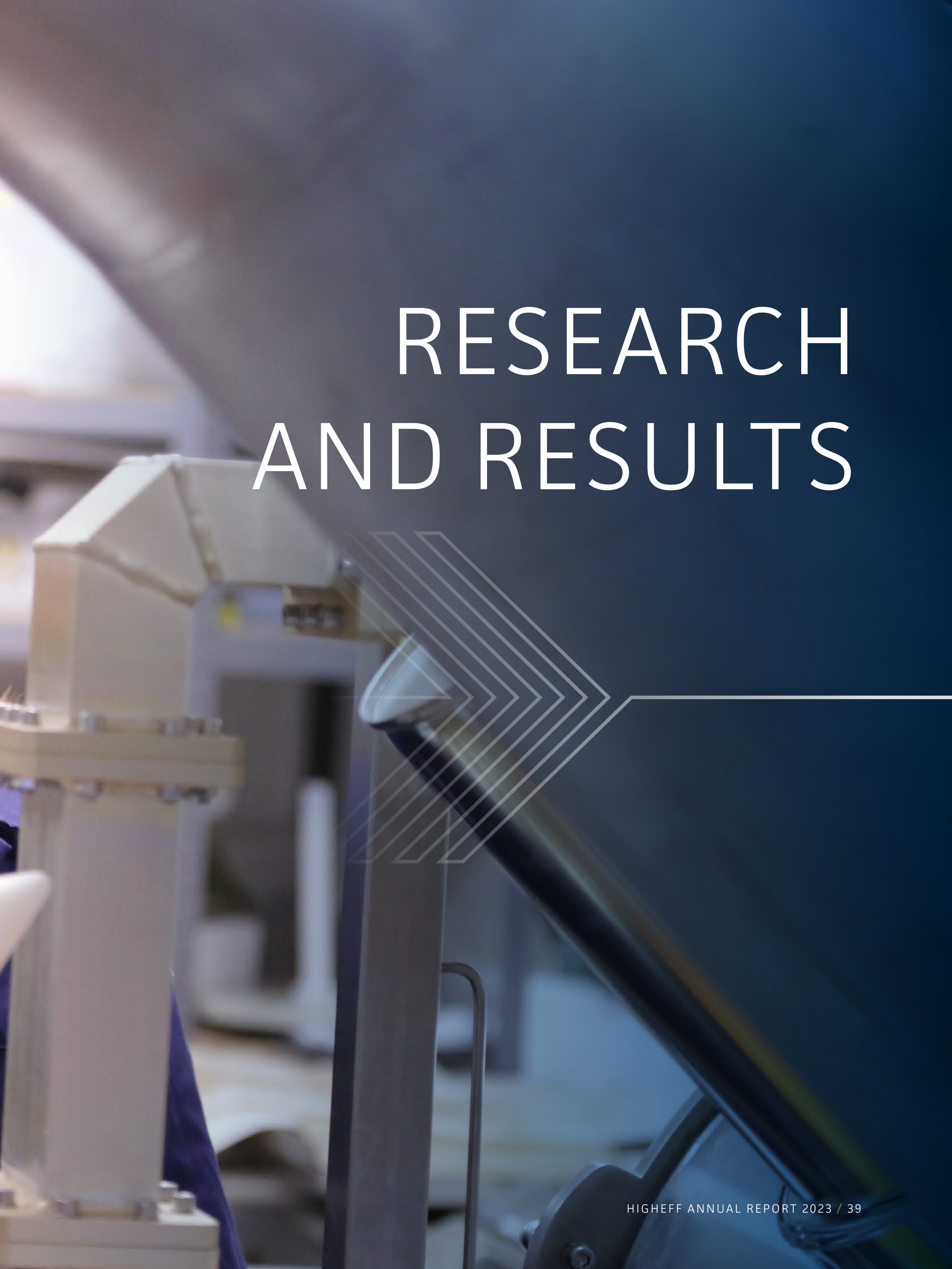
SINTEF is currently developing and performing experiments with small high-speed steam turbo-compressors for high-temperature steam heat pumps. This activity is co-funded by HighEFF and the EU project FRIENDSHIP. The goal is to utilise solar heat to produce high-pressure steam for industrial processes by upgrading solar heat through high-temperature heat pumps. This process aims to generate steam up to 15 bar/200°C.

In more general terms, High Temperature Heat Pumps are receiving much attention with regard to their potential for replacing fossil fuels for heating and increasing energy efficiency in the industry in general. A good overview of technology status and the maturity for different required temperature levels and capacity can be found in the recent IEA HPT Annex 58 Task 1 Report, 2023, for which SINTEF has contributed on behalf of Norway. (Task 1 - Technologies - Annex 58 (heatpumpingtechnologies.org)).



The compact high-speed turbo compressor is the key component in the steam-based high-temperature heat pump. Read more about it in the results section of Cycles – RA3, on page 46.

RESEARCH AND RESULTS



Methodologies - RA1

RA LEADER
Egil Skybakmoen, Research Manager, SINTEF
egil.skybakmoen@sintef.no

The main objective of Methodologies is to improve existing – and develop new – methodologies for improved energy efficiency in industrial plants. For that reason, solutions that are thermodynamically more efficient will serve as our main driver. Also, changes in the framework conditions related to energy, environment, new technologies and markets are closely considered in our work. We aim to look for new solutions to increase the energy efficiency of industrial processes and reduce their carbon emissions.

A summary of our work in 2023

The activities in RA1 are of a fundamental character with considerable focus on PhD education and postdoc research. We originally had six PhDs and two postdocs. One of the PhDs withdrew halfway, and the remaining funds were used to recruit a third postdoc.

One PhD defended her thesis in 2023 (Cristina Zotica, NTNU), and one in January 2024 (Suzane Cavalcanti, MIT), so the academic work force in RA1 is now reduced to only one remaining postdoc. Since its start, HighEFF has also recognised so-called Associated PhDs that have contributed considerably to the Centre's research and publications without being funded by HighEFF. Four such Associated PhDs have contributed to the activities in RA 1; two of these in the early days of the Centre (2017-2019) and two in the late phase. Ting He (double degree NTNU and Shanghai JTU) defended in May 2023 and Siyue Ren (Xi'an JTU) returned to China October 2023 and is expected to defend her thesis in June 2024.

The PhD student who finished in 2023 (Cristina Zotica) studied the *Optimal Operation and Control of Thermal Energy Systems*. During her PhD programme, she received a Best Paper Award (among 250 papers) from ESCAPE-29 in Eindhoven, The Netherlands, in 2019. Associated PhD Ting He studied liquefaction of natural gas with high ethane content (that was extracted) while capturing CO_2 using a low temperature process. Associated PhD Siyue Ren used a Stirling Engine and heat from the sun to improve the Round-Trip Efficiency (RTE) of Liquid Air Energy Storage for power from renewables.

The PhD students and postdoc that have contributed to RA1 in 2022/2023 have produced 13 journal publications in 2023 and attended two conferences with presentations and short papers. They are Julia J. Romero, Zhongxuan Liu, Cristina Zotica, Juejing Sheng (who discontinued), Nidret Ibric, Ting He and Siyue. Ren.

We continued work on the Excel tool that compares potential benefits of new energy-saving or CO_2-mitigating solutions. In collaboration with Hydro, we focused on documenting and rigorously testing this tool. Currently, we are revising it to address specific usability challenges. The goal is to create a flexible and well-documented tool that will be readily available to the industry by the spring of 2024.

Additionally, we made strides in refining the INTERCUR model — originally developed as part of an earlier NEIC activity. The aim was to enhance its dynamism and align it more closely with the KPI recommendations for HighEFF. In the autumn of 2023, we conducted a workshop at Mo Industrial Park to explore how this model could better cater to the industry's specific needs.

A mapping study was conducted for the energy use, greenhouse gas emissions, and sustainability of the different aluminium production technologies that have been investigated by WP 1.3 since HighEFF's launch. The work performed in 2023 revisited the different technologies previously studied, looking at their energy consumption, climate footprints and sustainability. The study further highlighted the importance and impact of the energy source on the environmental friendliness and sustainability of aluminium production. Figure 1 displays the energy source trends and CO_2 footprints of the different technologies based on three of the major energy sources considered. A conference paper, *Sustainability of Different Aluminium Production Technologies*, was presented at the TMS 2024 conference in March 2024 in Orlando, Florida.

In addition to the aforementioned conference papers, two more papers will be presented and are partly financed by HighEFF:

a) *A. Solheim, Aluminium Carbide and Carbon Dust in Aluminium Electrolysis Cells. A Conceptual Model for Loss in Current Efficiency.*
b) *A.Solheim, Limits for the Current Efficiency in Hall-Héroult Cells*

Both papers are of fundamental character but examine important topics for understanding and improvements of efficiency for the Al electrolysis process. We assume all three papers will gain a lot of international interest at the conference.

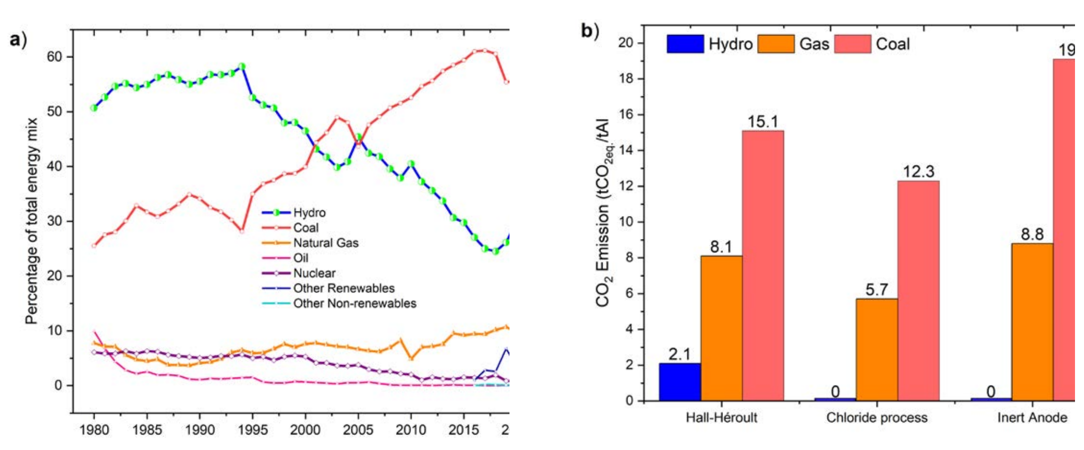


Figure 1. a) Energy source trends for the aluminium industry. b) CO_2 equivalent emissions from the electrolysis process of the three technologies including the emissions from the energy sources. Data taken from International Aluminium Institute.

Components - RA2

RA LEADER
Armin Hafner, Professor, NTNU
armin.hafner@ntnu.no

Our main objectives are to develop components required for cost-effective implementation of efficient systems for heat pumping and conversion. The focus is on heat exchangers, compressors, and expansion work recovery.

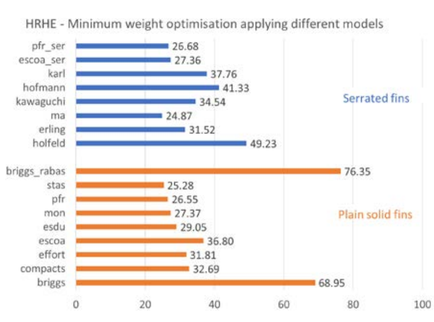
To achieve these goals, the team develops methods and tools required for designing components. Focus is given to cycles with natural working fluid mixtures, thermodynamic properties, system optimisation, and experimental investigations in the field. The research area also performs design, supports integration, and maintains flexible component test facilities for the HighEFFLab infrastructure of NTNU and SINTEF.

A summary of our work in 2023

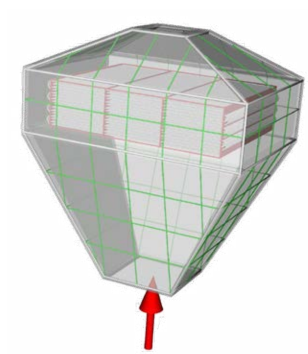
Heat Exchangers

CFD model

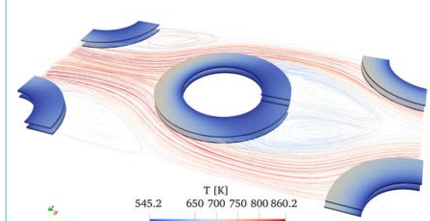
In WP2.1, the team develops models and methodology to study the simultaneous effects of process and heat exchanger geometry optimisation. The methodology depends on the underlying physical descriptions being valid over the operating range, and on the models including the effects of all the geometry parameters subjected to optimisation. The underlying models are developed by laboratory measurements, but to be able to "measure" over a wider range of geometries, these can be supplemented with Computational Fluid Dynamics (CFD). Previously, the team established a link between the optimisation models and a CFD model, so that we can numerically verify the result. This led to a paper where we compared CFD results with literature data from experiments, and with results from the developed heat exchanger optimisation model using a traditional tube-in-fin heat exchanger as case. This work continued in 2022 in combination with a NTNU



Example of effects from different models



Minimisation of total weight of an OTSG



CFD model used on optimised design

master's student's work. The work in 2022 validated the CFD model against experimental data on heat-recovery heat exchangers relevant for offshore power bottoming cycles. Effects of geometry parameters were studied. In 2023, a case study was conducted that illustrates how the choice of design models impacts minimum weight when optimising a heat recovery heat exchanger (OTSG).

The illustration above shows that when optimising a number of free geometry variables for a finned tube bundle, the choice of models will have a significant impact on the result. The optimised design is analysed with the CFD model in order to evaluate which model is suitable for a compact design. This work continues and will be published in 2024.

Plate Heat Exchanger measurements at HighEFF Lab: Experiments for evaporation of hydrocarbon and hydrocarbon mixtures at 15 – 25 bar were done in the HighEFFLab heat exchanger test facility. The HighEFF test rig performed well with obtaining stable conditions and good agreement on the heat balance. High pressure loss on the Hydrocarbon side was measured due to an inlet flow restriction. For this same reason, the planned condensation experiments at the same pressures were not possible.

Work Recovery & Compressors

The R&D focus is directed at compressors and technologies for expansion work recovery. The application of environmentally friendly and future-proof natural refrigerants is a novelty of

the research conducted by FME HighEFF. While the experimental investigation on the compressors was delayed due to Covid-19, the modelling achieved a major step forward.

Compressors

New compressors are under development that have an extended operation envelope e.g.: towards higher temperatures. These compressors are paving the way for compact and reliable industrial high-temperature heat pumps (HTHP) as applied in WP 3.2 (HTHP, Cooling and Drying) and used as input to RA6 Case Studies. HTHP's delivering process heat up to 200°C can utilise renewable energy and may cover up to 37% of all industrial need for process heat.

The spin-off project IPN-SkaleUP, with Dorin, TINE, Cadio and SINTEF Energy Research joined forces with Skala Fabrikk. An industrial 300 kWth High Temperature Heat Pump was successfully installed and tested at TINE Tunga, in Trondheim, in 2021. The HTHP was operated until June 2022. The compressors have been sent for inspection and there are plans for further tests in 2024. The analysis on both the R290- and R600 compressor efficiencies were carried out and are comparable to the lab scale 30 kWh system installed at HighEFFLab. The total efficiency, combining isentropic and motor efficiency, are in the range from 0.65 to 0.78 at pressure ratios of 2.5 to 7. These are slightly elevated values for industrial scale compressors, mainly caused by thermal losses. Volumetric efficiencies are comparable as well, decreasing from values of about 0.85 to 0.66, when the pressure ratios increase from 2.5 to 7.

A newly designed and implemented ammonia compressor test facility was established within HighEFFLab. The test facility was commissioned in Q2 2023 and will be able to operate compressors with an electric power of up to 150 kW and suction flow rates of up to 330 m3/h.

Motion modelling in piston compressor valves has been further developed through a novel method coupling computational fluid dynamics (CFD) and finite element method (FEM). The model accounts for the complex physics of the reciprocating compressor. It was demonstrated that it is necessary to consider the particular aspects of the flow inside the cylinder head as it exits through the discharge valve. Using a typical inlet boundary condition to the valve cage cannot capture the full physics of the flow. Employing a full model of the cylinder space captures in detail the reversed flow that occurs when the piston passes top dead centre, which leads to a more rapid closing of the valve. This modelling enables investigation of the volumetric efficiency. The coupled simulation has also shown that the effect of pressure inhomogeneity in the flow field leads to a significant rotation of the valve ring, due to the gas damping effect and the mechanical impacts that occur subsequently, giving a lower maximum lift in terms of centre-of-mass.

Expansion work recovery

The HighEFF lab test rig "EXPAND" arrived in Q1 2022 in Trondheim. Due to unsolved challenges identified during commissioning, major components were sent back to the manufacturer, and have not been returned during 2023. The setup is dimensioned to provide experimental data of turbines/expanders in the 10-100 kW range using natural working media.

Natural Working Fluids

The HighEFFLab Heat Exchanger test rig was installed and connected to local infrastructure at NTNU and SINTEF's thermal laboratories at Gløshaugen, during the spring of 2021. In 2022, the facility was operated mainly for an industrial project. In 2023, finally, preparations were carried out for tests with propane (R290) condensed on one side while butane (R600) is evaporated on the other side of a cascade heat exchanger. The results will be used to develop and validate a detailed model of such cascade heat exchangers to be used as a design and optimisation tool.

Cycles - RA3

RA LEADER
Trond Andresen,
Senior Research Scientist, SINTEF
trond.andresen@sintef.no

The overall goals of RA3 Cycles are to develop improved cycles and concepts for converting and upgrading energy sources, focusing on technologies and applications with high potential impact for Norwegian industries. Research in RA3 targets novel developments and improvements within heat pumping, energy storage, and heat-to-power conversion across different industry sectors. Three highlights from our 2023 activities are summarised below.

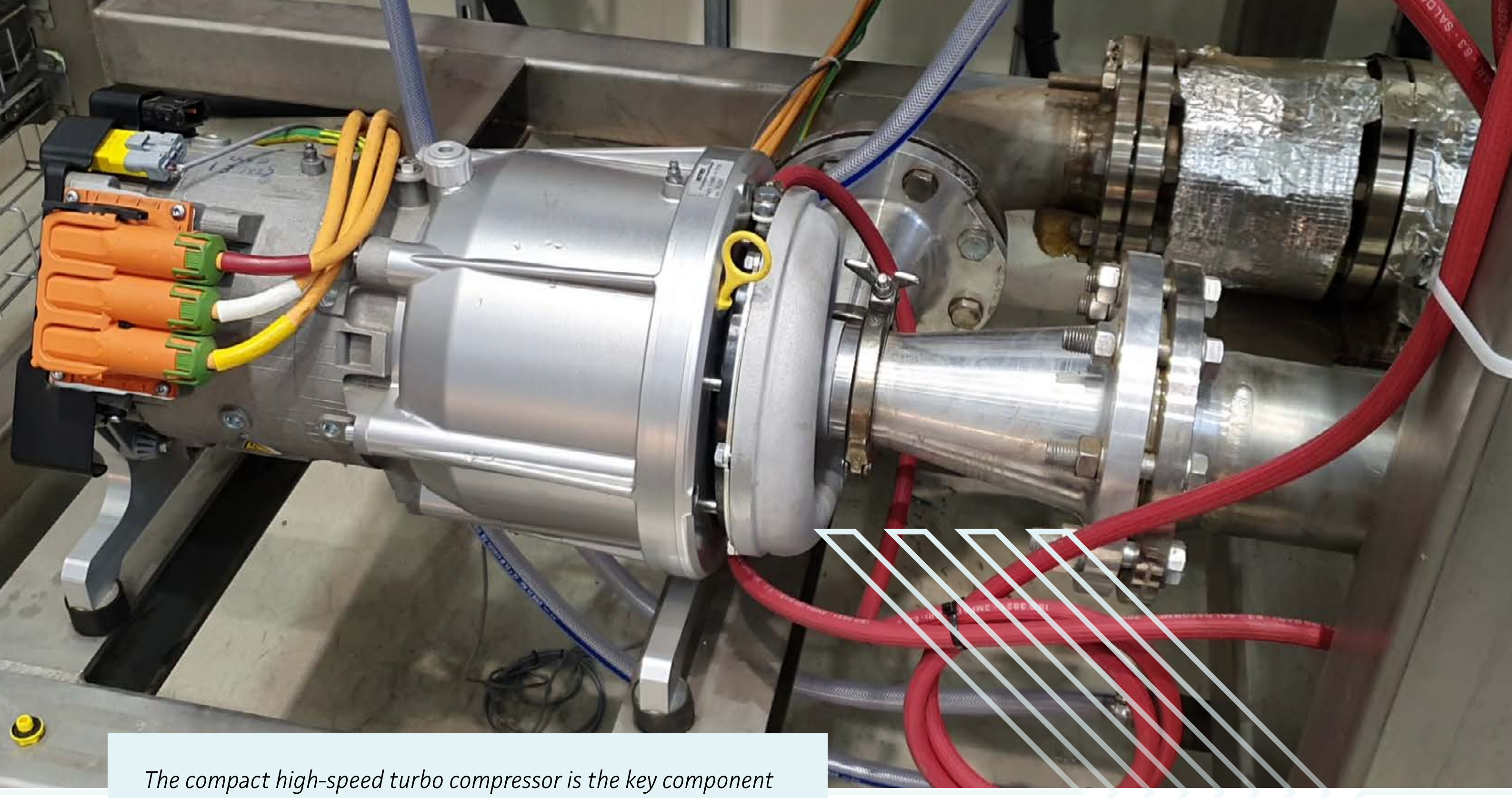
High-temperature heat pumps using water as refrigerant

Heating demands in the Norwegian industry are still to a large degree covered via fossil fuel sources, such as natural gas or oil, or using inefficient electric heaters and boilers. At the same time, the same heat-intensive industries generate a significant amount of waste heat which could be upgraded and re-used back into the process using High-Temperature Heat Pumps (HTHPs). HTHPs will therefore significantly contribute to reducing industrial emissions, but also to improving energy efficiency through utilisation of waste heat, and to reducing the load on the electrical grid. HighEFF, in collaboration with the EU project FRIENDSHIP, is currently developing and experimenting with HTHP cycles to cover industrial heating demand up to 200 °C based on compact high-speed steam turbo-compressors.

Water/Steam (R718) is an excellent natural refrigerant in many ways: It is cheap and readily available; It is one of the few natural refrigerants which can achieve condensation temperatures of 200°C or more, which means that it is very suitable industrial processes which require steam supply at 10-20 bar; It can be compressed to supply steam directly to the process in an open heat pump cycle, also known as Mechanical Vapor Recompression (MVR). Moreover, unlike synthetic refrigerants, water has no detrimental effects on the climate and the environment. Since it is neither toxic nor flammable, it is very convenient to handle compared to other natural refrigerants used in heat pumps, such as hydrocarbons or ammonia.

In a HTHP, the compressor is the critical component, and one of the main technical barriers is to qualify the compressor to operate reliably at very high temperatures. With heat supply at 180-200°C, the compressor discharge temperatures can be up to 300°C or above. At such high temperatures, it is an advantage to have oil-free compression, since high temperatures degrades the lubricating properties of the oil. Therefore, electrically-driven high-speed centrifugal compressors, also known as turbo-compressors, have been chosen.

Experimental work to characterise the compressors and map their performance is now underway. Turbo-compressors have limited pressure and temperature increase per stage compared to positive displacement compressors. Therefore, a set of two turbo-compressors are installed in series as a two-stage system, in order to maximise the final pressure and temperature of the system. The compressors have been tested up to impeller speeds of 72.000 rpm. Each stage has achieved a pressure ratio of



The compact high-speed turbo compressor is the key component in the steam-based high-temperature heat pump.

2.2, with maximum isentropic efficiency of 0.7. The maximum achieved discharge pressure from the stage-2 compressor is 5.25 bara, which corresponds to a steam condensation temperature of 154°C. The maximum thermal capacity of the system is around 700-800 kW. Another great benefit of this compressor type is its compactness. The whole system including the compressor, gearbox and motor is only 70 cm long and weighs less than 80 kg. The experimental work will continue to map the performance of the system up to condensing temperatures of 180-200°C.

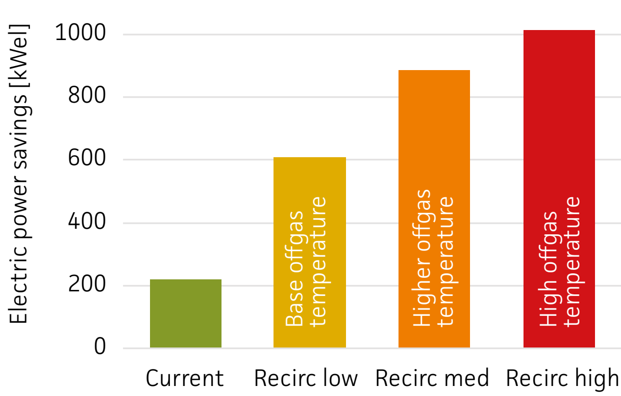
Energy recovery from future aluminium production facilities

Norwegian metal production is an important industry sector with very considerable energy demands. Therefore, increasing the energy efficiency of metal production can have a large impact on overall industrial energy consumption in Norway. Energy efficiency in the metal industry has been studied from several angles already within HighEFF. In 2023, a new study building on previous HighEFF work on aluminium electrolysis has been performed – aiming to quantify the impact on practical heat recovery potential of possible changes to the core process in aluminium plants of the future.

Aluminium is produced in large electrolysis cells where the core temperature is about 1000°C. The chemical reaction produces gas (mainly CO_2), initially at the same high temperature as well. However, to maintain the integrity of cell and surrounding equipment, the produced gas is continuously mixed with ambient air drawn into the cell and cooled down. Therefore, the off-gas typically has a temperature of about 150°C – far colder than the core of the electrolysis cell. If the off-gas temperature were higher, we could recover energy from it much more efficiently than today. One possible modification to the aluminium production process has a side effect that could make this possible. Research is currently being done on “off-gas recycling” – a measure to increase the CO_2 content of electrolysis off-gas, primarily to increase the technological and economic feasibility of CO_2 capture.

A side effect of this redesign is that the off-gas likely becomes significantly warmer, and heat recovery or gas cooling is a process requirement. When cooling it down, it is possible to recover heat and (for example) turn it into electricity – at a much better rate than with present-day off-gas temperatures. In our study, we have calculated how much more electricity a future aluminium plant could produce, compared to the current solutions.

The results show that the potential energy output of an organic Rankine cycle (ORC) could be more than four times larger in a plant with off-gas recycling compared to a present-day plant. This could lead to a large amount of saved energy in the electrolysis process. The work underlines a key finding that has been demonstrated many times in HighEFF: Energy efficiency has a much larger potential when the core processes are designed with such solutions in mind. This work was presented at the ORC2023 conference in Sevilla.



The total system power savings from recovering heat from off-gas in four different cases. The first case represents the current aluminium plants, and three cases represent future plants where off-gas recycling is implemented.

Thermochemical energy storage: The next generation thermal batteries?

Thermochemical energy storage (TCES) involves storing heat by employing reversible reactions that release or absorb energy. Thermochemical storage provides high energy densities and the ability to store energy for extended periods. However, it necessitates complex systems and precise control mechanisms to effectively manage the chemical reactions.

HighEFF research in TCES started in 2022 with mapping the possibilities of TCES for waste heat recovery. The temperature range of TCES technologies is extensively wide, and the focus was directed on the most unexplored range, 100-300°C, as this fits the waste heat generated in several industry processes. NEIC project ITChES (Integration of ThermoChemical Energy Storage), was granted and started in December 2022, allowing more profound research on the potential of TCES. The knowledge building within HighEFF has shown TCES to be a relevant research topic for SINTEF Energy Research, and the work will be continued in further initiatives (e.g., KSP-initiative HiTES).

As a parallel activity, the possibilities of TCES using waste materials from the metal industry has been considered. Manganese-rich sludge from Eramet Norway was considered as a particularly interesting candidate. Unfortunately, experimental analysis revealed that the sludge is unsuitable for phase change or thermochemical energy storage due to the absence of phase transitions and water sorption properties. However, the material had suitable properties for sensible heat storage, and this possibility will be investigated further.

Manganese-rich sludge being analysed with respect to its potential as a thermal energy storage material.

Applications – RA4

RA LEADER
Aud Nina Wærnes,
Senior Business Developer, SINTEF
aud.n.warnes@sintef.no

The overall goals of Applications are to:

- Generate more energy-efficient processes and improved heat capture and utilisation concepts.
- Enable recovery of surplus heat with a focus on high utilisation of significant industrial sources
- Further develop the potential of green industry clusters and local thermal grids

Recycling off-gas from silicon furnaces

Silicon (Si) is produced by carbothermal reduction of quartz to Si, using carbon reductants, which are a source of CO_2 emissions. Although there have been initiatives for finding alternative carbon-neutral processes, it is still the carbothermal route that dominates the industry, and hence, the process must be modified to achieve emission reductions. Out of several proposed alterations of the conventional production process, retrofitting post-combustion carbon capture (PCC) to Si smelters is increasingly receiving attention. Flue gas recirculation (FGR) could in this sense be a tool to increase CO_2 concentration in the off-gas from Si production. Higher CO_2 concentrations in the off-gas reduces the costs of carbon capture and could also enable additional CC technologies if increased sufficiently. In the PhD work of Vegard Andersen, FGR has been experimentally and theoretically studied to evaluate its effects on the process, including CO_2 concentration in the off-gas, possible future carbon capture technologies and reduced NO_x emissions. This has been done through mass and energy modelling of the Si process and a coupled carbon capture process. Small-scale experiments have been conducted to investigate the effect of different gas atmospheres on silica fume formation. A larger pilot-scale experiment of FGR for silicon production has also been conducted, demonstrating the concept in close to industrial conditions. Combustion of the process gases SiO and CO in the tapping gas has also been studied on an industrial scale during a measurement campaign on a large silicon furnace.

Modelling the Si process showed that FGR is an efficient way of increasing the CO_2 concentration in the off-gas, with the benefit of not increasing off-gas temperature. The cost of carbon capture in a conventional scrubber stripper setup was found to be reduced with increasing FGR as higher CO_2 off-gas concentrations allowed for more efficient capture with smaller components and a lower solvent flow, leading to lower specific energy consumption.

Small-scale experiments of SiO combustion in different atmospheres indicated that replacing O_2 in the combustion air with CO_2 had an insignificant impact on silica fume morphology. However, expanding the combustion of SiO gas from a small-scale to a pilot-scale test resulted in indications that the specific surface area of the silica fume increases with increasing FGR. The pilot-scale experiment was also a successful demonstration of how CO_2 concentrations could be increased to over 20 vol % and with reduced specific NO_X emissions, although not as significantly as previously predicted by modelling. During the tapping gas measurement campaign, inert gas injection in the tapping gas intended to suppress NO_X formation was performed but was not successful. NO_X generation was however found to be more strongly correlated to the energy added to the tapping gas stream than to the amount of SiO combustion, as previously assumed. It was observed that particulate matter (PM) formed from the oxidation of liquid Si did not generate NO_X to the same extent as the combustion of SiO gas directly from the taphole. Process crater temperatures were estimated to be in the range of 1890 to 2200°C, using the concentration of PM and CO_2 in the tapping gas.

A report has been finished on 1D flame model applied to the study of chemistry in silicon furnaces: Gas-phase chemistry and approximate treatments of gas-solid reactions.

The emission of Polycyclic Aromatic Hydrocarbons (PAH) from processes (especially related to metal processing and production industries) is considered to originate from the combustion of the carbon materials in furnaces that contain PAH and aliphatic fuels. The use of detailed CFD simulations to predict PAH emissions from industrial processes is impractical due to the very high computational overhead, and to the relatively high uncertainty in the input data. To address this, a post processing approach is proposed to predict PAH evolution which uses the results of the CFD simulation of the major process gases based on a relevant skeletal mechanism as the input to PSR reactors using detailed PAH chemistry. Our report describes the underlying assumptions of the proposed approach and its implementation. The prediction from the proposed approach is compared with results of CFD simulation employing detailed PAH chemistry for the case of a co-flow burner burning a mixture of C_2H_2 and H_2 at various flue gas recycling levels and fuel inlet velocities. The results show that the proposed approach can predict the PAH emission, at a reasonable accuracy and a fraction of computational cost, using an appropriate value of the tuning parameter used in the definition of the residence time of the PSR model.

Energy distribution inside Manganese-alloy furnaces

The experimental work on understanding internal energy distribution inside Manganese-alloy furnaces has continued in 2023. The activity started with the PhD work of Trine A. Larsen. A knowledge gap was identified previously; a challenge which will become more critical as the industry switches to more biocarbon to replace fossil carbon. Therefore, the focus has been to investigate if the volatiles that evolve from biocarbon behave differently from those that evolve from traditional fossil carbon, and how it influences the prereduction of manganese ores. Previous experiments have shown that the presence of biocarbon improves prereduction when reduced without an external gas flow, and this has been attributed to the presence of volatiles. Two summer interns have participated in the experimental work where different manganese ores were reduced in the presence of biocarbon, fossil carbon or no carbon. The experiments in this work were done with an external gas flow of CO/CO_2 to more closely simulate real furnace conditions. With the presence of an external reducing gas flow, the characteristics of the carbon were of less importance to the reduction rate of the ores, particularly at low temperatures. This indicates that the positive effect of biocarbon on prereduction due to volatiles may be less significant in a real furnace than previous experiments have indicated.

Recovering excess heat from aluminium production

The Norwegian industry produces approximately 20 TWh of excess heat every year, where the aluminium industry is the largest producer of low temperature excess heat (below 250°C). The off-gas from aluminium electrolysis is a significant source of surplus heat that is currently unused. In order to enable utilisation of this surplus heat, the industry requires cost- and space-efficient heat exchangers that can withstand the challenging conditions in the off-gas channels.

A prototype of the novel heat exchange concept that has been developed for aluminium smelter off-gas during the last years has now been built. The plan for the rest of the Centre period is to test its performance at an industrial site. The test location that has been identified is the Alcoa plant in Mosjøen. The site has been inspected and discussion with the relevant personnel at the site has been initiated to identify what steps need to be taken to prepare for the installation and testing of the prototype heat exchanger. One of the first steps was to design a cooling system that allows to remove the heat captured by the heat exchanger. The heat exchanger was also further modified to install a window to allow for internal inspection.

The activity on knowledge building and spreading on the topic of surplus heat utilisation is also continuing, and the goal during the last part of the Centre is to summarise the activities on the topic in both a popular science and an academic article. The work is in progress in collaboration with WP 3.1. As a first step, a blog article has been published on SINTEF Blog with the title "How to get from knowledge building on surplus heat recovery to practical and attractive demonstrators?"

Industrial clusters

Circular economy and industrial symbiosis are gaining momentum as pathways towards a low-carbon and energy-efficient society. Industry networks and clusters are viewed as key instruments to promote these strategies, and in 2023 we have investigated three different topics:

Potential for synergies between metal and food industries at Orkdal by producing microalgae: Sustainable fish feed is becoming increasingly more important. In this task, the production of microalgae, one of the possibilities of sustainable feed, has been investigated. The work will be continued in 2024 with the aim of giving a potential for how much carbon dioxide and excess heat can be utilised to produce microalgae, as well as an overall assessment of production feasibility.

Heat integration at industrial parks: To satisfy the increasing demand for cooling water in Mo Industrial Park, one could reuse dirty cooling water from smolt production. Kvarøy Smolt already utilises dirty water for heat recovery. In this task, the operation of the existing plate heat exchangers was evaluated using a heat exchanger model described in MS Excel. Relatively high UA-values were calculated, and the heat exchangers are therefore considered to be functioning well. This indicates that plate heat exchangers are suitable for use with dirty water and that the current chemical cleaning is sufficient. The Excel model was also used to evaluate a case where the dirty water from Kvarøy Smolt is used to cool a planned hydrogen production plant. Only around 10% of the wastewater from Kvarøy Smolt's heat exchangers would have to be used to achieve the planned cooling capacity. Use of dirty cooling water will increase both the investment costs and operational costs for the heat exchangers.

Green and blue KPIs for industries: Until now, HighEFF has focused on KPIs related to reduced emissions and specific energy use. Loss of biodiversity and use of land are, however, at least as important, if not more. A lot of land-intensive industry is expected to be built in Norway in the coming years (e.g., battery factories, land-based farming, data centres). Similarly, there are also industrial activities planned in the oceans (e.g., wind farms, macro-algae production).

Among other international initiatives, the Taskforce on Nature-related Financial Disclosures has been working on defining KPIs that can give indications on the impact that industrial activities have on nature. These KPIs have been collected, summarised and exemplified in a memo, with the goal of further learning on the importance and potential of sustainability metrics as well as inform HighEFF partners about the importance of the topic. The preliminary results from this work were presented in May at HighEFF's Annual Consortium Meeting. The work on this topic will be further finalised and disseminated through a blog article in 2024.

Society - RA5

RA LEADER
Line Rydså, Research Scientist, SINTEF
line.rydsa@sintef.no

The overall aims of Society are to manage the innovation activities and handle dissemination, communication, and the general flow of information in the Centre. Additional goals are to form the innovation strategies and technological roadmaps for the industry sectors and share them among partners to enhance cooperation and synergies.

Innovation management includes research on internal and external interactions, as well as on the barriers and enablers for innovation and realisation of HighEFF technologies and concepts.

Innovation, barriers, and enablers

In 2023, HighEFF partner organisation NTNU Social Research (*NTNU Samfunnsforskning AS*) completed publications and synergistic project development activities building on previous HighEFF research. Particular attention was given to the recently completed (2022) PhD research by Jens Petter Johansen into the representational, political, and rhetorical dimensions of energy efficiency.

A journal article was published[1], expanding on HighEFF work to critically analyse claims, contradictions, and paradoxes around digital infrastructure expansion. Another article on sustainability-as-managemental-technology, based on major work by Jens Røyrvik and the PhD thesis of Jens Petter Johansen, was submitted to an academic journal for review.

During the year, HighEFF partner organisation Nord University focused on research dissemination for policymakers, firms, research scientists, and the public through research-based presentations. One specific highlight was the participation at the DRUID 23 conference, which is one of the world's premier academic conferences on innovation. At this event, Nord University presented novel research on how research centres strive to satisfy public sponsors in innovation activities. This research suggests that these centres employ various strategies to highlight the potential innovation outcomes they produce. Additionally, Nord University scientists presented research on how firms can achieve growth through effectual leadership over time. Another specific highlight related to research dissemination was a seminar titled "How to build a business-related research environment" organised by Nord University's Centre for Business Development. The event featured a debate involving businesses, research scientists – including HighEFF's Centre Manager, and Research Council of Norway representatives. The topic was policy initiatives to develop business-relevant research.

In late 2023, Nord University research scientists focused on cross-sectoral open innovation collaborations for circularity. For example, they explored the possibility of establishing tomato production based on waste resources from various industries in Northen Norway, and how actors from these industries could develop the project together, from the idea-generation phase to a viable business case. The findings show that the viable business case is dependent on a cross-sectoral collaboration where the actors involved perform multiple open innovation activities and where some of them can take the role of innovation champion throughout the collaboration.

This role can be played by multiple actors in the project and is contingent upon the experience and knowledge the actors have and can contribute with throughout the various stages of the collaboration. This research is now to be considered for a book chapter in a book on bio-circular economy and innovation development.

On the project development side, the new RCN-funded project Limits to digitalisation was launched to investigate the emerging data centre industry. The research looks at the industry's efforts around circularity, which include ambitions for surplus heat reuse and symbiotic activities with other industry clusters around data centre sites. NTNU Social Research is involved in this project.

Novel Emerging and Innovative Concepts (NEIC)

Our internal funding scheme allows us to invest in ideas that are not covered by ongoing activities within HighEFF. The Novel Emerging and Innovative Concepts (NEIC) aims to foster new ideas and innovations through collaboration and research within HighEFF. The evaluation criteria and the HighEFF NEIC evaluation committee were set in 2021. The committee is composed of two members from the industry, one from a university and two from the R&D sector. One more member from R&D is invited as an observer.

The final call for Novel Emerging and Innovative Concepts (NEIC) was announced with a deadline for applications January 20, 2023. Six applications were received, of which three were funded:

1) PrintUp – Enhanced capability of natural refrigerant-based heat pumps and refrigeration units through innovative Additive Manufacturing (PrintUP)
This project encompasses both numerical simulations with a dedicated CFD simulation environment as well as experimental activities related to 3D-printing of ejector components and testing those components at SINTEF laboratory rigs. The aim of the project is to prove the concept of using additive manufacturing to further develop heat pumps. Since the energy efficiency of heat pumping installations (specifically high-temperature heat pumps of industrial capacity) remains their most important performance indicator, boosting their energy performance by using ejectors for expansion work recovery has gained a lot of interest from the industry in the last decade. Still, using traditional manufacturing technologies for industrial-size ejectors limits the potential benefits: 1) the geometry cannot be fully optimised due to technological and economic constraints, 2) integration with other components like heat exchangers or phase separators is challenging, when at all possible. For these reasons, the project aims at 1) mapping the potential hurdles in the implementation of 3D-printing to the ejector manufacturing process, and 2) delivering tangible test results of selected 3D-printed ejector geometries compared to the results obtained through traditional means. The effects of surface roughness after the 3D-printing and surface quality of complex shapes of the flow channel are the main points of interest in the project. The project is a cooperation between SINTEF Energy Research, SINTEF Industry and SINTEF Ocean.

2) HighEFFEC – Reduction of CO_2 emissions from industrial processes through integration of high-efficiency H_2O/CO_2 electrolysis

This project uses the so-called fuel-assisted solid oxide electrolytic cell (FA-SOEC) technology. The FA-SOEC is a new conceptual development of SOEC technology where combustible gases are introduced in the anode of the cell and react with the oxygen that diffuses from the electrolyte. The heat produced from this reaction is then used inside the cell to maintain high operational temperature in the electrolyte, reducing kinetic losses and thus the electric power consumption required for the electrolytic process. Excess heat from the industrial process is used, together with the hot gas produced at the anode, to heat-up the H_2O/CO_2 feed to the cathode. This reduces the overall electricity consumption of the cell. When the excess heat is in form of hot water (40–100°C) or steam (above 100°C), it can be used directly as an H_2O source to hydrolysis. The project is a collaboration between SINTEF Energy Research (project lead), the Department of Energy and Process Engineering at NTNU, and the metal processing group at SINTEF Industry.

3) Biochar from Seaweed for Metal Production

This project aims at investigating the utilisation potential of seaweed cultivated along the coastline of Norway for metal production, by answering research questions relating to 1) Producing biochar from seaweed with sufficient quality for the metal industry; 2) Using surplus heat for the biochar production; and 3) Investigating the potential for extracting critical elements in the seaweed. The project is executed through a cooperation between SINTEF Industry, SINTEF Ocean, SINTEF Energy Research, Elkem and Eramet.

Update on projects that have been granted before 2023, with ongoing activity in 2023:

1) SOCTES – Innovative State-of-charge and Output control of PCM-TES systems

This project outlines a new methodology based on ultrasound sensors for controlling thermal energy storage using phase change materials. The aim of the project was to validate and implement highly innovative real-time state-of-charge monitoring and heat output control methods for PCM-TES systems, enabling optimal energy utilisation and reliable heat (or cold) supply. Results from several measurements have shown that the concept could be realised into application. Further development is needed however, due to the complex relations between ultrasound recordings and state of charge determinations. The challenge lies in the difference in the behaviour of the phase change process when comparing solidification and melting of the TES media. Nevertheless, a patent application has been submitted and is pending. New projects have also been initiated in which the concept will be further developed. The project was conducted via a cooperation between SINTEF Energy Research and NTNU.

2) TES-AS – Monitoring and analysis of a pilot thermal energy storage (TES) unit to supply air conditioning (AC) in commercial refrigeration systems

This project aims to demonstrate that the TES technology developed at HighEFF can reduce the AC nominal capacity of a supermarket, increase the commercial refrigeration system stability, and improve the system's overall energy efficiency. Shifting the AC load to off-peak hours can result in valuable flexibility and cost savings for the system owner. The project is a cooperation between SINTEF Energy Research, the

Department of Energy and Process Engineering at NTNU, and industry partner REMA 1000.

3) ITChES – Integration of ThermoChemical Energy Storage

The objective of this project was to analyse the performance potential of selected steam absorption TCES compounds to recover excess heat in the range of 50-300°C in a lab scale reactor. The project also aimed at providing a technoeconomic study for large-scale implementation of this method in industry processes. The work was done as a collaboration between SINTEF Industry and SINTEF Energy Research.

Dissemination and Communication

Efforts have been made on the communications front in 2023 to convey the Centre's message on key topics such as excess heat, thermal energy storage and natural refrigerants. The Centre continued using its established channels (the website, the LinkedIn page, the webinars and the various workshops and seminars) to reach its objectives. Additionally, there was a concerted push to coordinate the writing of an EU whitepaper on energy efficiency. Work on this whitepaper started in the spring of 2023 and ended with its launch in early 2024. The document aims to provide recommendations to policymakers on how to best leverage energy efficiency to help facilitate the energy transition.

For more details, see the Communications chapter on page 63.

1 Gjefsen and Johansen, "Transforming Sufficiently? Data Centers and the Paradoxes of Digital Infrastructure", published in Beta Scandinavian Journal of Business Research 37(1)

Case Studies - RA6

RA LEADER
Brage Rugstad Knudsen, Research Manager, SINTEF Energy Research
brage.knudsen@sintef.no

Case Studies are performed to promote HighEFF innovations and obtain measurable results from the implementation of HighEFF technologies in various industrial sectors. The overall goals for the case studies are to develop technology concepts that can lead to a 20-30% reduction in specific energy use and a 10% reduction in CO_2 emissions through implementing technologies and solutions.

CO-rich off-gas

A previous, technology-focused case study on utilisation of CO-rich off-gas from manganese ferroalloy production has been complemented by an overview of how EU regulations are impacting the techno-economic evaluation of the different utilisation options. Various regulatory frameworks are covered, including the taxonomy for sustainable activities, the corporate sustainability reporting directive, the industrial emissions directive, and the emission trade system (ETS). The report focuses on how the new or updated regulations and directives may influence the investment decisions for ferroalloy producers. The ETS's allocation methods for free emission allowances and how the ETS interacts with the upcoming, new carbon border adjustment mechanism (CBAM) for ferroalloy producers seem to be particularly impactful.

Industrial Energy Communities

Several industrial actors are aiming to electrify their processes but are frequently met with the challenge of limited capacity in the electricity grid. In the literature, energy communities are typically investigated as a means to incentivise efficient resource utilisation, e.g. to reduce electricity peak demands. The research on energy communities has so far mainly focused on households, electric vehicle charging, and to some degree commercial building such as offices. In this work, we have investigated the potential for integrating an industrial actor – more specifically a dairy – into an energy community. We investigate how energy storage can enable reduced loads in the dairy, thereby lowering the grid tariffs, which are typically driven by the peak electricity demand within a given month. We compare the cases of a thermal energy storage optimised for the industrial actor, to a case where the storage is used for reducing the peak demand of the entire area. We find that thermal energy storage is favourable compared to a battery, and that the energy storage may potentially contribute to 1 MW of increased grid capacity for the area, at the same time as it reduces costs both for the industry actor and the area.

Energy efficiency potential of retrofit projects in fish processing plants

Conversion of Kollsnes furnaces from natural gas to hydrogen

At the Gassco Kollsnes gas processing plant, three gas-fired furnaces are used to heat oil. Reducing the CO_2 emissions from the furnaces is an objective. As hydrogen is expected to be available at the Kollsnes plant by the end of the decade, full or partial replacement of natural gas with hydrogen is of interest. The aim of this case study is to investigate the conversion of Kollsnes' furnaces from natural gas to hydrogen (or a mixture of them) to reduce CO_2 emissions. A CFD model of the Kollsnes furnace was built, and simulations with natural gas as fuel were performed and validated against data received from Gassco. Natural gas has been replaced with hydrogen in the model, and simulations are ongoing.

Cost estimation of seaweed drying

This ongoing study considers the costs of establishing and operating a cultivated seaweed value chain, from seed deployment to dried product. Techno-economic analysis methods are used to evaluate the cost of using surplus heat from the metallurgical industry sector for the processing step, in order to assess the potential of this contributing to an upscaling of production. Uncertainties related to this upscaling, as well as to geographical variations and the use of immature technology, have been integrated into the study by use of stochastic input data combined with statistical output analysis. In 2023, preliminary results were presented for typical Norwegian conditions and for a Karmøy-based case study. These estimate that the cost of using surplus heat for processing will be marginal compared the cost of cultivation, indicating this as a promising option for upscaling the value chain should energy availability become a concern. With current seaweed prices however, the production is not profitable without including carbon pricing, and thus the carbon removal potential of this value chain is also included in the study going forward.

Research Infrastructure

Industry seldom implements new technology without a thorough testing period, to ensure efficiency and reliability. Such testing requires pre-industrial lab installations for performance analyses, component validations and prototyping to enable successful implementation in the industry. These needs are covered to some extent by HighEFFLab installations, which were officially opened in May of 2022. This infrastructure will make emerging, sustainable solutions feasible to the industry, closing the gap between TRL1-4 and TRL7-9.

HighEFFLab is a joint national laboratory between various departments at SINTEF and NTNU. It consists of five laboratories, with a total of 12 experimental rigs and 8 analysis instruments. The laboratories also include tools for calibration and field measurements, as well as computers and software for designing, modelling and simulating various processes. The facilities are mainly located at the NTNU Gløshaugen campus in Trondheim, except for one installation that is located at the SINTEF Energy Lab at Blaklia, also in Trondheim. The laboratories are as follows:

1. **The Heat Exchanger Laboratory**
   Flexible heat exchanger test rig for evaporation and condensation of hydrocarbons and mixtures of these

2. **The Expander Tests Laboratory**
   Developing efficient and reliable units for excess heat recovery with natural working fluids

3. **The Natural Refrigerants Laboratory**
   a. ClimaTest – Climate chamber with wide-range and accurate environmental control to test the new generation of display cabinets, condensing units and heat pumps
   b. JetTest-Rack – CO_2 compressor rack to characterise ejectors that will help push away the so-called CO_2 equator
   c. MultiTest-Rack – Multifunctional setup to test innovative components for tomorrow's CO_2 vapour compression systems
   d. Osenbrück 4.0 Heat Pump Cycle – Hybrid absorption-compression heat pump with ammonia-water mixture as natural working fluid
   e. SuperSmart-Rack – Energy-efficient and environmentally- friendly integrated CO_2 vapour compression units for supermarkets
   f. Turbo2Steam – R718 heat pump for steam generation

4. **The Dewatering Laboratory**
   a. Modified Atmosphere Dryer – High quality drying of food and biological material assisted by microwave in an inert atmosphere
   b. Heat Pump Drying – Recovery of thermal upgrade of drying energy

5. **The Gas and Material Characterisation Laboratory**
   a. Portable FTIR gas analyser – High-resolution spectrometer for field applications. Multivariate calibration capabilities
   b. QCL online CF4 analyser – Laser for CF4 monitoring. Stack mountable
   c. LECO CS844 – Carbon and sulfur content determination in inorganic samples by combustion of sample
   d. Alytech Liquid/Gas mixer – Mixer of gases and liquids with cascade dilution. Passivated for use with sticky/corrosive gases
   e. Protea ProMass EI-MS – Fast process gas analyser with quadropole mass spectrometer

Master of Science Marco Bless making adjustments to the propane-butane high-temperature heat pump at HighEFFLab.

f. Agilent 490 PRO micro GC – Fast gas chromatograph with thermal conductivity detector. Standalone for field applications
g. Optical microscope Leica DMi8 A – Automated image analysis of carbon materials
h. Optical microscope Leica M 205 – General characterisation of materials in 3D

The laboratories were made possible thanks to financing provided by the Research Council of Norway's Research infrastructure effort (INFRASTRUKTUR), that was launched in 2009.

Education, researcher training and recruitment

Developing knowledge and expertise at various levels is a main objective and major task in HighEFF. The focus is on energy efficiency in industrial processes, and the main sub-activities are (i) methodologies for analysis, design, control and optimisation, (ii) improved equipment and cycles, and (iii) systems integration including industrial parks (clusters). The education activity takes place at different levels: Master's students having theses related to HighEFF, PhDs and postdocs with research and publications related to energy efficiency in industry, and employees from user partners taking tailormade intensive courses to become energy efficiency experts in their companies.

Recruitment and completion

By the end of 2023, HighEFF had recruited 21 PhDs and 6 postdocs. One of these PhDs discontinued, and remaining funding for this position and unused budgets during the pandemic made it possible to recruit postdoc number 6 for 2 years in 2022. HighEFF has also identified 11 so-called associated PhDs working on HighEFF related topics. Considerable contributions in research and publications have been made by these associated PhDs.

Since the start of HighEFF, 15 PhDs, 5 postdocs and 8 associated PhDs have completed their programs successfully. 3 PhDs and 2 associated PhDs finished in 2023. We have also had 53 master's students since the start of HighEFF – however none in 2023. This is probably due to the fact that PhDs had either finished or were in the final stage of their program. With only one year left for the Centre, the PhDs and postdocs had spent 98.1% of the time and funding available by the end of 2023.

Photo: Aziz Nasuti

International university partners

HighEFF's education program spans across countries and continents. Academic partners in the Centre currently include 2 universities in Norway (NTNU and Nord University), 2 more from Europe (KTI in Sweden and University of Manchester in the UK), 3 in the US (MIT, CMU and University of Illinois) and 2 in Asia (Doshisha in Japan and Shanghai Jiao Tong University in China); a total of 9 universities.

Publications

With 24 journal papers in 2023 where PhDs/postdocs are authors, the accumulated number since the start of HighEFF is 241. In addition, HighEFF has produced 92 papers in total since the start of HighEFF without contributions from PhDs/postdocs.

Communications

HighEFF has continued to reach the general public, policymakers and key members of the industry through its communications efforts in 2023.

In its next-to-last year, focus has been on highlighting results and success stories, as well as giving attention to what remains to be done: both in terms of new discoveries and in terms of realising the potential of Centre innovations.

Why communications matter for HighEFF

HighEFF's vision of making Norwegian industry the world's cleanest requires sharing new knowledge and information to the industry. It also requires industrial and political willingness, as well as public acceptance. Communication is therefore a core strategic activity of HighEFF.

Communication activities extend beyond the HighEFF consortium and scientific community to provide facts about energy efficiency and promote innovations to industry.

Strategic communication efforts

In April, HighEFF participated in a consultation meeting about energy efficiency, at the invitation of Norway's Ministry of Petroleum and Energy. The Centre commented on four key recommendations to leverage the potential 20 TWh of surplus heat generated by Norwegian industry. In short, the comments were to set a cost for wasting surplus energy; to amend the Energy Law to include cost-benefit assessments for using surplus heat in both new and existing facilities; to support solutions that provide societal benefits (as opposed to exclusively economic benefits); and to increase funding for research programmes related to environmentally friendly energy and green transition. You can read more about HighEFF's Input to the energy efficiency consultation on the Centre's website.

HighEFF was represented at Norwegian political lobbying festival Arendalsuka. The Centre organised the event "Can Norway achieve a power surplus through industrial energy efficiency?" (in Norwegian: *Kan industrien spare Norge til kraftoverskudd?*). The event featured as participants the Norwegian Water Resources and Energy Directorate (NVE); HighEFF partner ERAMET; HighEFF Centre Director Petter Røkke; and representatives from six Norwegian political parties.

"Can Norway achieve a power surplus through industrial energy efficiency?" was the question asked by HighEFF at Arendalsuka this year. Left to right: Centre Director Petter Røkke; Director Climate and Manganese Alloys at Eramet Marit Kittilsen; and Head of Section at NVE Maren Aschehoug Esmark.

HighEFF's Scientific Coordinator Petter Nekså participated in the UN Climate Summit COP28 in Dubai, where he touted the merits of natural refrigerants. Use of these refrigerants can both result in energy savings and in a reduction of cooling and heating's carbon footprint, since natural refrigerants have a much lower climate footprint than traditional fluorinated refrigerants. Another benefit is that natural refrigerants are not persistent in nature, as opposed to fluorinated refrigerants that break down into harmful PFAS.

In the media

HighEFF and its scientists are increasingly associated in the media with topics such as leveraging excess heat, thermal energy storage and natural refrigerants. Throughout the year, the Centre's research scientists were featured in articles by Teknisk Ukeblad (in both May and October, about heat pumps and excess heat respectively); Arbeidsliv i Norden (in May, about using excess heat from data centres for district heating; Gemini (in January, about new heat pump technology) and in trade publications such as VVSforum, Nordic labour journal and Arbeidsliv i norden. In addition, Centre Director Petter Røkke was the guests of podcasts Stormkast and Handlevogna, discussing various energy efficiency measures.

Also in the media was HighEFF's Scientific Coordinator Petter Nekså, who received the prestigious 2023 "Årets døråpner" award from the Trondheim municipality. Petter Nekså was central in bringing the Gustav Lorentzen Conference on natural refrigerants back to Trondheim in 2022.

HighEFF events

HighEFF organised or participated in a series of relevant events during the course of the year. In September, a free lunch webinar was organised by NITO – The Norwegian engineer and technology union, on the topic of energy efficiency. The same month, Centre scientists hosted a visit by Hanne Moe Bjørnbet, Per Olav Hopsø and Ina Pedersen, from the Trøndelag Labour party.

The communications team also supported the organisation of the Annual Consortium Meeting in May, being involved to an even greater extent than previously. Communications staff both moderated discussions during the Conference, which was open to the public, and documented both the Consortium Meeting and the Conference with pictures and articles on both days. October's Cross-sector Workshop was supported in much the same way. These events have previously been described by consortium participants as a productive occasion for exchanges and cross-pollination, and the format of the events was adjusted this year to strengthen these benefits even more.

Website, blogs & newsletters

The website www.higheff.no is continuously updated with activities and results, and serves as the Centre's communications hub. It is intended as a first stop for anyone interested in finding out more about HighEFF's activities.

HighEFF participants are encouraged to create blog articles about their tasks throughout the year. Many blog articles summarise project results or scientific publications but are targeted at different groups such as private industry or policymakers. Other blogs

Photo: Mari Greta Bårdsen, SINTEF

Centre Director Petter Røkke shows the lab installations to Labour politician Per Olav Hopsø. Also on the photo: HighEFF Scientific Coordinator Petter Nekså.

are aimed at fellow research scientists working in energy-efficiency and related fields. Some are targeted at the public.

During 2023, a total of 10 blog articles were published across a variety of HighEFF topics, six in English and four in Norwegian. Seven newsletters were sent to the HighEFF newsletter list.

Social media

Following the success of LinkedIn for other major scientific research centres, the communications team established a HighEFF page on the platform in 2021. The page continued to grow in 2023, reaching a total of 494 followers on 31 December 2022 (compared to 252 on the same date the previous year).

Following the rebranding of Twitter to X, the decision by the company to deprioritise core tasks such as content moderation, the exodus of millions of its users and the departure from the platform of key advertisers, a judgement has been made by the communications team that it had lost its usefulness for the purposes of communicating Centre results and activities. The Centre's account has therefore stopped being updated.

The Annual Consortium Meeting is an occasion to publish updates on the Centre's LinkedIn page.

Appendix

Statement of accounts

Costs (in 1000 NOK)	
Host institution	22 651
Research partners	18 969
User partners	5 152
Total	**46 772**

Funding (in 1000 NOK)	
Research Council of Norway	25 689
Host institution	3 700
Research partners	3 755
User partners	13 627
Total	**46 772**

Personnel

Key researchers

Name	Institution	Main research area
Adriana Reyes Lua	SINTEF Energy Research	Industry clusters
Afaf Saai	SINTEF Industry	FEM modelling, WP2.2
Ángel Pardiñas	SINTEF Energy Research	Expander test laboratory, Case studies F&C, Refrigeration
Anton Beck	AIT	Steam thermal storage, white paper on industrial TES
Armin Hafner	NTNU	High temperature heat pumps, cold thermal storage, NEIC TES-AC
Arne Petter Ratvik	SINTEF Industry	Novel emerging concepts
Asbjørn Solheim	SINTEF Industry	HH improvement, Case study Al
Asle Gauteplass	NTNU SR	Society - NEC shared resources and alternative business models
Aud Nina Wærnes	SINTEF Industry	Process improvements
August Brækken	SINTEF Energy Research	High-T heat pump, Case studies F&C, Dirty water heat exchangers at MIP
Avinash Subramanian	NTNU	Polygeneration systems for chemical and Energies
Balram Panjwani	SINTEF Industry	Process improvements
Bin Hu	SJT Univ.	Steam high temperature heat pump
Brage Knudsen	SINTEF Energy Research	Thermal energy storage potential for the industry, modelling and optimiziation of energy exchange in clusters. Industrial cluster case studies and measurement of HighEFF overall goals. RA6 lead
Brede Hagen	NTNU	Surplus heat-to-power conversion
Catharina Lindheim	NTNU SR	Society - NEC shared resources and alternative business models
Cecilia Gabrielii	SINTEF Energy Research	Low temperature cooling, steam production aluminum industry
Christian Schlemminger	SINTEF Energy Research	High temperature heat pumps and thermal energy storage for industrial processes, Compressors and expansion work recovery, NEIC PrintUP

Name	Institution	Main research area
Cristina Zotica	SINTEF Energy Research	Optimal Operation and Control of flexible Heat-to-Power Cycles
David Perez Pineiro	NTNU	Optimal operation and control of energy storage systems
Egil Skybakmoen	SINTEF Industry	RA1 Methodologies leader. HH improvements, Case study Al, Surplus Heat recovery Al
Ehsan Allymehr	NTNU	Heat transfer and pressure drop in small diameter pipes for natural working fluids and mixtures
Einar Rasmussen	Nord Univ.	Supervisor Irina Isaeva
Eivind J Øvrelid	SINTEF Industry	NEIC PrintUP
Elisa Magnanelli	SINTEF Energy Research	Surplus heat recovery
Erik S Svendsen	SINTEF Ocean	NEIC TES-AC modelling
Even Evensen	SINTEF Energy Research	Sommerstudent
Francesco Finotti	SINTEF Energy Research	Oil and gas case studies
Frida Sæther	SINTEF Energy Research	WP6.3, Energy efficiency in food and chemical sector.
Gabriella Tranell	NTNU	Recycling of furnace gas, supervisor for Vegar Andersen
Geir Skaugen	SINTEF Energy Research	Heat exchangers
Gerwin Drexler-Schmid	AIT	High-temperature thermal energy storage, High Temperature heat pumps
Gonzalo del Alamo	SINTEF Energy Research	NEIC HIGHEFFEC
Goran Durakovic	SINTEF Energy Research	Surplus heat-to-power conversion, RA6 case studies; industry clusters
Gudveig Gjøsund	NTNU SR	Organizational analysis
Hagar Elarga	SINTEF Energy Research	System modelling, NEIC ITChES
Halvor Dalaker	SINTEF Industry	Process improvements
Han Deng	SINTEF Energy Research	Heat exchangers, natural working fluids
Hanne Kauko	SINTEF Energy Research	Thermal energy storage, potential in industry clusters, High-temperature TES for industrial processes, Industrial Clusters
Helle B Eidissen	SINTEF Energy Research	Heat exchangers
Henri Cloete	SINTEF Industry	NEIC ITChES, reactor tests
Hiroshi Yamaguchi	Doshisha Univ.	Refrigeration technology
Håkon Selvnes	SINTEF Energy Research	Cold thermal storage for industrial applications, NEIC TEA-AC
Ida Teresia Kero	SINTEF Industry	Metallurgy, materials science, process improvements
Ingrid C Claussen	SINTEF Energy Research	Dissemination, society
Irina N. Isaeva	Nord Univ.	Industry/University collaboration for environmental innovations
Ivar S. Ertesvåg	NTNU	Exergy Analysis of Offshore Oil & Gas Processing Systems
Jan Bengsch	SINTEF Ocean	NEIC TES-AS Modelling
Jens O D Røyrvik	NTNU SR	Societal, social and organizational conditions for energy efficiency
Jens P Johansen	NTNU SR	Industrial clusters, barriers /enablers for energy efficiency and exchange
Johan Fahlstrøm	SINTEF Industry	
Johan Raftevold	SINTEF Energy Research	Heat exchangers, CFD maodelling
Johannes Jäschke	NTNU	Optimization of Energy Efficiency in Industrial Systems under Uncertainty
Jonas Bueie	SINTEF Energy Research	Heat exchangers
Jorge S Beceiro	SINTEF Energy Research	NEIC, material conformation, characterization and analysis
Jorunn Skjermo	SINTEF Ocean	NEIC Biochar
Joshua Dowdell	SINTEF Energy Research	NEIC PrintUP

Name	Institution	Main research area
Judith Sanquist	SINTEF Energy Research	NEIC Biochar
Julia Jimenez Romero	Univ. of Manchester	Reduction of Industrial Energy Demand through Sustainable Integration of distributed Energy Hubs
Julian Straus	SINTEF Energy Research	RA6 case studies; industry clusters
Kai Zhang	SINTEF Industry	
Khalid Hamid	NTNU	High temperature Hybrid heat pump
Knut Emil Ringstad	NTNU	CFD for improving components of R744 vapor compression units
Kristian L Aas	SINTEF Industry	Thermo electric generation
Kristina N Widell	SINTEF Ocean	Reducing GHG emissions of food cold chain in Norway; HTHP, Cooling and Drying and Case studies food
Krzyzstof Banasiak	SINTEF Energy Research	NEIC PrintUP
Kurian Vachaparambil	SINTEF Industry	Process Improvements
Lars O. Nord	NTNU	Supervisor
Leif Andersson	SINTEF Energy Research	Steam thermal storage for Elkem Thamshavn
Line Rydså	SINTEF Energy Research	Industrial clusters, synergies between food and metal industries, Society, Communication
Mads Dahl Gjefsen	NTNU SR	Energy efficiency and societal challenges
Magnus Rotan	SINTEF Energy Research	NEIC ITChES; Material conformation and characterization, NEIC SOCTES
Magnus Windfeldt	SINTEF Energy Research	Heat-to-power conversion, NEIC Biochar, surplus heat utilisation
Marcel Ahrens	NTNU	High temperature Hybrid heat pump
Marcin Pilarczyk	NTNU	Compact bottoming cycles for offshore power production
Marco Bless	SINTEF Energy Research	Varmepumper
Margaux Gouis	SINTEF Energy Research	Case study surplus heat utilisation, Visualization of TES technologies
Marianne Steinmo	Nord Univ.	Industry/research collaboration in FME centres
Marit Sandrød	SINTEF Industry	
Matias Vikse	SINTEF Industry	KPIs, energy & exergy analyses
Merete Tangstad	NTNU	Energy Distribution in Mn-alloy Furnaces
Mette Bugge	SINTEF Energy Research	CFD modelling, primary measures to reduce emissions
Michael Lauermann	AIT	High Temperature Heat Pump
Michael Schöny	AIT	NEC CETES
Mina Shahrooz	KTH	Low temperature waste-heat-to-power conversion
Mona Hassel	SINTEF Industry	
Morten D Selfors	Nord Univ.	Society
Muhammed Z Saeed	NTNU	Energy Efficient Air Conditioning Systems
Nidret Ibric	NTNU	Postdoc; Work and Heat Integration
Nina Dahl	SINTEF Industry	Board member
Odne Burheim	NTNU	NEIC HIGHEFFEC
Olaf Trygve Berglihn	SINTEF Industry	KPIs, energy & exergy analyses, process improvements
Olav Galteland	SINTEF Energy Research	NEIC HIGHEFFEC, NEIC SOCTES, Optimal operation of steam system
Ole H Meyer	SINTEF Energy Research	RA2 Components
Ole Jacob Broch	SINTEF Ocean	Case study surplus heat utilisation
Ole Marius Moen	SINTEF Energy Research	High temperature heat pump

Name	Institution	Main research area
Paul I Barton	MIT	Supervisor Suzane Cavalcanti
Peder Seglsten	SINTEF Industry	
Per Lundqvist	KTH	Supervisor Mina Shahrooz
Petter Nekså	SINTEF Energy Research/ NTNU	Energy efficiency in industry, management
Petter Røkke	SINTEF Energy Research	Management
Ragnhild Sæterli	SINTEF Energy Research	Management
Rahul Anantharaman	SINTEF Energy Research	Oil and gas case studies
Rediet Eidshaug	SINTEF Industry	
Roberto Agromayor	NTNU	Turbomachinery for waste heat recovery applications
Robin Smith	Univ. of Manchester	Reduction of Industrial Energy Demand through Sustainable Integration of distributed Energy Hubs
Samuel Senanu	SINTEF Industry	HH improvement, Gas recycling Al cells., NEIC Biochar
Sander Holum	NTNU	Summer researcher oil and gas case studies
Schalk Cloete	SINTEF Industry	NEIC IThES; techno-economical analysis
Signe Kjelstrup	NTNU	Establish KPIs with Focus on Energy Efficiency in HighEFF
Sigurd Skogestad	NTNU	Process systems engineering
Siyue Ren	NTNU	Liquid Air Energy Storage for Power
Stefan Andersson	SINTEF Industry	Process improvements
Stefanie Blust	NTNU	Detector cooling with R744 refrigeration technology
Stein Rørvik	SINTEF Industry	NEIC Biochar
Stian Trædal	SINTEF Energy Research	Heat exchanger laboratory HighEFFlab
Suzane Cavalcanti	MIT	Nonsmooth approaches for process flowsheet simulation and optimization
Sverre Foslie	SINTEF Energy Research	High-T heat pumps and thermal storage for industrial processes
Sylvain Gouttobroze	SINTEF Industry	NEC
Ting He	NTNU	Liquefaction of Natural Gas with Ethane Extraction
Tom S. Nordtvedt	SINTEF Ocean	HTHP, Cooling and Drying and Case studies food
Tomas Lauvås	Nord Univ.	Industry/university collaboration in FME centres
Trond Andresen	SINTEF Energy Research	Surplus heat-to-power conversion
Truls Flatberg	SINTEF Industry	NEC INTERCUR
Truls Gundersen	NTNU	Pinch and Exergy analyses, low temperature processes
Trygve Eikevik	NTNU	Natural refrigerants
Trygve Schanche	SINTEF Industry	Process improvement Mn, NEIC HIGHEFFEC
Tuva Grytli	SINTEF Industry	NEC INTERCUR
Vegar Andersen	NTNU	Recycling of furnace gas
Yessica Arellano	SINTEF Energy Research	Heat integration - oil and gas applications
Zack Klockar	SINTEF	Kvalitetssikring Rapport om EU reguleringer
Zawadi Mdoe	NTNU	Optimal control for industrial processes under uncertainty
Zhongxuan Liu	NTNU	Modeling and optimization of networks of distributed energy hubs
Åsmund Ervik	SINTEF Energy Research	RA2 components, work recovery and compression

Postdoctoral researchers with financial support from the Centre budget

Name	Nationality	Period	Gender	Topic
Elisa Magnanelli	Italy	04 2017 - 04 2019	F	Establish KPIs with Focus on Energy Efficiency in HighEFF
Haoshui Yu	China	03 2017 - 06 2019	M	Thermodynamic Approach to Work and Heat Exchange Networks
Håkon Fyhn*	Norway	11 2017 - 10 2021	M	Future success factors of industrial clusters
Àngel Àlvarez Pardinas	Spain	05 2018 - 05 2020	M	Expander Test Laboratory
Marcin Pilarczyk	Poland	07 2018 - 07 2022	M	Compact and efficient bottoming Cycles for offshore Power Production
Nidret Ibric	Bosnia-Herzegovina	09 2022 - 08 2026	M	Heat Integrated Water Networks

** Technically a research scientist position*

PhD students with financial support from the Centre budget

Name	Nationality	Period	Gender	Topic	Completed
Brede A. L. Hagen	Norway	08 2018 - 01 2022	M	Power production from medium temperature heat sources	Yes
Cristina Zotica	Romania	08 2017 - 06 2021	F	Optimal Operation and Control of flexible Heat-to-Power Cycles	No
David Pérez Piñeiro	Spain	08 -2019 - 08 2022	F	Optimal operation and control of energy storage systems	No
Ehsan Allymehr	Iran	07 2018 - 07 2022	M	Heat transfer and pressure drop in small diameter pipes for natural working fluids and mixtures - Measurement and modelling	Yes
Håkon Selvnes	Norway	08 2017 - 06 2021	M	Cold Thermal Energy Storage for Industrial Applications	Yes
Irina Nikolayevna Isaeva	Norway	01 2018 - 12 2021	F	Industry/University collaboration for environmental innovations	Yes
Jens Petter Johansen	Norway	09 2017 - 06 2021	M	Barriers and enablers for energy- efficiency and exchange	Yes
Juan Cristancho	Colombia	06 2017 - 02 2018	M	Compact and efficient bottoming Cycles for offshore Power Production	Terminated
Juejing Sheng	China	09 2017 - 02 2021	F	Exergy Analysis of Offshore Oil & Gas Processing Systems	Terminated
Julia Jimenez Romero	Ecuador	10 2017 - 03 2021	F	Reduction of Industrial Energy Demand through Sustainable Integration of distributed Energy Hubs	Yes
Khalid Hamil	Pakistan	08 2021 - 08 2024	M	Compression absorption high temperature heat pump	No
Knut Emil Ringstad	Norway	08 2018 - 10 2021	M	CFD based calculation tools for improving components of R744 vapor compression units	No
Mandar Thombre	India	08 2017 - 12 2020	M	Optimization of Energy Efficiency in large-scale Industrial Systems under Uncertainty	Yes
Matias Vikse	Norway	09 2016 - 12 2019	M	Development of Optimization Models for Work and Heat Exchange Networks	Yes
Mina Shahrooz	Iran	05 2017 - 04 2020	F	Low Temperature Power Cycles for Waste Heat utilization with Mixtures of natural Fluids	No

Name	Nationality	Period	Gender	Topic	Completed
Saif Rahaman Kazi	India	01 2017 - 12 2020	M	Optimization of Multi-Stream Heat Exchangers with Phase Change	Yes
Suzane Cavalcanti	Brazil	06 2017 - 05 2021	F	Nonsmooth Approaches for Process Flowsheet Simulation and Optimization	No
Trine Asklund Larssen	Norway	08 2017 - 07 2020	F	Energy Distribution in Mn-alloy Furnaces	Yes
Vegar Andersen	Norway	01 2020 – 12 2022	M	Recirculating of furnace off-gas	No
Zhongxuan Liu	China	09 2018 - 10 2022	F	Modelling and Optimization for Design and operation of a Network of Distributed Energy Hubs	Yes

PhD students working on projects in the Centre with financial support from other sources (associated PhDs)

Name	Funding	Nationality	Period	Gender	Topic	Completed
Adriana Reyes Lúa	NTNU	Mexico	09 2016 - 08 2019	F	Optimal Operation and Control of Vapor Compression Cycles	Yes
Julian Straus	Yara/NTNU 50/50	Germany	09 2016 - 03 2018	M	Minimizing Energy Consumption in an Ammonia Plant by Optimal Operation	Yes
Avinash Subramanian	NTNU	India	09 2017 - 08 2021	M	Optimal Design and Operation of Polygeneration Production Chains	Yes
Daniel Rohde	KPN INTERACT	Germany	09 2016 - 12 2018	M	Dynamic Simulation of Future Integrated Energy Systems	Yes
Roberto Agromayor	KPN COPRO	Spain	01 2017 - 07 2020	M	Turbomachinery for Waste Heat Recovery Applications	Yes
Silje Marie Smitt	NTNU	Norway	08 2017 - 08 2021	F	Design and Control of Energy Efficient, Integrated Vapor Compression Units for HVAC and Sanitary Hot Water Systems in high performance Building	Yes
Marcel Ulrich Ahrens	NTNU Energy / xx	Germany	10 2018 – 09 2022	M	Development of a combined absorption compression heat pump test facility at high temp operation	No
Stefanie Blust	NTNU	Germany	02 2019 – 01 2023	F	Large Hadron Collider (LHC) detector cooling with R744 refrigeration technology	No
Zawadi Mdoe	NTNU	Tanzania	09 2019 – 08 2023	M	Optimal Control of Energy Efficient Industrial Processes under Uncertainty	No
Ting He	SJTU / CSC	China	10 2021 - 11 2022	F	Natural gas liquefaction with high ethane content	No

Master's degrees (total over Centre period)

Name	Gender	Period	Topic
Avinash Subramanian	M	2017	Reducing Energy Consumption in the production of Hydrogen from Natural Gas
Håkon Selvnes	M	2017	Energy Distribution Concepts for Urban Supermarkets including Energy Hubs
Silje Marie Smitt	F	2017	Integrated Energy Concepts for high Performance Hotel Buildings
Roxane Giametta	F	2017	Integration of LNG Regasification and Air Separation Units
Morten Dahle Selfors	M	2017	HighEFF partners' expectations for innovation
Jakub Bodys	M	2017	Design and simulations of Refrigerated Sea Water Chillers with CO_2 ejector pumps for marine applications in hot climates
Kun Wan	M	2017	Surrogate model development for an Ammonia synthesis process
Monika Nikolaisen	F	2017	Evaluation of Rankine cycles with mixed component working fluids
Alessandro Francesco Castelli	M	2017	Optimization of ORCs for low grade heat recovery: working fluid selection, methodology and applications
Mathias Grønberg Gustum	M	2018	Modelling of gas-solid reactions: Usage of industrial off-gas for pre-reduction of manganese ores
Goran Durakovic	M	2018	Effect of design specifications for off-design operation of low temperature Rankine cycles using zeotropic mixtures and pure working fluids
Inés Encabo Cáceres	F	2018	Techno-economic and thermodynamic optimization of Rankine cycles
Jacopo Degl'Innocenti	M	2018	Compressed air energy storage for clean offshore energy supply
Marius Reed	M	2018	Nonsmooth modelling of multiphase multicomponent heat exchangers with phase changes
Oliver Sale Haugberg	M	2018	Model predictive control of an LNG liquefaction process using Jmodelica.org
Francisco Javier Taguas Garzón	M	2018	Improvement of energy efficiency in a brewery
Espen Halvorsen Verpe	M	2018	Low temperature plate freezing of fish on boats using R744 as refrigerant and cold thermal energy storage
Simon Birger Byremo Solberg	M	2019	Energy-Efficient Designs of Systems – From Nature to Chemical Engineering
Håkon Helland	M	2019	Modeling and Optimization of an Organic Rankine Cycle
Eskild Aas	M	2019	Optimization of Heat Exchanger Networks using Aspen Energy Analyser and SeqHENS
Martin Grimstad	M	2019	Using surplus heat to pre-heat carbon anodes for aluminium electrolysis
Simon Lingaas	M	2019	Energy recovery from batchwise metal casting
Ida Andersskog	F	2019	Plantwide control of thermal power plants
Zawadi Mdoe	M	2019	Optimal control of thermal energy storage under supply and demand uncertainty
Eirik Starheim Svendsen	M	2019	Energy flow analysis of a poultry process plant
Hamza Bajja	M	2019	Experimental Analysis of R744 Multi-ejector Modules
Hendrik Poetting	M	2020	Optimization of Energy Systems for Polygeneration Plants
Changhun Jeong	M	2020	Dynamic use of Energy Storage
Andreas S. Bunæs	M	2020	Synthesis of Heat Exchanger Networks using SeqHENS
Sandeep Prakash	M	2020	Optimal operation of Thermal Energy Storage
Johannes Doll	M	2020	Evaluation of Ejector supported Supermarket Refrigeration Systems
Patrick Koschel	M	2020	Experimental Investigation of "Waterloop" Refrigeration Systems for Supermarkets
Marie Roux	F	2020	Experimental Study of evaporating Hydrocarbon Flow Characteristics in different small sized Test Tubes

Name	Gender	Period	Topic
Luca Contiero	M	2020	Experimental Analysis of advanced R744 Refrigeration System
Merethe Selnes	F	2020	Experimental Analysis of an advanced R744 Multi-Ejector
Hesam Pourfallah	M	2020	Dynamic models for combined mass- and energy exchange
Kjetil-Andre Sponland	M	2020	Heat balances and -usage in anode baking furnaces
Even Kristian Tønsberg	M	2020	Modeling Approach for a Liquid-injected NH3-H2O Screw Compressor
Petter Engblom Nordby	M	2021	The Flexible Design Problem for Renewable Energy Systems
Håkon Dalbakken	M	2021	Safety Aspects of Organic Rankine Cycles (ORC) with Combistible Working Fluids
Jason Foulkes	M	2021	Future Low Emission Oil and Gas Platforms
Erik Andre Klepp Vik	M	2021	Advanced Control Structures for balancing Supply and Demand in Steam Distribution Networks
Alireza Mirzaei	M	2021	Dynamic Energy Storage
Seyedeh F Hosseini	F	2021	High Temperature Cascade Heat Pump for Industrial Applications
Martin Nilsen	M	2021	Industrial Drying of Raw Materials and By-products in Aluminum Production
Mari Elise Rugland	F	2021	Development of an Object-Oriented Framework for the Optimization of Flexible Renewable Energy Systems
Agnes Camilla Tysland	F	2021	Optimal Operation and Design of a Thermal Energy Storage Tank
Christine Grodås Jørs	F	2021	Cold Thermal Energy Storage for Supermarket Application
Luca Contiero	M	2021	Experimental Analysis of Advanced R744 Refrigeration System
Saleh Sakka Amini	M	2021	Experimental Investigation of a Cold Thermal Energy Storage System for Industrial Application
Kristian Strøm Fiskum	M	2021	How Norsk Hydro approached Circular Economic Production of Aluminum
Ole Albrekt Egeland	M	2021	How Norsk Hydro approached Circular Economic Production of Aluminum
Madita Kruse	F	2022	Investigation of a high temperature cascade heat pump as an energy-efficient solution for generating process heat

Publications 2023

Peer reviewed journal publications

Search criteria: *From:* 2023 *To:* 2023 *Sub-category:* Academic article *Sub-category:* Academic literature review *Sub-category:* Academic chapter/article/Conference paper *All publishing channels*

1. **Beceiro, Jorge Salgado; Sæterli, Ragnhild; Rotan, Magnus; Cloete, Jan Hendrik; Gouis, Margaux; Sevault, Alexis Gerard Edouard.** Thermochemical Energy Storage: an approach to integration pathways. I: *2023 8th International Conference on Smart and Sustainable Technologies - SpliTech*. IEEE (Institute of Electrical and Electronics Engineers) 2023 ISBN 978-953-290-128-3. SINTEF ENERGISINT
2. **Bengsch, Jan; Svendsen, Eirik Starheim; Galteland, Olav; Widell, Kristina Marianne Norne; Selvnes, Håkon; Sevault, Alexis Gerard Edouard.** Dimensioning and techno-economic-assessment of thermal energy storages in the food processing industry using energy load profiles. I: *10th Conference on Ammonia and CO_2 Refrigeration Technologies*. International Institute of Refrigeration 2023 ISBN 978-2-36215-054-8. p. 238-247. ENERGISINT OCEAN
3. **Bucelli, Marta; Johnsen, Birk Tørudstad; Hjorth, Ida.** Handling of ammonia accidental fuel leakages on ships. I: *SNAME 8th International Symposium on Ship Operations, Management and Economics, Athens, Greece, March 2023*. Society of Naval Architects and Marine Engineers 2023 ISBN 0-000-00001-9. ENERGISINT
4. **Foslie, Sverre Stefanussen; Knudsen, Brage Rugstad; Korpås, Magnus.** Integrated design and operational optimization of energy systems in dairies. *Energy* 2023 ;Volume 281. p. -. NTNU ENERGISINT
5. **Foslie, Sverre Stefanussen; Straus, Julian; Knudsen, Brage Rugstad; Korpås, Magnus.** Decarbonizing integrated chlor-alkali and vinyl chloride monomer production: Reducing the cost with industrial flexibility. *Advances in Applied Energy* 2023 ;Volume 12. ENERGISINT NTNU

6. **Gjefsen, Mads Dahl; Johansen, Jens Petter Kirkhus.** Transforming Sufficiently? Data Centers and the Paradoxes of Digital Infrastructure. *Beta* 2023 ;Volume 37.(1). SAMFORSK
7. **Hafner, Armin.** Smart CO_2 refrigeration and heat pumping systems. I: *10th Conference on Ammonia and CO_2 Refrigeration Technologies*. International Institute of Refrigeration 2023 ISBN 978-2-36215-054-8. p. 10-18. NTNU
8. **Liu, Zhongxuan; He, Ting; Kim, Donghoi; Gundersen, Truls.** Optimal utilization of compression heat in liquid air energy storage. *Industrial & Engineering Chemistry Research* 2023 ;Volume 62. p. 5097-5108. NTNU ENERGISINT
9. **Martins Nakama, Caroline Satye; Knudsen, Brage Rugstad; Tysland, Agnes Camilla; Jäschke, Johannes.** A simple dynamic optimization-based approach for sizing thermal energy storage using process data. *Energy* 2023 ;Volume 268. NTNU ENERGISINT
10. **Pardiñas, Ángel Á.; Kauko, Hanne Laura Pauliina; Hazarika, Mihir Mouchum; Selvnes, Håkon; Banasiak, Krzysztof; Hafner, Armin.** Two-stage evaporator for R744 heat pumps using greywater as heat source. *Energy and Buildings* 2023 ;Volume 289. ENERGISINT NTNU
11. **Saeed, Muhammad Zahid; Contiero, Luca; Blust, Stefanie; Allouche, Yosr; Hafner, Armin; Eikevik, Trygve Magne.** Ultra-Low-Temperature Refrigeration Systems: A Review and Performance Comparison of Refrigerants and Configurations. *Energies* 2023 ;Volume 16.(21) p. - NTNU
12. **Selvnes, Håkon; Alvarez Pardinas, Angel; Hafner, Armin.** Cold thermal energy storage for air conditioning in a supermarket CO_2 booster refrigeration system. I: *10th Conference on Ammonia and CO_2 Refrigeration Technologies*. International Institute of Refrigeration 2023 ISBN 978-2-36215-054-8. p. 183-190-. NTNU ENERGISINT

Presentations

Search criteria: *From:* 2023 *To:* 2023 *Main category:* Conference lecture and academic presentation *All publishing channels*

1. **Andresen, Trond; Bueie, Jonas.** Geothermal power production in Norway?. HighEFF Webinar; 2023-06-21. ENERGISINT
2. **Andresen, Trond; Bueie, Jonas.** Geothermal power production in Norway?. HighEFF Annual consortium meeting; 2023-05-04. ENERGISINT
3. **Andresen, Trond; Windfeldt, Magnus Kyrre; Johansen, Jens Petter Kirkhus.** Symbiose overskuddsvarme i HighEFF. Overskuddsvarmeworkshop Mosjøen; 2023-01-10 - 2023-01-11. ENERGISINT SAMFORSK
4. **Bakkene Aasen, Vegard; Beceiro, Jorge Salgado.** Experimental development of Thermal Energy Storage materials and systems: Utilization of Mn-rich sludge. HighEFF Cross-Sector Workshop; 2023-10-18 - 2023-10-18 ENERGISINT NTNU
5. **Beceiro, Jorge Salgado.** ITChES: Integration of Thermo-chemical Energy Storage. HighEFF Annual Consortium Meeting; 2023-04-04 - 2023-10-04. ENERGISINT
6. **Beceiro, Jorge Salgado; Sæterli, Ragnhild; Rotan, Magnus; Cloete, Jan Hendrik; Gouis, Margaux; Sevault, Alexis Gerard Edouard.** Thermochemical Energy Storage: an approach to integration pathways. 2023 8th International Conference on Smart and Sustainable Technologies (Spli-Tech); 2023-06-20 - 2023-08-24. NTNU ENERGISINT SINTEF
7. **Bueie, Jonas; Windfeldt, Magnus Kyrre; Andresen, Trond.** Potential for surplus-heat-to-power conversion in current and future aluminium production process with off-gas recycling. HighEFF Webinar; 2023-09-20. ENERGISINT NTNU
8. **Bueie, Jonas; Windfeldt, Magnus Kyrre; Andresen, Trond.** Potential for surplus-heat-to-power conversion in current and future aluminium production process with off-gas recycling. HighEFF Cross-sector Workshop 2023; 2023-10-18. ENERGISINT NTNU
9. **Bueie, Jonas; Windfeldt, Magnus Kyrre; Andresen, Trond.** Potential for surplus-heat-to-power conversion in current and future aluminium production process with off-gas recycling. ORC2023 - 7th international seminar on Organic Rankine Cycles Power Systems; 2023-09-04 - 2023-09-06 ENERGISINT NTNU
10. **Espelund, Johan Raftevold; Skaugen, Geir.** 25 or 70 tonnes heat exchanger - effects of model selection. HighEFF cross sector work shop; 2023-10-18 - 2023-11-18 NTNU ENERGISINT
11. **Foslie, Sverre Stefanussen.** Flexibility potential of energy intensive industries in Grenland. HighEFF - Cross sector workshop; 2023-10-18 - 2023-10-18. ENERGISINT
12. **Kauko, Hanne Laura Pauliina.** Industri som fleksibilitets-tilbyder. Energieffektivisering: Slik vil industrien frigjøre 20 TWh konfliktfri energi; 2023-05-03 - 2023-05-03. ENERGISINT
13. **Kauko, Hanne Laura Pauliina.** 7 years of TES research in FME HighEFF: From internal reports to a White Paper. Thermal Energy Storage Workshop 2023; 2023-11-30 - 2023-12-01. NTNU ENERGISINT
14. **Kauko, Hanne Laura Pauliina; Sannan, Sigurd.** Om bærekraft i datasentre og bruk av overskuddsvarme. Workshop restvarme Heggvin; 2023-09-06 - 2023-09-06 ENERGISINT NTNU
15. **Røkke, Petter Egil; Andresen, Trond; Kero, Ida.** HighEFF resultater for Eramet. Eramet prosessworkshop; 2023-09-13. ENERGISINT NTNU
16. **Schlemminger, Christian; Jenssen, Sigmund.** From -5°C to 118°C with a new developed R290 / R600 HTHP cascade. Enough/PCM-STORE / HighEFF workshop; 2023-05-23 - 2023-05-24. ENERGISINT
17. **Schlemminger, Christian; Jenssen, Sigmund; Dallai, Mauro.** SkaleUP - Industrial HTHP for simultaneous cooling and heating. HighEFF Webinar; 2023-02-15 - 2023-02-15. ENERGISINT
18. **Schlemminger, Christian; Moen, Ole Marius.** Electrification by high temperature heat pumps?. Meeting of The Belgian food and drink industry - Fevia; 2023-03-09 - 2023-03-09. ENERGISINT
19. **Schlemminger, Christian; Moen, Ole Marius.** Forskning og utvikling på høytemperatur varmepumper med naturlige kuldemedier. Spillvarmens rolle i et energisystem – Industrivarmepumper; 2023-10-24 - 2023-10-24. ENERGISINT
20. **Selvnes, Håkon.** NEIC TES-AC: Piloting cold thermal energy storage for flexibility in supermarket refrigeration systems. HighEFF Cross sector workshop 2023; 2023-10-18 - 2023-10-18. ENERGISINT

21. **Selvnes, Håkon; Bengsch, Jan; Svendsen, Eirik Starheim; Widell, Kristina Marianne Norne.** Energy efficiency in the dairy industry: Rørosmeieriet. HighEFF Webinar Series; 2023-09-06 - 2023-09-06. ENERGISINT OCEAN
22. **Selvnes, Håkon; Røkke, Petter Egil; Magnanelli, Elisa.** FME HighEff: Energieffektivisering i industrien og overskuddsvarme som ressurs. Spillvarmens rolle i et energisystem – Industrivarmepumper; 2023-10-24 - 2023-10-24. ENERGISINT
23. **Vinnes, Magnus Kyrkjebø; Stang, Hans Georg Jacob; Trædal, Stian; Skaugen, Geir.** Status heat transfer measurements for plate heat exchanger. HighEFF Cross-sectional workshop; 2023-10-18 - 2023-10-18 ENERGISINT
24. **Svendsen, Eirik Starheim.** Dimensioning and techno-economic-assessment of thermal energy storages in the food processing industry using energy load profiles. 10th IIR Conference on Ammonia and CO_2 Refrigeration Technologies; 2023-04-27 - 2023-04-29. OCEAN
25. **Vachaparambil, Kurian J.; Panjwani, Balram.** On developing a post processing approach to investigate PAH evolution for industrial applications. 11th European Combustion Meeting (ECM 2023); 2023-04-26 - 2023-04-28. SINTEF NTNU
26. **Windfeldt, Magnus Kyrre.** Energy demand of seaweed processing. HighEFF Webinar Series: Biochar from Seaweed for Metal Production; 2023-01-19 - 2023-01-19 ENERGISINT

Books/theses and reports

Search criteria: *From:* 2023 *To:* 2023 *Main category:* Report/thesis *Sub-category:* Encyclopaedia *Sub-category:* Reference material *Sub-category:* Popular scientific book *Sub-category:* Textbook *Sub-category:* Non-fiction book *All publishing channels*

1. **Belsnes, Michael Martin; Bjørndal, Mette; Elverhøi, Anders; Espegren, Kari Aamodt; Fæhn, Taran; Jaehnert, Stefan; Kjølle, Gerd Hovin; Korpås, Magnus; Marstein, Erik Stensrud; Røkke, Petter Egil; Sandberg, Nina Holck; Tande, John Olav Giæver; Thiis, Thomas Kringlebotn; Winther, Tanja; Inderberg, Tor Håkon Jackson; Tomasgard, Asgeir.** Energikrisen i Europa og det norske kraftmarkedet. Trondheim: NTNU 2023 36 p. NTNU Rapport 429810(01/2023). IFE UiO ENERGISINT SSB NHH NTNU NMBU SINTEF FNI CICERO
2. **Nordtvedt, Tom Ståle.** Evaluation of the concept Algscaleup. Trondheim: FME Higheff 2023 11 p. OCEAN
3. **Røkke, Petter Egil.** HighEFF annual report 2022. Trondheim: SINTEF Energi AS 2023 72 p. ENERGISINT

Blogs and information material

Search criteria: *From:* 2023 *To:* 2023 *Main category:* Information material(s) *All publishing channels*

1. **Magnanelli, Elisa.** HighEFF workshop – How to get from knowledge building on surplus heat recovery to practical and attractive demonstrators?. ENERGISINT
2. **Røkke, Petter Egil.** Energieffektivitet: Hvordan frigjøre 20 TWh konfliktfri energi. ENERGISINT
3. **Røkke, Petter Egil.** Energy efficiency: How to unlock 20 TWh of conflict-free energy. ENERGISINT
4. **Røkke, Petter Egil.** HighEFF at Arendalsuka. ENERGISINT
5. **Røkke, Petter Egil.** HighEFF's 2023 Cross-Sector Workshop: Shaping the future of industrial energy efficiency. ENERGISINT
6. **Røkke, Petter Egil.** Input to energy efficiency consultation. ENERGISINT

Media contributions

Search criteria: *From:* 2023 *To:* 2023 *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 *Sub-category:* Short communication All publishing channels

1. **Kauko, Hanne Laura Pauliina.** Fjernvarme, varmepumper og energieffektivisering kan bidra til å løse Norges effektutfordringer. VVSforum [Business/trade/industry journal] 2023-06-18. ENERGISINT
2. **Kauko, Hanne Laura Pauliina.** Fjernvarme, varmepumper og energieffektivisering kan bidra til å løse Norges effektutfordringer. TU [Business/trade/industry journal] 2023-05-26. NTNU
3. **Røkke, Petter Egil.** "Saving the environment" with liquid-cooled data centres. Nordic labour journal [Business/trade/industry journal] 2023-05-30. ENERGISINT
4. **Røkke, Petter Egil.** Selektiv statistikk gir uryddig matprisdebatt / ENØK i butikk / bulgarsk MFU. Virke 2023 ENERGISINT
5. **Røkke, Petter Egil.** Sparer miljøet med vannbåren kjøling av datasenter. Arbeidsliv i norden [Business/trade/industry journal] 2023-05-30. ENERGISINT
6. **Røkke, Petter Egil.** Stormkast Live - Kloakken som varmer. Storm Communications 2023. ENERGISINT
7. **Røkke, Petter Egil.** Vil hente 20 ukontroversielle terawattimer fra spillvarme. TU [Business/trade/industry journal] 2023-10-12. ENERGISINT

HighEFF – Centre for an Energy Efficient and Competitive Industry for the Future
HighEEF is a Centre for Environment-friendly Energy Research (FME). The objective of the FME-scheme is to establish time-limited research centres which conduct concentrated, focused and long-term research of high international calibre.

Contacts
Centre Director Petter E. Røkke - Petter.E.Rokke@sintef.no
Centre Coordinator Ragnhild Sæterli - ragnhild.saterli@sintef.no

Read our digital annual report
www.sintef.no/higheff_2023

Norwegian Centre for
Environment-friendly
Energy Research

alldesign.no