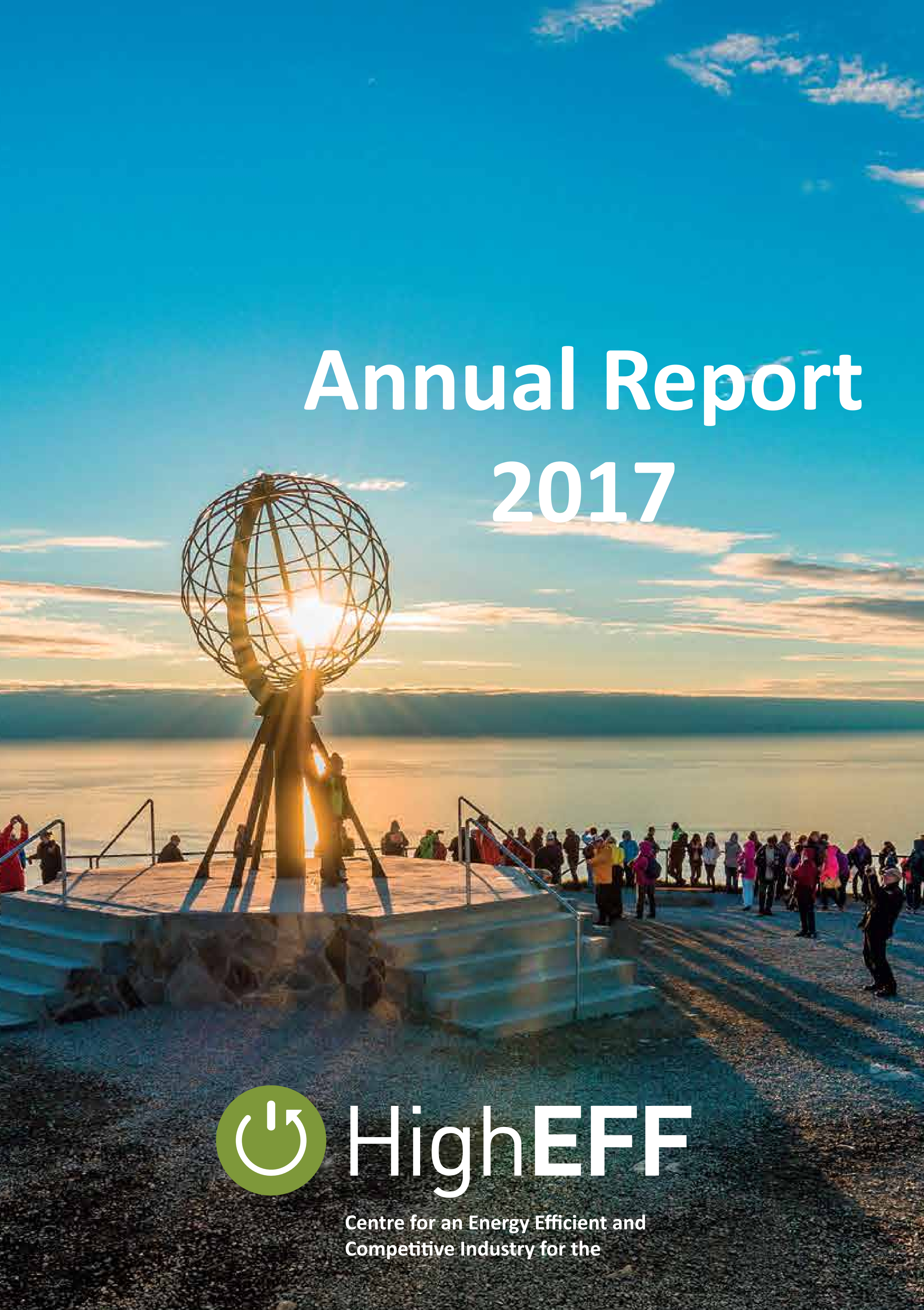


# Annual Report 2017

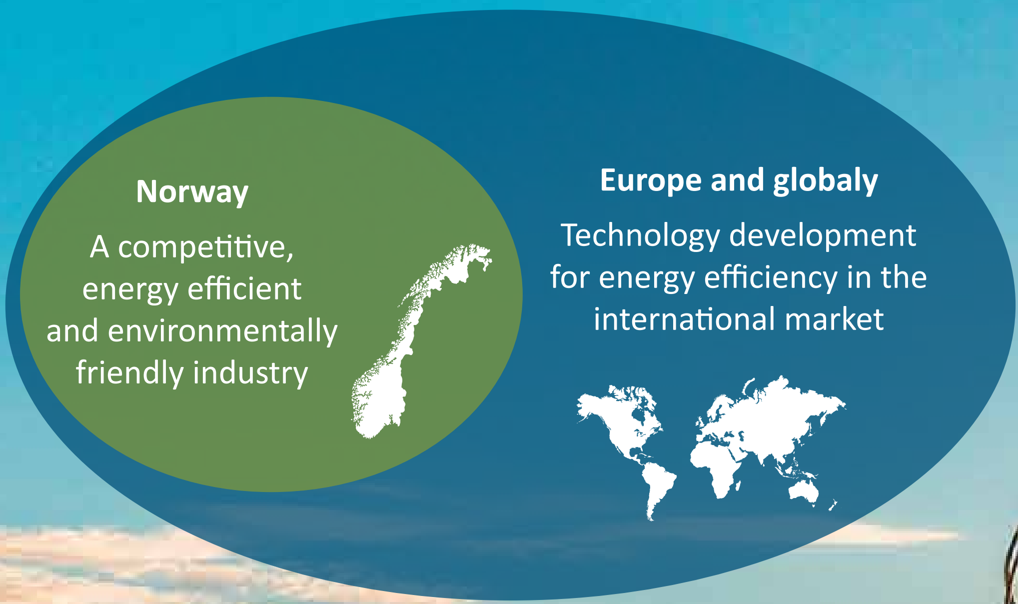
HighEFF

Centre for an Energy Efficient and
Competitive Industry for the

## HighEFF

Energy in different forms – thermal, mechanical, electrical and chemical – and with different qualities is consumed and produced in industrial processes. In addition to optimization of components and processes, there is a need for a holistic approach in order to maximize system energy efficiency and to avoid sub-optimal solutions.

HighEFF will develop future knowledge and technology for an energy efficient industry through fundamental research on thermodynamic systems, heat and mass transfer processes and fluid mechanics. Energy efficiency will be addressed at different levels, from equipment to process, plant, cluster and geographical region; reducing energy use in processes and branches where energy consumption is high and large amounts of surplus heat is available.

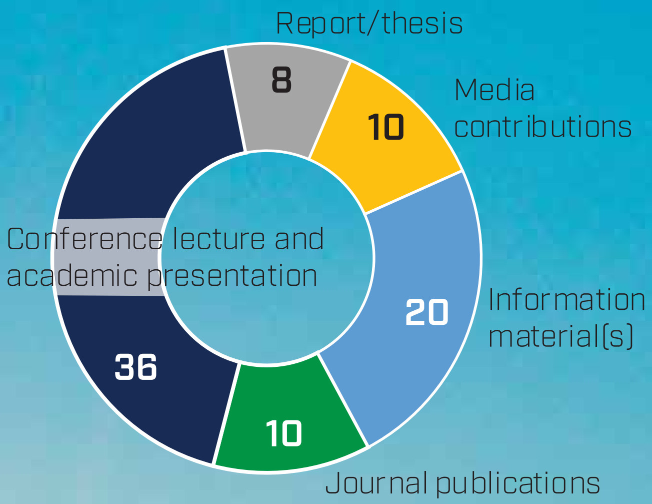


**45** partners

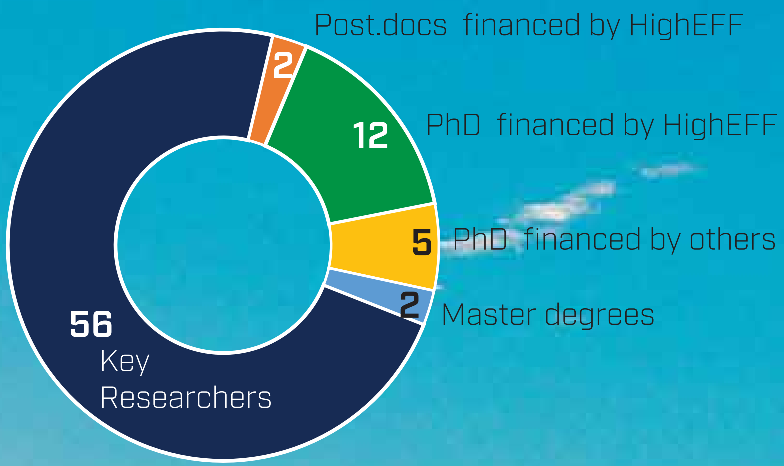
**42,7** million

**8** years

## Publications




## Personnel

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## PETTER E. RØKKE

Petter Røkke is the Centre Director of HighEFF.

His current position is Research Director for the Thermal Energy department in SINTEF Energy Research.

Petter earned a PhD in Mechanical Engineering from NTNU in 2006.
During his career in 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, is currently member of the board for FME Bio4Fuel and member of the EnergiX program board in the Research Council of Norway. Internationally, he is coordinator of the Joint Programme «Energy Efficiency in Industrial Processes» within the European Energy Research Alliance.

# Message from the Director

Welcome to the first annual report from FME HighEFF!

Even though we formally started up late 2016 with contract negotiations and kick-off meeting, 2017 was the first "normal" operative year for FME HighEFF. From this report you can now see that the *joint effort for creating a competitive, energy efficient and environmental friendly industry for the future* is well in progress.

From my point of view, I am glad to see that there is significant interaction between the R&D partners and the user partners of the Centre. Both when it comes to influencing the contents and plans for the Centre in the continuation and when it comes to the specific R&D performed. In particular, the case studies of Research Area 6 (RA6) attracts interest and contribution from user partners and we have made visible examples of what the potential impact of using best available technology and optimizing the processes can be for specific cases for our user partners (e.g. case study for Tine).

14 PhDs and Postdocs have already been employed within the Centre and all are well in progress with their research. We have seen presentations from these both in technical meetings and in discussions with the consortium.

An important aspect for all activities within FME HighEFF is communication of all the results between our partners as well as to the society. We will during 2018 focus even more on popular communication in addition to the scientific part. FME HighEFF has the ambition to become a visible actor and a knowledge base for the public debate and society.

During 2017 we arranged two workshops for the consortium and we will do the same in 2018. I hope to see, meet and talk to all the partners during these workshops. The next workshop is planned for 2$^{nd}$ and 3$^{rd}$ May 2018, in Trondheim. In this workshop we are planning input from our international partners, strategic discussions, PhD/Postdoc sessions and some specific more technical parts.

I hope you find this annual report interesting and share it internally in your company!

## ARNE ULRIK BINDINGSBØ

Arne Ulrik is Chairman of the HighEFF Board.

His current position is Leading Researcher, Energy efficiency and $CO_2$ reducing technologies, Research & Technology, Statoil.

Arne Ulrik Bindingsbø earned a PhD in Materials Science from NTH in 1992.

He has more than 25 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 Operations & Maintenance. As the field of O&M consists 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, Department of Marine Technology, NTNU.

# Message from the Chairman of the Board

Improved energy efficiency is expected to play a crucial role in protecting the global environment. Significant changes in both production and consumption of energy are needed to avoid a global temperature rise of more than two degrees.

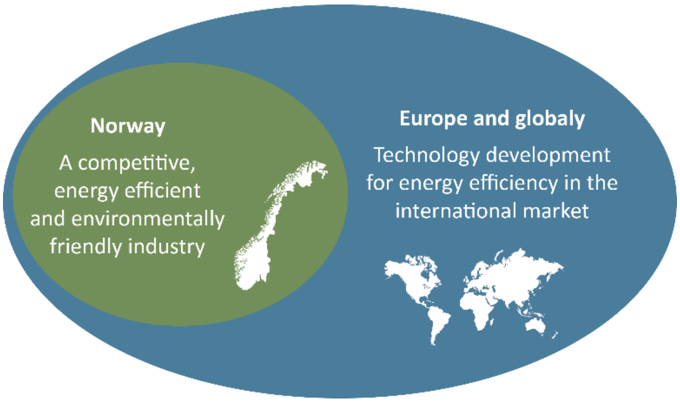
The Norwegian land based industry and offshore oil & gas production are already among the world leaders in energy efficiency compared to similar industries in other countries. Nevertheless, the greenhouse gas emissions from these operations account for a large part of Norway's total emissions. There is a need for technology development and subsequent implementation to further increase the energy efficiency and reduce the greenhouse gas emissions.

The HighEFF mission started in late 2016 with a vision to create a competitive, energy efficient and environmental friendly industry for the future. Together, we are more than 45 universities, research institutions and industrial partners working together to achieve this vision. Our strength is in the cross industrial collaboration with all the largest industry sectors in Norway: material and metal producing industries, oil, gas and energy industry, food and chemical industry as well as industry clusters with different sectors.

We have already identified significant energy efficiency potentials through the completed case studies and will pursue these and others further by developing and implementing both new and existing technologies and processes.

## Vision

***Joint effort** for creating a competitive, energy efficient and environmental friendly industry for the future*




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

The EU has energy and climate targets of 40% reduction in greenhouse gas emissions and 27% increase in energy efficiency by 2030. 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. For instance, if one industrial plant can be more energy efficient, there will be more available energy for other purposes. Also, Norway 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.

HighEFF will build an internationally leading Centre for strategic research within industrial energy efficiency. For one thing, HighEFF will enable a 20-30% reduction in specific energy use and 10% in emissions, hence, supporting the EU energy targets. HighEFF will also allow value creation for the Norwegian industry by developing 15-20 new innovative solutions for energy and cost-efficient plants, energy recovery and utilization of surplus heat, and develop methods and tools for analysis, design and optimization of energy efficient systems.

## Goals

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

- Enable 20-30% reduction in specific energy use and 10% in emissions through implementation of the developed technologies and solutions, hence support the EU target of 40% reduction in greenhouse gas emissions and 27% increase in energy efficiency by 2030.
- Allow value creation for the Norwegian industry by developing 15-20 new innovative solutions for energy and cost-efficient plants, energy recovery and utilization of surplus heat.
- Develop methods and tools for analysis, design and optimization 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/Post.doc candidates, 50 MSc candidates, and training/recruitment of 30 experts in industrial energy efficiency.
- Disseminate and communicate project results; 150 journal articles and conference papers.

# Research Plan and Strategy

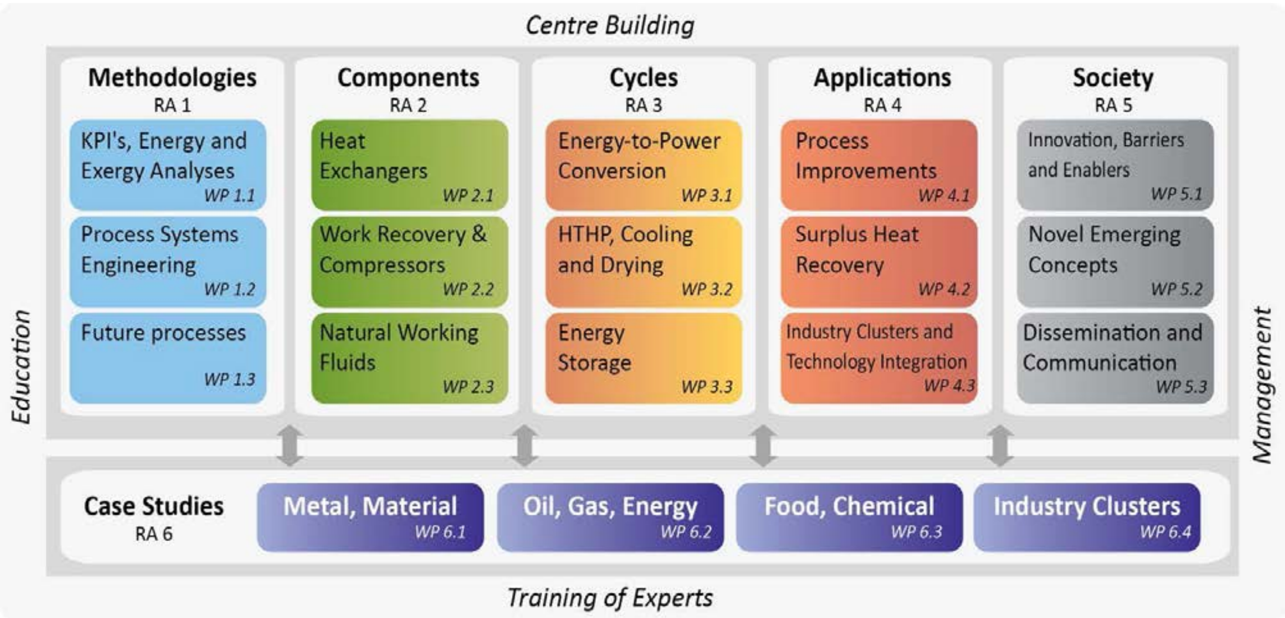
## Research Plan

The research topics covered by HighEFF require in-depth studies of fundamental aspects related to research on thermodynamic systems and operation, heat and mass transfer processes and fluid dynamics, in addition to social science. The fundamental knowledge is implemented in development of components, cycles and applications.

HighEFF addresses the research and development areas in 6 *Research Areas (RA),* with a special focus on industry related case studies in RA6 where measurable results from the implementation of HighEFF technologies in the different industry sectors is obtained. Sector-based workshops are arranged to identify the path for concept development and the key areas where undertaking energy efficiency measures is likely to give the most significant impact. The KPIs and energy and exergy analyses from RA1 will be utilized in making these decisions. The case studies give input to the innovation strategies and roadmaps in RA5 as well as to the concepts studied in RAs 2-4.

To ensure collaboration and exchange of results across the RAs and WPs, researchers from academia and research institutes are working closely with industrial experts. The research methods include lab experiments, industrial measurements and pilot plants, as well as modelling efforts at different levels for simulation and optimization. Fundamental technological R&D involving thermodynamics, kinetics and transport phenomena are conducted for increased insight and competence building that could act as a catalyst to innovation. The international partners participate in research and education activities.

Education on PhD and Post-doc level, as well as on a Master level, is an important part of the centre activity.



## Innovation Strategy

Innovation and new ideas are best created at the interface between different research communities, industrial end-users and vendors. HighEFF will create a dynamic interface and thereby contribute to innovation and value creation within our cross-sectorial cooperation among the 45 partners. Through participation from Innovation Norway and Enova, the innovation processes will be further stimulated and bridge the market and state-of-the-art technology.

An innovation plan and measures to improve innovation awareness is of importance for HighEFF to succeed with innovations. Already in the proposal, 20 potential innovations were indicated. Innovation can be a product, a technology, a component, a process or sub process, a model or sub model, a concept, an experimental rig or a service that is new or significant improved with respect to properties, technical specifications or ease of use. Innovation can also be new applications of existing knowledge or commercialization of R&D results. The innovation should be adopted by somebody, or be ready for utilization provided that it is made probable that the innovation will be utilized within a limited timeframe. A culture of innovation is facilitated by arranging annual workshops and conferences where the needs of industry and expertise of academia are merged. Subsequently, innovation strategies and technology roadmaps will be written for each industrial sector guiding the direction for R&D and innovation. To reinforce the innovation potential HighEFF has allocated 1.5 MNOK/year for funding Novel Emerging Concepts related to the HighEFF research and innovation objectives within emerging, energy efficient and cross-sectorial technologies for the participating industrial sectors (Metal and Materials - Oil, Gas and Energy – Food and Chemicals).

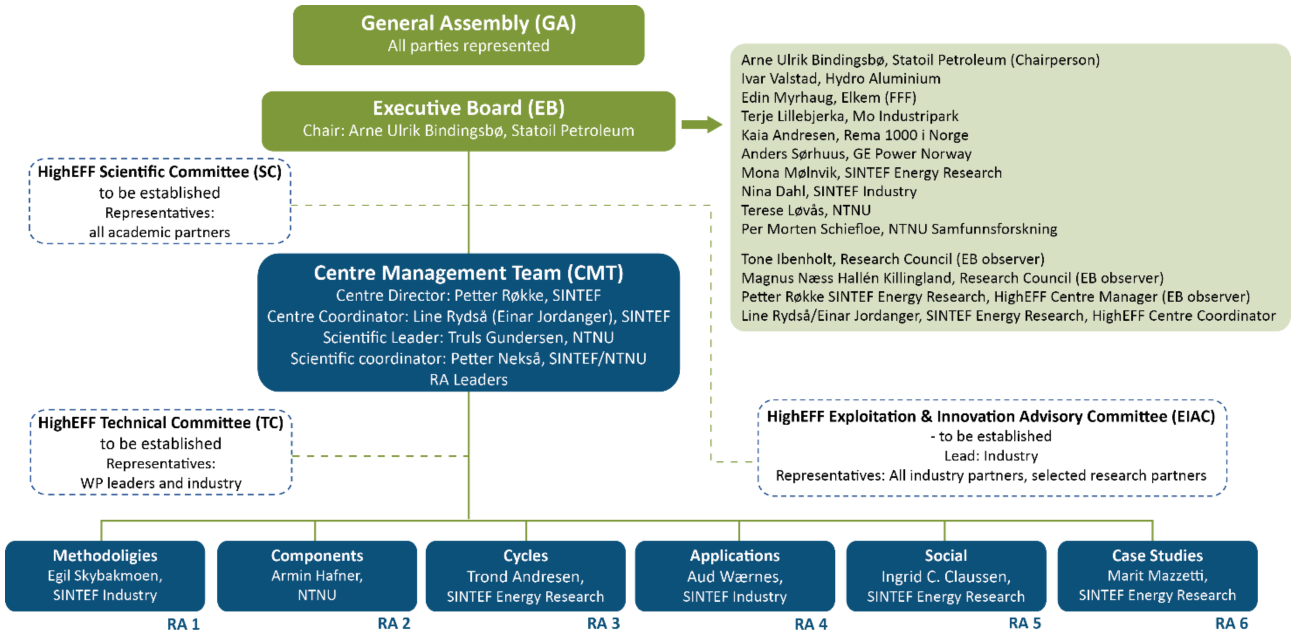
An introduction to an innovation potential assessment shows some general issues worth considering when planning for innovation potential management in HighEFF and FME Centres in general, and these are;

- Innovation expectations
- Reliance on vendor industry for innovation realization
- External framework conditions- markets and regulations
- Dynamic financing in the Centre
- Broadness vs focus
- Spin-offs vs in-house realization
- FME and IPRs (Intellectual property rights)

Differences in expectations, both between industry partners and between research – and industry partners could evolve into conflicts of interest if not addressed early. Therefore, HighEFF will aim to on an early stage define expected innovation and build a strategy for supporting the realization of the idea/activity.

# Organisation and Location

## Organizational Structure




FME HighEFF is hosted by SINTEF Energy Research and the Centre Director is Petter E. Røkke. The General Assembly (GA) where all partners (31 industry partners and 14 research partners) and the Executive Board Chair are represented, makes decision 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 approved the members of the Executive Board (EB) and Arne Ulrik Bindingsbø (Statoil Petroleum) was appointed Chair of the EB at the first GA meeting in June 2017. In addition to Arne Ulrik Bindingsbø, the other members of the EB are Ivar Valstad (Hydro Aluminium), Edin Myrhaug (Elkem/FFF), Terje Lillebjerka (Mo Industripark), Marianne Fossum/Kaia Andresen (REMA 1000 Norge), Anders Sørhuus (GE Power Norway), Mona Mølnvik (SINTEF Energy Research), Nina Dahl (SINTEF Industry), Terese Løvås (NTNU), and Per Morten Schiefloe (NTNU Samfunnsforskning).

The Centre Management Team (CMT) consists of the Centre Director Petter E. Røkke (SINTEF Energy Research), Centre coordinator Line Rydså (Einar Jordanger, deputy), 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 Marit Mazzetti (SINTEF Energy Research). The CMT is responsible for the strategic and executive centre management, including issues relating to coordination between work packages, and centre performance such as support functions that will be part of the daily operations and management. CMT will arrange regular meetings as required for coordinating the activities in the Centre. The Centre management reports on scientific, technical and financial matters as well as actual progress relating to EB.

**Methodologies**
RA1

**Egil Skybakmoen**
SINTEF Industry

**Components**
RA2

**Armin Hafner**
NTNU

**Cycles**
RA3

**Trond Andresen**
SINTEF Energy Research

**Applications**
RA4

**Aud N. Wærnes**
SINTEF Industry

**Society**
RA5

**Ingrid Camilla Claussen**
SINTEF Energy Research

**Case Studies**
RA6

**Marit Mazzetti**
SINTEF Energy Research

**Scientific Coordinator**

**Petter Nekså**
SINTEF Energy Research

**Scientific Leader**

**Truls Gundersen**
NTNU

FME HighEFF Centre management is located at NTNU Gløshaugen in Trondheim.

In addition to the above-mentioned structure, HighEFF also have a Core Team (CT) consisting of the Centre Director, Centre Coordinator, Scientific Leader and the Scientific Coordinator, discussing matters concerning budget, educational activities and other scientific topics.

## Partners

### Research & Education Institutes

| | | | |
|---|---|---|---|
| SINTEF Energy Research | Norwegian University of Science and Technology | SINTEF Industry | NTNU Samfunnsforskning AS |
| Nord Universitet | SINTEF Ocean | Kungliga Tekniske Högskolan, KTH | Carnegie Mellon University |
| The University of Manchester | Shanghai Jiao Tong University | AIT Austrian Institute of Technology GmbH | Doshisha University |
| Massachusetts Institute of Technology | | | |

### Vendors & Technology providers

| | | | |
|---|---|---|---|
| Danfoss AS | EPCON AS | Officine Mario Dorin | Parat Halvorsen AS |
| Mayekawa MFG Co., Ltd | Kuldeteknisk AS | Hybrid Energy AS | Cadio AS |
| OTECHOS AS | Alfa Laval Corp AB | | |

## Enablers

| | |
|---|---|
| ENOVA | Innovasjon Norge |

## User Industry

| | | | |
|---|---|---|---|
| Statoil Petroleum AS | Aker BP ASA | Gassco AS | GE Power Norway AS |
| Finnfjord AS | Hydro Aluminium AS | Eramet Norway AS | 56 Norsk Alcoa AS |
| Elkem AS | Glencore Nikkelverk ASA | Glencore Manganese Norway AS | Marine Harvest ASA |
| Mo Industripark AS | Bulk Infrastructure AS | Wacker Chemicals Norway AS | Borregaard AS |
| Rema 1000 I Norge AS | Tine SA | Orkla AS | Vedde AS, member of TripleNine Group |

## How we work together

The vision of HighEFF strongly rely on creating good arenas for cooperation between industry, academia and research partners. Our vision is founded on the words of Professor Arne Bredesen, stating that excellent research best can be produced through three means: Knowledge-Friendship-Teamwork. HighEFF will build upon and bridge the good means through common goals, joint research and teamwork.

All partners are able to contribute to the technical discussions and take part in research activities, and affect the direction and ambitions for the next year's work plan. There are many arenas for technical discussions and initiating new activities.

In addition to all the meetings for specific sectors, research areas, topics, activities or tasks, 2017 saw the following larger meeting places and workshop open for all partners:

- 4 *Sector Workshops*, dedicated to relevant topics for each of the industry sectors in HighEFF
- *Cross-sector Workshop,* highlighting both the sector-specific and the wide-relevance technology development, barriers and enablers
- Annual Consortium meeting

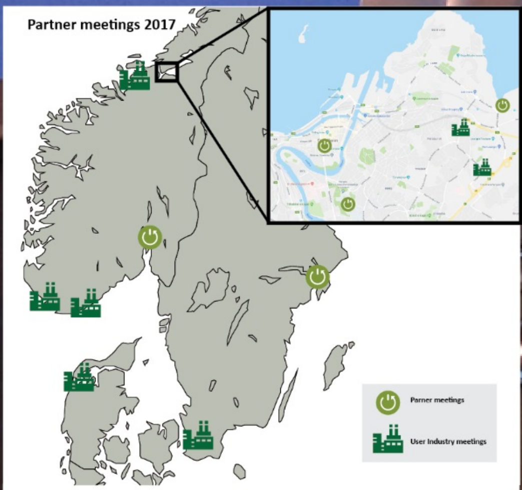
To ensure that all suggestions and input to research tasks are taken into consideration, the Scientific Coordinator will have the overall overview of the process.

2017 has been a very good start for cooperation, and the years to come may hold even more:

- An annual internal PD and PhD workshop for the entire center is planned from 2018
- Industry partners hosting open workshops is under planning

Centre management and the decision-making groups have consistent meeting frequencies:

- Executive Board (EB)- 5 meetings in 2017
- General Assembly (GA) – 1 meeting in 2017
- Centre Management Team (CMT) - every 3rd week
- RA Work meetings

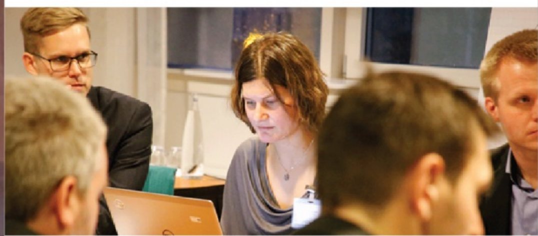



Some HighEFF partner-meetings and site visits in 2017, related to ongoing research activities. Many more will surely follow in the years to follow.


Anne Karin Hemmingsen (SINTEF Energi), Annual Consortium meeting 2017

Participants at the HighEFF Kick-off meeting november 2016

RA6 presentation
(Marit Mazzetti, SINTEF Energi in front)



RA3 group work at the HighEFF Kick-off meeting

HighEFF visit at Glencore Nikkelverk.
From left; Torjus Åkre (Glencore), Ole Edvard Kongstein (SINTEF Industri), Trond Andresen (SINTEF Energi), Egil Skybakmoen (SINTEF Industri)

# HIGHLIGHTS

## Research Infrastructure (HighEFFLab)

In June 2017 the National Laboratories for an Energy Efficient Industry (HighEFFLab) was granted a total amount of 50 MNOK funding for upgrading and investments in research infrastructure needed for technological development in the areas of industrial energy efficiency, where large reductions in specific energy use and emissions can be expected: energy efficient processing and surplus heat utilization. HighEFFLab will include infrastructure for experimental development of equipment for improved utilization of available industrial surplus heat and a reformation of the efficiency in various industry processes.

HighEFFLab will provide the advanced research facilities required to fulfil the goals of FME HighEFF: Enable 20-30 % reduction in specific energy use and 10 % reduction in climate gas emissions for the Norwegian Industry.

Developing and testing advanced Components such as novel heat exchangers for heat capture, energy transfer and heat recovery. Cycles and applications to maximize energy efficient processing such as high temperature heat pumping technology or surplus-heat-to-power processes


*SINTEF researcher Christian Schlemminger and Michael Bantle are installing a propane-butane cascade heat pump with prototype compressors from Dorin. The installation can deliver hot water at 115 °C without the use of fossil fuels and is 2.5 times as energy efficient as direct driven boilers.*

HighEFFLab is a joint national laboratory between various departments at SINTEF and NTNU. The facilities will be located at the NTNU Gløshaugen campus in Trondheim, ensuring close collaboration between students and researchers coupled to the university. The RI will be accessible for all the partners in HighEFF.

HighEFFLab

**HighEFFLab installations:**

- The Heat Exchanger Laboratory
- The Expander Test Laboratory
- The Natural Refrigerant Laboratory
- The Dewatering Laboratory
- The Gas and Material Characterization Laboratory

**Facts:**

- 5-year project
- Hosted by SINTEF and NTNU
- Total funding from the Norwegian Research Council 50 MNOK

**www.sintef.no/highefflab**

## Research Activities and Results

### Evaluation of fully integrated industrial refrigeration and HTHP systems

Karoline H. Kvalsvik (MSc), SINTEF Energi

**Find a new solution for a more energy efficient dairy plant in two weeks**

HighEFF was given two weeks to evaluate several solutions for the energy system of a new dairy plant in Bergen, meant to replace the older, too small existing plant and be much more efficient, to reach TINE's ambitious climate goals. The suggested HighEFF concept was to use integrated heat pumps, which combines the need for heating and cooling for the production processes at different temperature levels. Cooling is removal of heat, and this is used as a heat source for a heat pump, which transforms this removed, surplus heat to another temperature level and delivers heat where needed (heat sink).

To find an as efficient solution as possible, calculations involving comparison of seven different options, the standard solution today and six more innovative ones, were performed. All utilized surplus heat from the cooling system, but had different ways of utilizing this heat; some utilized heat directly, others used an indirect system. This is a more normal, accepted solution, but generally less effective. Some solutions included a propane/butane heat pump to deliver heat to 102°C, some included a hybrid heat pump instead. There are few heat pump technologies that currently can reach such high temperatures.

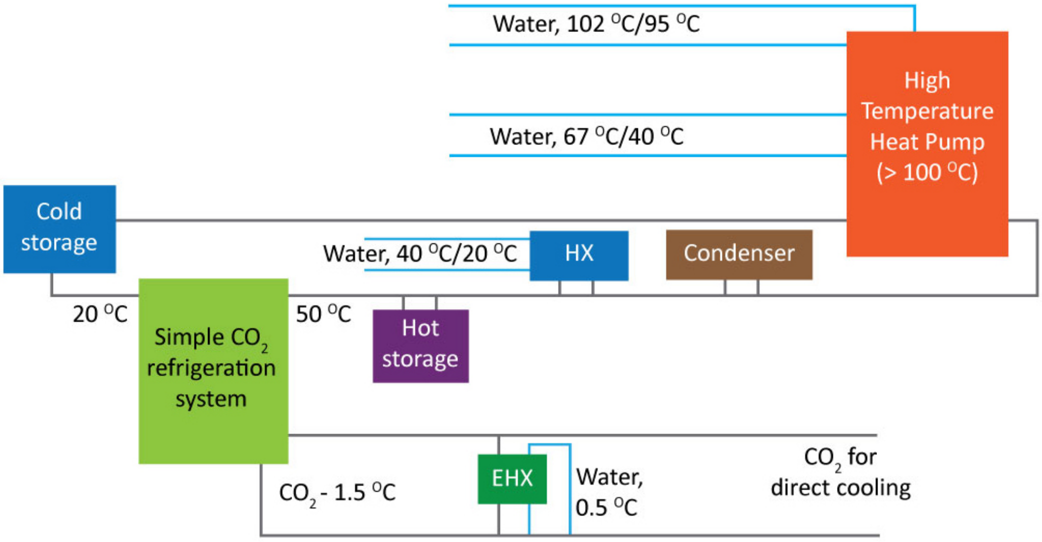
**Calculations showed promising results using High Temperature Heat Pump**

The savings are mainly obtained from the:

- Integration of heating and cooling demand
- Large energy storages
- Use of a high temperature heat pump

This is how the new dairy in Bergen will look like, with higher capacity and high energy efficiency…

Estimated savings also benefitted from the use of a highly efficient refrigeration system, but this was not chosen due to the higher costs. The expected savings are thus a bit lower than calculated, but should be in the same range.




All solutions involved efficient, direct cooling with $CO_2$, and indirect for the processes, energy storages and two different types of high temperature heat pumps. They differed in choice of direct/indirect heat transfer, temperature levels and type of heat pump. The storages are vitally important, because cooling and heating demands do not necessarily occur simultaneously, and hence, surplus heat must be stored until it is needed, or otherwise it must be wasted. The heat demands must then be covered by other heat sources (district heat in this case), and no energy savings are obtained.

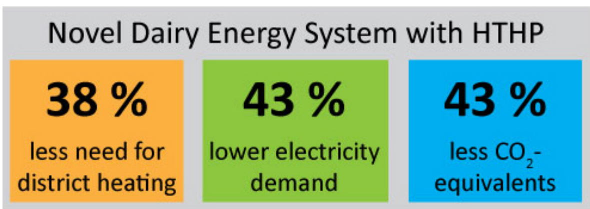
**The chosen solution is one of those with highest savings and technological maturity.**
The energy system will have district heat as backup and deliver heat and cold at three different temperature levels.

The focus of HighEFF is on research that benefits all partners, and evaluate individual concepts which can be transferred to other sectors or industries. The strong eagerness to start implementing more environmentally friendly solutions (now!) and the high calculated savings are clearly good news.
The result of the industry pushing us researchers have this year resulted in three Enova-applications for funding and implementation of suggested energy efficient solutions. This project is now granted funding, and it is to be built during the two nest years, starting operation by the end of 2019.

**This project is part of the HighEFF RA6 Case studies.**

**GOAL**
Obtain measurable results from the implementation of HighEFF technologies in the different industry sectors

**OBJECTIVES**
- Develop technology concepts that can lead to a 20-30% reduction in specific energy use and minimum 10% in $CO_2$ emissions for each case through implementing technologies and solutions
- Improve energy effectivity & energy efficiency in industrial plants
- Promote HighEFF innovations through spurring development of novel concepts based on needs of Case Industry partner



# Saving the cold for later: Decoupling supply and demand

Håkon Selvnes, PhD student at NTNU

**Energy efficiency is a challenge. Due to large variations in the need for cooling, the refrigeration system operates few hours on maximum installed capacity. As a result, refrigeration systems are mostly over dimensioned for daily operation and uses more electricity than what is necessary. HighEFF is working on a solution to this challenge: CTES technology.**

Refrigeration systems surrounds us in our daily life and are a crucial part of modern society. The applications range from providing satisfying indoor comfort by air-conditioning, to ensuring good food quality at supermarkets and in refrigerators at home. According to the International Energy Agency, the demand for cooling worldwide is expected to rise significantly in the coming decades, especially due to requirement for air conditioning in developing economies as standards of living rise. Designing flexible and energy-efficiency refrigeration systems will therefore be very important to limit the energy use and carbon footprint of the sector.

**The challenge**

So, what is the challenge in designing refrigeration systems for efficient operation? In many industrial systems, the demand for cooling forms distinct peaks in energy consumption during the day, following the amount of product that goes through the plant. The maximum capacity peak demands usually last for a very short time, meaning the system operate at low capacity for most of the time. Moreover, since the refrigeration system is designed for giving best efficiency at full capacity, part-load operation gives lower efficiency. The result is an increase the energy use of the system. What is then the solution to this? PhD-candidate Håkon Selvnes argues that one possible solution is to use cold thermal energy storage (CTES). Storing some of the cooling needed for peak hours in advance can give better flexibility for plant owners, and in addition provide the opportunity to reduce the installed capacity of the system.

**Old technology**

Storing cold energy in ice is a good example on how a system of CTES can work, as it changes phase from liquid to solid at 0 °C. Storing ice for cooling purposes has been going on for nearly as long as man has walked this earth. Before the development of refrigeration technology, we had to cut the ice from frozen lakes during the winter and then store it until it was needed. The Persians learned how to store ice for food conservation in special caves in the middle of the desert as early as 400 BC. As technology has advanced, providing cooling for our demands has been industrialized. The current research now focuses on the possibility to use phase-change materials, also known as PCMs, for storing cold energy at temperatures even lower than 0 °C for cooling and freezing applications. PCM is the term given to materials where the latent heat capacity is actively taken advantage of to store energy. Typical product temperatures in food processing plants are +2 °C for cooling and -40 °C for deep freezing. Therefore, direct integration of a cold thermal energy storage in a modern industrial plant will require materials with lower phase-changing temperatures than water.

Even though the plan is to explore more exotic materials than water to use as PCM, the primary focus for the research is to use water for the initial testing. It is an excellent starting point for a PCM as its non-toxic, cheap, available and its thermal properties are well known. After successful experiments with water, the technology will be tested for a variety of other PCMs. Materials with phase change temperatures in the range from 0 °C down to -50 °C are of interest for the project. This can be obtained by mixing in a salt in the water, usually calcium chloride or sodium chloride, which lowers the freezing point of water depending on the concentration of the salt.

**Preparation is the key**

The basic idea is to use the refrigeration equipment in the plant to charge the storage during the night, when the demand for cooling in the plant is low. The PCM in the storage exchanges heat with the refrigeration system and becomes a solid. As the working day starts and products begin to move through the plant, refrigeration demand rises. Then the solid PCM in storage can be used to handle a part of the cooling demand, and consequently melts to liquid again. The process is then repeated every day through the working week.

When you want some ice in your drink on a hot summer day, it is more convenient to have some in the freezer at home than to go to the nearest supermarket to buy it. The very same principle applies to a CTES system in a large-scale operation. You are better prepared for warm days and large product batches to process with some of the cooling needed already in storage.

**The chicken factory**

Testing of the technology is ongoing at the refrigeration laboratories at NTNU. The group of researchers working with the project is excited to see the results and have big plans for the new CTES storage modules.

The plan is to test the technology in full scale after the testing of finish the pilot testing in the lab. PhD candidate Håkon Selvnes is writing his thesis on cold thermal energy storage. REMA 1000 is one of the leading supermarket chains in the country and an industrial partner in HighEFF. They are in the planning phase of building a huge poultry processing plant in central Norway, and they have very high ambitions on using the latest technology to be best in class of similar plants. This is the perfect case example where a CTES technology can be implemented. The cooperation between the researchers and the industry is very important to develop technology that has high potential and is interesting to the users. The goal is to introduce the new CTES system in the new poultry processing plant, to show a real-life application of the technology.

**Many benefits**

There are many benefits of shifting the load to off-peak hours by using a CTES system:

- The CTES can offer backup cooling in case of a power short out
- Gives plant owners the flexibility to use electricity when it is cheapest on the market
- Reduces the load on the electrical grid, postponing large investments for grid companies
- Enables use of renewable energy when it is available, lowering the $CO_2$ footprint
- Stabilizing the load on the refrigeration system, making it possible to run it more efficiently, reducing the electricity consumption in the plant

The researchers are eager to get satisfying results from their testing, and hope that they can convince plant owners to go with the technology. The plant owners are the ones who finally decides whether to invest in the technology or not, so the technology should be competitive and cost-efficient. That is why testing in the lab is very important. Nobody would buy a new car if there where uncertainties whether it drives or not. Håkon is excited to see what the upcoming months will bring. He indicates that if the system performs as predicted, it could be a real game-changer. A success in this project will encourage other plant owners to consider the technology as well. This research fits very well within the vision of NTNU: "Knowledge for a better world"

## Potential uses of CO-rich off-gas from Mn ferroalloy production

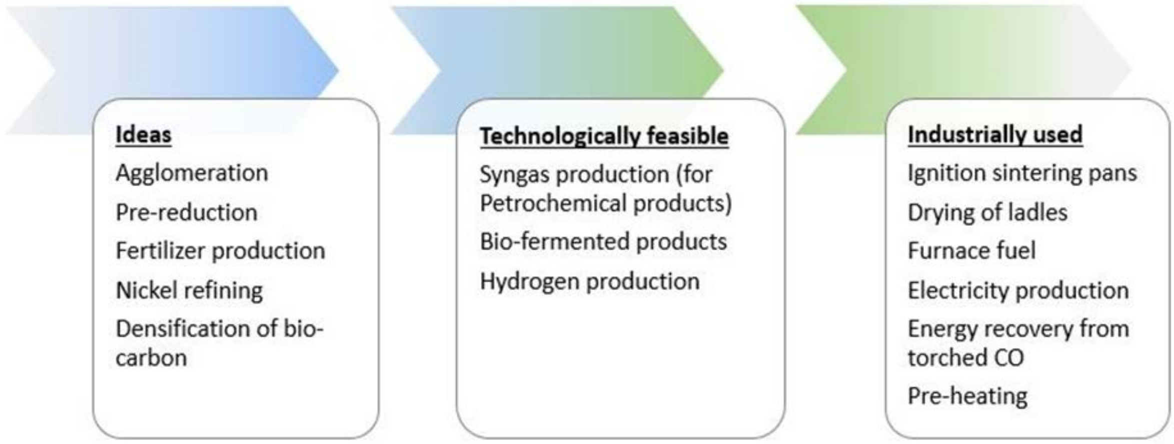
SINTEF Report No 2018:00171 by I.T. Kero, H. Dalaker, S. Fosse-Håkonsen and R.Khalil

Ida T. Kero

**Mapping a landscape of possibilities**

In the FME HighEFF, a number of case studies will be carried out in the research area (RA) 6 for the Materials and Metals sector. In 2017, funding from work packages 6.1 and 6.4 are combined in one case study on the possible ways to utilise CO-rich off-gas from Mn ferroalloy production. A way to make use of the large and diverse consortium was to collect ideas on potential uses for CO gas. An e-mail was sent out in the FME consortium in an attempt to collect and identify unconventional and "crazy" ideas. In addition, the task would summarize the more conventional lines of thought for solutions which may serve as a basis for new business opportunities.

It is clear from the current report that it is possible to use CO gas for many things, including some exciting new opportunities. The report identifies, however, a number of risks, challenges and possible show stoppers. Gas composition (purity) will be an important issue for several applications. For many applications, it will be necessary to address the challenges connected to variations in gas pressure, availability and composition. Nonetheless, there are good reasons to pursue many of the ideas listed herein.

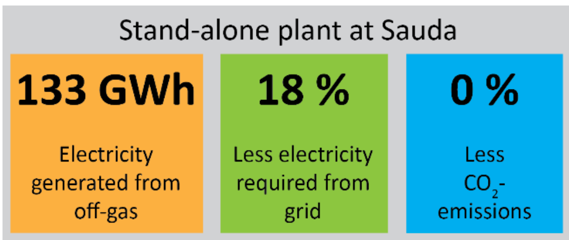



**Off gas utilisation example: Stand-alone plant at Sauda**

Currently, the CO-rich furnace off-gas is flared but the combustible gas can be burned for thermal power generation instead, reducing the electricity bought from the grid by 18%.

Power generation would not result in lower greenhouse gas emissions but in significantly improved gas utilisation and energy efficiency of the plant.

Thermal power plants for flue gas are commercially available and off gas with around 60% CO have reportedly given efficiencies of around 37% for power generation.



## Methodologies (Research Area 1)

The main objective of Methodologies is to improve existing, and develop new, methodologies for improved energy efficiency in industrial plants. This requires close interaction with industry and the outcome will be disseminated and applied in other Research Areas.

In Methodologies, we believe that technological enhancements are better drivers of innovation than cost reductions. 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 market will be closely considered in our work.

www.sintef.no/higheff-ra1

Process Systems Engineering (PSE) includes methods and tools for modelling, simulation, design, optimization, control and operation of process plants, all from a systems viewpoint. PSE could hence be seen as a “toolbox” in the search for increased energy efficiency.

Within Future Process Frameworks we intend to create new ideas and innovations for possible new processing concepts and/or clusters of different processes relevant for the HighEFF partners.
The results from RA1 should be disseminated and applied in other RAs, in particular RA3, RA4 and RA6. The work in RA1 will require strong interaction with industry to define relevant cases for evaluation and further development of methods. Such data will be collected in close collaboration with RA6 Case Studies and RA4 Process Improvements.

**Results 2017**
Recruitments of PhD students (5) and PDs (2) is in place at NTNU. Together with SINTEF and MIT resources this has result in a very good and impressive publication production with 7 journal papers and 10 proceedings/papers for conferences. International collaboration is established with UoM and MIT and will be even more strengthen the coming years. Participating with MIT/Prof. Barton in development of a new paradigm for simulation and optimization is established. The work is non-smooth analysis for (hybrid)modelling and applied to LNG processes. Work and heat integration is established as a new field. A special session was organized at PRES’2017 in Tianjin and was appointed to be the “highest attended and best session of the conference.”

*KPIs, Energy and Exergy Analyses:*
One important task for RA1 is to use relevant KPIs for energy and resource efficiency. Internal meetings, as well as the 3 workshops arranged by RA6 case studies, have been very useful to define and evaluate different methods. Discussions and work regarding KPIs and usage of exergy metrics is published in journal (draft version for reviewing) as well as reported in own report. This work will be continued in closer co-operation with HighEFF members in 2018 and coming years. A workshop is planned to be arranged with industrial partners in 2018.

*Future Processes:*
Production of aluminium is a very energy intensive process and emits also huge amounts of $CO_2$. Inert anodes (non-fossil carbon) have been evaluated as an alternative process. However, inert anodes will use 3 MWh/t Al more DC energy consumption than carbon anodes. Hence then the energy source for Al production will be essential for lowering the $CO_2$-footprint. Only usage of renewable energy sources will give less $CO_2$ emissions with inert anodes. Usage of carbon anodes with CCS technology consumes less power than inert anodes. A truly inert anode has not yet been developed. The paper "Inert Anodes – the Blind Alley to Environmental Friendliness?" will be presented in a large international conference (TMS) in March 2018 with all the worlds Al producers to be present.

## Components (Research Area 2)

The main objective is to develop components required for cost-effective implementation of efficient systems for heat pumping and conversion, with main focus on the categories heat exchangers, compressors and work recovery.

To achieve these goals, we develop methods and tools required for designing components and cycles with natural working fluid mixtures; thermodynamic properties, system optimization, and experimental development. The research area also perform design, support integration and maintain flexible component test facilities for the HighEFFLab infrastructure.

www.sintef.no/higheff-rA2

**Results 2017**

*Heat Exchangers:*

Heat exchanger for cold thermal energy storage (CTES), applicable for display cabinets in supermarkets, has been developed and implemented into a dedicated $CO_2$ laboratory refrigeration cycle. The CTES will increase the performance of display cabinets and enable power peak shaving.

A new laboratory rig, financed by the infrastructure project HighEFFlab, for testing of heat exchangers used in low temperature heat to power applications is under planning. A pinch point analysis of relevant hydrocarbon working fluids with low ODP and GWP has been performed to investigate which working fluids are the most interesting for testing in the laboratory rig and the optimal operating conditions for these.

*Work recovery & Compressors:*

Design and testing of Multi-ejector expansion modules**,** intended as a substitute for standard high-pressure electronic expansion valves, for performance mapping of four ejector cartridges is completed. Results shows that four ejector geometries perform their vapour compression duties efficiently within the assumed range of operating conditions, offering the highest ever recorded values of ejector efficiency up to 36.8%. the liquid compression reduces the effectiveness significantly, where the highest recorded recovery values of ejector efficiency were equal to 12.6%.

The propane - butane High Temperature Heat Pump test facility has been installed successfully and delivering heat sink outlet temperature of 116 °C. The R600 compressor from DORIN is functioning within expectation with a total compressor efficiency of 71%.

*Natural Working fluids:*

In the evaporator/sublimator process of $CO_2$ (R744) ultra-low temperature cascade heat pump system, it is known, as a problem, that dry-ice blockage makes the system operation fail. The design of an expanding channel for the evaporation/sublimation process is one solution to solve the problem. In order to give better understanding to heat transfer process in the refrigeration system, particular attention is focused for $CO_2$ dry-ice solid-gas two-phase flow to obtain the effectivity of heat transfer and to verify the flow-phenomena where a visualization test apparatus is placed horizontally.

Development of a mathematical model for baseline and the enhanced systems for the next generation of refrigeration systems for chilling of fish in fishing vessel. By applying adapted ejector technology and parallel compression, these units can be applied globally with a significant energy saving compared to traditional system layouts.

## Cycles (Research Area 3)

The overall goals are to develop improved cycles and concepts for converting and upgrading energy sources, including power production from surplus heat, energy storage systems, and heat upgrade using heat pumps. Technologies and applications where HighEFF research have large impact potential are emphasized.

www.sintef.no/higheff-ra3

**Results 2017**

*Energy-to-power conversion:*
Criteria for evaluating heat-to-power concepts in the HighEFF context were developed – this ensures fair comparison of different technologies, and guides research activities in the Centre towards solutions with high, real impact potential for participating industry.

12 classes of heat-to-power technologies were explored for use in a low/medium temperature HighEFF scenario. The technologies were rated for maturity, simplicity, performance. Results shall be used to guide future, in-depth technology development activities. Two more in-depth studies for selected technologies (advanced Rankine cycles and thermoelectric generation) and industrial applications were started.

*High temperature heat pumps, cooling and drying:*
Turbo compression for steam heat pump as well as high temperature butane heat pumps have been assessed and will move forward to be experimentally verified in 2018. Three energy efficient drying systems and a novel concept low temperature freezing at -50 °C were investigated. Different solutions for integrated heating and cooling cycles are summarized in cooperation with relevant cases studies from RA6. Two spin-off projects (IPN – national innovation projects) for compressor development and heat pump drying were granted based on outcome and recommendations from this work.

*Energy storage:*
2017 activities spanned concepts for high-, medium and cold thermal energy storage, as well as thermal-electric energy storage for the interface between electric grid with fluctuating renewable energy sources and high thermal energy demands.

A state-of-the-art report on energy storage in industry was a main output in 2017. The report shows that energy storage is little practiced by the industry, despite indications of both benefit and promising technologies. Significant non-technical barriers exist, including knowledge gap, aversion against additional complexity, and dependencies across company boundaries.

A modelling case-study was carried out on the application of phase change materials (PCMs) for industrial batch processes. PCMs have high potential for process heat applications, in the range of 100-300 °C. Funding for experimental evaluation of such systems has been applied for in 2018.

PhD candidate Håkon Selvnes started his work on cold thermal energy storage related to a food processing factory. A laboratory test rig for testing the storage system will be built in 2018.

# Applications (Research Area 4)

Examination of applications that will integrate basic research and concepts, components, and cycles developed in other RAs into specific industry settings, to generate more energy-efficient processes and improved heat capture and utilisations concepts are targeted. The exploitable potential in surplus heat found in partner industries, and next generation surplus heat capture and utilization will be investigated. Using industrial examples, the potential of "green" industry clusters and local thermal grids on a Nordic scale will be developed further. The aim is identification of potential and concepts for possible use of process gas, develop a metal furnace concept with 20% lower total energy use.

www.sintef.no/higheff-ra4

**Results 2017**

*Process improvements:*
A comprehensive literature review has been made on finalized and on-going projects within The Norwegian Ferroalloy Producers Research Association (FFF) with respect to energy recovery. Processes with high potential for energy recovery (in terms of energy quality and quantity) are identified and selected for further analysis together with the industry. Recycling of flue gas into ferroalloy furnaces is the first activity.

A report/paper on the technical and economical feasibility of simultaneously energy recovery and emission reduction has been made by linking activities within EnergiX-project "SCORE" to HighEFF. Two papers are prepared: 1) Experimental verification and operation presented at Infacon 2018, 2) a technical and economical evaluation submitted to SPIS/Flogen 2018.

*Surplus heat recovery:*
The framework for the database of thermodynamic potential in surplus heat sources has been developed, with extended scope compared to the initial idea. Work on data acquisition has begun for the metals and materials sector. So far, data from Alcoa, Hydro, Wacker Chemical, Eramet, and Elkem have been received.

The initial activity on "surplus heat database" has been tentatively extended to "Energy flow database", to also include energy and material input streams for each subprocess in the industry plants. This should enable the database to be useful for various activities in many RAs and WPs in HighEFF. Completed entries for individual plants in the "Energy flow database" has been presented as process flow diagrams showing energy and materials flows. Several site visits were arranged to observe authentic plant scenarios and conditions, and scrutinize the energy flow data on-site.

*Industry Clusters and Technology Integration:*
A Modelica-based modelling and optimization framework for coordinated exchange of surplus heat in industry clusters has been developed. Preliminary results have illustrated both advantages and challenges of using optimization-based control and intermediate storage as a means of leveraging varying surplus-heat streams and demands to improve utilization of surplus heat in industry clusters.

# Society (Research Area 5)

The overall aims are to manage the innovation activities and handle dissemination, communication and general flow of information in the Centre. Additional, the goals are to form the innovation strategies and technological roadmaps for the industry and sectors, and share them among partners, to enhance cooperation and synergies. Innovation management will include research and internal and external interaction, as well as on the barriers and enablers for innovation and realization of HighEFF technologies and concepts.

www.sintef.no/higheff-ra5

**Results 2017**

*Innovation, barriers and enablers:*
A first survey of innovation potential and cooperation relations in HighEFF has been conducted. This has included an literature review, interviews of researchers and industry representatives, and resulted in input to centre innovation structures and roadmaps, further management of industry/research collaboration and new cooperation arenas especially between RAs 4/5/6. We have also conducted case studies that include, among other things, document studies, interviews and industrial visits, which resulted in an article on the sociotechnical aspect of energy sharing in heterogeneous constellations. A case study on regulatory frameworks (such as emission trading) for industrial clusters that share CO-gas was also conducted, the results of which appear in an article in addition to a pentagon analysis of organizational dependencies in industrial clusters.

*Novel Emerging Concepts (NEC):*
Novel emerging concepts produced through cooperation between HighEFF partners and research assignment, will be actively looked for and handled. To build upon the innovation task force in the Centre, HighEFF has allocated 1.5 MNOK/year for funding of NECs related to the research and innovation objectives within the Centre. Evaluation procedures for spin-offs and novel emerging concepts have been developed and agreed on. The procedures for evaluation of the Concepts and execution and follow up on Concepts that have been granted support is prepared. In short, the report describes 5 stages for handling the Concepts; (1) The Call, (2) The Evaluation, (3) Plan and Budget Approval, (4) Concept Execution, and, (5) Post Project. First announcement will be in Q1 /2018.

*Dissemination and Communication:*
A first outline of the Dissemination and Communication plan is finished, and will be actively used and updated every year. The content is based on close cooperation with SINTEF ER's communication staff and RA5. The HighEFF Website is established (www.higheff.no) showing relevant news and upcoming events, in addition to HighEFF results. Dissemination standards and design, such as HighEFF logo, PP-template, deliverable template, are available. In total 13 blog articles and 4 newsletters (Highlights) were published during the first period of FME HighEFF. Our ambition is to increase these numbers even more in 2018.

## Case Studies (Research Area 6)

Case Studies will be performed to obtain measurable results from the implementation of HighEFF technologies in the different industry 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/or minimum 10% in $CO_2$ emissions for each case through implementing technologies and solutions.

The research area shall promote HighEFF innovations through spurring development of novel concepts for power production cycles and heat pumping technologies as well as novel business methods for collaboration between industrial plants

www.sintef.no/higheff-ra6

### Results 2017

*Metals, Materials and Industry Parks:*
Novel and conventional uses of CO rich off-gas from Mn-alloy production have been explored based on input from several consortium partners. The most relevant ideas will be evaluated from two different perspectives in future work; an industrial cluster in Mo i Rana and a stand-alone plant in Sauda. Potential for new business opportunities and technological solutions will be prioritized when selecting ideas for further study. Spin-off activities include a KPN application to EnergiX on reduced $CO_2$ emissions in metal production, which was granted in December 2017.

*Oil, Gas & Energy:*
The main activity in Oil, Gas & Energy was a case study on waste heat upgrading and heat production at an electrified LNG facility. Simulation results demonstrate that state-of-the-art, high temperature heat pumps can save in the order of 30 % electricity consumption at the facility compared to a scenario where the total heat demand is covered with electric heating. The work package has also been involved in a spin-off KPN application to PETROMAKS2 on compact bottoming cycles for offshore use entitled COMPACTS2, granted in December 2017.

*Food:*
5 initial studies of different industry cases relevant for the food sector have been completed, with focus on novel concepts for thermal upgrading of excess heat and improved process efficiency. Applications for support funding by ENOVA have been submitted and approved for two of the cases, including a green field plant at TINE that is currently in the design phase. For this case, more than 38 % reduction in electricity demand and 40 % reduction in $CO_2$ emissions has been determined using state-of-the-art heat pumps.

# Education and Recruitment

## Education, researcher training and recruitment

Developing knowledge and expertise at various levels is a main objective and major task in HighEFF. Focus is on energy efficiency in industrial processes, and the main sub-activities are (i) methodologies for analysis, design and optimization, (ii) improved equipment and cycles, and (iii) systems integration including industrial parks (clusters). The education activity takes place at different levels such as Master students having their thesis related to HighEFF, PhDs and Post.docs 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.

By the end of 2017, HighEFF had recruited a total of 15 candidates (12 PhDs, 2 Post.docs and 1 Researcher). The Researcher is a Post.doc position that has been converted to a Researcher at NTNU Societal Research (partly funded by HighEFF). Still to be recruited then are 7 PhDs and 1 Post.doc). These positions will be active from 2018 or 2019 at the latest.

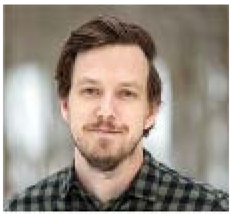
Our education program also spans across countries and continents. HighEFF academic partners currently include 2 from Norway (NTNU and Nord University), 2 more from Europe (KTH in Sweden and University of Manchester in the UK), 2 in the US (MIT and Carnegie Mellon University) and 2 in Asia (Shanghai Jiao Tong University in China and Doshisha University in Japan), a total of 8 universities.

The considerable number of recruited candidates has also resulted in a large number of publications and conference presentations. The statistics show that HighEFF had 9 journal publications and 9 conference presentations in 2017 that had at least one of the recruited candidates as author/co-author. Prospects for 2018 indicate even larger numbers.

The number of master students within HighEFF was only 2 in 2017. The fact that master students finish in the spring semester, is the explanation for the low number this first active year.

Professor Truls Gundersen (NTNU), Scientific Leader

## Selected PhDs and Postdocs



PhD **Jens Petter K. Johansen**

***What are you researching?***
I am researching the barriers, enablers, pre-conditions and consequences of inter-firm energy exchange (industrial symbiosis). Thus, in my PhD I seek to understand the non-technical factors affecting implementation of energy efficient solutions and energy exchange concepts. This is done through case studies of establishment processes of industry clusters as well as investigating the dynamics of industrial symbiosis in mature clusters.

***Who is involved in your research?***
The PhD is a part of RA5.1: *Innovation, Barriers and Enablers* led by Jens Olgard Dalseth Røyrvik. This is a part of RA5: *Society* with a broader focus innovation and implementation of energy efficient solutions led by Ingrid Camilla Claussen. PhD supervisor is Per Morten Schiefloe at NTNU Social Research. My work is also strongly connected and completely relies on input from industry partners in HighEFF through case studies.

***Why is your research important?***
Previous research has shown that establishment of inter-firm energy exchange and implementation of novel solutions can be challenging and many attempts fail due to non-technical issues. There is also limited research on inter-firm energy exchange in a Norwegian industry context. It is important to better understand the pre-conditions and organizational consequences, frame conditions, contextual and cultural factors affecting such establishment processes to suggest strategies, organization models and policy recommendations.

***Tell us about an interesting result.***
While still at an early stage, interesting results has emerged by comparing two industry clusters employing inter-firm energy exchange. They have organized themselves very differently in terms of operations concept and reliance on formal and informal structures for coordination. The cases show how clusters can be robust in different ways by drawing on formal and/or informal capabilities for dealing with changes or external events (i.e. unforeseen events and change in energy prices).

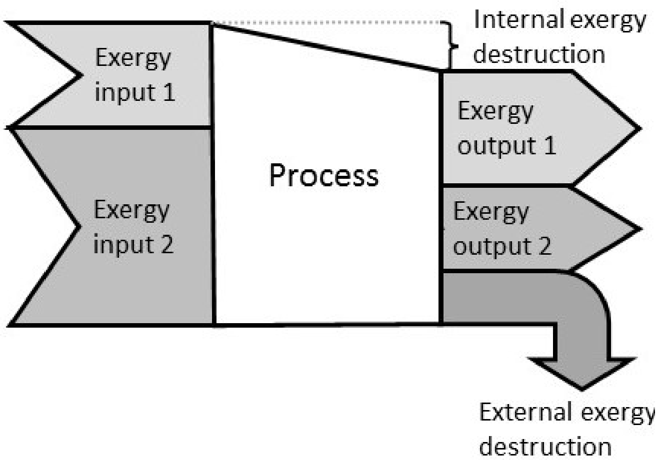
## PD **Elisa Magnanelli**

***What are you researching?***
Industrial processes are very complex. It is often challenging to assess their performances and compare alternative solutions, especially when they make use of energy and resources with different "quality". In our approach, we express energy and material resources in terms of exergy (i.e. their maximum ability to perform work). By doing so, we can not only account for the differences in resources' quality, but also localize where most of the work potential is lost in the process.

***Who is involved in your research?***
I am part of RA1, where we work to develop tools that can help increasing energy efficiency. These tools can find different applications, and this is why we are currently working with many other research areas to individuate challenging cases where to apply our methodology. We are in contact with WP 4.1, WP 6.2, and WP 6.3, which are working with case studies from different industry sectors.

***Why is your research important?***
The exergy analysis of a process can be a very helpful tool. It does not only allow us to assess how the process performs in thermodynamic terms, but it can also give important insights on when and where efforts should be spent to improve the process. Thermodynamic limits can serve as ideal targets that can guide process improvements.

***Tell us about an interesting result.***
In one of the cases we are working now, we are evaluating the different options that have been proposed by RA6 as alternatives to an existing process. These alternatives make use of electric power, fuels and/or heat, in different proportions, so they are not trivial to compare. There are of course many factors to take into account, like for instance $CO_2$ emissions and costs, but by using exergy analysis, we can point at the solution that is the best from a thermodynamic viewpoint.



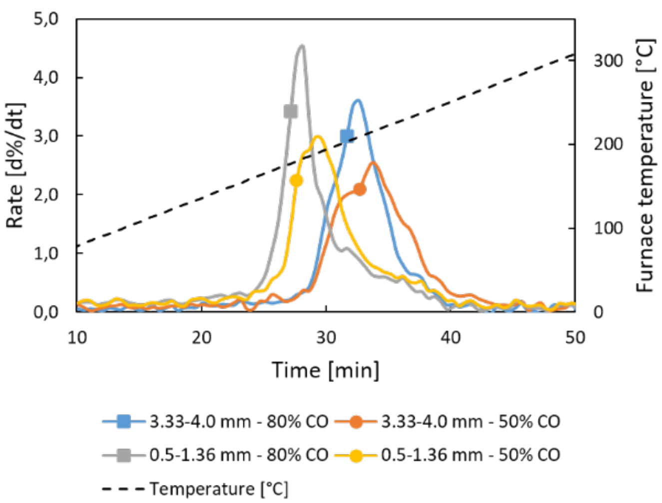
## PhD **Trine Asklund Larssen**

***What are you researching?***
I am part of work package 4.1 – Applications: Process Improvements in HighEFF. My work is focused on the production of manganese ferroalloys, and thus the overall goal is to improve the process in terms of energy efficiency and climate gas emissions. Currently, I am investigating the gaseous reduction of manganese ores by evaluating the CO-reactivity at different conditions. The goal is to see how water content, oxygen content and volatiles in the raw materials affect the energy consumption, furnace temperatures and off-gas composition.

***Who is involved in your research?***
There are two companies producing manganese ferroalloys in Norway, Eramet Norway AS and Glencore Manganese Norway AS, both of which are industrial partners in HighEFF. The approach of my work has been discussed and determined in collaboration with representatives from the industrial partners, in addition to my supervisors Professor Merete Tangstad and Ida Kero (SINTEF).

***Why is your research important?***
The metal producing industry is a high consumer of energy and produces an off-gas containing significant amounts of CO(g). Thus, potential improvements would be beneficial both in terms of the environment and also from an economical point of view. The efficiency of the process is to a large extent dependent on the reactions occurring in the upper part of the furnace. Increasing the knowledge on the behaviour of this specific zone, and the effects the respective variations have on the overall furnace operation, could reveal measures that can further optimize the process.

***Tell us about an interesting result.***
My experiments are conducted in a vertical tube furnace that continuously measures weight, temperatures and gas composition. The reduction of manganese oxides produces $CO_2$-gas, which causes a weight loss. Hence, the extent of the reductions and corresponding rates can be found from the weight reduction behaviour. Some of the preliminary results can be seen in figure 1, which shows the reduction rate, given as percentage weight reduction, for one of the investigated manganese ores. The curves show that smaller size fractions reduce at a lower temperature compared to larger fractions. In addition, it can be seen that increasing CO-content in the gas atmosphere results in a higher maximum reduction rate.




Weight reduction rate (d%/dt) for manganese ore in two different size fractions evaluated in two different gas compositions. Remainder of gas atmosphere is $CO_2$(g).

PhD **Mina Shahrooz**

***What are you researching?***

My project is about low temperature power cycles for industrial waste heat utilization. The solution for this case is well-known Rankine cycle. I am using numerical tools with thermodynamic cycle modelling to investigate the environmental-friendly natural refrigerants and their mixtures to design optimum cycles and achieve the best possible performance. The heat source in my case is hot air having a temperature range of $125 - 250$ ℃.

***Who is involved in your project?***

This project is conducted in collaboration of KTH Royal Institute of Technology in Stockholm and NTNU and SINTEF Energy in Trondheim. My Main supervisors are Prof. Per Lundqvist and Prof. Petter Nekså in Stockholm and Trondheim, respectively.

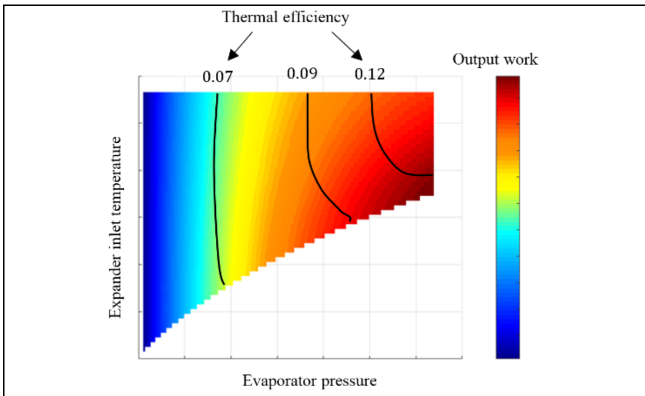
***Why is your research important?***

There is a huge potential of industrial waste heat which is released into the environment, constantly. However, it could be utilized properly to generate electricity and meanwhile not to inject too much heat into the ambient. Besides, focusing on alternative natural refrigerants helps to lower the environmental issues of fluids with high Global Warming Potential (GWP), in case they are leaked into the atmosphere.

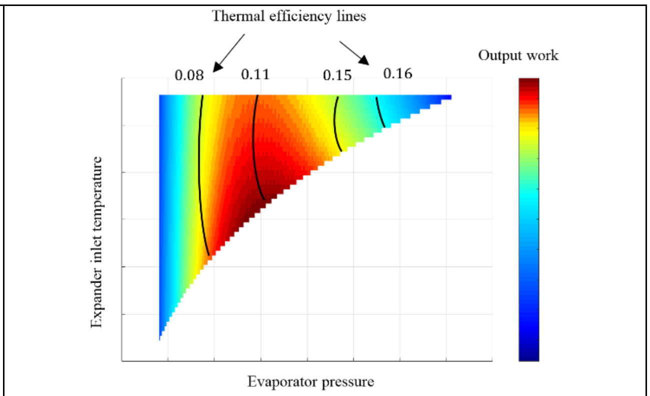
***Tell us about Interesting results.***

In the first phase of the project, I was focused on thermal performance optimization of cycles based on output power, thermal efficiency and exergy efficiency. I was curious to observe the behavior trends of different natural refrigerants rather than just pointing to one or two specific fluids as my optimum fluids. The results of my optimizations revealed two major behaviors in subcritical cycles: type A and type B. As it is clear in the figure below, in type A behavior, the optimum output work and thermal efficiency points are close to each other while in type B, these optimum points are far from each other. The transition from type A to type B occurs at $(T_c/T_h = 0.9)$. For the values lower, the fluid exhibits type A behavior and for the values above 0.9, type B behavior is observed.

$T_c$: Critical temperature of the fluid (K)
$T_h$: Heat source inlet temperature (K)




**Type A**




**Type B**

Output work and thermal efficiency contours, left: type A behavior, right: type B behavior

## PhD **Matias Vikse**

***What are you researching?***

I am looking into developing optimization models for Work and Heat Exchanger Networks (WHENs). Heat integration is a familiar concept for improving energy efficiency in industrial processes. However, most processes also contain variable pressure streams and it is therefore important to account for these pressure manipulations in process integration. Theorems for correct integration of compressors and expanders have been developed by our group at NTNU. In my research, I am trying to develop robust mathematical optimization model that includes the insight from these theorems, and which will be used for improving the energy efficiency of industrial processes. In addition, I am looking at practical applications of WHENs, where as part of a research collaboration with MIT, I have been part of a project on developing a robust simulation and optimization tool for liquefaction processes for natural gas.

***Who is involved in your research?***

I am involved as a PhD-candidate in RA1, where I am a part of both WP 1.1 and WP 1.2. In addition, I collaborate closely with MIT, which is one of the university partners in HighEFF. As part of this collaboration, I am also planning a research stay at MIT during the academic year of 2018 - 2019.

***Why is your research important?***

Mathematical optimization is necessary for designing WHENs for larger and more complex industrial processes. However, to ensure an optimum exergy efficiency for the integrated process, the insights from the theorems must be embedded in the model. The ultimate goal of the project is to develop a tool that can be used both during the design phase and for evaluating existing systems. From the optimization results, we also hope to gain additional insight into the concept of work and heat integration.

Liquefaction processes for natural gas are notoriously difficult to analyze due to small temperature differences in the heat exchangers. Commercial process simulation tools struggle to simulate these processes, and cannot guarantee flowsheet convergence to a design with feasible driving forces. There are also issues with flowsheet optimization, particularly when using derivative based optimization algorithms for complex LNG processes. Therefore, we are looking at developing a stand-alone simulation and optimization tool by using a novel modeling approach developed by the collaborators at MIT.

***Tell us about an interesting result.***

Working models have already been developed both for single mixed and dual mixed refrigerant processes. The simulation models have been shown to offer several advantages compared to commercial simulators. The models contain additional degrees of freedom and guarantee flowsheet convergence to a feasible design, making it easier for the designer to obtain feasible results even for more complex systems. In addition, the tool has been proved successful for optimizing both single mixed and dual mixed refrigerant processes.

# HighEFF PhDs and Postdocs

One important task of HighEFF is to educate masters and doctoral students to become the next generation energy researcher and employees for the industry. During the first period 12 PhD fellows have been recruited and two postdoctoral fellows are in the starting pit. In addition, two master degrees and two summer scientists have been accomplished their work.

**PhD Students**

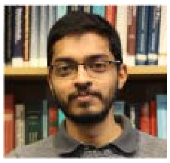
**Matias Vikse**,PhD
Development of Optimization Models for Work and Heat Exchange Networks
Supervisor: Prof. Truls Gundersen

**Haoshui Yu,** PD
Thermodynamic Approach to Work and Heat Exchange Networks (WHENs)
Supervisor: Prof. Truls Gundersen

**Mina Shahrooz**, PhD
Low Temperature Power Cycles for Waste Heat Utilization with Mixtures of natural Fluids
Supervisor: Prof. Per G. Lundqvist,

**Juan Cristancho**, PhD
Compact and efficient Bottoming Cycles for Offshore Power Production
Supervisor: Lars O. Nord

**Håkon Selvnes**, PhD
Cold Thermal Energy Storage for Industrial Applications
Supervisor: Prof. Armin Hafner



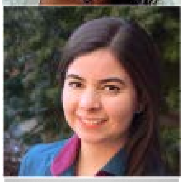
**Mandar Thombre,** PhD
Optimization of Energy Efficiency in Large-Scale Industrial Systems under Uncertainty
Supervisor: Johannes Jäschke

**Juejing Sheng,** PhD
Exergy Analysis of Offshore Oil & Gas Processing Systems
Supervisor: Ivar S. Ertesvåg

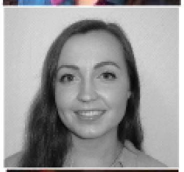
**Håkon Fyhn,** Researcher
Human factors in development of industrial symbiosis
Supervisor: Leiv Kolbeinsen

**Saif Rahaman Kazi,** PhD
Optimization of Multi-stream Heat Exchangers (MHEXs) with Phase Change
Supervisor: Prof. Lorenz T. Biegler

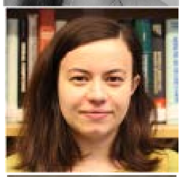
**Elisa Magnanelli,** PD
Establish KPIs with focus on Energy Efficiency for HighEFF
Supervisor: Prof. Signe Kjelstrup



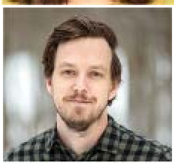
**Suzane Cavalcanti**,PhD
Research topic: Nonsmooth Approaches to Process Flowsheet Simulation and Optimization
Supervisor: Prof Paul I. Barton



**Trine Asklund Larsen**, PhD
Energy Distribution in Mn-alloy Furnaces
Supervisor: Merete Tangstad



**Cristina Zotica,** PhD
Optimal Operation and Control of Flexible Heat-to-Power Cycles
Supervisor: Sigurd Skogestad



**Jens Petter Johansen,** PhD
Collective Energy Systems
Supervisor: Prof. Per M. Schiefloe

**Julia N. Jimenez Romero,** PhD
Reduction of Industrial Energy Demand through Sustainable Integration of Distributed Energy Hubs
Supervisor: Robin Smith

## HighEFF Master and Summer Scientists

**Avinash S.R. Subramanian**, 2017, WP 1.1, Male, India, Msc student

- Supervisor: Truls Gundersen, NTNU, Dept. of Energy and Process Engineering
- Thesis: *Reducing Energy Consumption in the Production of Hydrogen from Natural Gas*

**Roxane E.H. Giametta**, 2017, WP 1.2, Female, France, MSc student

- Supervisor: Truls Gundersen, NTNU, Dept. of Energy and Process Engineering
- Thesis: *Integration of LNG Regasification and Air Separation Units*

**Simon Høgås**, 2017, WP 2.1, Male, Norway, Summer scientist

- Supervisor: Trond Andresen
- Task: *Numerical workflow for automatic 3D-printing of heat exchanger designs* (Related deliverable D2.1_2017.04)

**Goran Durakovic**, 2017, WP 3.1, Male, Norway, Summer scientist

- Supervisor: Brede Hagen
- Task: *Optimization of power generation from aluminum production exhaust gas waste heat* (Related deliverable D3.1_2018.09)

**Espen Verpe**, 2017, WP 3.2, Male, Norway, Summer scientist

- Supervisor: Michael Bantle
- Task: *Evaluation of low temperature plate freezing of fish products using R744 heatpump* (Related deliverable D3.2_2017.02)

*Summer Scientist Conference* at SINTEF Energy Research

# Communication and Dissemination

Dissemination and exploitation of results are important for the FME HighEFF centre, to ensure widest-possible outreach, involvement and cross-sectorial interaction with relevant industry and academia. The dissemination and dissemination strategy is built up to maximise the use of existing physical meeting points (seminars, centre workshops and RA meetings) and existing communication platforms and media channels, such as project partners' existing communication channels.

## Dissemination

The scientific community will be addressed through publications in scientific journals and conferences; the goal is 150 publications in peer-reviewed journals and conference proceedings. For the widest possible sharing of project results, open access journals will be preferred when possible.

The Dissemination Plan, together with the Dissemination standards, provide the key document for developing guidelines and serving as a quality check tool for delivery among all media types, including online, offline and print.

A set of dissemination and communication standards are prepared or under development to ensure that a corporate image is associated to the project.

The standards created cover:

- Project logo,
- Website structure and layout,
- Project presentation slides layout,
- E-newsletter layout,
- Report templates
- Publication templates, such as roll-ups, leaflets etc.

## Communication 2017

Open and engaging communication of scientific results is a strategic activity in HighEff and an integral part of the management's responsibility. Communication will extend beyond the HighEff consortium and scientific community to provide facts in the public energy about efficiency debate and promote innovations to industry.

Communication in numbers 2017:

- Information material/blogs 13
- Media contributions 12
- Newsletters 4

## Communication channels

**Web**

The HighEFF web- www.higheff.no was launched in 2016. The webpage provides open information from the centre.

- The web has had 435 unique visitors.
- There have been 1 818 views on the webpages.
- Visitors to the webpage come mainly from Norway, Canada, Italy, Sweden, United States and Japan

**Newletters**

4 newsletters were sent to 135 subscribers

- December 20, 2017: HighEFF Newsletter 4-2017
- October 20, 2017: HighEFF Newsletter 3-2017
- September 13, 2017: HighEFF Newsletter 2-2017
- July 10, 2017: HighEFF Newsletter 1-2017: Celebrating new HighEFF Lab and more ..

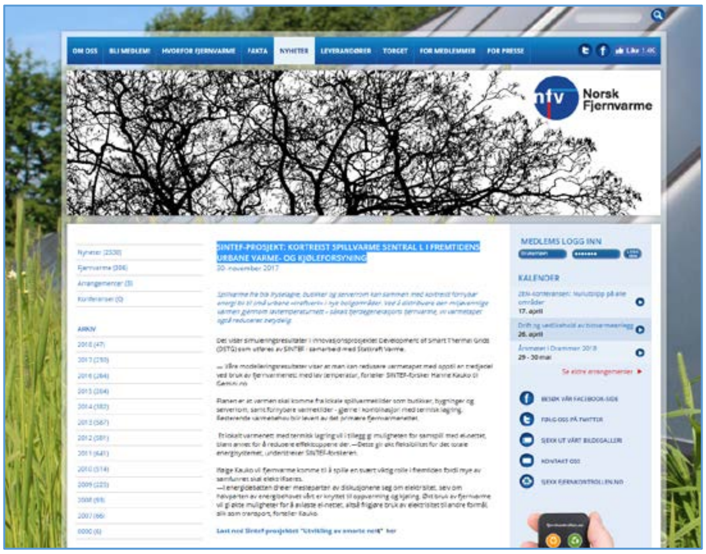
**Media contributions**

Media contributions published during the first period of HighEFF:

- 400-500 millioner til Forsknings-Trondheim. Adresseavisen, 2017-06-27
- 60 millioner for å gjøre industrien mer klimavennlig. Adresseavisen, 2017-06-27
- Green cooling with CO2. Gemini 2016-10-25
- MIP med i nytt forskningssenter for miljøvennlig energi. Mo Industripark AS, 2016-05-26
- Norway Unveils World's Largest Center for Research into Industrial Energy Efficiency. World Industrial Reporter, 2016-12-09
- Vil bli internasjonalt flaggskip. Mo Industripark AS, 2016-07-15
- 1,3 milliarder til forskning på miljøteknologi. Gemini, 2016-05-26
- Spillvarme inn i varmen. Gemini, 2016
- Spillvarme inn i varmen. Dagens næringsliv, 2016
- CO2 gir grønn kjøling. Dagens næringsliv, 2016 s. 27-
- -La naturens egne stoffer overta som kjølegasser. ITBAktuelt 2016-10-28
- CO2 gir grønn kjøling. GEMINI, 2016-10-21

Norsk Fjernvarme 2019-11-30

SINTEF-prosjekt: Kortreist spillvarme sentral l i fremtidens urbane varme- og kjøleforsyning


SINTEF-PROSJEKT: KORTREIST SPILLVARME SENTRAL L I FREMTIDENS URBANE VARME- OG KJØLEFORSYNING

30. november 2017

NRK 2017-12-27

Håpar fjordvarme kan lage miljøvenleg asfalt


# Håpar fjordvarme kan lage miljøvenleg asfalt

Varme frå fjordane kan gi industrien rein og rimeleg energi. No kan Fjordvarmen i Førde bli til asfalt.

Asgeir Heimdal Reksnes
Journalist

Publisert 27. des. 2017 kl. 08:54

OPTIMISTISKE: asfaltproduksjonsanlegget i Førde går på propangass, men kanskje kan fjordvarme vere ei meir klimavenleg løysing. Even Solheim, distriktsleiar i Veidekke (t.v.) og Leif Olstad i Førdefjorden energi.
FOTO: ARNE STUBHAUG / NRK

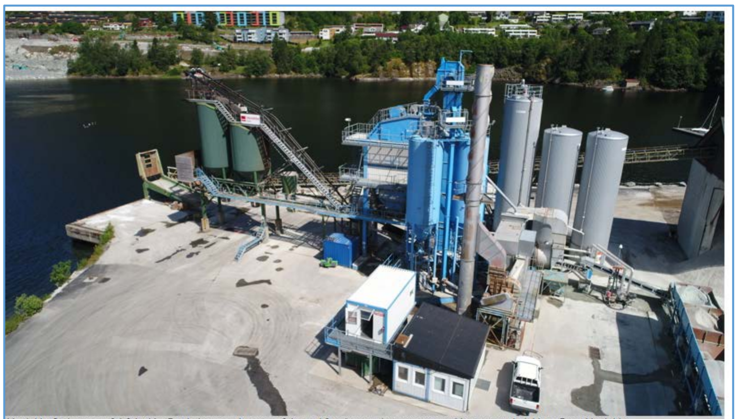
– Vi har ein unik moglegheit med fjordvarme nær Veidekke sin asfaltfabrikk, så må vi få til økonomien og teknologien, seier dagleg leiar Leif Olstad i Førdefjorden energi.

Fjernvarmeanlegget som skal varme opp Førde sentrum ligg like ved ein asfaltfabrikk. No har Førdefjorden energi, Veidekke og SINTEF saman fått 450 000 frå Forskingsrådet. Håpet er å bruke fjordvarme framfor gass når asfalt skal produserast. Dermed kan utsleppa av propangass som blir brukt i dag erstattast.

Even Solheim er distriktsleiar i Veidekke, som nasjonalt har 30

Byggeindustrien 2017-12-29

[Utvikler løsning for å produsere Veidekke-asfalt med fjordvarme]



Veidekke Industris asfaltfabrikk i Førde kan produsere asfalt med fjordvarme hvis et nytt utviklingsprosjekt lykkes. Foto: Veidekke

# Utvikler løsning for å produsere Veidekke-asfalt med fjordvarme

**Førdefjorden Energi og SINTEF jobber sammen med Veidekke Industri for å utvikle en løsning for å bruke fjernvarme fra Førdefjorden til asfaltproduksjon.**

Sindre Sverdrup Strand

## Blogs

HighEFF has published 6 blogs on the #SINTEFblog in 2017.

#SINTEFblog 2017-10-10

[HighEFF collaboration – KIFEE Professor Yamaguchi from Doshisha University visits Trondheim]


#SINTEFblog

#ENERGY #BUILDING #OCEAN #DIGITAL #HEALTH #SOCIETY #INDUSTRY

HighEFF collaboration – KIFEE Professor Yamaguchi from Doshisha University visits Trondheim

BY INGRID CAMILLA CLAUSSEN COMMENTS
OCTOBER 10, 2017 0

Professor Hiroshi Yamaguchi from Doshisha University, one of the KIFEE professors, visited NTNU and SINTEF for a two week period starting from the end of August 2017, hosted by Adjunct Professor Petter Nekså, Professor Trygve M. Eikevik and Professor Armin Hafner. The visit was financed by the KIFEE Intpart program.

Professor Hiroshi Yamaguchi from Doshisha University

Central topics for discussions were university collaboration between NTNU and Doshisha and project collaboration through the new FME (Centre for environmentally-friendly energy

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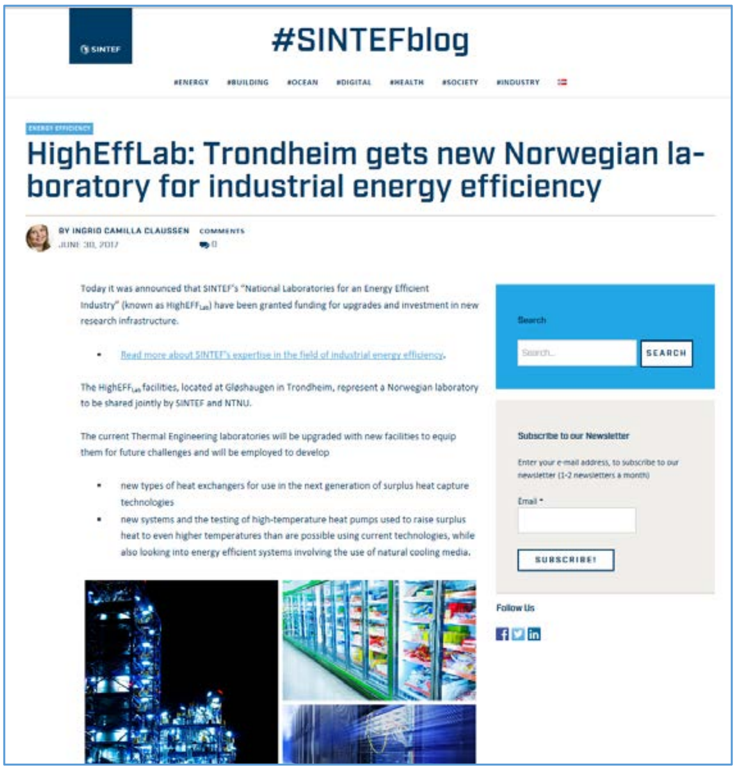
#SINTEFblog 2017-06-30

[HighEffLab: Trondheim gets new Norwegian laboratory for industrial energy efficiency]


#SINTEFblog

#ENERGY #BUILDING #OCEAN #DIGITAL #HEALTH #SOCIETY #INDUSTRY

HighEffLab: Trondheim gets new Norwegian laboratory for industrial energy efficiency

BY INGRID CAMILLA CLAUSSEN COMMENTS
JUNE 30, 2017 0

Today it was announced that SINTEF's "National Laboratories for an Energy Efficient Industry" (known as $HighEFF_{Lab}$) have been granted funding for upgrades and investment in new research infrastructure.

- Read more about SINTEF's expertise in the field of industrial energy efficiency.

The $HighEFF_{Lab}$ facilities, located at Gløshaugen in Trondheim, represent a Norwegian laboratory to be shared jointly by SINTEF and NTNU.

The current Thermal Engineering laboratories will be upgraded with new facilities to equip them for future challenges and will be employed to develop

- new types of heat exchangers for use in the next generation of surplus heat capture technologies
- new systems and the testing of high-temperature heat pumps used to raise surplus heat to even higher temperatures than are possible using current technologies, while also looking into energy efficient systems involving the use of natural cooling media.

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# APPENDICES

# Appendices

## Appendix 1 Personnel involved in the Centre in 2017

Number of personnel for various categories:

| Personnel category | Number |
|---|---|
| Key researchers | 56 |
| Visiting researchers | - |
| PDs financed by HighEFF | 2 |
| PDs financed from others | - |
| PhDs financed by HighEFF | 12 |
| PhDs financed from others | 5 |
| Master degrees | 2 |

### Centre Administration

| | | |
|---|---|---|
| Petter Egil Røkke | SINTEF | Centre Director |
| Line Rydså | SINTEF | Centre Coordinator |
| Einar Jordanger | SINTEF | Centre Coordinator (deputy) |
| Truls Gundersen | NTNU | Scientific Leader |
| Petter Nekså | SINTEF/NTNU | Scientific Coordinator |

### Web and design

Astrid B. Lundquist and Christoffer Solberg SINTEF

### Key researchers

| Name | Institution | Main research area |
|---|---|---|
| Trond Andresen | SINTEF Energi | Cycles, Surplus heat-to-power conversion, heat recovery |
| Michael Bantle | SINTEF Energi | HTHP, low temp cooling, drying systems |
| Olaf Trygve Berglihn | SINTEF Industri | KPIs, exergy and energy analyses |
| Ingrid Camilla Claussen | SINTEF Energi | Dissemination, food case |
| Halvor Dalaker | SINTEF Industri | Utilization of CO-rich off-gas from Mn-alloy production |
| Han Deng | SINTEF Energi | Heat exchangers |
| Gerwin Drexler-Schmid | AIT | Thermal Energy storage |
| Trygve Eikevik | NTNU | Natural refrigerants |
| Sverre Stefanussen Foslie | SINTEF Energi | HTHP/ TES potential for the industry |
| Cecilia H. Gabriellii | SINTEF Energi | Low temperature cooling |
| Gudveig Gjøsund | NTNU SR | Organizational analysis |
| Per Egil Gullsvåg | SINTEF Energi | Experimental work |
| Truls Gundersen | NTNU | Pinch analyses |
| Brede A.L. Hagen | SINTEF Energi | Surplus heat-to-power conversion |
| Armin Hafner | NTNU | HTHP / Cold thermal storage for industrial applications |
| Torgeir Kolstø Haavik | NTNU SR | Sociotechnical analysis |
| Anne Karin T. Hemmingsen | SINTEF Energi | Management |
| Bin Hu | SHANGHAI | High temperature heat pumps |
| Erlend Indergård | SINTEF OCEAN | HTHP, Cooling and Drying and Case studies food |
| Hanne Laura Pauliina Kauko | SINTEF Energi | Energy storage, energy exchange |

| | | |
|---|---|---|
| Ida Teresia Kero | SINTEF Industri | Metal- CO case fluegas |
| Brage Rugstad Knudsen | SINTEF Energi | Energy storage, energy exchange |
| Leiv Kolbeinsen | NTNU | Industrial clusters |
| Karoline Husevåg Kvalsvik | SINTEF Energi | Integrated heat pump concepts |
| Øyvind Langørgen | SINTEF Energi | HLNG |
| Michael Lauermann | AIT | High temperature heat pumps |
| Thomas A. Lauvås | NORD | industry/research collaboration in FME centres |
| Yong Li | SHANGHAI | High temperature heat pumps |
| Catharina Lindheim | NTNU SR | Innovation and industry collaboration |
| Bjørn Tore Løvfall | SINTEF Industri | Process improvements |
| Marit Jagtøyen Mazzetti | SINTEF Energi | Offshore oil & gas and industrial clusters |
| Petter Nekså | SINTEF Energi | Energy efficiency in industry |
| Monika Nikolaisen | SINTEF Energi | Surplus heat-to-power conversion |
| Tom Ståle Nordtvedt | SINTEF OCEAN | HTHP, Cooling and Drying and Case studies food |
| Balram Panjwani | SINTEF Industri | Process improvements |
| Torbjørn Pettersen | SINTEF Industri | Case study modelling in report KPIs |
| Arne Petter Ratvik | SINTEF Industri | Novel emerging concepts |
| Eli Ringdalen | SINTEF Industri | Utilization of CO-rich off-gas from Mn-alloy production |
| Jens Røyrvik | NTNU SR | Societal, social and organizational conditions for energy |
| Christian Schlemminger | SINTEF Energi | HTHP and Thermal Energy Storage |
| Akhilesh Kumar Srivastava | Tel-Tek | Thermo-electric power generation |
| Christian Schøning | SINTEF Industri | Energy in Al process and industry |
| Hans Langva Skarsvåg | SINTEF Energi | Natural working fluid properties |
| Geir Skaugen | SINTEF Energi | Heat exchangers |
| Vidar Torarin Skjervold | SINTEF Energi | Surplus heat recovery |
| Sigurd Skogestad | NTNU | Process system engineering |
| Egil Skybakmoen | SINTEF Industri | Utilization of Low Temperature Heat in Al electrolysis |
| Asbjørn Solheim | SINTEF Industri | Chloride Al processes, inert anode and initial HH |
| Marianne Steinmo | NORD | industry/research collaboration in FME centres |
| Stian Trædal | SINTEF Energi | Natural refrigerants for power production cycles |
| Aud Nina Wærnes | SINTEF Industri | Process improvements |
| Ruzhu Wang | SHANGHAI | High temperature heat pumps |
| Kristina Norne Widell | SINTEF OCEAN | HTHP, Cooling and Drying and Case studies food |
| Bernd Wittgens | SINTEF Industri | Process improvements |
| Christoph Zauner | AIT | High-temperature PCM TES |
| Bjarte Arne Øye | SINTEF Industri | Chloride Al process study |

## Appendix 2 Statement of Accounts 2017

| Costs (1000 NOK) | Amount |
|---|---|
| Host institution (SINTEF Energi) | 27 375 |
| Research partners | 22 747 |
| User partners | 5 967 |
| Equipment | 0 |
| **Total** | **56 089** |

| Funding (1000 NOK) | Amount |
|---|---|
| Research Council of Norway | 23 250 |
| Host institution (SINTEF Energi) | 10 528 |
| Research partners | 7 125 |
| User partners | 15 186 |
| **Total** | **56 089** |

## Appendix 3 Publications

### Journal publications

**Fu, Chao; Vikse, Matias; Gundersen, Truls.**
Challenges in work and heat integration. *Chemical Engineering Transactions* 2017; Volum 61. s. 601-606

**Haavik, Torgeir Kolstø; Røyrvik, Jens Olgard Dalseth; Lindheim, Catharina.**
A question of power: the politics of kilowatt-hours. *Nordic Journal of Science and Technology Studies* 2017; Volum 5.(1) s. 17-29

**Straus, Julian; Skogestad, Sigurd.**
Use of Latent Variables to Reduce the Dimension of Surrogate Models. *Computer-aided chemical engineering* 2017; Volum 40. s. 445-450

**Vikse, Matias; Fu, Chao; Barton, Paul I; Gundersen, Truls.**
Towards the use of mathematical optimization for work and heat exchange networks. *Chemical Engineering Transactions* 2017; Volum 61. s. 1351-1356

**Watson, Harry AJ; Vikse, Matias; Gundersen, Truls; Barton, Paul I.**
Reliable flash calculations: Part 1. Nonsmooth inside-out algorithms. *Industrial & Engineering Chemistry Research* 2017; Volum 56.(4) s. 960-973

**Yamasaki, Haruhiko; Yamaguchi, Hiroshi; Hattori, Kazuyuki; Nekså, Petter.**
Experimental Observation of $CO_2$ Dry-ice Behavior in an Evaporator/Sublimator. *Energy Procedia* 2017; Volum 143. s. 375-380

**Yu, Haoshui; Gundersen, Truls.**
Review of work Exchange Networks (WENs) and work and Heat Exchange Networks (WHENs). *Chemical Engineering Transactions* 2017; Volum 61. s. 1345-1350

### Conference lecture and academic presentation

**Andresen, Trond.**
HighEFF - RA3 Cycles. FME HighEFF kick-off; 2016-11-28 - 2016-11-28

**Andresen, Trond; Nekså, Petter.**
Thermodynamics for dummies. HighEff Annual Consortium Meeting 2017; 2017-06-19 - 2017-06-20

**Bantle, Michael.**
Energy Demand in the Norwegian Food and Chemical Industry. Energy Demand in the Norwegian; 2017-03-13 - 2017-03-13

**Bantle, Michael.**
Steam turbocompressors for cost efficient high-temperature heat pumping. HighEFF Annual Consortium Meeting 2017; 2017-06-19 - 2017-06-20

**Claussen, Ingrid Camilla.**
HighEFF - RA5 Society. FME HighEFF kick-off; 2016-11-28 - 2016-11-28

**Hagen, Brede Andre Larsen; Andresen, Trond.**
Numerical framework for power cycle simulation and optimization. HighEFF Centre; 2017-11-30 - 2017-11-30

**Hemmingsen, Anne Karin Torstveit.**
FME HighEFF - Energy Efficient and Competitive Industry for the Future. Ung i SINTEF; 2016-11-10 - 2016-11-10

**Hemmingsen, Anne Karin Torstveit.**
HighEFF - RA6 Case Studies. FME HighEFF kick-off; 2016-11-28 - 2016-11-28

**Hemmingsen, Anne Karin Torstveit.**
HighEFF education program. FME HighEFF kick-off; 2016-11-28 - 2016-11-28

**Johansen, Jens Petter.**
Collective energy systems - green industry clusters. HighEFF Annual Consortium Meeting 2017; 2017-06-19 - 2017-06-20
**Kauko, Hanne.**
Sustainable small-scale district heating and cooling grids. Workshop on district heating and cooling with a delegation from China; 2017-11-16 - 2017-11-17
**Krishnamoorthy, Dinesh; Straus, Julian; Skogestad, Sigurd.**
On combining self-optimizing control and extremum seeking control - applied to ammonia reactor case study. AIChE Annual meeting 2017; 2017-10-29
**Kvalsvik, Karoline Husevåg.**
Heat pump concepts for combined heating and cooling applications in industrial food processing. HighEFF Annual Consortium Meeting 2017; 2017-06-19 - 2017-06-20
**Lillebjerka, Terje; Mazzetti, Marit Jagtoyen.**
Energy Efficiencyin an Industry Cluster -Technology Development Needs. HighEFF Sector Workshop - Metals, Materials & Industrial Parks; 2017-04-24 - 2017-04-24
**Magnanelli, Elisa.**
Quantifying resource quality and efficiency in a circular economy. HighEFF Annual Consortium Meeting 2017; 2017-06-19 - 2017-06-20
**Mazzetti, Marit Jagtoyen.**
A highlight: Case study. HighEFF Cross-sector workshop; 2017-10-25 - 2017-10-26
**Mazzetti, Marit Jagtoyen.**
Case Studies Methodology & Process. HighEFF Sector Workshop - Metals, Materials & Industrial Parks; 2017-04-24 - 2017-04-24
**Mazzetti, Marit Jagtoyen.**
Case Studies Methodology & Process. HighEFF Case Studies Workshop - Food; 2017-03-14 - 2017-03-14
**Nekså, Petter.**
HighEFF, energiforskning for industriell, grønn konkurransekraft. Industri 2016; 2016-09-28 - 2016-09-29
**Nekså, Petter.**
HighEFF Work Plans. FME HighEFF Kick-off; 2016-11-28 - 2016-11-28
**Nekså, Petter.**
Low carbon solutions for the blue economy: The role of technology and innovation. Arctic Frontiers, Arctic Environment Forum; 2017-01-23 - 2017-01-26
**Nekså, Petter; Hemmingsen, Anne Karin Torstveit.**
FME HighEFF-Centre for an Energy Efficient and Competitive Industry for the Future –aktivitet relatert til norsk kjølebransje. Norsk Kjøleteknisk Møte 2017; 2017-04-20 - 2017-04-21
**Nikolaisen, Monika.**
Feasibility study of selected technology and industry process (heat-to-power conversion). HighEFF centre; 2017-12-14 - 2017-12-14
**Rohde, Daniel.**
Using dynamic models for analysis and design of complex energy systems. HighEFF Annual Consortium Meeting 2017; 2017-06-19 - 2017-06-20
**Rydså, Line.**
HighEFF in-kind: examples and reporting. HighEFF Annual Consortium Meeting 2017; 2017-06-19 - 2017-06-20
**Røkke, Nils Anders.**
Welcome to FME HighEFF kick-off. FME HighEFF kick-off; 2016-11-28 - 2016-11-28
**Røkke, Petter Egil.**
FME HighEFF progress: Status, expectations and highlights. HighEFF Cross-sector workshop; 2017-10-25 - 2017-10-26

**Skjervold, Vidar T.**
Design and evaluation tools for surplus heat recovery concepts. HighEFF Centre; 2017-12-21 - 2017-12-21
**Solheim, Asbjørn.**
Alternative processes for aluminium production. HighEFF Annual Consortium Meeting 2017; 2017-06-19 - 2017-06-20
**Straus, Julian; Skogestad, Sigurd.**
Economic NMPC for Heat-Integrated Chemical Reactors. 21st International Conference on Process Control; 2017-06-06 - 2017-06-09
**Straus, Julian; Skogestad, Sigurd.**
Variable Reduction for Surrogate Modelling. Foundations of Computer-Aided Process Operations; 2017-01-08 - 2017-01-12
**Sørheim, Roger.**
Opportunistic researchers and impatient industry partners. HighEFF Annual Consortium Meeting 2017; 2017-06-19 - 2017-06-20
**Vikse, Matias.**
Optimization of work and heat exchange networks. HighEFF Annual Consortium Meeting 2017; 2017-06-19 - 2017-06-20
**Wittgens, Bernd.**
From industrial needs to application (design) - Use case metallurgical industries. HighEFF Annual Consortium Meeting 2017; 2017-06-19 - 2017-06-20
**Yu, Haoshui.**
Applications of ORC (Organic Rankine Cycle) in industry. HighEFF Annual Consortium Meeting 2017; 2017-06-19 - 2017-06-20

## Report/thesis

**Andresen, Trond.**
Potential tube configurations design for 3D printing – status from 2017 FDM 3D printing activities: SINTEF Energi AS 2017 19 p.
**Drexler-Schmid, Gerwin; Kauko, Hanne.**
High-temperature phase change material thermal storage for components and cycles: FME HighEFF 2017 16 p.
**Foslie, Sverre Stefanussen.**
Possibilities for energy recovery by steam compression cycles: SINTEF Energi AS 2017 34 p.
**Foslie, Sverre Stefanussen; Knudsen, Brage Rugstad; Kauko, Hanne; Stavset, Ole; Schlemminger, Christian.**
Industrial energy storage - State-of-the-art report with focus on thermal energy storage: SINTEF Energi AS 2017 40 p.
**Nikolaisen, Monika.**
Technologies for medium-temperature heat-to-power conversion. Trondheim: Sintef Energi AS 2017 28 p.
**Skjervold, Vidar T.**
Designing novel concepts for surplus heat recovery SINTEF Energi AS 2017 15 p.
**Skjervold, Vidar T.**
Status on surplus heat database SINTEF Energi AS 2017 9 p.
**Srivastava, Akhilesh Kumar.**
Evaluation of TG industry implementation process: SINTEF Energi (FME HighEFF) 2017

## Media contributions

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