Annual report 2022

HighEFF

Centre for an Energy Efficient and Competitive Industry for the Future

Contents

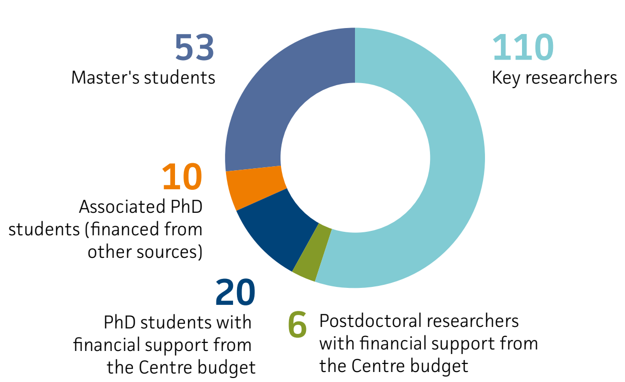
By numbers

40 PARTNERS

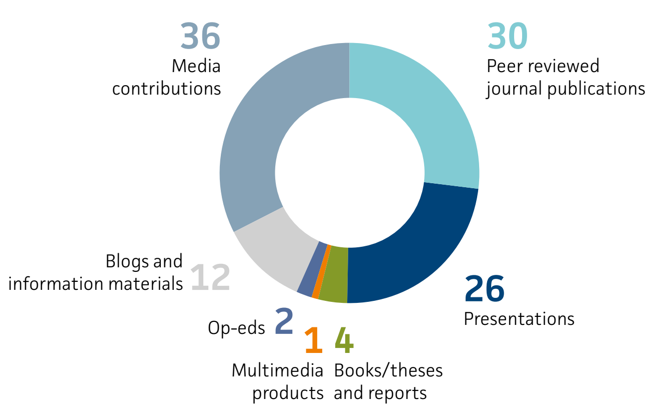
8 YEARS

400 MNOK

People



Communication and dissemination*



** Total numbers for 2022 only.*

Energy efficiency: smart, profitable, uncontroversial

The message of energy efficiency is easy to sell. Using less energy to achieve the same goal makes sense, both from an emissions perspective and from a balance sheet perspective. On top of that, unlike many other climate solutions which require increased industrialisation or land use, energy efficiency measures are largely uncontroversial.

These advantages had the EU Commission's Ditte Juul Jørgensen tout the merits of energy efficiency, when she launched the International Energy Agency's guide on energy saving in the wake of the Russian invasion of Ukraine. "Energy efficiency has the potential to be the most important policy initiative for reducing our dependence on Russian imports and responding to the current energy market challenges", she said.

Despite all this, there is still some low-hanging fruit to be picked in industrial energy efficiency. Why? Some solutions require costly investments; some involve research challenges that need to be solved, which we work on at HighEFF; some could be set in motion with small adjustments to the regulatory framework. As an example of such a change: while grid companies are obliged to offer a contract to an electricity customer that produces its own energy, there is no corresponding scheme for heat. This means that excess heat far too often goes unused.

2022: A fruitful year

Five more HighEFF PhDs defended their theses during the course of the year. They will increase the pool of available experts for the industry and research community to meet the energy efficiency challenge. Progress has continued on Centre innovations, and their technology readiness levels (TRL) has increased. You can see examples of these on pages 32-39.

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.

The way forward

As HighEFF enters its final sprint, work will redouble to ensure deliveries that fulfil the Centre's goals. At the same time, the people of HighEFF are already looking one step further, to what needs to happen next to make Norwegian industry carbon neutral.

Research Scientist Elisa Magnanelli (SINTEF) at work at HighEFFLab.

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 2022

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. This new scheme will be called Novel Emerging and Innovative 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 11 funding applications were received and evaluated, which led to three NEIC being awarded funding in 2022. Applications were evaluated by Nancy Jorunn Holt (Hydro), Arve Solheim (Enova), Jens Olgard Dalseth Røyrvik (NTNU), Petter Nekså (SINTEF), Camilla Claussen (SINTEF) and Arne Petter Ratvik (SINTEF).

SOCTES – Innovative State-of-Charge and Output Control of PCM-TES systems

The aim is 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. The project is led by SINTEF Energy Research, with NTNU as a partner.

ITChES – Integration of ThermoChemical Energy Storage

The aim is to analyse the performance potential of selected steam-absorption thermochemical energy storage compounds to recover excess heat in the range of 120-300°C in a lab-scale reactor, and to provide a techno-economic study for a large-scale implementation in industry processes. The project is led by SINTEF Energy Research, with SINTEF Industry as a partner.

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 TES technology developed at HighEFF to reduce the required installed capacities of supermarket refrigeration systems and improve energy efficiency. The project is led by SINTEF Energy Research, with NTNU-EPT and REMA 1000 as partners.

Results adopted by the industry

Excess heat recovery and use: Felleskjøpet Skansen, Trondheim

Felleskjøpet's animal feed factory in Trondheim will be the site of a pilot for excess heat use and steam production with high-temperature heat pumps. The project is supported by ENOVA, and owned by Aneo and Felleskjøpet Agri. The technology will be tested on production lines, and is expected to result in energy savings of 2.4 GWh/year.

SkaleUP – High-temperature heat pumps at Tine Tunga

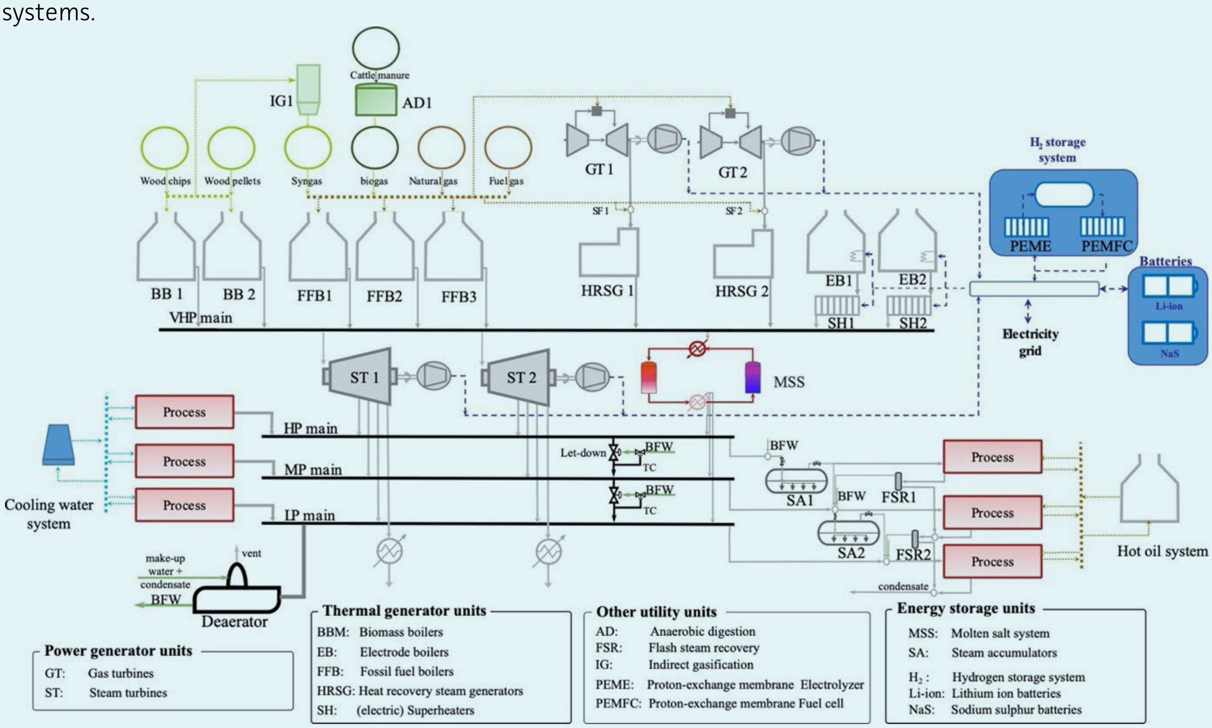
A spin-off IPN project called SkaleUP will see HighEFF partners TINE SA, Cadio AS, Officine Mario Dorin S.p.A. and SINTEF Energy join forces with heat pump manufacturer Skala Fabrikk AS. The objective is to design a flexible, industrial scale high-temperature heat pump for hot water production. A pilot has been in operation at the Tine Tunga dairy since the summer of 2021. Analyses show that it results in energy savings of upwards of 55%.

PhDs completed in 2022

Julia Jimenez-Romero, PhD, University of Manchester

Industrial energy transition: Optimization-based framework for sustainable design of utility systems

Changing the way in which industry generates and uses energy is one of the most effective but also most challenging ways to reduce greenhouse gas emissions. High-energy consumption, combined with heavy reliance on fossil fuels, has resulted in industry being one of the largest CO_2 emitters. Most process industries rely on utility systems to meet their heat and power requirements. If emissions are to be reduced and driven to zero, fundamental changes in the design and operation of such systems are required. Shifting to low-carbon source/technology is imperative, but to date, the efforts to do so are often siloed. Along with viable solutions, the energy transition requires a strategy to shift current systems to sustainable ones within legislative and financial constraints. This research project focuses on the development of an optimisation-based tool that incorporates multiple energy sources and technologies to provide cost-effective pathways and guidelines for economic and energy-efficient transition to low-carbon technologies and/or fuel switching in industrial utility systems.



Brede Hagen, PhD, NTNU
Industrial surplus heat-to-power conversion – opportunities and challenges

The energy intensive Norwegian industry generates a lot of heat that currently is wasted. One reason for this is the lack of sufficient energy demand near the industrial facilities. This heat, however, could be used by converting it to electric power, because electricity can be transported over long distances. The main challenge for the profitability of heat-to-power systems is that the thermodynamic laws constrain the power output to a small fraction of the heat input. I tried to address this issue by developing methods to design highly efficient heat-to-power conversion systems. These methods were applied to design and analyse a system converting the heat released from the casting process at a ferroalloy plant to power (see figure a). More specifically, three designs were generated and evaluated over a one-year period considering four control strategies (see figure b). The results show that the VRS and VIGV control strategies generate significantly more electricity than the traditional sliding pressure control strategy.

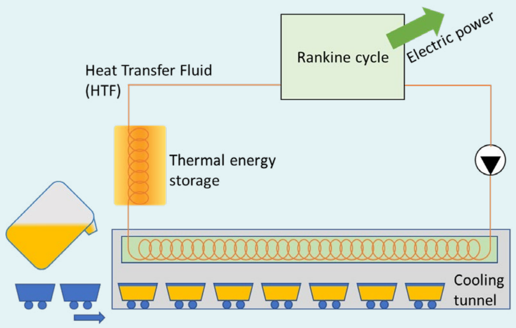


Figure a

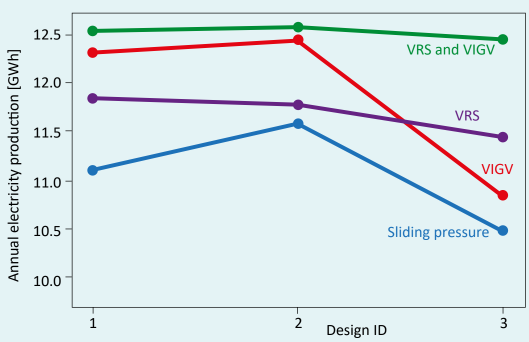
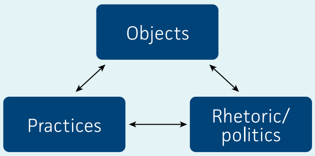


Figure b

Jens Petter Johansen, PhD, NTNU
Energy efficiency-ing. How an energy-efficient world is produced through practices, objects, rhetoric, and politics

Energy efficiency is referred to as an instrument that can contribute to solving contemporary challenges related to climate change, the energy crisis, energy security and economic growth – without negative consequences. But what does it mean for a technology, process or industry to be energy efficient, and how does it come about? And what are we really talking about when we talk about energy efficiency?

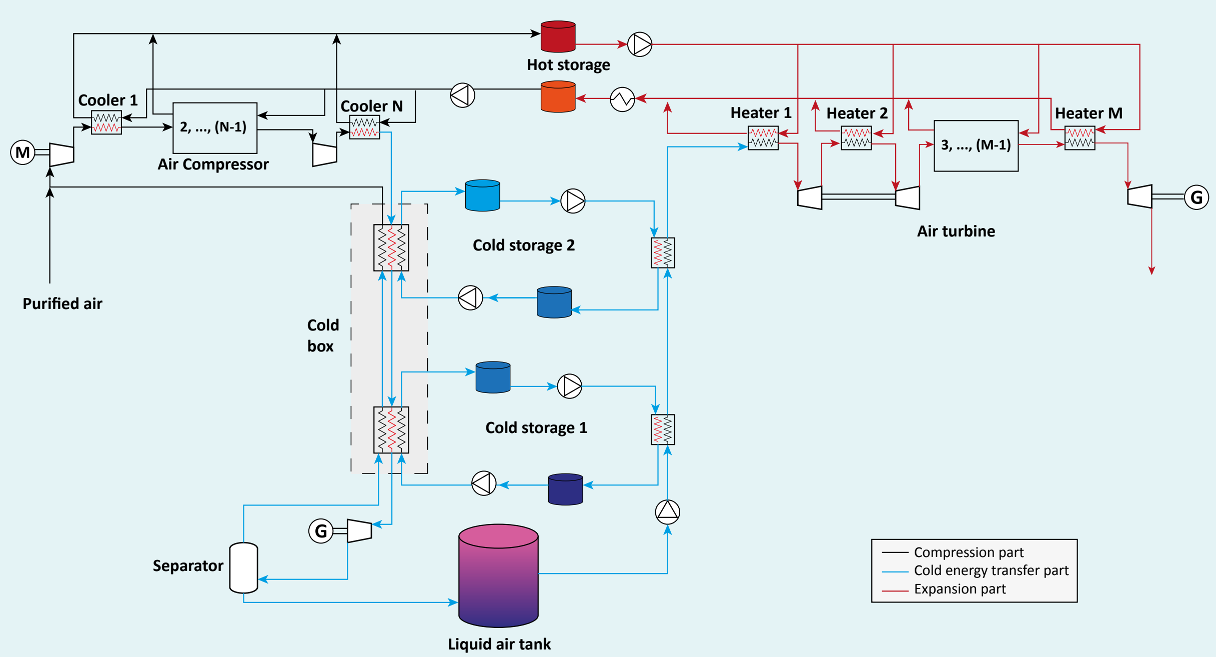
My PhD in social sciences attempts to answer these questions, through qualitative case studies of innovation projects to develop energy-efficient production technologies and attempts to utilise excess heat in industrial clusters, in addition to document and media analyses of how energy efficiency is quantified and promoted in research, incentive programs and public discourse. The project investigates the implications of moving beyond a technical understanding of energy efficiency as a measurement or technical quality, to denoting the work of a multitude of actors in developing and implementing technologies, how efficiency becomes represented in numbers and models, and how these are applied rhetorically and politically in research, as well as policy domain.



Zhongxuan Liu, PhD, NTNU

Performance Improvements of Standalone Liquid Air Energy Storage

Energy storage technologies are required to ensure stability of energy systems when the share of renewable energy forms (wind and solar) is increasing. Liquid air energy storage (LAES) is a promising technology for storing electricity with certain advantages, such as high energy density and being geographically unconstrained. However, one drawback of a standalone LAES is the relatively low round-trip efficiency (RTE). My PhD project mainly focuses on developing process models of the modified LAES for systematic optimisation in order to objectively assess measures for performance improvement. This research work includes the development of different configurations for the cold energy recovery cycles, the investigation of the effect of various combinations between the compression and expansion sections on the LAES, and the utilisation of surplus compression heat in additional thermodynamic cycles, such as Organic Rankine Cycle (ORC), Absorption Refrigeration Cycle (ARC), and High-Temperature Heat Pump (HTHP).



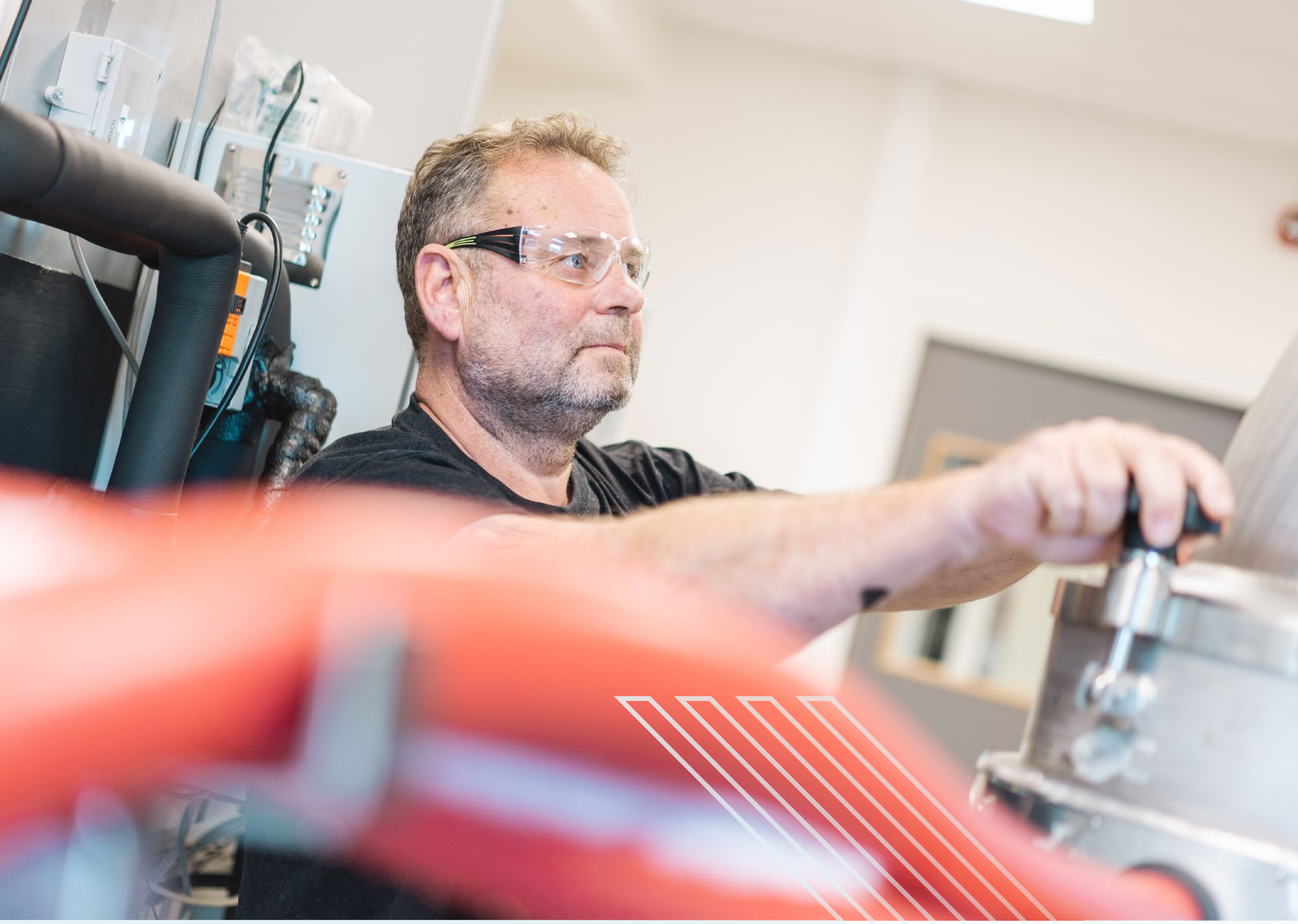
Håkon Selvnes, PhD, NTNU

Development of cold thermal energy storage for industrial applications

Industrial refrigeration systems are large users of energy, providing freezing and cooling to food products, often in batch processes at low temperatures. Cold thermal energy storage (CTES) technology applied to these systems can help shift the refrigeration load to off-peak hours and reduce the maximum electrical power demand. Large quantities of thermal energy can be stored in a phase change material (PCM), in the phase transition between liquid and solid. The focus of my research has been the development and demonstration of CTES technology with PCM suitable for industrial-scale applications. The work has consisted of developing a novel CTES unit and test facility and demonstrating the proof-of-concept. The research has demonstrated the technology at a laboratory scale and proven the flexible design of the developed CTES unit, being suitable for several different cooling systems, temperature levels, required storage capacities and power requirements.

One of the motivations for investigating the potential of CTES was the planned construction of a new poultry processing plant of Norsk Kylling in Orkanger, owned by HighEFF partner REMA 1000.

Photo: Allsidig Design



Birger Rønning, Senior Engineer, at NTNU and SINTEF's Thermal Engineering Laboratories.

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 year. The war in Ukraine and Russia's reduced gas export to Europe, the transition to a more electrified society, and the preservation of nature while developing 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 that is what HighEFF is all about.

In Norway, both the industry and the public are now more aware of energy having varying qualities, such as power and thermal. HighEFF has not only produced a significant number of scientific articles, but has also been an active player in the public debate on energy efficiency.

The Centre is now in the final harvesting phase. Technologies for increased energy efficiency, value creation and competitiveness, while decreasing greenhouse gas emissions in a broad span of industrial processes, are developed and being made ready for implementation. Highly qualified experts are required to implement these technologies, and 25 PhDs / PostDocs have been educated through HighEFF and will contribute to this.

We are just in the beginning of the energy transition, and I hope to see the good work and collaboration achieved at HighEFF continue well beyond the completion of the project.

Arne Ulrik Bindingsbø

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

2022 was a year where the awareness of energy as a valuable and limited resource was raised significantly. The war in Ukraine had consequences for Europe with a suddenly limited gas supply and increased energy prices. As we know, Norway was also affected by these price increases, and insufficient power lines between the northern and southern parts of the country gave huge differences in power prices nationally.

The topics we are studying at HighEFF are even more relevant when contemplating a future where Norway is facing a power deficit. Existing industry aims to increase its production and new energy-intensive industries will be established. Within a few years, the country will need more renewable energy supply, and the need to use this energy as efficiently as possible is clear and obvious.

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.

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

Our message repeated many times in 2021, calling for the use of the 20 TWh of available surplus heat, becomes even more important. During 2022 we collaborated with other FMEs to communicate knowledge-based facts to the public and the authorities through the "Energy crisis" workshop series hosted by the Norwegian Academy of Technological Science and FME NTRANS. Seven workshops were arranged and HighEFF contributed to three of these. We also wrote a report together with Oslo Economics for the Energy commission, where we gave estimates for future energy needs in Norwegian industry (this is now publicly available).

In addition to these strategic perspectives, the research at HighEFF has an increased focus on how we can address and achieve the overall targets of the Centre. We are entering our last two years of activity, and have started preparations for a possible continuation of the centre after August 2024. Looking forward, the focus of R&D at HighEFF will be to maximise the efforts towards ideas, concepts, technologies, solutions etc. that contribute towards the overall target achievement, and by that also maximising the impact of HighEFF. For this, we will be working closer together with user partners and following up how knowledge developed at HighEFF is being taken up by user partners and possibly taken further towards realisation.

The value of a kWh is more evident in the current situation and our original message "The best kWh is the one that you don't need to produce" is even more important now – and for the future. As a bonus, energy efficiency measures are totally conflict free!

I look forward to the remaining two years of HighEFF and even more towards a continuation of the centre!

Petter E. Røkke

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.

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.

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.

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.

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.

New models for collaboration can promote the use of surplus heat for heating purposes

Authors:


Hanne Kauko


Magnus Rotan


Ingrid Camilla Claussen


Ann Kristin Kvellheim

The ongoing energy crisis in Europe together with the increasing share of electricity production from variable renewable energy sources such as wind and solar has turned electricity into a valuable commodity. In Norway, households account for as much as 30 % of electricity consumption, and the majority of this goes to heating. Space heating is something that can be covered with other, lower-quality energy carriers than electricity, given that the buildings are adapted for district heating.

> *Using surplus heat for heating purposes will reduce the need for energy from other sources, and thus contribute to ensuring a sustainable energy supply at a more affordable price.*

Research centre HighEFF previously estimated that there is approximately 20 TWh of industrial surplus heat available in Norway, corresponding to nearly 10 % of the total final energy demand – and this figure does not include various urban surplus heat sources, such as data centres. The use of surplus heat for building heating is however more complex and riskier than the purchase of district heating or electricity, with respect to both investment and operating costs, and to security of supply. A recent study carried out at the research centre FME ZEN showed that good collaboration models can help to overcome these barriers and promote the use of surplus heat. The study looked at four different models: direct collaboration through one-on-one agreements, third-party ownership, local energy markets and the open district heating model from Sweden.

Open district heating is without a doubt an effective approach for integrating several surplus heat sources in a larger district heating network. Third party ownership, where an external company takes responsibility for the investment and operation of the heat recovery system, can still be a better approach for individual cases. Winns, NTE and Trøndelag County Municipality are among companies considering this approach. Local energy markets can be a helpful solution in areas with a lot of local production of electricity and heat. One-on-one agreements are the simplest approach when the number of actors is small but will not necessarily promote more widespread use of surplus heat as efficiently as the other models.

In addition, there are a number of regulatory and economic barriers that can prevent the use of surplus heat. The Energy Act treats heat and electricity very differently; while grid companies are obliged to offer a contract to an electricity customer that produces its own energy, there is no corresponding scheme for heating. There is no framework for pricing surplus heat, nor are there any other schemes that support the establishment of businesses with surplus heat available near potential users for the heat.

Good demonstration projects, with the ensuing positive media attention, are important to get more projects realised – which will naturally contribute to the development of collaborative models and a market that promotes the use of surplus heat. In this context, research centres such as FME ZEN and FME HighEFF have an important role to play.

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 will spearhead the development and commissioning of emerging, energy efficient and cross-sectorial technologies for the industry, and:

- 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.

Research Scientist Magnus Rotan and Research Manager Ingrid Camilla Claussen (SINTEF) at HighEFFLab's Dewatering Laboratory.

Gender equality

HighEFF maintains a list of people involved in centre activities. Our list for 2022 shows a total of 168 men and 72 women. For the Research and innovation partners taken together, the numbers are 82 men and 29 women.

The Centre's six Research areas are led by 2 women and 4 men. Of the 25 recruited PhD candidates, 9 are women and 16 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, 2022 saw the following larger meeting places and workshops open for all partners.

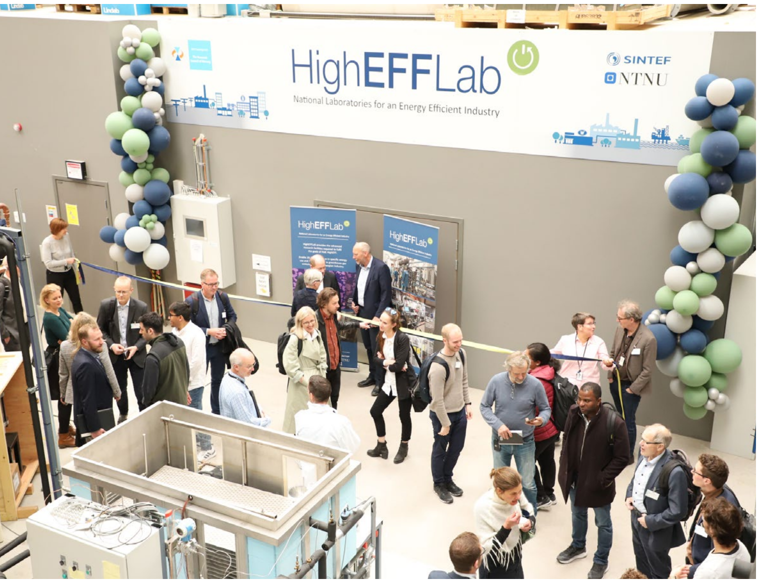
Dr. Kazuhiro Hattori speaks about what HighEFF partner Mayekawa aims to achieve through the Centre.

Annual Consortium meeting

The Annual Consortium meeting was held on 18-20 May. It started with a seminar that was open to the general public, titled: "HighEFF – Making Norwegian industry the world's greenest". It also presented highlights from the Centre and featured a PhD seminar on the last day.

Camille Fleuriault, Senior Project Manager at ERAMET, describes plans for energy recovery and carbon capture at the Sauda Ferroalloy smelter.

Elisa Magnanelli, Research scientist at SINTEF, explains the thermodynamic potential of excess heat from the Norwegian aluminium industry.



Official opening of HighEFFLab

The Annual Consortium meeting featured an important side-event: the official opening of HighEFFLab, complete with ribbon ceremony and facility visit. See pages 55-56 for a complete description of the laboratories.

The official ribbon cutting with Inge Gran, CEO of SINTEF Energy and Tor Grande, Pro-Rector for Research and Dissemination at NTNU.

Ellen Myrvold, Process Development Manager at Alcoa, speaks of the potentials and challenges linked to improving energy efficiency in the aluminium industry, at the 2022 HighEFF Cross-sector workshop.

Cross-sector workshop 2022

The Cross-sector workshop this year featured a programme that was heavily oriented towards the industry, and how it can use results to achieve Centre targets.

The 2022 HighEFF Cross-sector workshop gathered project partners from the metal industry; oil, gas and energy; food and chemicals; and industry clusters.

Excess heat "agriclusters"

In May, HighEFF Research scientist Julian Straus (SINTEF) presented the concept of "agriclusters" at an event organised by the Sauda and Suldal municipalities. The idea is to use excess heat from the area's existing and future industry in food production: greenhouses, aquaculture, insect farming and production and drying of kelp, for example. The presentation was well-attended and well-received by participants.

Webinars

HighEFF organised a total of 15 webinars during the course of 2022. 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.

- Seven ways for greener aluminium
- The role of thermal energy storage in the decarbonisation of the process industry
- Managing multiple goals in university-industry collaboration
- IPCC Sixth Assessment Report: Mitigation of Climate Change
- From factory fume to fish feed
- Using low-temperature surplus heat: the concept of an "Agricluster"
- Gradient-based optimisation of Rankine cycles
- Energy efficiency measures in fish meal processing
- The life and work of Gustav Lorentzen – A giant within the refrigeration and heat pump field
- Energy efficiency-ing – How an energy efficient world is produced through practices, objects, rhetoric, and politics
- Optimal operation and control of thermal energy systems
- New white paper release: Industrial thermal energy storage – Supporting the transition to decarbonise industry
- Future silicon production – from incremental improvements to radical changes
- KSP project LEAN: Low-energy anodes for sustainable electrowinning
- Launch event for the white paper on Thermal energy storage

Workshops

HighEFF was closely involved in a series of workshops about the energy crisis, organised by the Norwegian Academy of Technological Sciences in collaboration with FME NTRANS. Presentations by HighEFF scientists highlighted the potential of industrial energy efficiency measures to reduce overall energy needs.

Spin-off projects

HighEFF contributed to the lauch of several spin-off projects, solving specific challenges for the industry. The following Collaborative and Knowledge-building projects (KSP) were awarded funding in 2022.

BioCarb Upgrade – Sustainable biocarbon value chains for the metallurgical industries

ADVENCCS – Integrating CO_2 capture and energy recovery in the ferroalloy industry

Centre director Petter Røkke speaks at one of NTRANS' energy crisis workshops, on 13 May in Oslo.

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 NTRANS: HighEFF participated in a workshop series about the energy crisis, jointly organised by FME NTRANS and the Norwegian Academy of Technological Science.
- FME ZEN: Collaboration on the topics of energy efficiency in buildings and integration into the energy system
- FME NCCS: Collaboration in the generation and launch of spin-off projects (ADVENCCS)
- SFI Metal Production: Collaboration in the fields of energy intensive industry and metal production
- Petrocenter LowEmission: Collaboration on energy efficiency in offshore oil and gas production

Cooperation is important in order to achieve maximum impact. The different centres complement each other in many ways. In its final years, HighEFF will be cooperating with FME NTRANS on some policy briefs and position papers – in other words, a collaboration aiming at spreading our common message. This is in line with the guidelines laid out by the board of HighEFF.

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.

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: Integration of steam producing heat pumps to solar heat production.

PREMA: Energy efficient, primary production of manganese ferroalloys through the application of novel energy systems in the drying and pre-heating of furnace feed materials (completed in 2022).

TRINEFLEX: 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: Demonstrator of industrial carbon-free power generation from ORC-based waste-heat-to-energy systems.

FLXenabler: Flexible heat and cooling systems integrated with geothermal energy storage for decarbonised integrated energy systems.

High-Temperature
Heat Pump Symposium

High Temperature Heat Pump Symposium 2022, 29-30 March

The 3rd High-Temperature Heat Pump Symposium was held in Copenhagen on 29-30 March 2022. The event was partially financed by the Research Council of Norway and organized by the Danish Technological Institute, SINTEF and DTU - Mechanical Engineering. The symposium included presentations and posters from both the research community as well as industry and other stakeholders. It gathered

The Symposium gathered nearly 300 participants in Copenhagen.

a total of almost 300 participants. The Norwegian HighEFF partners' presentations included topics such as operational experience with high-temperature heat pump technology piloted on two Norwegian dairies, Tine Bergen and Tine Tunga, as well as new research on topics such as high temperature steam-generating heat pumps based on mechanical vapour recompression, and hybrid-ammonia-water heat pumps. As an example, Energy and CO_2-savings of 64% and 95% were presented by SINTEF researcher Christian Schlemminger for HighEFF spin-off project SkaleUP.

The urgency to decarbonise and electrify heat supply for the industry, as well as the necessity for increased energy efficiency through making use of excess heat means that research and development of high temperature heat pumps is more important than ever before. The event was an opportunity for all stakeholders to network and discuss the current challenges and opportunities, as summarised by the Symposium's book of presentations:

"We can observe that the huge potentials for high-temperature heat pumps are recognized by process industries as an integral part of their strategy to reduce CO_2 emissions and that more and more technology providers are developing heat pump technologies capable of temperatures well above 100°C. In turn, we can also observe challenges for both sides to work with an emerging technology. The application potential in industries is strongly dependent on their willingness to adapt to heat pump-based process heating, while such strategic decisions require a clear picture of the potential of the technology. In turn, technology providers need a clear market perspective to justify the development of high-temperature heat pump technologies. This context, especially when considering the urgency in the transition towards green process heating, makes it obvious that efficient communication between technology providers, process industries, consultants, energy-planners, policy makers, R&D institutions, and many more is key to enabling a successful exploitation of the great potential of high-temperature heat pumps."

High-temperature heat pumps are an important research focus of HighEFF's Research Area 3.

Gustav Lorentzen Conference 2022, 13-15 June

The 15th IIR Gustav Lorentzen Conference on Natural Refrigerants took place in Trondheim, organised by NTNU and SINTEF. This scientific conference hosted over 350 participants from 30 countries around the world, who attended around 170 scientific presentations. The conference is particularly relevant for the research performed at HighEFF. A total of approximately 50 presentations or publications were from people involved in the centre.

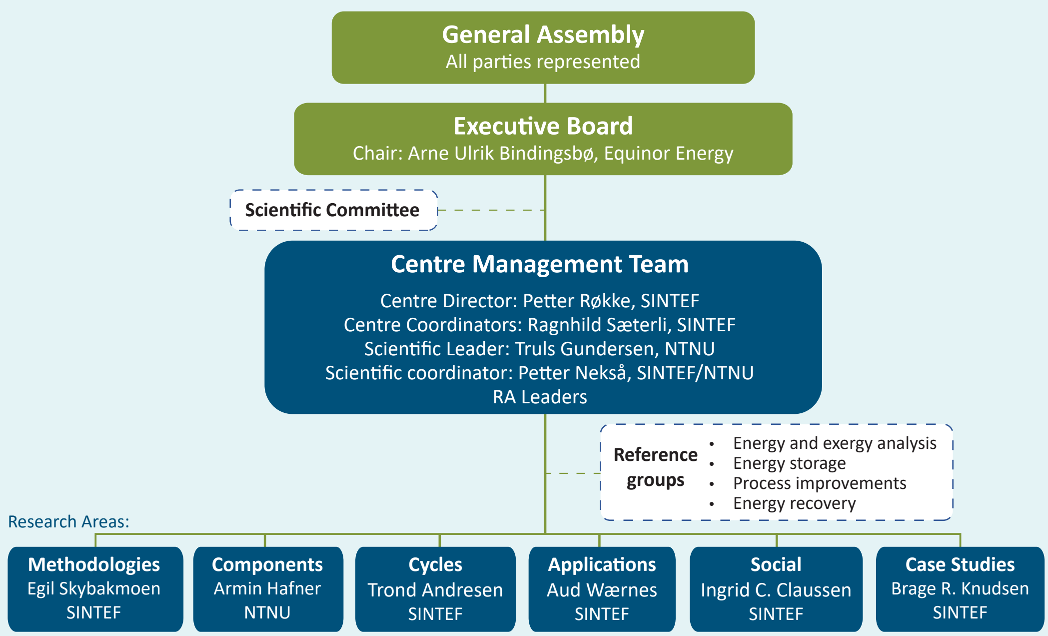
GL2022

15th IIR-Gustav Lorentzen Conference on Natural Refrigerants

NTNU professor Trygve M. Eikevik, chair of the GL2022 organising committee, opened the conference.

The conference was also an occasion for some technical visits. Here, SINTEF Research Scientist Krzysztof Banasiak shows the refrigeration and heating system of the Rema 1000 shop on Prinsensgate, in Trondheim. The system uses CO_2 as a refrigerant.

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. 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 will further 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 Dean Research 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), Ingrid Camilla Claussen (SINTEF Energy Research) and Brage R. Knutsen (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

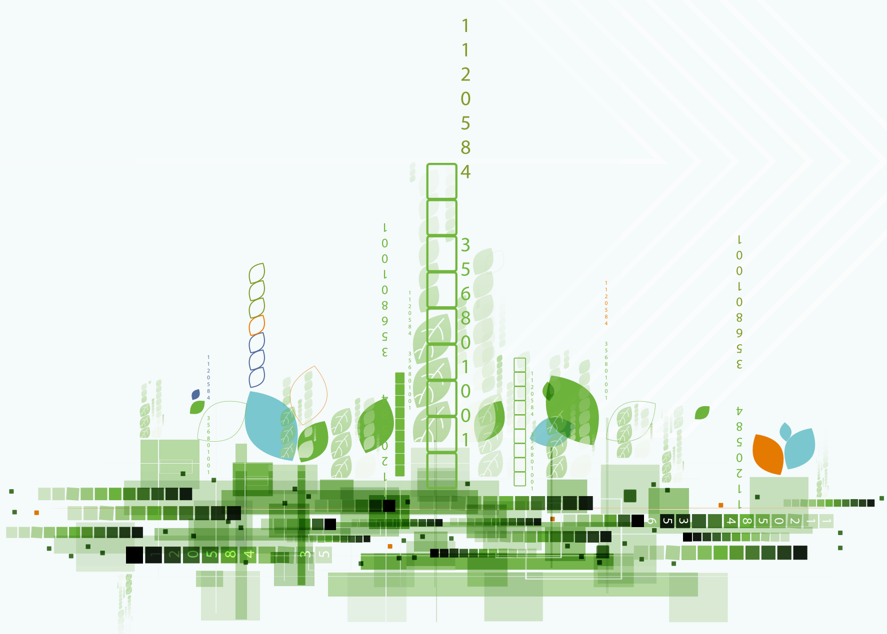
Innovations

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

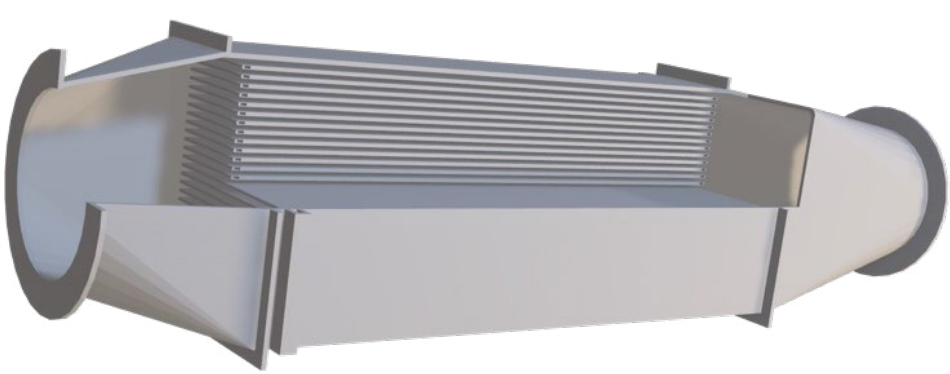


Novel heat exchanger concept for aluminium electrolysis off-gas

In traditional aluminium production, a significant amount of heat leaves the electrolysis cells in the off-gas. Several applications of this heat have been proposed, such as district heating or industrial drying processes, but recovery is a technical challenge due to damaging scale formation on equipment caused by particles in the gas. Commercially available heat exchangers resistant to scale formation have not seen widespread use due to large sizes and costs.

A novel plate-based heat exchanger concept has been proposed and developed to TRL 3 in collaboration with the SFI Metal Production research centre. Here, the formation of scale has been studied in detail, with findings suggesting that it primarily occurs when the off-gas impacts perpendicular surfaces at high velocity. HighEFF's modelling efforts have shown that a plate-based heat exchanger mostly avoiding these conditions can be designed with a compactness approaching clean gas concepts. However, the acquirement process for a prototype has revealed that the proposed design might challenge traditional construction methods.

Current research efforts aim to perform in-situ testing of this heat exchanger prototype at an aluminium production plant. This is mainly in order to examine its resistance to scale formation, but will also help validate the models used in the design process. If sufficient scaling resistance can be shown, the concept will have reached TRL 5 by the end of the HighEFF centre period.



Pilot project for excess heat utilisation at Felleskjøpet Skansen, in Trondheim

This pilot project aims to use high-temperature heat pumps to produce steam from waste heat. The project is supported by ENOVA and owned by Aneo and Felleskjøpet Agri. The technology will be tested on two feed lines and demonstrate heat recovery, upgrade and supply with a capacity of 1.2 MW. The expected energy delivery is 3.6 GWh/year, resulting in an electric energy saving of about 2.4 GWh/year.

The heat pump which will be installed is based on a new concept developed by SINTEF, through research carried out within HighEFF. It combines two different heat pumps, a bottom cycle and a top cycle, into one system to produce high-pressure steam. The bottom cycle is a newly developed ammonia heat pump that produces low-pressure steam (at around 85°-90°C). In the top cycle, the steam pressure is lifted to the required level through multistage steam compression. EPCON Evaporation Technology AS provides the top cycle and is responsible for the system solution, while GEA provides the bottom cycle. The TRL of this innovative system is considered to be at 7-8, whereas the bottom and top cycles are at 8-9.

Photo: Felleskjøpet Agri

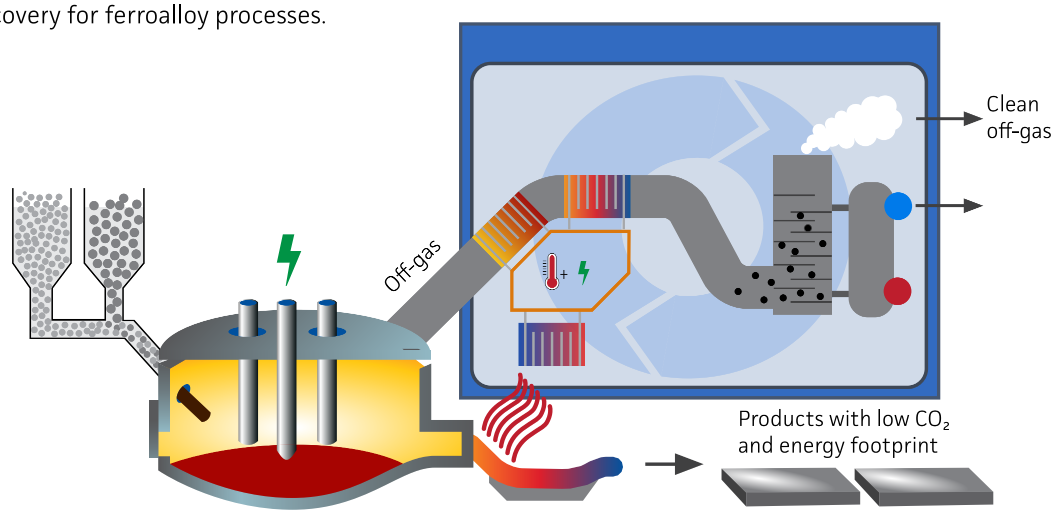
Optimal integration of combined CO_2 capture and advanced energy recovery for ferroalloy processes

ADVENCCS is an interdisciplinary project bringing together process development, energy efficiency and CO_2 capture in the Norwegian ferroalloy industry. HighEFF partners Elkem and Eramet have set very ambitious energy and climate goals, to which HighEFF results will contribute. But the potential impact can be much higher when combined in more holistically optimised solutions. Starting in 2023, ADVENCCS will build on and further develop research performed in FMEs HighEFF and NCCS, as well as SFI Metal Production.

Overall, the project will ensure a quicker transition towards a zero-emission society and promote efficient, competitive, low-carbon Norwegian industry. ADVENCCS will contribute to reaching these goals by promoting cost-effective decarbonisation of the ferroalloy industry through optimal development and efficient integration of combined CO_2 capture and advanced energy recovery for ferroalloy processes.

The project will conduct CO_2 capture development by combining optimisation of material selection and process design targeting utilisation of waste heat. It will focus on improved energy recovery to minimise external power input and provide heat to cover all demands, thereby enabling cost-efficient CO_2 capture.

Solutions will be developed for the Norwegian ferroalloy industry with the aim of delivering CO_2 to Northern Lights, thereby increasing value creation from the Longship project. As the ferroalloy industry is increasing its use of bio-carbon, CO_2 capture from these processes will enable BECCS (Bio Energy CO_2 Capture and Storage), which can contribute to the Norwegian process industry's goal of carbon neutrality by 2050. The combined concept of this project is currently at a TRL level of 3-4.



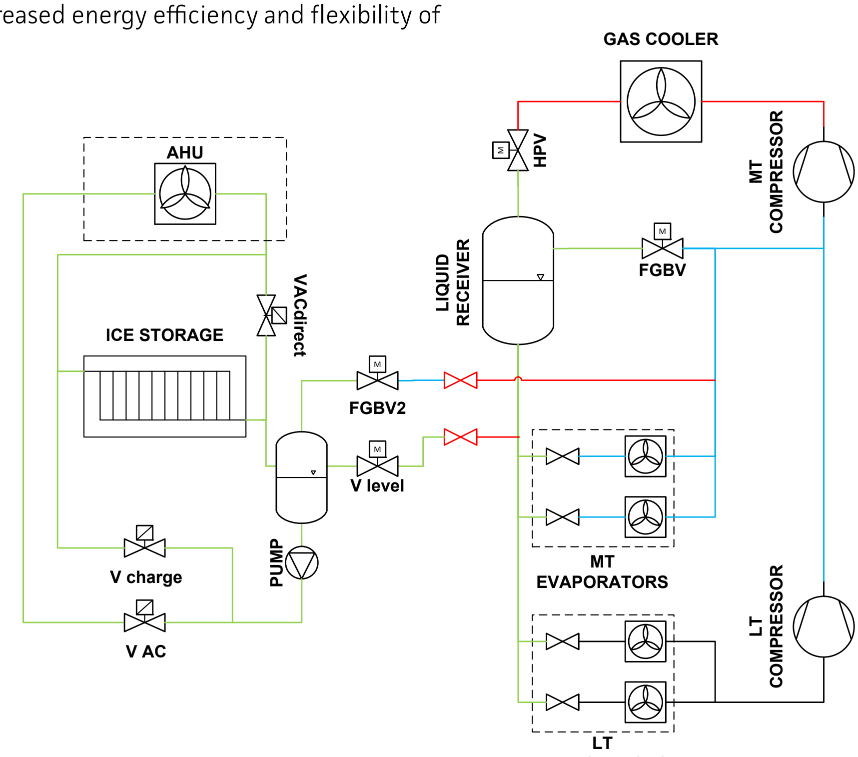
eraMeT Elkem NCCS TUM NTNU SINTEF

Thermal energy storage and air conditioning

Monitoring and analysis of a pilot thermal energy storage (TES) unit to supply Air Conditioning (AC) in commercial refrigeration systems

Refrigeration systems using CO_2 have become the preferred choice in supermarket applications in recent years. The refrigeration system in the supermarket ensures that the milk is kept cold, ice cream is kept frozen and the air inside the shop is kept at the correct temperature during warm summer days. The warmest day of the year gives the specification of the required capacity of the refrigeration system, which means the plant operates at part load capacity for most of the year.

Thermal Energy Storage (TES) is a key technology for increased energy efficiency and flexibility of refrigeration systems. The TES-AC project aims to demonstrate TES technology developed at HighEFF to reduce the required installed capacity of supermarket refrigeration systems and improve energy efficiency by decoupling AC production from the demand. Latent TES technology integrated into refrigeration systems has been taken to a TRL of 5 within the HighEFF project. The TES-AC project aims to demonstrate the technology by establishing a full-size pilot in a supermarket in Q2 2023 and lift the TRL to 7 by the end of the project in Q1 2024. The results of this innovation will be the possibility to reduce the required installation capacity of supermarket refrigeration systems and provide flexibility of operation to the system owner.



Use of CO_2 as refrigerant to improve energy efficiency, reducing power demand by 35%

HighEFF partner REMA 1000 has been a pioneer in using the refrigerant R-744 (CO_2) in the energy systems of their supermarkets. The CO_2 energy systems contribute to serve several demands for refrigeration of display cabinets and storage rooms, as well as heating demands and air conditioning.

From 2017 to 2020, almost 100 supermarkets were converted from HFCs as refrigerant to CO_2. The results are very clear. The average power demand has been reduced by 35% after conversion. Power demand has in average been reduced from 395 kWh/m^2 to 256 kWh/m^2 for supermarkets with an average size of 1300 m^2, spanning in size from 500 to 2500 m^2. The span in reduction was from 10 to 50%, believed to be related to the age of the HFC systems replaced. Conversion of all of the supermarkets of REMA is planned for the years to come based on the positive outcomes in improving energy efficiency, at the same time as it is sound from an economical point of view.

The conversion from HFCs to CO_2 has another very beneficial environmental effect since the HFCs replaced have global warming potential values of up to 4200, meaning that they contribute 4200 times more to global warming than the same quantity of CO_2. So, this is really a win-win situation, taking into account that refrigeration systems in supermarkets often leak 10-20 % of their charge per year. CO_2 being a relatively cheap gas compared to HFCs, the switch also makes sense in terms of costs. This innovation is at a TRL level of 8-9 (some elements of it are at 7-8).

These promising results have inspired us to investigate further improvements of REMA's supermarkets and their related industries within the HighEFF Centre, e.g. novel cold thermal storage systems.

Photo: Rema 1000

Biochar from Seaweed for Metal Production

The metal industry is required to increase their biocarbon usage to reach their carbon neutral goals by 2050. Increase use of biocarbon materials provides an opportunity for carbon neutrality. However, a survey by the Prosess21 group showed a deficit in biocarbon materials in the form of wood reserves for the process industry. Thus, it is crucial to explore alternative sources for biocarbon materials.

The NEIC project "Biochar from Seaweed for Metal Production" under the sponsorship of the HighEFF research centre looks at the possibility of using biochar from seaweed as an alternative biocarbon material for the metal industry. The processing of the seaweed into the required biocarbon material will also use the surplus heat coming from the metal industry – for the drying – thereby creating value for a resource currently wasted. The innovative working principle is given by Figure 1.

Results from the NEIC Biochar project showed that by treating the raw seaweed with an acidic media prior to washing in water, the inorganic content (ash content) is reduced with a consequent increase in the fixed carbon, however, more work is needed to get to levels suitable for the metal industry. Figure 2 shows images depicting the washed and un-washed biochar as well as the crystal structure.

Also, chemical composition analysis of the dirty liquid after the washing process showed relatively high concentration for the critical element lithium (200 μl/l). In comparison, the concentration of lithium in seawater is ca. 0.2 ppm. Thus, the innovative concept of using biochar from seaweed for metal production could provide another industry for the extraction of lithium and other relevant critical elements. The NEIC Biochar project is still in the development stage as more data is needed to confirm the presence of critical elements. Furthermore, an efficient washing is needed to further reduce the ash content to industrial levels. Thus, current TRL of the NEIC project is set to 4. More work is needed before industrialisation.

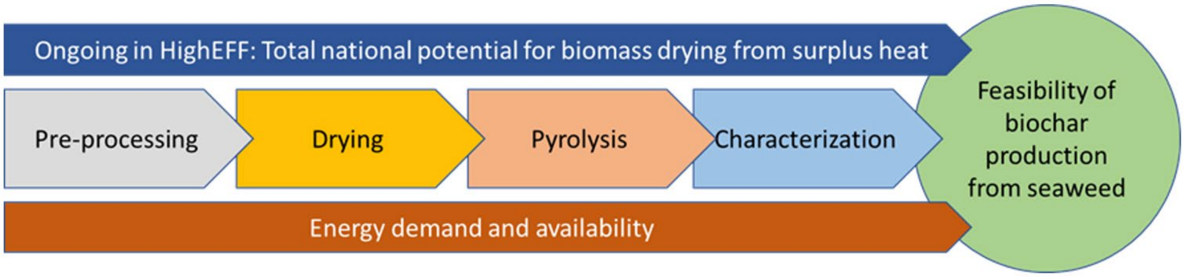


Figure 1: Outline of project.

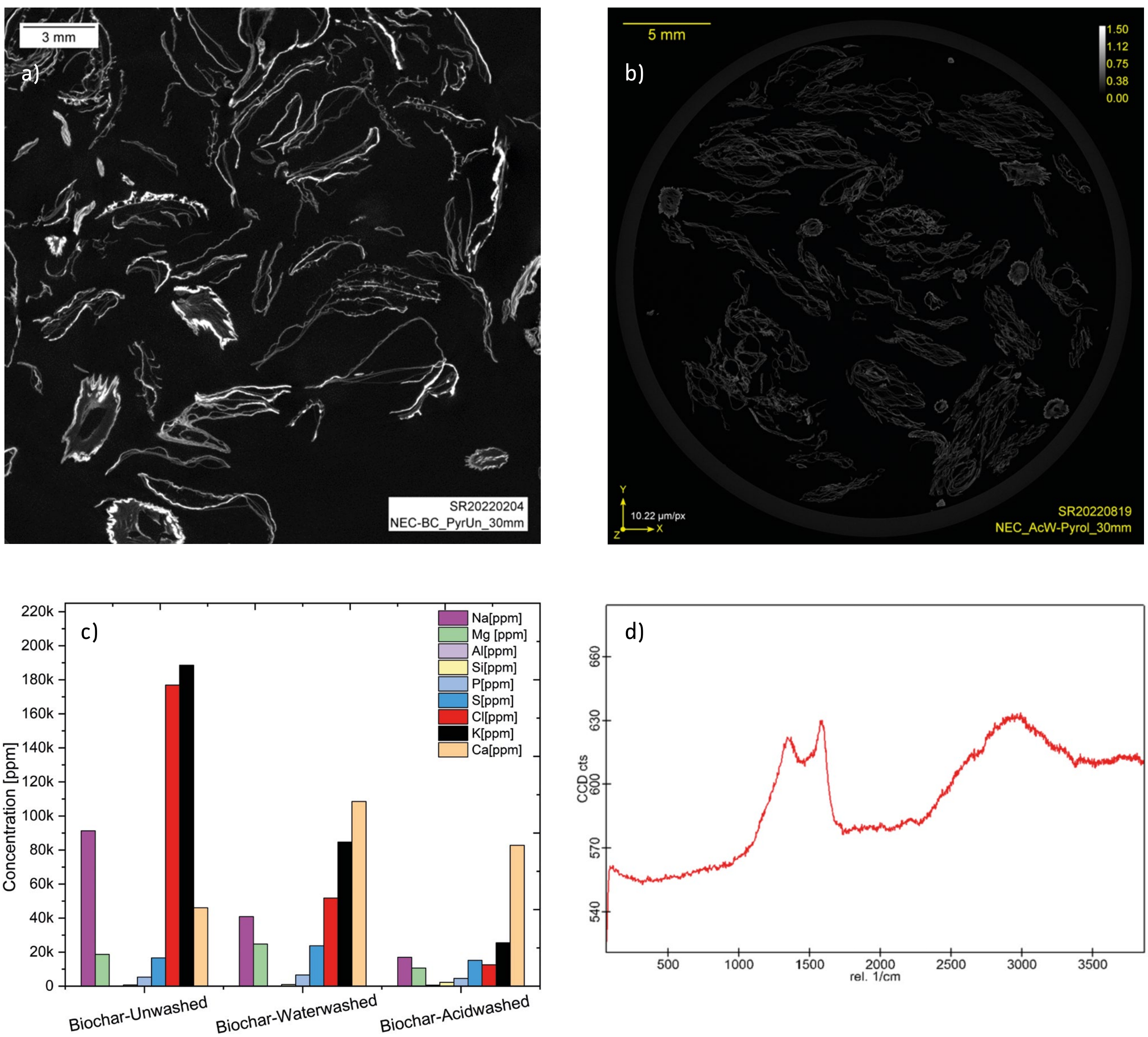


Figure 2: Characterisation of biochar from seaweed. a) µCT image of the unwashed biochar, white patches represent the ash content. b) µCT image of the acid-washed very little white patches. c) Bar graphs depicting the concentration of the components of the ash content. d) Raman spectroscopy analysis result showing the carbon spectra for the biochar of seaweed.

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 2022

PhD activities

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 remaining funds were used to recruit a third postdoc. Two PhDs defended their thesis in 2022 (Julia Jimenez Romero and Zhongxuan Liu), and one in February of 2023 (Cristina Zotica), so the academic work force in RA1 is now reduced to one PhD and one postdoc. An important element of the education programme in RA1 has been international collaboration with MIT in the US and the University of Manchester in the UK. The professor-pair model was implemented with these 2 universities.

The two PhD students that finished in 2022 (Romero and Liu) both studied future energy systems related to the transition from fossil fuels to renewable energy forms (solar and wind). Romero focused on improving complex industrial utility systems, including steam level placement, flexibility and energy storage. Liu has demonstrated that the Round-Trip Efficiency (RTE) for Liquid Air Energy Storage (as a promising way to store electricity from renewables) can be improved from 54 to 68% by optimising the flowsheet structure and selection of working fluids to exchange and store hot and cold thermal energy.

Three PhD students in RA1 (Cristina Zotica, Julia Jimenez Romero and Zhongxuan Liu) have produced seven journal publications in 2022 and attended four conferences with presentations and short papers. Interestingly, these three PhDs have all considered energy storage; Julia and Zhongxuan for design and Cristina for control.

KPI work

The year 2022 saw a sidestep or an elaboration on the KPI work that has already been carried out as part of RA1. After meetings with HighEFF partner Hydro, we saw the need to expand the current perspective to enumerate other potential benefits of new energy-saving or CO_2-mitigating solutions, especially for projects that at first glance do not look so promising, due to other seemingly more attractive projects in the portfolio. To accommodate this request, considerable work was put into making an excel based tool that allows the user to attribute various benefits to new projects and rank them based on different aspects such as contributions to HSE guidelines, company or societal reputation, work environment, and risk mitigation. In addition, the tool includes a total operating and investment cost breakdown, as well as the KPIs that have already been developed within RA1. Hydro played an active role in the development of the tool and provided useful input along the way. Relevant case studies were also devised to test the tool's capabilities and to demonstrate its potential in the decision phase. The plan is to continue working on this tool in 2023 and have a complete version ready by the end of the year.

Flue gas recycling and energy recovery

Also, flue gas recycling and energy recovery has shown from the work done in 2021 and 2022 to provide an excellent opportunity for the aluminium industry to reduce its total energy consumption and to prepare for a possible future carbon capture and storage or utilisation technology. Gas recycling enables increased CO_2 concentration and more efficient recovery of energy from the flue gas. The work performed in 2022 presented some of the challenges with this technology, including increased concentrations of other pot gases such as CO, SO_2 and HF and possible increased fugitive emissions due to reduced suction. Increased concentration of CO is particularly unwanted, since it is a lethal compound. Thus, catalytic conversion of CO to CO_2 is crucial for HES (Health, Environment and Safety) reasons, and it also increases the amount of collectible heat. However, high concentration of SO_2 can pose problems to equipment, including the heat exchanger units, due to the formation of sulfuric acid when the acid dew point is reached. Two papers with topics relating to the challenges of pot gas recycling were presented at the TMS 2022 conference in Anaheim in the USA from 27 February to 3 March 2022.

Furthermore, a pilot scale plant was installed at the Alcoa Mosjøen plant in Northern Norway through the AGATE project (led by REEL Norway). The plan was to perform some measurements there, however due to unforeseen challenges the measurements had to be postponed to 2023. Despite the challenges, a work on the theoretical evaluation of the dynamic gas concentration behaviour in the aluminium electrolysis cell was done. This work would be complemented by the industrial gas measurements to be done in 2023.

The potential for increased heat recovery is huge in the aluminium industry (up to 1.8 TWh estimated in RA1 and RA6), and if part of this energy can be used in the CCS process, it would enhance future developments for CCS from Al electrolysis process in the future. But several technological issues relating to heat exchanger design, etc. need to be solved before implementation. RA4 investigated the design of heat exchangers for utilisation of waste heat at the Hydro Sunndalsøra and Alcoa Mosjøen plants.

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 development. The research area also performs design, supports integration, and maintains flexible component test facilities for the HighEFFLab infrastructure.

A summary of our work in 2022

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 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 and effects of geometry parameters were studied. This work also developed a direct link between the optimisation tool and the CFD model.

Work Recovery & Compressors

The R&D focus is tuned towards 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.

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 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 and successfully installed and tested (HTHP) at TINE Tunga, in Trondheim, in 2021. The HTHP was operated until June 2022. The compressors have been sent for inspection and will be installed again Q2 in 2023. The analysis on both the R290- and R600 compressor efficiencies were carried out and are comparable to the lab scale 30 kWth 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 High-EFFLab. The test facility will be commissioned in Q2 2023 and will be able to operate compressors with an electric power of up to 150 kWel and suction flow rates up to 330 m^3/h.

Motion modelling in piston compressors further developed 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 as it exits through the 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 some challenges identified during commissioning, major components have been returned to the manufacturer. Therefore, the experiments to verify the operation envelope are planned in Q3 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, propane (R290) will be 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 Cycles are to develop improved cycles and concepts for converting and upgrading energy sources of many kinds. Technologies and applications for heat-to-power conversion, heat pumps and energy storage with high potential impact for Norwegian industry are emphasised.

Research in RA3 targets novel developments and improvements for important production processes across different industry sectors. A few example activities and results from 2022 are outlined below.

Heat exchanger test rig – HighEFFLab.

Natural working fluids in cycles for surplus heat-to-power conversion

For decades, the refrigeration technology research groups at NTNU and SINTEF have been developing components, cycles and tools to promote attractive solutions using natural working fluids instead of synthetic fluids with undesirable environmental properties. This strongly contributed to the current situation where natural refrigerants such as CO_2 and hydrocarbons are commonly and competitively used in e.g. supermarket refrigeration and high-temperature heat pumps.

With growing interest in surplus heat and energy recovery, we again experience a situation where more environmentally friendly and secure long-term options for working fluids are needed; this time in efficient and competitive heat-to-power systems, such as Organic Rankine Cycles. With basis in developed knowledge from both refrigeration and heat-to-power, HighEFF students and researchers have searched for new potential applications of surplus heat-to-power conversion and applied themselves to broad technology development.

In a session keynote presentation at the 2022 Gustav Lorentzen Conference, the overall history of surplus heat-to-power research at SINTEF and NTNU was summarised, and our considerations related to benefits and drawbacks of relevant fluids discussed. The main point from comparing natural and synthetic fluids is that there is no difference in performance levels. Between CO_2 and hydrocarbons, a fully competitive natural alternative can be found with respect to performance.

Hybrid ammonia-water absorption compression high temperature heat pump

High temperature heat pumps (HTHPs) are regarded as one of the main tools for increased energy efficiency in industrial processes. HTHPs enable industrial waste heat to be upgraded to elevated temperatures and reused into the process, using only a fraction of the energy compared to fossil fuel or direct electric heating.

One promising HTHP technology is the absorption-compression heat pump system (ACHP). The functionality of this technology has already been proven in the industrial sector using available standard components up to 120°C. A main advantage of this type of heat pump is that the ammonia-water fluid mixture allows for heat delivery at higher temperatures compared to traditional ammonia heat pumps, which are typically limited to 90°C. The heat delivery and uptake occur at gliding temperatures, which is beneficial when pairing against heat sinks and heat sources where sensible heat is transferred, e.g. heating of pressurised hot water.

Through the state-of-the-art ACHP test facility at HighEFFLab, specifications up to 40 bar system pressure, 200 kW capacity and 180°C operating temperature have been made possible. Construction of the rig was completed in 2022, and experimental activities led by HighEFF PhD student Khalid Hamid are set to begin during winter 2023.

The aim of the test facility is to achieve heat delivery up to 140°C and investigate key system characteristics such as COP, temperature lift and glides, as well as thermal capacity. System optimisation through investigation of different settings of the operational conditions, such as the ammonia-water composition, the circulation rate between the pump and the compressor, and pressure and temperature levels will also be performed.

View of the installed combined absorption-compression heat pump test rig.

White paper on Industrial thermal energy storage

SINTEF Energy Research with Hanne Kauko and Alexis Sevault co-authored a white paper on Industrial thermal energy storage together with researchers from Durham University (UK), TNO (the Netherlands), CIRCE (Spain) and AIT (Austria). The process was started in late 2021, and the white paper was officially launched during a digital event in December 2022, with 135 viewers from all over the world.

Industry accounts for one quarter of the total final energy consumption in the European Union. Within that quarter, over 80% is consumed by heating and cooling processes. The continued, wide-scale use of gas, oil, coal, and other fossil fuels for industrial thermal processes leads to estimated greenhouse gas emissions of 513 Mt CO_2 equivalent per year; which corresponds to 12% of total GHG emissions.

Thermal energy storage can assist in the decarbonisation of industrial heating and cooling and increase energy system flexibility and security. In the white paper, it is estimated that the full roll-out of industrial thermal energy storage could enable a potential 1,793 TWh of fossil fuel replacement by renewable energy and surplus heat.

While the general energy discussion is mostly focused on electrical energy storage such as batteries, the potential of thermal energy storage is largely overlooked. The aim of the white paper is to increase awareness of the potential of thermal energy storage as an enabler for decarbonisation and increased energy system flexibility among policy makers, industries, energy companies and the general public.

Steam accumulator at the Norsk Kylling plant in Orkanger.

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

An important activity has been the recycling of off-gas from silicon/ferrosilicon-furnaces, to increase the CO_2 content of the off-gas and make CO_2 capture easier. This is a continuation of the work done in 2021.

Off-gas recycling also influences the gas-phase chemistry in other ways such as PAH (polycyclic aromatic hydrocarbons) emission. Controlling PAH emissions is important for the industry, so it is necessary to establish how any new process or process modification influences PAH formation and oxidation. SINTEF Industry developed kinetic methods for PAH formation and PAH oxidation based on a chemical reactor network (CRN) approach to be used in post-processing of CFD (computational fluid dynamics) models to model the formation, oxidation and distribution of PAH during gas recycling.

Gas recycling may also indirectly influence the conditions below the charge surface of the furnace. Changes in silicon monoxide (SiO) gas condensation will mean a change in how much SiO-gas leaves the charge surface (influencing Si-yield), and the concentration of SiO-gas that enters the combustion zone (influencing amount and possibly also quality of micro silica produced). SINTEF Industry are looking at how this influences the conditions for SiO-gas condensation, by modelling the kinetics of relevant reactions.

Ferromanganese: status update

Variations in energy efficiency in Mn-furnaces occur due to variations in the prereduction zone. Ferromanganese prereduction mechanisms have been studied previously at HighEFF by PhD-candidate Trine Larssen. She has also gone through the large amounts of experimental data that have been produced over the years, as well as several models, and evaluated them for consistency and general applicability. A knowledge gap that was identified and which will only become ever more critical as the industry switches to more bio-carbon is the effect of volatiles on prereduction. Experimental work started in 2022 on this task and will continue in 2023. Eramet Manganese Norway and Eramet Ideas in France are closely involved, serving in an advisory capacity for this project.

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.

At HighEFF, we have explored a modified plate-type heat exchanger concept without fins on the gas-side for this purpose. This work has continued in 2022. A supplier capable of constructing this prototype has been found. Material testing for aluminium has successfully been performed at Hydro Sunndal, and measurements of cooling water pressure drop through a heat exchanger plate have been performed at the SINTEF laboratories. The prototype design has been revised in conversation with the supplier M-tech, and a detailed site analysis has been performed together with Alcoa to ensure compatibility. Preliminary plans for a final test setup have been made.

HighEFF organised a workshop on the topic "Competitive surplus heat recovery – how to get from knowledge building to practical and attractive demonstrators". The workshop included both academic and industrial viewpoints to energy recovery and conversion and had the goal of being an arena for mutual learning and discussions. The meeting aimed at targeting topics that have general applicability in terms of industry relevance and focused on what are the types of external use we should recover heat for, and how to get to a demo system.

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 we have investigated policy mechanisms, funding schemes and facilitation attempts to orchestrate their development.

The work on industry clusters in WP4.3 was conducted in close collaboration with WP5.1 (barriers, enablers, and innovation). Together, these WPs have gathered an extensive database of existing clusters and surplus heat exchange and significantly improved our knowledge on innovation challenges, enablers, organisational models, and local factors promoting energy efficiency improvements.

With the social science work in RA4 drawing to a close, we focused in 2022 on direct dissemination of results and outreach activities to clusters and industrial actors within and outside of HighEFF. This was done both to widen the impact of research results, but also to collect best-practices and novel insights useful for HighEFF partners and stimulate to collaboration and innovation. These activities include bilateral meetings, conference attendance, HighEFF workshops, and presentations as invited speakers in related projects.

Society - RA5

RA LEADER
Ingrid Camilla Claussen,
Research Manager, SINTEF
ingrid.c.claussen@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 interaction, as well as on the barriers and enablers for innovation and realisation of HighEFF technologies and concepts.

Innovation, barriers, and enablers

We provided research-based knowledge on how industry and research partners manage to collaborate for the enhancement of knowledge and innovation. Through a close collaboration with NTNU Social Research and Nord University, we studied how researchers and companies collaborate in HighEFF and can attain jointly beneficial outcomes in open innovation projects. We discovered that partner alignment happens through practices that are influenced by structured coordination at the partnership level and mainly unstructured coordination at the project level, which led to a paper published in IEEE Transaction on Engineering Management. We also studied how company representatives are able to integrate knowledge developed in research centres into their organisation, and how this is done over different stages of the research centre. This led to a paper published in International Journal of Innovation and Sustainable Development.

To summarise, our research provides important insight to companies and research partners, about how to participate in research centres, and how to manage their outcomes; and to policymakers, about how such engagement should be funded and structured to reach the goals of generating new knowledge and industrial innovations. Furthermore, our research provides insights into political, organisational, and collaborative challenges for energy efficiency innovations and surplus heat exchanges.

A particular focus in 2022 was on dissemination of research from RA5 for industries, policy makers, researchers, and the general public outside of HighEFF through presentations as well as other means of communication such as workshops and podcast episodes. We also explored the changing rhetoric and politics of energy efficiency in the context of the emerging energy crisis in Europe, and how it potentially affects frame conditions for research and industries.

HighEFF PhD student Jens Petter Johansen defended his thesis "Energy efficiency-ing. How an energy efficient world is produced through practices, objects, rhetoric, and politics" in September of 2022. The thesis discusses the implications of moving from a technical understanding of energy efficiency as a measurement or technical quality, to denoting the work of a multitude of actors in developing and implementing technologies, how efficiency becomes represented in numbers and models, and how these are applied rhetorically and politically in the policy domain.

Novel Emerging and Innovative Concepts (NEIC)

Our internal funding scheme allows us to invest in ideas that are not covered by ongoing or enabled activities within HighEFF. The call is Novel Emerging and Innovative Concepts (NEIC) and is built upon the idea that new ideas and innovations are created 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.

Two calls for NEIC applications were published in 2022, one in January and one in September. In total, 11 project proposals were received by the two deadlines in 2022, and three projects were funded:

1) Innovative State-of-charge and Output control of PCM-TES systems (**SOCTES**). The project outlines a new methodology based on ultrasound sensors for controlling thermal energy storage using phase change materials. The aim of the project is 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. The project is a cooperation between SINTEF Energy Research and NTNU.

2) Monitoring and analysis of a pilot thermal energy storage (TES) unit to supply Air Conditioning (AC) in commercial refrigeration systems (**TES-AC**). The project aims to demonstrate TES technology developed at HighEFF to reduce the required installed capacity of supermarket refrigeration systems and improve energy efficiency. By shifting the AC load to off-peak hours, valuable flexibility and cost savings for the system owner are provided. The project is a cooperation between SINTEF Energy Research, NTNU-EPT and industry partner REMA 1000.

3) Integration of ThermoChemical Energy Storage (**ITChES**). The objective of the project is to analyse the performance potential of selected steam absorption TCES compounds to recover excess heat in the range of 120-300°C in a lab scale reactor and provide a technoeconomic study for large-scale implementation in industry processes. The project is a cooperation between two SINTEF institutes: Industry and Energy Research.

Dissemination and Communication

Higher focus on communication and dissemination for increased research and innovation impact have been the goal for the communications activities in 2022. The focus was to raise awareness of energy efficiency as a key for reaching the target of a maximum of 1.5 degrees of warming. How energy efficiency is part of the big picture is another key point, as well as paving the ground for further research and development of technology to help the industry be more energy efficient. The Centre used newsletters and social media channels such as LinkedIn, in addition to workshops and seminars, for these objectives. Our strategy ensures a widest possible outreach, involvement and cross-sectorial interaction with relevant industry and academia. The dissemination strategy is built up to maximise the use of existing physical meeting points and existing communication platforms and media channels, such as project partners' own communication channels.

For more details, see the Communications chapter on page 59.

Case Studies - RA6

RA DEPUTY LEADER
Håkon Selvnes, Research Scientist,
SINTEF Energy Research
hakon.selvnes@sintef.no

Case Studies are performed to promote HighEFF innovations and obtain measurable results from the implementation of HighEFF technologies in the different 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.

Thermal energy storage technology air-conditioning for a CO_2 supermarket refrigeration system

Modern supermarket refrigeration systems are based on transcritical CO_2 booster systems, supplying cooling and freezing of the products in the store. Currently, the air-conditioning (AC) in REMA 1000 supermarkets is supplied by a glycol circuit which is cooled by the CO_2 rack. The design capacity of the rack must handle all the refrigeration load and the AC load during the warmest summer day, which results in overcapacity and part load operation for most of the year. In this case study, it is suggested to replace the glycol circuit to the air handling units by a combination of CO_2 circuit and a cold thermal energy storage. The thermal energy storage is using water/ice as the storage medium and can be used to store cold energy during the night and supply AC during the peak hours during the day. The simulation results in this study shows that the peak power load required from the electrical grid during a summer week can be reduced by 13%-19%, depending on the location. When investigating various scenarios for electricity pricing, it was found that the economic attractiveness of the technology is very sensitive to the pricing scheme and location. It is recommended to conduct a more in-depth study for a year of operation, and to investigate the possibility to establish a pilot installation to demonstrate the technology in a real supermarket. A conference paper based on this HighEFF case study has been written and accepted for presentation at the 2023 IIR Ammonia and CO_2 Refrigeration Technologies Conference.

Energy efficiency potential of retrofit projects in fish processing plants

This study builds on the work on energy efficiency measures in new fish processing plants conducted in 2021. The current case study evaluates potential energy efficiency measures for an existing fish meal and oil factory. Measurement data from a processing plant are analysed, identifying the heating demands and mapping the potential waste heat sources. The focus is on integration of high-temperature heat pumps upgrading waste heat from the factory to produce low-pressure steam for the cookers. Three waste heat sources were evaluated: condensate from the MVR evaporator, water from cooling towers and waste heat from a nearby freezing factory. In order to produce steam at 3 bar, two different heat pump solutions were considered: a closed loop steam heat pump and a butane heat pump with a steam top cycle. System solutions were considered using the different waste heat sources together. The results show a significant potential for using the waste heat sources to produce low pressure steam, particularly using the condensate from the MVR evaporator, which gave a COP of 2.3-2.7. Water from the cooling towers is likely not useful due to low temperatures.

Conversion of Kollsnes furnaces from natural gas to hydrogen

At the Gassco Kollsnes gas processing plant, three fuel gas-fired furnaces are used to heat the hot 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 fuel 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. Initial CFD simulations were performed for the Kollsnes furnace.

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

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 characterize 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

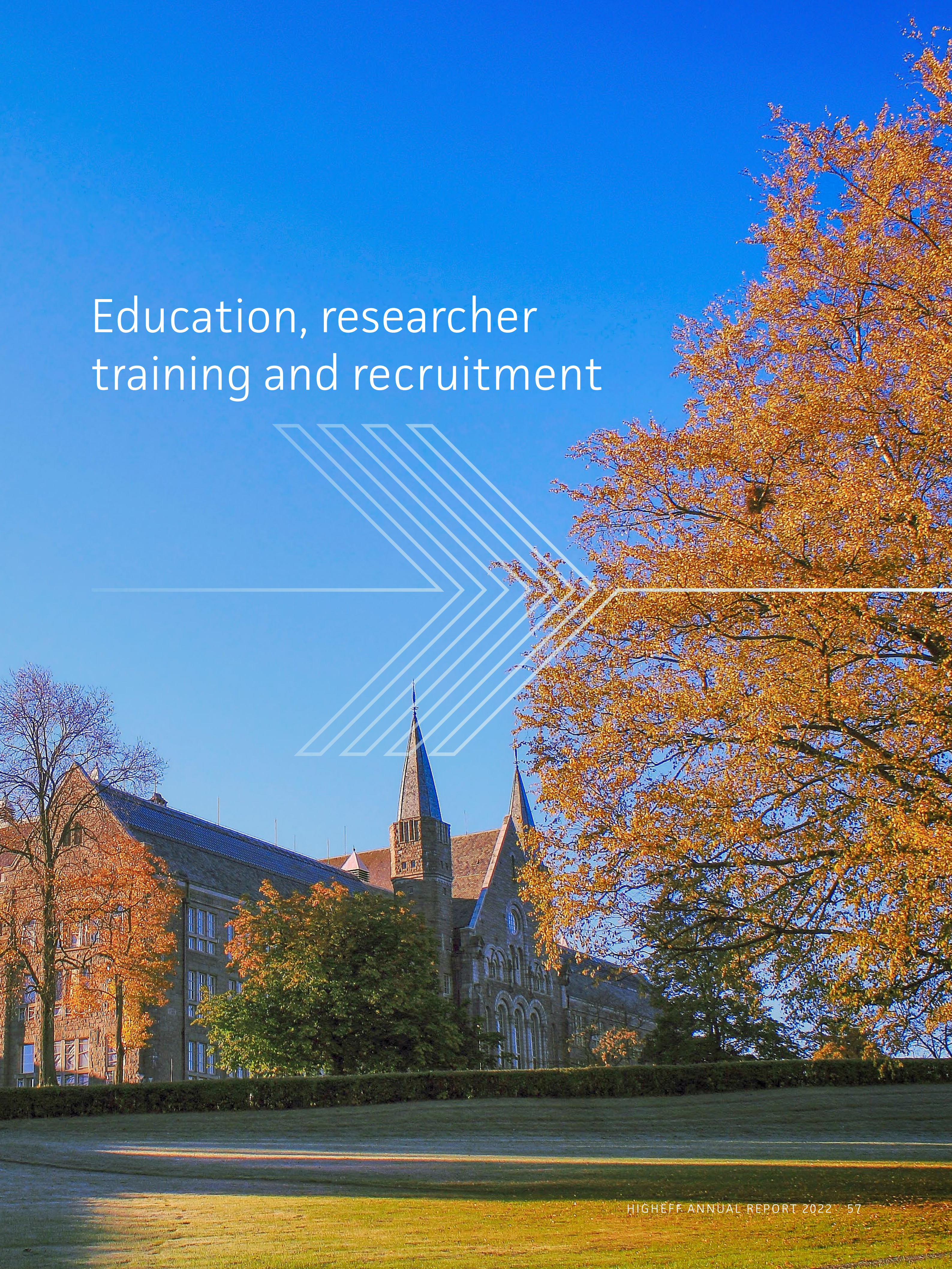
4. The Dewatering Laboratory
    a. Modified Atmosphere Dryer – High quality drying of food and biological material assisted by microwave in an inert atmosphere
    b. Heat Pump Drying – Recovery of thermal upgrade of drying energy

5. The Gas and Material Characterization Laboratory
    a. Portable FTIR gas analyser – High-resolution spectgrometer 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
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 of 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 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 2022, HighEFF had recruited 20 PhDs and 6 postdocs. One of these PhDs discontinued, and remaining funding for this position, together with unused budgets during the pandemic, made it possible to recruit postdoc number 6 for 2 years in 2022. HighEFF has also identified 10 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, 12 PhDs, 5 postdocs and 6 Associated PhDs have completed their programmes successfully. 5 PhDs and 1 postdoc finished in 2022. We have also had 53 master students since the start of HighEFF, but only 3 in 2022. With HighEFF's early recruitment start (13 candidates were recruited in 2017 and 7 in 2018), 95.3% of the time and funding available for PhDs and postdocs had been spent by the end of 2022.

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 26 journal papers in 2022, the accumulated number since the start of HighEFF is 220. For conference presentations, the corresponding numbers are 12 in 2022 (still affected by the pandemic) and 156 in total.

Communications

Communications efforts by the HighEFF team continued bearing fruit in 2022.

As the Centre approaches its final year, the emphasis is moving from establishing a brand and drumming up interest in HighEFF for prospective partners, to highlighting results and success stories. Attention is also given to what remains to be done: both in terms of new discoveries and in terms of realising the potential of Centre innovations.

2022 marked a return to normal after two years of disruptions due to Covid-19. We were pleased to support the organisation and promotion of the 15th IIR-Gustav Lorentzen Conference on Natural Refrigerants (GL2022), HighEFF's first major international event after the pandemic.

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

HighEFF was represented at political lobbying event Arendalsuka. Centre director Petter Røkke participated in the event "How can excess energy contribute to cheaper electrification?" (in Norwegian: *Hvordan kan overskuddsenergi bidra til billigere elektrifisering*?"), hosted by Norsk Fjernvarme. The event described how excess heat can be put to use in certain industrial processes, which in turn frees up electricity for other purposes.

In the media

Through continued efforts by the communications team, HighEFF and its scientists are increasingly associated in the media with the need to put excess heat and energy to use instead of letting it go to waste. The topic was the focus of articles by Teknisk Ukeblad (in September, featuring SINTEF Chief Scientist Petter Nekså), Energi og Klima (in April, featuring Centre director Petter Røkke), and Overskuddsenergi (in August, featuring Petter Røkke).

The official opening of HighEFFLab was the subject of a press release by SINTEF, which was republished by various outlets, including the paper version of Teknisk Ukeblad.

Bør skifte til CO_2 og ammoniakk i kjøleskap og varmepumper

KLIMA. Kjølemedier, gassene som brukes blant annet i kjøleskap og varmepumper, fikk på 1980-tallet skylda for å ødelegge ozon-laget. Gjennom Montrealprotokollen ble det bestemt at gassene skulle byttes til nye syntetiske kjølemedier. Det førte til at ozonlaget ble reddet.

Men de syntetiske kjølemediene har en negativ effekt på klimaet som gjør at flere bransjer nå ønsker å bytte til naturlige kjølemedier som har mye lavere klimaeffekt, som CO_2 eller ammoniakk. Dette teknologiskiftet kan bidra til å redusere global oppvarming med 0,5 grader.

En legendarisk forsker på temaet var norske Gustav Lorentzen (1915-1995), professor ved NTNU og forsker ved Sintef. Lorentzen var faktisk en så viktig figur i bransjen at han har en egen konferanse oppkalt etter seg. Konferansen holdes annethvert år og ble nylig arrangert i Trondheim med 350 internasjonale forskere.

Rema 1000 er blant de første som skifter kjølemedium på alle sine butikker. Kjeden regner med å være ferdig innen 2026.

Rema først ute: Sintef-forsker Krzysztof Banasiak viser fram et CO2 -drevet kjøle- og varmesystem fra Rema 1000-butikken i Prinsensgate i Trondheim. FOTO: DANIEL ALBERT, SINTEF

Legende: Professor Gustav Lorentzen fotografert ved NTNU i 1970.

On the occasion of the GL2022 conference, a short article touting the merits of natural refrigerants was written by the communications team for the print edition of Norwegian engineering magazine Teknisk Ukeblad. A press release on the same subject was picked up by some trade publications, including VVSForum and Dagligvarehandelen.

HighEFF events

HighEFF organised or participated in a series of relevant events during the course of the year. The "Energy crisis" workshop series hosted by the Norwegian Academy of Technological Science and FME NTRANS was an occasion to present energy efficiency as a solution. Energy storage was also on the agenda when Hanne Kauko (Senior Research Scientist, SINTEF) and Alexis Sevault (Research Manager, SINTEF) were guest speakers at an event organised by the European Energy Research Alliance Joint Programme for Energy Efficiency in Industrial Processes. The organisation launched a whitepaper outlining how industrial thermal energy storage can support the decarbonisation of industry.

The communications team also supported May's Annual Consortium Meeting and October's Cross-sector Workshop, both held in Trondheim. The events have previously been described by consortium participants as a productive occasion for exchanges and cross-pollination.

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

Website, blogs & newsletters

The website www.higheff.no is the communications hub for the research centre, and is the first port-of- call for those interested in finding out more. It was updated throughout the year with the latest news from the project.

HighEFF participants are encouraged to create blog articles about their tasks throughout the year. Many blog posts summarise project results or scientific publications but are targeted at different groups such as private industry or decision-makers in governments. Other blogs are aimed at fellow researchers working in energy-efficiency and related fields.

During 2022, a total of 14 blog articles were published across a variety of HighEFF topics, eight in English and six 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 had 252 followers on 31 December 2022 (compared to 67 on the same date the previous year).

The HighEFF communications team also maintains a Twitter account (@HighEFF_FME). At the end of 2022 it had 130 followers.

Appendix

Statement of accounts

Costs (in 1000 NOK)	
Host institution	22 244
Research partners	18 749
User partners	4 209
Equipment	785
Total	**45 988**

Funding (in 1000 NOK)	
Research Council of Norway	21 908
Host institution	6 100
Research partners	5 471
User partners	12 684
Total	**46 162**

Personnel

Key researchers

Name	Institution	Main research area
Adriana Reyes Lua	SINTEF Energi	Industry clusters
Afaf Saai	SINTEF Industri	FEM modelling, WP2.2
Ángel Pardiñas	SINTEF Energi	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
Arne Petter Ratvik	SINTEF Industri	Novel emerging concepts
Asbjørn Solheim	SINTEF Industri	HH improvment, Case study Al
Asle Gauteplass	NTNU SR	Society - NEC shared resources and alternative business models
Aud Nina Wærnes	SINTEF Industri	Process improvements
August Brækken	SINTEF Energi	Case study high temperature heat pump, Case studies F&C
Avinash Subramanian	NTNU	Polygeneration systems for chemical and energies
Balram Panjwani	SINTEF Industri	Process improvements
Bin Hu	Shanghai Jiao Tong University	Steam high temperature heat pump
Brage Knudsen	SINTEF Energi	RA6 lead, HighEFF overall goals, industrial cluster cases
Brede Hagen	NTNU	Surplus heat-to-power conversion
Catharina Lindheim	NTNU SR	Society - NEC shared resources and alternative business models
Cecilia Gabrielii	SINTEF Energi	Low temperature cooling, steam production aluminum industry
Christian Schlemminger	SINTEF Energi	High temperature heat pumps and thermal energy storage for industrial processes, Compressors and expantion work recovery
Cristina Zotica	NTNU / SINTEF Energi	Optimal Operation and Control of flexible Heat-to-Power Cycles
Daniel Rohde	SINTEF Energi	Energy-to-power conversion, and Industry clusters and technology integration
David Perez Pineiro	NTNU	Optimal operation and control of energy storage systems
Egil Skybakmoen	SINTEF Industri	RA1 Methodoogies leader. HH improvements, Case study Al, Surplus Heat recovery Al

Name	Institution	Main research area
Ehsan Allymehr	NTNU	Heat transfer and pressure drop in small diameter pipes for natural working fluids and mixtures
Einar Jordanger	SINTEF Energi	Management
Einar Rasmussen	Nord Universitet	Supervisor Irina Isaeva
Elisa Magnanelli	SINTEF Energi	Surplus heat recovery
Even Evensen	SINTEF Energi	Sommerstudent
Francesco Finotti	SINTEF Energi	Oil and gas case studies
Gabriella Tranell	NTNU	Recycling of furnace gas, supervisor for Vegar Andersen
Geir Skaugen	SINTEF Energi	Heat exchangers
Gerwin Drexler-Schmid	AIT	High-temperature thermal energy storage, High Temperature heat pumps
Goran Durakovic	SINTEF Energi	Surplus heat-to-power conversion, Case studies; industry clusters
Gudveig Gjøsund	NTNU SR	Organizational analysis
Halvor Dalaker	SINTEF Industri	Process improvements
Han Deng	SINTEF Energi	Heat exchangers, natural working fluids
Hanne Kauko	SINTEF Energi	Thermal energy storage, potential in industry clusters, High-temperature TES for industrial processes, Industrial Clusters
Helle Børset Eidissen	SINTEF Energi	Heat exchangers
Hiroshi Yamaguchi	Doshisha Univ	Refrigeration technology
Håkon Selvnes	NTNU / SINTEF Energi	Cold thermal storage for industrial applications, Case studies F&C, WP6.0 Methodology for goal achievement
Ida Teresia Kero	SINTEF Industri	Metallurgy, materials science, process improvements
Ingrid C. Claussen	SINTEF Energi	Dissemination, society
Irina N. Isaeva	Nord Universitet	Industry/University collaboration for environmental innovations
Ivar S. Ertesvåg	NTNU	Exergy Analysis of Offshore Oil & Gas Processing Systems
Jens O D Røyrvik	NTNU SR	Societal, social and organizational conditions for energy efficiency
Jens Petter Johansen	NTNU SR	Industrial clusters, Barriers and enablers for energy- efficiency and exchange
Johan Raftevold	SINTEF Energi	Heat exchangers , CFD maodelling
Johannes Jäschke	NTNU	Optimization of Energy Efficiency in large-scale Industrial Systems under Uncertainty
Jonas Bueie	SINTEF Energi	Heat exchangers
Jorge Beceiro	SINTEF Energi	Thermochemical energy storage
Julia Jimenez Romero	University of Manchester	Reduction of Industrial Energy Demand through Sustainable Integration of distributed Energy Hubs
Julian Straus	SINTEF Energi	RA6 case studies; industry clusters
Khalid Hamid	NTNU	High temperature Hybrid heat pump
Knut Emil Ringstad	NTNU	CFD for improving components of R744 vapor compression units
Kristian Leonard Aas	SINTEF Industri	Thermo electric generation
Kristina Norne Widell	SINTEF Ocean	Reducing GHG emissions of food cold chain in Norway; HTHP, Cooling and Drying and Case studies food
Kurian J Vachaparambil	SINTEF Industri	Process Improvements
Lars O. Nord	NTNU	Supervisor
Leif Andersson	SINTEF Energi	Steam thermal storage for Elkem Thamshavn

Name	Institution	Main research area
Line Rydså	SINTEF Energi	Industrial clusters, synergies between food and metal industries
Lucia Liste	NTNU SR	Society - NEC shared resources and alternative business models
Magnus Windfeldt	SINTEF Energi	Heat-to-power conversion
Marcel Ahrens	NTNU	High temperature Hybrid heat pump
Marcin Pilarczyk	NTNU	Compact bottoming cycles for offshore power production
Marianne T Steinmo	Nord Univ.	Industry/research collaboration in FME centres
Matias Vikse	SINTEF Industri	KPIs, energy & exergy analyses
Merete Tangstad	NTNU	Energy Distribution in Mn-alloy Furnaces
Michael Bantle	SINTEF Energi	High temperature heat pump (HTHP), low temp cooling next gen drying systems, food and chemical case studies
Michael Lauermann	AIT	High Temperature Heat Pump
Michael Schöny	AIT	NEC CETES
Mina Shahrooz	KTH	Low temperature waste-heat-to-power conversion
Morten Dahle Selfors	Nord Univ.	Society
Nina Dahl	SINTEF Industri	Board member
Olaf Trygve Berglihn	SINTEF Industri	KPIs, energy & exergy analyses, process improvements
Ole H Meyer	SINTEF Energi	RA2 Components
Ole Marius Moen	SINTEF Energi	High temperature heat pump
Paul I Barton	MIT	Supervisor Suzane Cavalcanti
Per Lundqvist	KTH	Supervisor Mina Shahrooz
Per M. Schiefloe	NTNU SSR	Innovation
Petter Nekså	SINTEF Energi/NTNU	Energy efficiency in industry
Petter Røkke	SINTEF Energi	Management, communication
Ragnhild Sæterli	SINTEF Energi	Management
Rahul Anantharaman	SINTEF Energi	Oil and gas case studies
Nidret Ibric	NTNU	
Roberto Agromayor	NTNU	Turbomachinery for waste heat recovery applications
Robin Smith	The University of Manchester	Reduction of Industrial Energy Demand through Sustainable Integration of distributed Energy Hubs
Samuel Senanu	SINTEF Industri	HH improvement, Gas recycling Al cells.
Sander Holum	NTNU	Summer researcher oil and gas case studies
Signe Kjelstrup	NTNU	Establish KPIs with Focus on Energy Efficiency in HighEFF
Sigurd Skogestad	NTNU	Process systems engineering
Silje Fosse Håkonsen	SINTEF Industri	HH improvement, Gas recycling Al cells.
Stefan Andersson	SINTEF Industri	Process improvements
Stefanie Blust	NTNU	Detector cooling with R744 refrigeration technology
Stein Rørvik	SINTEF Industri	
Stian Trædal	SINTEF Energi	Heat exchanger laboratory HighEFFlab
Suzane Cavalcanti	Massachusets Institute of Technology	Nonsmooth Approaches for Process Flowsheet Simulation and Optimization
Sverre Foslie	SINTEF Energi	High temperature heat pumps and thermal energy storage for industrial processes
Sylvain Gouttobroze	SINTEF Industri	NEC

Name	Institution	Main research area
Tom S. Nordtvedt	SINTEF Ocean	HTHP, Cooling and Drying and Case studies food
Trine Asklund Larssen	SINTEF Industri	Process improvement Mn
Trond Andresen	SINTEF Energi	Surplus heat-to-power conversion
Truls Flatberg	SINTEF Industri	NEC INTERCUR
Truls Gundersen	NTNU	Pinch and Exergy analyses, low temperature processes
Trygve Eikevik	NTNU	Natural refrigerants
Trygve Schanche	SINTEF Industri	Process improvement Mn
Tuva Grytli	SINTEF Industri	NEC INTERCUR
Vegar Andersen	NTNU	Recycling of furnace gas
Yessica Arellano	SINTEF Energi	Heat integration - oil and gas applications
Zawadi Mdoe	NTNU	Optimal control for industrial processes under uncertainty
Zhongxuan Liu	NTNU	Modeling and Optimization for the Design and Operation of a Network of Distributed Energy Hubs
Åsmund Ervik	SINTEF Energi	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 *researcher* 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

Name	Nationality	Period	Gender	Topic	Completed
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
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 andf 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 offgas	No
Zhongxuan Liu	China	09 2018 - 10 2022	F	Modelling and Optimization for Design and ope-ration 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	Sex	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

Name	Funding	Nationality	Period	Sex	Topic	Completed
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 CO2 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

Name	Gender	Period	Topic
Simon Birger Byremo Solberg	M	2019	Energy-Efficient Designs of Systems – From Nature to Chemical Engineering
Håkon Helland	M	2019	Modeling and Optimizastion 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
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 NH_3-H_2O 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 2022

Peer reviewed journal publications

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

1. **Ahrens, Marcel Ulrich; Brækken, August; Foslie, Sverre Stefanussen; Moen, Ole Marius; Lovas, Kim Andre; Bantle, Michael; Hafner, Armin; Eikevik, Trygve Magne.** Performance analysis of high temperature heat pumps and thermal energy storages for a dairy. I: *15th IIR-Gustav Lorentzen Conference on Natural Refrigerants - GL2022 - Proceedings - Trondheim, Norway, June 13-15th 2022*. International Institute of Refrigeration 2022 ISBN 978-2-36215-045-6. ENERGISINT NTNU
2. **Ahrens, Marcel Ulrich; Tolstorebrov, Ignat; Tønsberg, Even Kristian; Hafner, Armin; Wang, Ruzhu; Eikevik, Trygve Magne.** Numerical investigation of an oil-free liquid-injected screw compressor with ammonia-water as refrigerant for high temperature heat pump applications. *Applied Thermal Engineering* 2022 ;Volum 219. Suppl. A s. - NTNU
3. **Ahrens, Marcel Ulrich; Tønsberg, Even Kristian; Tolstorebrov, Ignat; Hafner, Armin; Eikevik, Trygve Magne.** Modeling and simulation of oil-free liquid-injected screw compressors using ammonia-water mixture as working fluid. I: *15th IIR-Gustav Lorentzen Conference on Natural Refrigerants - GL2022 - Proceedings - Trondheim, Norway, June 13-15th 2022*. International Institute of Refrigeration 2022 ISBN 978-2-36215-045-6. s. 1118-1127. NTNU
4. **Andersen, Vegar; Gaertner, Heiko; Grådahl, Svend; Ksiazek, Michal Tomasz; Einarsrud, Kristian Etienne; Tranell, Gabriella.** Measurement and Evaluation of Tapping Gas Energy from the Silicon Furnace. *Social Science Research Network (SSRN)* 2022 NTNU SINTEF
5. **Andersen, Vegar; Gaertner, Heiko; Grådahl, Svend; Ksiazek, Michal Tomasz; Einarsrud, Kristian Etienne; Tranell, Gabriella.** Tapping Gas from the Silicon Submerged Arc Furnace: An Industrial Measurement Campaign. *JOM* 2022 ;Volum 74.(11) s. 1-10. SINTEF NTNU
6. **Andersen, Vegar; Solheim, Ingeborg; Gaertner, Heiko; Sægrov-Sorte, Bendik; Einarsrud, Kristian Etienne; Tranell, Maria Gabriella.** Pilot-Scale Test of Flue Gas Recirculation for The Silicon Process. *Journal of Sustainable Metallurgy* 2022 s. - NTNU SINTEF
7. **Andresen, Trond; Deng, Han; Skaugen, Geir.** Design optimization of a novel heat exchanger concept with varying channel geometries. I: *15th IIR-Gustav Lorentzen Conference on Natural Refrigerants - GL2022 - Proceedings - Trondheim, Norway, June 13-15th 2022*. International Institute of Refrigeration 2022 ISBN 978-2-36215-045-6. s. 1285-1292. ENERGISINT
8. **Andresen, Trond; Hagen, Brede Andre Larsen.** Natural working fluids in cycles for surplus heat-to-power conversion – Perspectives and history from Trondheim. I: *15th IIR-Gustav Lorentzen Conference on Natural Refrigerants - GL2022 - Proceedings - Trondheim, Norway, June 13-15th 2022*. International Institute of Refrigeration 2022 ISBN 978-2-36215-045-6. s. 1555-1567. ENERGISINT
9. **Contiero, Luca; Fabris, F; Pardiñas, Ángel Á.; Hafner, Armin.** Performance improvements of supermarket R744 systems by pivoting compressor arrangements. I: *15th IIR-Gustav Lorentzen Conference on Natural Refrigerants - GL2022 - Proceedings - Trondheim, Norway, June 13-15th 2022*. International Institute of Refrigeration 2022 ISBN 978-2-36215-045-6. ENERGISINT NTNU
10. **Ervik, Åsmund; Saai, Afaf; Berstad, Torodd; Meyer, Ole; Tsuji, Takuma; Oku, Tatsuya; Hattori, Kazuhiro; Yamada, Kazuya; Delhaye, Virgile Roger; Nekså, Petter.** Coupled fluid-solid modelling of the valve dynamics in reciprocating compressors. I: *15th IIR-Gustav Lorentzen Conference on Natural Refrigerants - GL2022 - Proceedings - Trondheim, Norway, June 13-15th 2022*. International Institute of Refrigeration 2022 ISBN 978-2-36215-045-6. s. - SINTEF NTNU ENERGISINT
11. **Espelund, Johan Raftevold; Skaugen, Geir; Meyer, Ole.** Numerical modelling of fin side heat transfer and pressure loss for compact heat recovery steam generators. *Linköping Electronic Conference Proceedings* 2022 ;Volum 192. NTNU ENERGISINT
12. **Hafner, Armin; Hazarika, Mihir Mouchum; Lechi, Federico; Zorzin, Alvaro; Pardiñas, Ángel Á.; Banasiak, Krzysztof.** Experimental investigation on integrated two-stage evaporators for CO2 heat-pump chillers. I: *15th IIR-Gustav Lorentzen Conference on Natural Refrigerants - GL2022 - Proceedings - Trondheim, Norway, June 13-15th 2022*. International Institute of Refrigeration 2022 ISBN 978-2-36215-045-6. NTNU ENERGISINT
13. **Hagen, Brede Andre Larsen; Andresen, Trond; Nekså, Petter.** Equation-oriented methods for optimizing Rankine cycles using radial inflow turbine. *Energy* 2022 ;Volum 252. ENERGISINT NTNU
14. **Larssen, Trine Asklund; Tangstad, Merete.** Effect of Moisture, Hydrogen, and Water–Gas Shift Reaction on the Prereduction Behavior of Comilog and Nchwaning Manganese Ores. *Metallurgical and Materials Transactions B* 2022 ;Volum 53. s. 2104-2116. SINTEF NTNU
15. **Liu, Zhongxuan; Kim, Donghoi; Gundersen, Truls.** Optimization and analysis of different liquid air energy storage configurations. *Computers and Chemical Engineering* 2022 ;Volum 169. ENERGISINT NTNU
16. **Liu, Zhongxuan; Kim, Donghoi; Gundersen, Truls.** Techno-economic Analysis of Different Liquid Air Energy Storage Configurations. *Chemical Engineering Transactions* 2022 ;Volum 94. s. 241-246. NTNU ENERGISINT
17. **Nakama, Caroline Satye; Tysland, Agnes Camilla; Knudsen, Brage Rugstad; Jäschke, Johannes.** Simultaneous Optimal Operation and Design of a Thermal Energy Storage Tank for District Heating Systems with Varying Energy Source. *Computer-aided chemical engineering* 2022 ;Volum 49. s. 1951-1956. ENERGISINT NTNU
18. **Ringstad, Knut Emil; Banasiak, Krzysztof; Ervik, Åsmund; Hafner, Armin.** Swirl-Bypass Nozzle for CO2 Two-Phase Ejectors: Numerical Design Exploration. *Energies* 2022 ;Volum 15.(18) s. - NTNU ENERGISINT
19. **Rohde, Daniel; Beck, Anton; Wilpert, Paul; Dusek, Sabrina; Windfeldt, Magnus Kyrre; Andersson, Leif Erik.** Thermal energy storage for increased waste heat recovery at a silicon production plant in Norway. *Applied Thermal Engineering* 2022 ;Volum 215. ENERGISINT
20. **Schlemminger, Christian; Bantle, Michael; Jenssen, Sigmund; Dallai, Mauro.** Industrial high temperature heat pump for simultaneous production of ice-water and process-heat. I: *15th IIR-Gustav Lorentzen Conference on Natural Refrigerants - GL2022 -*

Proceedings - Trondheim, Norway, June 13-15th 2022. International Institute of Refrigeration 2022 ISBN 978-2-36215-045-6. s. 1045-1051. ENERGISINT

21. **Selvnes, Håkon; Allouche, Yosr; Hafner, Armin; Schlemminger, Christian; Tolstorebrov, Ignat.** Cold thermal energy storage for industrial CO<inf>2</inf> refrigeration systems using phase change material: An experimental study. *Applied Thermal Engineering* 2022 ;Volum 212. s. - ENERGISINT NTNU
22. **Shahrooz, Mina; Lundqvist, Per; Nekså, Petter.** Performance of binary zeotropic mixtures in organic Rankine cycles (ORCs). *Energy Conversion and Management* 2022 ;Volum 266. ENERGISINT
23. **Sheng, Juejing; Voldsund, Mari; Ertesvåg, Ivar Ståle.** Advanced exergy analysis of the oil and gas processing plant on an offshore platform: A thermodynamic cycle approach. *Energy Reports* 2022 ;Volum 9. s. 820-832. ENERGISINT NTNU
24. **Skybakmoen, Egil.** Quality Evaluation of Nitride bonded SiC Sidelining Materials. Historical Trends 1997-2022 Including Results and Development of Test Methods. *The Minerals, Metals & Materials Series* 2022. s. 921-928 SINTEF
25. **Steinmo, Marianne Terese; Lauvås, Thomas Andre.** The role of proximity dimensions in university-industry collaboration: a review and research agenda. I: *Handbook of proximity relations*. Edward Elgar Publishing 2022. ISBN 9781786434777. NORD
26. **Steinmo, Marianne Terese; Lauvås, Thomas Andre; Rasmussen, Einar.** How R&D subsidies alter firm activities and behaviour. *Innovation: Organization and Management* 2022 s. - NORD
27. **Windfeldt, Magnus Kyrre; Andresen, Trond.** Dynamic analysis of a furnace off-gas energy recovery system integrating heat from batch-wise metal casting. I: *15th IIR-Gustav Lorentzen Conference on Natural Refrigerants - GL2022 - Proceedings - Trondheim, Norway, June 13-15th 2022*. International Institute of Refrigeration 2022 ISBN 978-2-36215-045-6. s. 1568-1574. ENERGISINT
28. **Yamaguchi, H.; Ishikawa, Yuki; Yamasaki, Hiroshi; Kamimura, Takeshi; Hattori, K; Nekså, Petter.** Ultra-low temperature refrigeration system of CO2 using cyclone separator/evaporator. I: *15th IIR-Gustav Lorentzen Conference on Natural Refrigerants - GL2022 - Proceedings - Trondheim, Norway, June 13-15th 2022*. International Institute of Refrigeration 2022 ISBN 978-2-36215-045-6. s. 1758-1763. ENERGISINT
29. **Yamasaki, Haruhiko; Wakimoto, Hiroyuki; Kamimura, Takeshi; Hattori, Kazuhiro; Nekså, Petter; Yamaguchi, Hiroshi.** Visualization and Measurement of Swirling Flow of Dry Ice Particles in Cyclone Separator-Sublimator. *Energies* 2022 ;Volum 15.(11). ENERGISINT
30. **Zotica, Cristina; Forsman, Krister; Skogestad, Sigurd.** Bidirectional inventory control with optimal use of intermediate storage. *Computers and Chemical Engineering* 2022 ;Volum 159. s. - NTNU

Presentations

Search criteria: *From:* 2022 *To:* 2022 *Main category:* Conference lecture and academic presentation *All publishing channels*

1. **Ahrens, Marcel Ulrich; Hamid, Khalid; Tolstorebrov, Ignat; Hafner, Armin; Eikevik, Trygve Magne.** Ongoing research for the utilization of NH3-H2O absorption-compression heat pumps at high temperature operation. High-Temperature Heat Pump Symposium 2022; 2022-03-29 - 2022-03-30. NTNU
2. **Ahrens, Marcel Ulrich; Schlemminger, Christian.** Fallbeispiele für die Nutzung von Hochtemperaturwärmepumpen für thermische Prozesse der Lebensmittelbe- und verarbeitung. Hohenheimer Technologie-Seminar; 2022-03-23 - 2022-03-23. NTNU. ENERGISINT
3. **Ahrens, Marcel Ulrich; Schlemminger, Christian.** High Temperature Heat Pumps - Using Natural Refrigerants in the Food Industry. Norsk Kjøleteknisk Møte 2022; 2022-04-28 - 2022-04-29. NTNU ENERGISINT
4. **Andresen, Trond; Deng, Han; Skaugen, Geir.** Design optimization of a novel heat exchanger concept with varying channel geometries. 15th IIR-Gustav Lorentzen conference on Natural Refrigerants; 2022-06-13 - 2022-06-15. ENERGISINT
5. **Andresen, Trond; Hagen, Brede Andre Larsen.** Natural working fluids in cycles for surplus heat-to-power conversion – Perspectives and history from Trondheim. 15th IIR-Gustav Lorentzen conference on Natural Refrigerants; 2022-06-13 - 2022-06-15. ENERGISINT NTNU
6. **Andresen, Trond; Kauko, Hanne; Moen, Ole Marius.** Selected take-aways from HighEFF research - RA3 Cycles. HighEFF WP leader workshop; 2022-08-25. ENERGISINT
7. **Sæterli, Ragnhild; Beceiro, Jorge Salgado.** Thermochemical storage: The next generation thermal batteries?. SINTEF Workshop on Thermal Energy Storage; 2022-11-10 - 2022-11-10. ENERGISINT
8. **Brækken, August; Ahrens, Marcel Ulrich; Bantle, Michael.** Performance analysis for a dairy - HTHPs and thermal energy storages. High-Temperature Heat Pump Symposium 2022; 2022-03-29 - 2022-03-30. ENERGISINT NTNU
9. **Hafner, Armin; Ahrens, Marcel Ulrich; Hamid, Khalid; Ren, Shuai.** Untersuchungen einer NH3-H2O Hybrid-Wärmepumpen-Testanlage. Deutsche Kälte- und Klimatagung; 2022-11-16 - 2022-11-18. NTNU
10. **Kauko, Hanne.** Den kilowattimen du tenkte ikke kunne brukes. Varmeteknisk konferanse; 2022-05-11 - 2022-05-12. ENERGISINT
11. **Kauko, Hanne.** Industri i det Norske energisystemet – muligheter med overskuddsvarme og termisk fleksibilitet. Energikommisjonen besøker SINTEF og NTNU; 2022-06-15. ENERGISINT
12. **Kauko, Hanne.** Termisk energi i framtidens energisystem. OEDs energi- og vannressursavdeling besøker SINTEF og NTNU; 2022-05-05. ENERGISINT
13. **Kauko, Hanne; Sevault, Alexis.** Challenges and barriers to thermal energy storage. EERA JP EEIP White Paper Launch webinar; 2022-12-13 - 2022-12-13. ENERGISINT
14. **Kauko, Hanne; Sevault, Alexis.** EERA White Paper release: Industrial Thermal Energy Storage. SINTEF Workshop on Thermal Energy Storage; 2022-11-10 - 2022-11-10. ENERGISINT
15. **Schlemminger, Christian.** Hochtemperaturwärmepumpen mit großem Temperaturhub. Deutsche Kälte-und Klimatagung 2022; 2022-11-17 - 2022-11-18. ENERGISINT
16. **Schlemminger, Christian.** Varmepumpeløsninger i industrien. Skala LT-Line Brukerforum; 2022-11-22 - 2022-11-23. ENERGISINT
17. **Schlemminger, Christian; Bantle, Michael; Jenssen, Sigmund.** Industrial high temperature heat pump for simultaneous process cooling and heating. 3ed High Temperature Heat Pumps Symposium (HTHP); 2022-03-29 - 2022-03-30. ENERGISINT
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21. **Sevault, Alexis; Kauko, Hanne.** New White Paper release: Industrial Thermal Energy Storage - Supporting the transition to decarbonise industry. FME HighEFF Webinar Series; 2022-11-02 - 2022-11-02. ENERGISINT
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1. **Kruse, Madita.** Test Report Propane-Butane HTHP – Investigation of a high temperature cascade heat pump as an energy-efficient solution for generating process heat. : NTNU 2022 94 p. NTNU
2. **Røkke, Petter Egil.** HighEFF Annual Report 2021. Trondheim: SINTEF Energi 2022 116 p. ENERGISINT
3. **Thapa, Saroj; Kauko, Hanne; Selvnes, Håkon.** Development of a fossil-free heating system for chicken barns based on heat pumps and thermal storage. SINTEF akademisk forlag 2022. NTNU ENERGISINT
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1. **Røkke, Petter Egil.** intervju ifm Arendalsuka. SINTEF Energi 2022. ENERGISINT

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1. **Kauko, Hanne.** Varmelagring kan gi byer viktig strømsparehjelp. *Dagens næringsliv* 2022. ENERGISINT
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1. **Andersen, Vegar; Solheim, Ingeborg.** Recirculating exhaust gas in silicon production – A step towards carbon capture. SINTEF NTNU
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3. **Claussen, Ingrid Camilla.** HighEFFLab har revitalisert Avvanningslaboratoriet ved SINTEF og NTNU. ENERGISINT
4. **Claussen, Ingrid Camilla.** Laboratoriet for naturlige kuldemedier. ENERGISINT
5. **Nekså, Petter.** Bør jeg kjøpe varmepumpe? Vil det lønne seg?. NTNU
6. **Røkke, Petter Egil.** HighEFF - Making Norwegian industry the world's greenest. ENERGISINT
7. **Røkke, Petter Egil.** HighEFF - Making Norwegian industry the world's greenest. ENERGISINT
8. **Røkke, Petter Egil.** HighEFF Cross Sector Workshop: making plans for the landing and next take-off. ENERGISINT
9. **Røkke, Petter Egil; Kauko, Hanne; Nekså, Petter.** Industrial neighbours can share excess energy. ENERGISINT NTNU
10. **Selvnes, Håkon.** Cold thermal energy storage. NTNU
11. **Selvnes, Håkon.** Cold thermal energy storage: Boosting the efficiency of refrigeration systems. NTNU
12. **Steenstrup-Duch, Anne.** Disse møter du fra SINTEF Energi på Arendalsuka. ENERGISINT

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Search criteria: *From:* 2022 *To:* 2022 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. **Banasiak, Krzysztof.** Bør skifte til CO2 og ammoniakk i kjøleskap og varmepumper. TU [Business/trade/industry journal] 2022-06-28. NTNU
2. **Banasiak, Krzysztof.** Norsk kjøleteknologi reduserer global oppvarming. Mat og marked [Business/trade/industry journal] 2022-06-17. NTNU
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4. **Bantle, Michael.** Rush etter supervarmepumper. NemiTek [Business/trade/industry journal] 2022-05-05. ENERGISINT

5. **Bantle, Michael.** Suddenly everyone wants ‘super-hot’ heat pumps. Norwegian SciTech News [Business/trade/industry journal] 2022-05-31. ENERGISINT
6. **Bantle, Michael; Moen, Ole Marius; Schlemminger, Christian.** The Heat Pump Market, Research and Policy in Norway. IEA HTP [Business/trade/industry journal] 2022-05-31. ENERGISINT
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8. **Claussen, Ingrid Camilla.** Ny nasjonal forskningsinfrastruktur for norsk industri. NordicNews [Newspaper] 2022-05-31. ENERGISINT
9. **Kauko, Hanne.** Hver kilowattime teller. NemiTek [Business/trade/industry journal] 2022-04-05. ENERGISINT
10. **Kauko, Hanne.** Reglene stopper strømkrisehjelp fra vannbåren varme. NemiTek [Business/trade/industry journal] 2022-09-05 ENERGISINT
11. **Kauko, Hanne.** Stor interesse for varmeteknikk. NemiTek [Business/trade/industry journal] 2022-02-15. ENERGISINT
12. **Kauko, Hanne; Sevault, Alexis.** White paper launch: Industrial Thermal Energy Storage. EERA [Internet] 2022-11-28 ENERGISINT
13. **Nekså, Petter.** Disse strømsparetiltakene har i praksis ingen effekt. Vestby Avis [Newspaper] 2022-11-10. ENERGISINT
14. **Nekså, Petter.** Industrien fyrer for kråkene. Aftenposten [Newspaper] 2022-09-10. ENERGISINT
15. **Nekså, Petter.** Norsk industri fyrer fortsatt for kråkene. DN [Newspaper] 2022-09-19. ENERGISINT
16. **Nekså, Petter.** Norsk industri fyrer fortsatt for kråkene. Byggeindustrien [Business/trade/industry journal] 2022-09-09 ENERGISINT
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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 Manager Petter E. Røkke - Petter.E.Rokke@sintef.no
Centre Coordinator Ragnhild Sæterli - ragnhild.saterli@sintef.no

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