Centre for an Energy Efficient and Competitive Industry for the Future (Annen støtte - FME)

Application Number: ES562672 Project Number: 257632

Applicant

Project Owner

Institution / company (Norwegian name)	SINTEF ENERGI AS
Faculty	
Institute	
Department	
Address	Postboks 4761, Sluppen
Postal code	7465
City	TRONDHEIM
Country	Norway
E-mail	energy.research@sintef.no
Website	
Enterprise number	939350675

eAdministration	

Project administrator

First name	Petter
Last name	Røkke
Date of birth	031174
Personal number	
Gender	Male
Position/title	Research Director
Phone	+4790120221
E-mail	petter.e.rokke@sintef.no
Confirmation	✔ The application has been approved by the Project Owner

Centre for an Energy Efficient and Competitive Industry for the Future (Annen støtte - FME)

Application Number: ES562672 Project Number: 257632

Project manager

First name	Anne Karin T
Last name	Hemmingsen
Date of birth	160871
Personal number	
Gender	Female
Institution / company (Norwegian name)	SINTEF Energi AS
Faculty	
Institute	
Department	Thermal Energy
Address	Postbox 4761 Sluppen
Postal code	7465
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Country	Norway
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Preferred language	Bokmål
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E-mail	AnneK.T.Hemmingsen@sintef.no

Project info

Project title

Project title	Centre for an Energy Efficient and Competitive Industry for the Future

Primary and secondary objectives of the project

Primary and secondary objectives	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 in industrial energy efficiency -Generate 6 KPN, 8 IPN, 8 DEMO and 5 EU spin-off projects -Enable competence building by educating 22 PhD/Post.docs candidates, 50 MSc candidates, and training/recruitment of 30 experts in industrial energy efficiency

Project summary

Project summary	Improved energy efficiency is expected to play a crucial role in protecting the global environment. 19 % of the contributions needed to reach the 2°C goal in climate change mitigation, which the Norwegian government has agreed to, should come from industrial energy efficiency improvements. This is more than the expected contribution from any renewable energy sources and contributes also to reduced pressure on an increasing power demand. While being crucial for climate change mitigation, efficient energy use is also a decisive competitive factor for the energy-intensive industry. In HighEFF, the research groups at SINTEF and NTNU will join forces with leading national and international industrial partners, vendors, universities and research institutions to follow the most obvious and immediate avenue to mitigate global warming: to improve energy efficiency in industry beyond state-of-the-art. The research groups represented in HighEFF are pioneers within the development of industrial processing knowledge, and within refrigeration, heat pumping and power cycles based on natural working fluids. The industry partners represent all the largest industry sectors in Norway: metal producing industries, oil and gas industry, chemical industry and the food industry, in addition to relevant vendors and technology providers.

	Energy efficiency will be addressed at different levels, from components to process, plant, cluster and geographical region. HighEFF will focus on technologies and processes with potential for large reductions in specific energy use: (i) energy efficient processing (6-10 % reduction), (ii) surplus heat utilization (10-12 % reduction), and (iii) green industrial clusters (4-8 % reduction). Through technologies developed in HighEFF, a total reduction in specific energy use of 20-30 % can thus be possible. Shifting to natural working fluids and reducing the fossil fuels consumption can allow 10 % reduction in greenhouse gas emissions.

Funding scheme

Supplementary info from applicant

Programme / activity	FME
Application type	Annen støtte
Topics	
Other relevant programmes/ activities/projects	
Discipline(s)	Energy use and conversion
If applying for additional funding, specify project number	
Have any related applications been submitted to the Research Council and/or any other public funding scheme	No
If yes, please provide further information	

Progress plan

Project period

From date	20160901
To date	20240831

Centre for an Energy Efficient and Competitive Industry for the Future (Annen støtte - FME)

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Main activities and milestones in the project period (year and quarter)

Milestones throughout the project	From		To	
KPI for system efficiency and CO2 footprint	2016	4	2017	2
Toolbox for energy and exergy analyses	2017	1	2022	4
Systematic approach to operational optimizati	2017	1	2018	1
Design for heat and power integration	2016	4	2020	1
Verified heat exhanger concetps	2016	4	2018	1
Expander concepts for working fluid mixtures	2017	1	2021	1
Verified rotating machinery design	2017	1	2021	1
Properties for relevant working fluid mixture	2016	4	2018	4
Heat-to-power technologies optimized per sect	2016	4	2023	4
System layouts for heating, cooling & drying	2017	1	2021	2
Technology concetps for efficient HTHPs	2017	1	2022	2
System layouts for energy storage concepts	2017	1	2021	1
Design for energy efficient process concepts	2017	1	2023	3
Concetps for surplus heat recovery systems	2016	4	2020	2
Design integration of energy efficient techno	2017	1	2019	4
Recommendations & concetps for clusters	2017	1	2020	3
Innovation Strategy and technology roadmaps	2016	4	2018	4
White papers on framework conditions	2017	1	2018	4
Novel emerging concepts	2020	1	2023	4
100 publications and 20 pop sciense reports	2017	1	2023	4
Webpage and blog	2016	3	2016	4
Case studies reported	2017	4	2023	4
19 PhD candidated disserted	2017	1	2023	4
2 post doc candidates finished	2017	1	2023	4
50 MSc candidates finished	2017	1	2023	4

Dissemination of project results

Dissemination plan

Energy efficiency is one of the most significant technologies measured in environmental impact, but does often not generate the same attention and is not perceived as being as exciting as other new climate technologies. Thus, communicating the environmental potential of HighEFF is a key activity.

The scientific community will be addressed through publications in scientific journals and conferences; the goal is 100 publications in peer-reviewed journals and conference proceedings.

To ensure the widest possible spread for the results, Open Access journals will be preferred when possible. Science communication to the public is important in order to have an impact on society and to participate in societal decisions about science and technology.

Public engagement is essential also to recruit students to work within research and industry.

The main audience groups of HighEFF are:

-Industry: Communicating the importance and impact of research results is vital in order to bridge the gap between researchers and industry. Internal communication will be prioritized, and ensured through regular meetings and workshops as well as through an electronic workspace and newsletters. Industries outside the project consortium, in Norway and Europe, will also be addressed. An international conference on industrial energy occurring every second year will be considered.

Politiciance and decision makers will be addressed to enable informed decision making on the framework for energy efficient industry

-Technology students and young talents will be addressed to recruit young talents to the industry and to create commitment towards energy efficiency

The general public: Science communication and literacy is important in order to gain general support towards energy efficiency research

Communication channels/platforms:

-Scientific platforms: Journals and national and international conferences.

-HighEFF web-pages: To share research results in a popular science format

-Social media: Will be used to engage the audience, share results and achieve public participation through two-way communication

-National and European media: Op-eds and popular scientific journals (e.g. GEMINI, ScienceNordic, alphagalileo.org, Aftenposten, Dagens Næringsliv and Teknisk Ukeblad)

-HighEFF blog: Newsletters based on the blog, written in Norwegian and English, will be regularly distributed to partners, industry, politicians and other interested stakeholders

-Event activities and school talks through the Norwegian Science week and the role models-program of the Norwegian Centre for Science Recruitment.

Budget

Cost plan (in NOK 1000)

	2016	2017	2018	2019	2020	2021	2022	2023	Sum
Payroll and indirect expenses	9395	23692	19741	18529	19340	17106	21001	41597	170401
Procurement of R&D services	6084	21267	25021	26000	26192	29558	26198	37486	197806
Equipment	133	400	400	400	400	400	400	666	3199
Other operating expenses	4388	14641	14838	15071	14068	12936	12401	20251	108594
Totals	20000	60000	60000	60000	60000	60000	60000	100000	480000

Specification

Other operating expenses include user-partners own work contributions.

Cost code (in NOK 1000)

	2016	2017	2018	2019	2020	2021	2022	2023	Sum
Trade and industry	2370	7110	7110	7110	7110	7110	7110	11850	56880
Independent research institutes	13140	34086	30870	31562	31036	29709	36390	68305	275098
Universities and university colleges	3222	12773	15792	14867	16396	18855	12709	13444	108058

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	2016	2017	2018	2019	2020	2021	2022	2023	Sum
Other sectors									0
Abroad	1268	6031	6228	6461	5458	4326	3791	6401	39964
Totals	20000	60000	60000	60000	60000	60000	60000	100000	480000

Funding plan (in NOK 1000)

	2016	2017	2018	2019	2020	2021	2022	2023	Sum
Own financing	2490	6200	5243	4949	5145	4604	5548	10723	44902
International funding	1020	3598	3646	3702	3459	3185	3055	5112	26777
Public funding	579	2691	3422	3400	3972	4568	3079	3257	24968
Private funding	5911	17511	17689	17949	17424	17643	18318	30908	143353
The Research Council	10000	30000	30000	30000	30000	30000	30000	50000	240000
Totals	20000	60000	60000	60000	60000	60000	60000	100000	480000

Specification	"Own financing" is only for the host. Other partners own financing is summarized under international, public and private funding.

Fellowship

Type of fellowship	Doctoral research fellowship
From date (yyyymmdd)	20170102
To date (yyyymmdd)	20191231

Type of fellowship	Doctoral research fellowship
From date (yyyymmdd)	20180101
To date (yyyymmdd)	20201231

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Type of fellowship	Doctoral research fellowship
From date (yyyymmdd)	20170102
To date (yyyymmdd)	20191231

Type of fellowship	Doctoral research fellowship
From date (yyyymmdd)	20170702
To date (yyyymmdd)	20200630

Type of fellowship	Doctoral research fellowship
From date (yyyymmdd)	20180101
To date (yyyymmdd)	20211231

Type of fellowship	Doctoral research fellowship
From date (yyyymmdd)	20190101
To date (yyyymmdd)	20221231

Type of fellowship	Doctoral research fellowship
From date (yyyymmdd)	20170102
To date (yyyymmdd)	20191231

Type of fellowship	Doctoral research fellowship
From date (yyyymmdd)	20180701
To date (yyyymmdd)	20210630

Type of fellowship	Doctoral research fellowship
From date (yyyymmdd)	20170102
To date (yyyymmdd)	20191231

Type of fellowship	Doctoral research fellowship
From date (yyyymmdd)	20170601
To date (yyyymmdd)	20200531

Centre for an Energy Efficient and Competitive Industry for the Future (Annen støtte - FME)

Application Number: ES562672 Project Number: 257632

Type of fellowship	Doctoral research fellowship
From date (yyyymmdd)	20170901
To date (yyyymmdd)	20200831

Type of fellowship	Doctoral research fellowship
From date (yyyymmdd)	20190901
To date (yyyymmdd)	20220831

Type of fellowship	Doctoral research fellowship
From date (yyyymmdd)	20170301
To date (yyyymmdd)	20200228

Type of fellowship	Doctoral research fellowship
From date (yyyymmdd)	20200701
To date (yyyymmdd)	20230630

Type of fellowship	Doctoral research fellowship
From date (yyyymmdd)	20200601
To date (yyyymmdd)	20230531

Type of fellowship	Doctoral research fellowship
From date (yyyymmdd)	20170401
To date (yyyymmdd)	20200331

Type of fellowship	Doctoral research fellowship
From date (yyyymmdd)	20191101
To date (yyyymmdd)	20221031

Type of fellowship	Doctoral research fellowship
From date (yyyymmdd)	20190501
To date (yyyymmdd)	20220430

Centre for an Energy Efficient and Competitive Industry for the Future (Annen støtte - FME)

Application Number: ES562672 Project Number: 257632

Type of fellowship	Post-doctoral research fellowship
From date (yyyymmdd)	20170701
To date (yyyymmdd)	20190630

Type of fellowship	Post-doctoral research fellowship
From date (yyyymmdd)	20210601
To date (yyyymmdd)	20230531

Partners

Partners under obligation to provide professional or financial resources for the implementation of the project

1

Institution/ company	SINTEF ENERGI AS
Department/ section	
Address	Postboks 4761, Sluppen
Postal code	7465
City	TRONDHEIM
Country	Norway
Enterprise number	939350675
Contact person	Anne Karin Hemmingsen
Contact tel.	+4793019669
Contact e-mail	AnneK.T.Hemmingsen@sintef.no
Partner's role	Financing and Research activity

2

Institution/ company	NTNU FAKULTET FOR INGENIØRVITENSKAP OG TEKNIKK
Department/ section	
Address	
Postal code	7491
City	TRONDHEIM

Centre for an Energy Efficient and Competitive Industry for the Future (Annen støtte - FME)

Application Number: ES562672 Project Number: 257632

Country	Norway
Enterprise number	981553276
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Partner's role	Financing and Research activity

3

Institution/ company	STIFTELSEN SINTEF
Department/ section	
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Partner's role	Financing and Research activity

4

Institution/ company	NTNU SAMFUNNSFORSKNING AS
Department/ section	
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City	TRONDHEIM
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Enterprise number	986243836
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Contact e-mail	jens.royrvik@samfunn.ntnu.no

Centre for an Energy Efficient and Competitive Industry for the Future (Annen støtte - FME)

Application Number: ES562672 Project Number: 257632

Partner's role	Financing and Research activity

5

Institution/ company	STIFTELSEN TEL-TEK
Department/ section	
Address	Kjølnes ring 30
Postal code	3918
City	PORSGRUNN
Country	Norway
Enterprise number	943161895
Contact person	Anne Marie Fatnes
Contact tel.	
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Partner's role	Financing and Research activity

6

Institution/ company	SINTEF FISKERI OG HAVBRUK AS
Department/ section	
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Contact person	Tom Ståle Nordtvedt
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Partner's role	Financing and Research activity

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Institution/ company	UNIVERSITETET I NORDLAND
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Centre for an Energy Efficient and Competitive Industry for the Future (Annen støtte - FME)

Application Number: ES562672 Project Number: 257632

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Partner's role	Financing and Research activity

8

Institution/ company	Carnegie Mellon University
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Enterprise number	
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Partner's role	Financing and Research activity

9

Institution/ company	Royal Institute of Technology (KTH)
Department/ section	
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Country	Sweden
Enterprise number	
Contact person	Per Lundquist

Centre for an Energy Efficient and Competitive Industry for the Future (Annen støtte - FME)

Application Number: ES562672 Project Number: 257632

Contact tel.	
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Partner's role	Financing and Research activity
10	
Institution/ company	Research Center for energy Conversion System Doshi
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Country	Japan
Enterprise number	
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Partner's role	Financing and Research activity
11	
Institution/ company	University of Manchester
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Country	United Kingdom
Enterprise number	
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Partner's role	Financing and Research activity
12	
Institution/ company	AIT Austrian Institute of Technology GmbH Environm

Centre for an Energy Efficient and Competitive Industry for the Future (Annen støtte - FME)

Application Number: ES562672 Project Number: 257632

Department/ section	
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Partner's role	Financing and Research activity

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Institution/ company	Shanghai Jiao Tong University
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Partner's role	Financing and Research activity

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Country	Austria

Centre for an Energy Efficient and Competitive Industry for the Future (Annen støtte - FME)

Application Number: ES562672 Project Number: 257632

Enterprise number	
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Partner's role	Financing and Research activity

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Institution/ company	STATOIL PETROLEUM AS
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Partner's role	Financing and Research activity

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Institution/ company	HYDRO ALUMINIUM AS
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Partner's role	Financing and Research activity

Centre for an Energy Efficient and Competitive Industry for the Future (Annen støtte - FME)

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Institution/ company	ERAMET NORWAY AS
Department/ section	
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Partner's role	Financing and Research activity

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Institution/ company	FINNFJORD AS
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Partner's role	Financing and Research activity

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Institution/ company	ELKEM AS
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Application Number: ES562672 Project Number: 257632

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Partner's role	Financing and Research activity

20

Institution/ company	FESIL RANA METALL AS
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Partner's role	Financing and Research activity

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Institution/ company	WACKER CHEMIE AG
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Country	Norway
Enterprise number	997415329
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Centre for an Energy Efficient and Competitive Industry for the Future (Annen støtte - FME)

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Partner's role	Financing and Research activity

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Institution/ company	GLENCORE MANGANESE NORWAY AS
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Partner's role	Financing and Research activity

23

Institution/ company	Alcoa Norway ANS - Mosjøen
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Country	Norway
Enterprise number	
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Partner's role	Financing and Research activity

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Institution/ company	MARS GmbH
Department/ section	

Centre for an Energy Efficient and Competitive Industry for the Future (Annen støtte - FME)

Application Number: ES562672 Project Number: 257632

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Partner's role	Financing and Research activity

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Institution/ company	MO INDUSTRIPARK AS
Department/ section	
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City	MO I RANA
Country	Norway
Enterprise number	914780152
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Partner's role	Financing and Research activity

26

Institution/ company	REMA FRANCHISE NORGE AS
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Country	Norway
Enterprise number	982254604

Centre for an Energy Efficient and Competitive Industry for the Future (Annen støtte - FME)

Application Number: ES562672 Project Number: 257632

Contact person	Henryk Huls
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Partner's role	Financing and Research activity

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Institution/ company	ORKLA ASA
Department/ section	
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Postal code	0213
City	OSLO
Country	Norway
Enterprise number	910747711
Contact person	Inger Johanne Eikeland
Contact tel.	
Contact e-mail	inger.johanne.eikeland@orkla.no
Partner's role	Financing and Research activity

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Institution/ company	MARINE HARVEST ASA
Department/ section	
Address	Sandviksbodene 77A/B
Postal code	5035
City	BERGEN
Country	Norway
Enterprise number	964118191
Contact person	Kurt Olav Oppedal
Contact tel.	
Contact e-mail	Kurt.Olav.Oppedal@marineharvest.com
Partner's role	Financing and Research activity

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Centre for an Energy Efficient and Competitive Industry for the Future (Annen støtte - FME)

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Institution/ company	GLENCORE NIKKELVERK AS
Department/ section	
Address	Postboks 604
Postal code	4606
City	KRISTIANSAND S
Country	Norway
Enterprise number	911575787
Contact person	Per O Ramsdal
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Contact e-mail	Per.Ramsdal@glencore.no
Partner's role	Financing and Research activity

30

Institution/ company	GASSCO AS
Department/ section	
Address	Postboks 93
Postal code	5501
City	HAUGESUND
Country	Norway
Enterprise number	983452841
Contact person	Gudmundur Kristjanson
Contact tel.	
Contact e-mail	gkr@gassco.no
Partner's role	Financing and Research activity

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Institution/ company	KULDETEKNISK AS
Department/ section	
Address	Stakkevollvegen 69B
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City	TROMSØ

Centre for an Energy Efficient and Competitive Industry for the Future (Annen støtte - FME)

Application Number: ES562672 Project Number: 257632

Country	Norway
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Contact tel.	
Contact e-mail	yves@kuldeteknisk.no
Partner's role	Financing and Research activity

32

Institution/ company	BULK INFRASTRUCTURE AS
Department/ section	
Address	Frognerstranda 2
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City	OSLO
Country	Norway
Enterprise number	996501876
Contact person	
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Contact e-mail	
Partner's role	Financing and Research activity

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Institution/ company	NORFRAKALK AS
Department/ section	
Address	Postboks 53
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Country	Norway
Enterprise number	987151196
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Contact tel.	
Contact e-mail	glenn.hakon.bekkeli@norfrakalk.no

Partner's role	Financing and Research activity

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Institution/ company	VEDDE AS
Department/ section	
Address	
Postal code	6030
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37

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38

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39

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40

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41

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43

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45

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Application Number: ES562672 Project Number: 257632

46

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47

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Partner's role	Financing and Research activity

48

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49

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50

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Attachments

Project description

Filename	HighEFF_final.pdf
Reference	ES562672_001_1_Prosjektbeskrivelse_20151125

Other items

Filename	LOI HighEFF Academia.pdf
Reference	ES562672_010_13_Annet_20151124

Filename	LOI Industry 251115.pdf
Reference	ES562672_010_19_Annet_20151125

Filename	HighEFF Partners.pdf
Reference	ES562672_010_20_Annet_20151125

Filename	CV HighEFF CMT and WP.pdf
Reference	ES562672_010_21_Annet_20151125

Filename	PhD and Post doc Topics.pdf
Reference	ES562672_010_22_Annet_20151125

Filename	Case Studies 25115.pdf
Reference	ES562672_010_23_Annet_20151125

Centre for an Energy Efficient and Competitive Industry for the Future (Annen støtte - FME)

Application Number: ES562672 Project Number: 257632

Filename	Proposed referees_HighEFF.pdf
Reference	ES562672_010_24_Annet_20151125

HighEFF

Centre for an Energy Efficient and Competitive Industry for the Future

HighEFF is a response to the call for "New Centres for Environment-friendly Energy Research" in the thematic priority area "Energy use and conversion". Globally recognized research groups at SINTEF and NTNU with their strong industrial experience, will join forces with leading national and international industrial partners, vendors, universities and research institutions to follow the most obvious and immediate avenue to mitigate global warming: to improve energy efficiency in industry beyond state-of-the-art. *HighEFF* corner stones and research areas are illustrated in Figure 1.

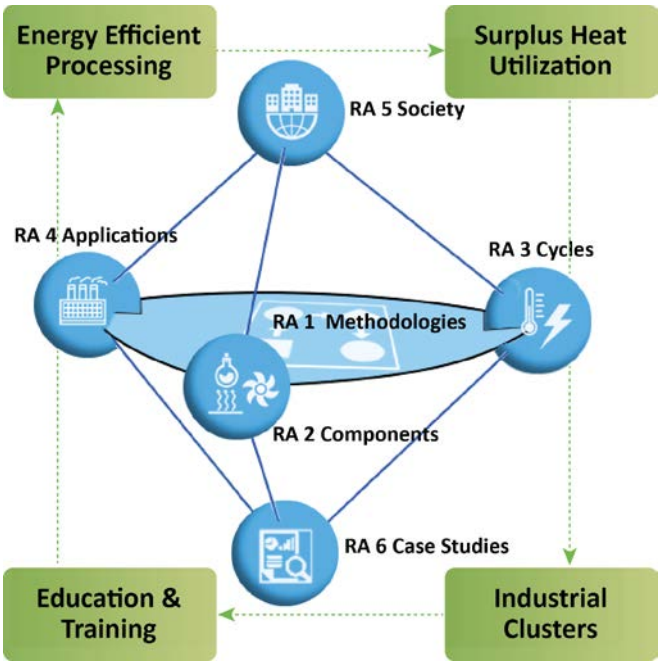

Figure 1:
***HighEFF* Cornerstones and Research Areas (RAs)**

Through close collaboration between universities, research institutes, vendors and industrial partners from major energy-intensive sectors, *HighEFF* aims to become a ***platform for innovation*** in industrial energy efficiency. This will contribute to ***value creation*** and increased ***competitiveness*** for the Norwegian industry, as well as lead to reduced environmental impact and increased productivity through better utilization of energy resources. Innovation and technology are two of the keys to the ***green shift***[1], where industry is a central driving force. Efficient commissioning of the developed technologies will be ensured by paying considerable attention to government legislation and framework conditions for the industry.

***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[2].
- 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, 8 DEMO and 5 EU spin-off projects
- Enable competence building by educating 22 PhD/Post.docs candidates, 50 MSc candidates, and training/recruitment of 30 experts in industrial energy efficiency.
- Disseminate and communicate project results; 100 journal articles and conference papers.

[1] Regjeringen.no (2014). Grønt skifte – klima- og miljøvennlig omstilling. https://www.regjeringen.no/no/tema/klima-og-miljo/klima/innsiktsartikler-klima/gront-skifte/id2076832/
[2] EU Energy Strategy (2015). https://ec.europa.eu/energy/en/topics/energy-strategy/2030-energy-strategy

The importance of energy efficiency: The environmental impacts of human activities pose a threat to mankind through climate change. A sustainable and energy-efficient industry is central in continuing to support the needs of an increasing population. The importance of energy efficiency to protect and improve the global environment has been emphasized in several recent publications, such as the European Strategic Energy Technology Plan (SET-plan)[3], and the International Energy Agency's (IEA) World Energy Outlook[4] and Energy Efficiency Market report[5]. The last-mentioned states that the avoided energy use from a long-term improvement in energy efficiency should be the largest contributor. According to the IEA Energy Technology Perspectives, 19% of the contributions needed to reach the 2°C goal in climate change mitigation, which the Norwegian government has also agreed to, have to come from industrial energy efficiency improvements[6]. The role of an energy-efficient industry is also highlighted as one of the main areas in the national energy technology strategy[7]. Norway's offshore O&G strategy lists energy-efficient and environmentally sustainable technologies as one of four focus areas for the 21st century[8].

***HighEFF* will focus on** technologies and processes with potential for large reductions in specific energy use in the areas of: (i) energy efficient processing (**6-10%** reduction[9]), (ii) surplus heat utilization (**10-12%** reduction[9]), and (iii) green industrial clusters (**4-8%** reduction[9]). These areas have been identified in the Energy21 strategic work, they are mostly of cross-industry-sectorial character and will by this maximize competence transfer between industrial branches. Industry-specific interfaces for technology integration will in addition enable effective and competitive applications. Development and optimization of *components, cycles and systems* will maximize overall plant energy efficiency. The *HighEFF* research areas (RAs) are illustrated in Figure 2.

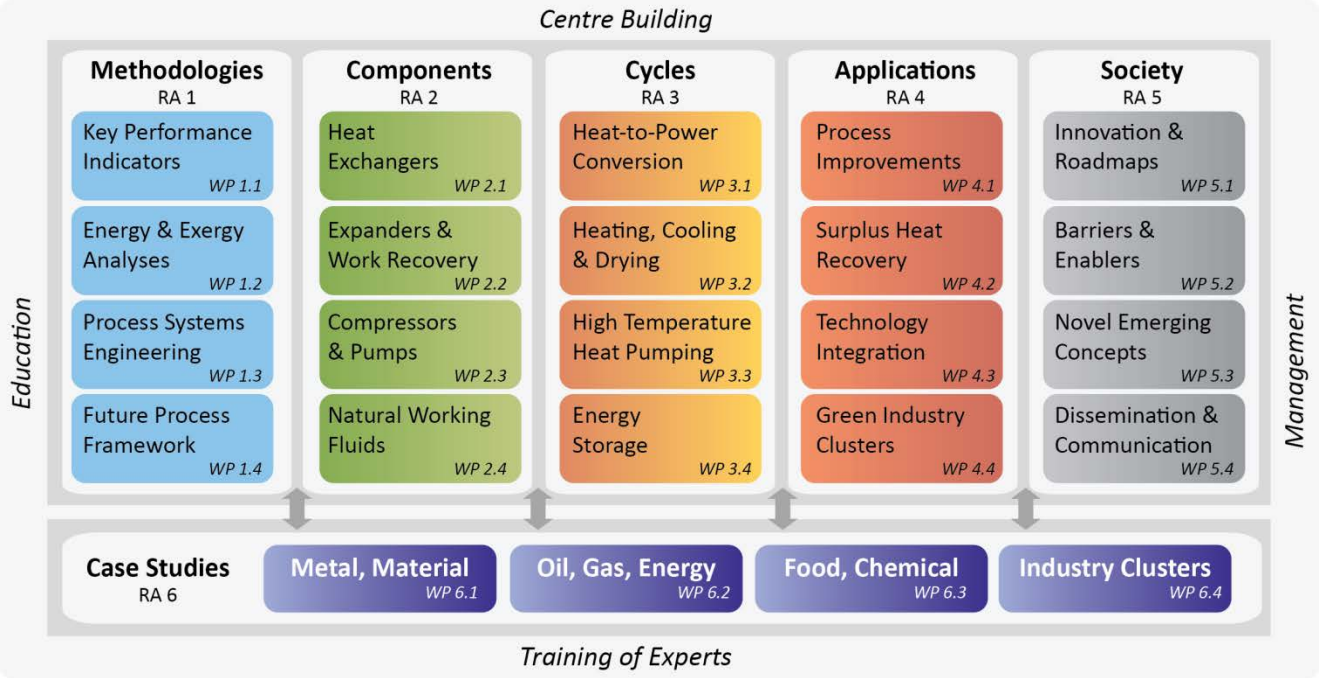

Figure 2: Work breakdown structure.

Norwegian excellence as exemplified by the *HighEFF* partners: The groups represented in *HighEFF* are pioneers and international leaders within the development of industrial processing knowledge, and within refrigeration, heat pumping and power cycles based on natural working fluids.

[3] European Commission (2007). A European Strategic Energy Technology Plan (SET-plan): 'Towards a low carbon future'.
[4] IEA, World Energy Outlook Special Report 2015: Energy and Climate Change
[5] IEA, Energy Efficiency Market Report 2014: Market Trends and Medium-Term Prospects.
[6] IEA (2014). Energy Technology Perspectives 2014: Harnessing Electricity's Potential.
[7] Energi21, Strategy 2014 - National strategy for research, development, demonstration and commercialisation of new energy technology.
[8] OG21 - Oil and Gas in the 21st Century (2012). Norway´s Technology Strategy for the 21st Century.
[9] Estimated potential for reduced specific energy use in 2030 compared to 2015 - by use of *HighEFF* technologies

Their know-how has already led to technological improvements in a large number of plants; however, there is still a considerable potential for improving energy efficiency in the industry, representing 41% of the total energy use, see Figure 3. Norway became industrialized due to four important natural resources; water falls, minerals, oil and gas, and fish. Cheap hydroelectric power enabled the growth of energy-intensive and technologically challenging fertilizer and metals production. The discovery of oil and gas in the North Sea made Norway a considerable energy provider, with challenges in long distance two-phase flow. The growth in the fishing industry would not have been possible without our world-class expertise in refrigeration engineering. More recently, there has been a focus on renewable energy sources. In all these areas, close collaboration between industry and R&D institutions has been a crucial success factor.

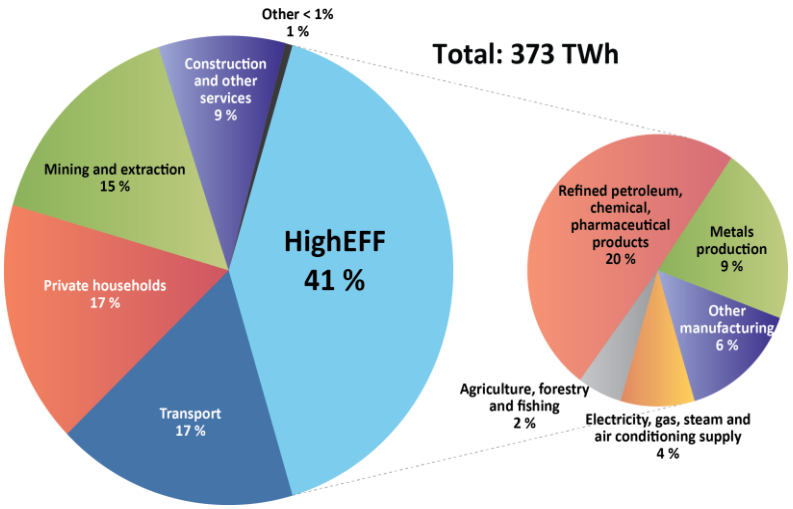

Figure 3 Total energy use in Norway.

From a long tradition of research collaboration and continuous innovation, the Norwegian *metal producing industries* are today the cleanest and most energy and resource efficient in the world. GHG emissions have been reduced by almost 40% during the last 20 years while the total production volume has increased. This industry is extremely power intensive due to the electrolytic and melting processes, consuming close to 1/3 of the total electricity supply in Norway. The high temperatures in some processes lead to generation of surplus heat that may be converted to electricity or used directly. Accelerated efforts are needed to keep the Norwegian metal producing industry at the forefront of innovation, productivity and sustainable energy utilization. This can be materialized through the extended collaborative efforts proposed in *HighEFF*.

The oil and gas industry is responsible for 26% of Norway's annual GHG emissions with 14 Mt of CO_2 equivalents released in 2014[10]. The Norwegian oil and gas industry is historically among the most energy efficient in the world, as measured by the amount of CO_2 per barrel of oil equivalent (boe) produced[11]. The Middle East has surpassed this only by a small margin since 2013. The largest contribution (78%) to CO_2 emissions on the Norwegian Continental Shelf (NCS) is from gas turbines used for power production. The CO_2 emissions per boe produced on the NCS were reduced by almost 20% in the period between 1990 and 2005, mainly due to reduced natural gas flaring and installation of waste heat recovery units (WHRUs)[12]. In this period, Statoil reduced their CO_2 emissions by 40 Mt on the NCS[13]. An example is Statoil's latest energy management project at Oseberg, which was completed in 2015 and resulted in annual CO_2 emission reductions of 1390 tonnes and cost savings of NOK 700k[14].

The chemical industry and oil refineries accounted for 29% of the total energy use in Norwegian onshore industry in 2007, corresponding to 22.3 TWh[15], of which 9.1 TWh was in refineries. Energy use in the chemical industry is primarily related to production of raw materials such as plastics, methanol, fertilizers and carbides. Although many plants already are quite energy efficient, the technical reduction potential of specific energy consumption is estimated at 20% from 2007 levels, equivalent to an annual intensity improvement of 1.7% until 2020. 82% of the identified measures are estimated to be profitable with an average payback time of 5.5 years.

[10] Norsk Petroleum (2015). Climate and environment. http://www.norskpetroleum.no/en/framework/climate-and-environment/
[11] Norsk Olje&Gass (2015). Environmental report 2015. https://www.norskoljeoggass.no/en/Publica/Environmental-reports/
[12] Norwegian Petroleum Directorate (2007). *Factbook on Oil and Gas Production*.
[13] Statoil (2010). Annual report 2010. http://www.statoil.com/AnnualReport2010/en/Pages/frontpage.aspx
[14] Helland, Knut (2015). "Energiledelse Oseberg", Lecture at "Ny energi for norsk sokkel" conference, RCN, Oslo.
[15] McKinsey (2009). Potensial for energieffektivisering i norsk landbasert industri. Enova.

The food industry had a total electricity use of about 3 TWh, equivalent to 5.6% of industry's total power consumption in 2006[16]. In addition, the food industry used about 1.7 TWh of other energy sources (oil, gas, waste, steam and district heating). The largest energy consumers are fish, meat and dairy industries, accounting for more than half of the energy use in the food industry. Overall energy-saving potentials for the food industry are estimated at 1301 GWh/year, corresponding to 30% of the energy consumption and 50 kt/year reduction in CO_2 emissions in this sector. The majority of the saving potentials can be realized for less than NOK 1,00/kWh, corresponding to 2 years payback time.

One of the *HighEFF* partners, *Mo Industripark*, is Norway's and one of the world's most energy efficient *industrial clusters*. Both energy and material streams are recycled and exchanged within the cluster, and heat is exported to the city of Mo i Rana. To reduce GHG emissions, increase competitiveness as well as to generate green jobs in the process industry, new "green" industry clusters following a circular economy approach are needed. The objective here is to identify potential industries, as well as novel process approaches, that can contribute to meeting these challenges by forming clusters and using advanced process and plant integration.

Figure 4 *HighEFF* collaboration.

In addition, *HighEFF* will team up with relevant *vendors and technology providers* to enable the development and implementation of novel components and concepts that will contribute to fast utilization of improved technologies in the end-user industries, and ultimately to create more "green" jobs. The tradition of close cooperation between *Industry, R&D providers and Technology vendors* (Figure 4) in research activities, guided by short and long term industrial needs, has proved fruitful. *HighEFF* will build on this experience and further develop such collaboration by involving an extended group of leading international academic groups as well as social scientists with expertise on energy research in order to fulfil the objectives of the Centre.

1. **National and International State-of-the-art:** This section outlines the state-of-the-art for the technologies to be developed, which research gaps that need to be filled, and how *HighEFF* will contribute to significant progress beyond today's situation within the research areas of the Centre.

Methodologies: Industrial processes are characterized by complex systems for consumption, production and conversion of energy in various forms (chemical, thermal, mechanical and electrical). In order to improve energy efficiency, *methodologies* with a holistic approach are needed to avoid local optima. ***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. The methodologies are routinely used in many industries, but the potential for large improvements still exists and an extension to analyze industrial clusters based on material, energy and exergy flows is needed. *HighEFF* will promote the use of the *exergy* concept, both as a post-design metric for energy efficiency and as a ***Key Performance Indicator*** *(KPI)*, and also as a guiding tool at the conceptual design stage. Exergy (i.e., the maximum ability to produce work) is a measure of both quality and quantity of available energy. Energy consumption in industry consists of both heat and power. Since these energy forms have different qualities, exergy should also be used in *measuring* energy efficiency. Science Europe[17] has suggested using destructed exergy as a thermodynamic metric for assessing sustainable use of natural resources[18], and as a new "footprint" for all industrial activity in Europe. The classical heat exchanger network synthesis problem can be extended to include compressors and expanders with exergy consumption and production as the objective function[19,20].

[16] NEPAS (2007). Store energipotensialer i næringsmiddelindustrien. Enova.
[17] Science Eu. Phys., Chem. and Mathem. Sci.Com., A common scale for our common future: Exergy, a thermodyn. metric for energy, D/2015/13.324/6.
[18] Kjelstrup, Dewulf and Nordén (2015) A thermodyn. metric for assessing sustainable use of natural resources, Int. Jl. of Thermodyn., 18(1), pp. 66-72.
[19] Fu C and Gundersen T (2015) Integrating compressors into heat exchanger networks above ambient temperature, AIChE Jl., 61(11), pp. 3770-3785.
[20] Fu C and Gundersen T (2015) Integrating expanders into heat exchanger networks above ambient temperature, AIChE Jl., 61(10), pp. 3404-3422.

This approach will elucidate how the current use of compressors and expanders in industry may be counter-productive. When focusing on energy, special systems-oriented methodologies such as ***Energy and Exergy Analysis*** based on the 1st and 2nd laws of thermodynamics are available. Furthermore, the concept of heat recovery pinch has been developed into a more general methodology called Process Integration. NTNU and SINTEF have world-class expertise on pinch and exergy analyses and some areas of PSE, such as Process Control and Operation. There is, however, a lack of knowledge and appreciation for the powerful tool of mathematical optimization. This is an area where Norway has a huge potential, both in education and industrial practice, and *HighEFF* will provide a golden opportunity to utilize this.

Components: Utilization of ***working fluids*** naturally occurring in the biosphere, such as CO_2, ammonia, hydrocarbons, and water, can reduce direct and indirect GHG emissions considerably[21,22]. Natural working fluids are competitive with the commonly used synthetic fluids in efficiency and applicability, but components and systems need to be developed further or adapted to fully exploit their thermophysical properties. For some applications, such as commercial refrigeration and medium temperature industrial heat pumps, components and systems using natural fluids have been developed. The last decade has seen a tremendous deployment of CO_2 transcritical commercial refrigeration systems in Europe, and this trend is spreading globally[23]. Natural working fluids are also making progress within systems for air cooling and heating. For other applications, such as industrial high temperature heat pumps (HTHPs) and low-medium temperature waste heat to power cycles, novel efficient components need to be developed. ***Working fluid mixtures*** is already a widely used concept in some refrigeration processes. Mixed working fluids have non-isothermal evaporation (gliding temperature), and the mixture can be optimized to fit the heating curve to the heat source in power cycles, thereby maximizing both the efficiency and the utilization of constrained heat sources. Further potential exists to increase efficiency and reduce costs by design and component improvements. ***Heat exchanger*** performance has a considerable impact on system efficiency and power output, and typically constitutes a substantial fraction of the total costs in waste heat-to-power and heat pumping systems. For heat-to-power processes, more compact components and solutions that enable efficient capture of the heat at the highest possible temperature level could therefore lead to overall cost savings and significantly increased power output. With working fluid mixtures, optimal condenser and evaporator design is crucial to exploit the temperature glide and the changes in composition during the heat exchange. Furthermore, for successful implementation in industry, heat exchangers requiring a minimum of maintenance should be developed. Other key components for heat pumping and heat-to-power conversion cycles are ***compressors, expanders and ejectors***. Expansion devices for natural working fluids and mixtures will have to be especially adapted. Application of ejectors in CO_2 refrigeration or heat pump systems is a novel approach to recover expansion work and reduce throttling losses, hence increasing system efficiency. The energy savings potential of ejector-equipped systems has been verified experimentally by a number of laboratory tests[24,25]. Efficient high-pressure pumps are crucial for power cycle efficiency, and new fluids will require adapted technology. There is a need for more research and development to improve the energy and cost efficiency of these components and to adapt them to matching fluids and different applications.

Cycles: ***Power production*** from thermal sources is dominated by the steam-based Rankine cycle (RC) for high temperature heat sources found in nuclear, coal, oil, gas and large biomass fired plants. For lower temperatures (< 350°C) and capacities (< 5 MWe), other working fluids, e.g. organic fluids,

[21] UNEP 2014: 2014 Report of the Refrigeration, Air Conditioning and Heat Pumps Technical Options Committee.
[22] Nekså P, Hafner A and Walnum H T (2010) CO_2 - a refrigerant from the past with prospects of being one of the main refrigerants in the future. Proceedings of the 9th IIR-Gustav Lorentzen Conference on Natural Working Fluids, Sydney, Australia.
[23] Shecco 2014: "GUIDE 2014: Natural Refrigerants - Continued Growth & Innovation in Europe", available from www.publications.shecco.com
[24] Elbel S.W. (2011). Historical and present developments of ejector refrigeration systems with emphasis on transcritical carbon dioxide air-conditioning applications, Int. J. Refrig. 34 1545-1561.
[25] Banasiak, K., Hafner, A., Andresen, T., Experimental and numerical investigation of the influence of the two-phase ejector geometry on the performance of the R744 heat pump, Int. J. Refrig. 35 (2012), pp. 1617-1625.

are favoured[26]. Commercial organic Rankine cycles (ORC) have been available for 25 years, and have been applied to produce power from geothermal, smaller biomass plants and industrial surplus heat[27]. Current research in RC technology is focusing on component development and working fluid selection. There is also an ongoing development of alternative conversion technologies; such as the Kalina cycle®, Stirling engines[28], flash cycles, transcritical Rankine cycles, Rankine cycles with mixed working fluids, and thermoelectric generation. Thermoelectric generators (TEGs) offer highly reliable and silent operation. Only small scale TEGs have been tested for industrial waste recovery so far; Tel-Tek and Eramet (Norway) have installed a 350 W TEG at an industrial hot air duct. Further development should include benchmarking of industrial scale concepts and comparison with alternative power conversion technologies. High capacity industrial ***high temperature heat pumps*** (HTHPs) can upgrade low quality heat to temperatures of 85°C and above, levels often required by industrial processes. The HTHPs face several challenges related to e.g. lubrication, environmentally benign working fluids, material challenges at high temperatures, safety and cost. Different HTHP concepts exists, such as mechanical vapour recompression systems (MVR), vapour compression heat pumps (reversed Carnot cycle), single phase heat pumps (Stirling cycle), absorption heat pumps, and compression-absorption concepts. HTHP systems for drying are important for industrial applications, both for food and material industries. In metal production, significant energy savings may be realized by preheating material flows either by direct use of surplus heat or by heat pumping. ***Integrated heating and cooling concepts*** for refrigeration, heating and AC systems, e.g. in supermarkets, can allow 30% reduction in energy use[29]. Efficiency can be further improved by applying ejectors; recent work has demonstrated an increase in coefficient of performance (COP) by up to 20% at high ambient temperatures[30], but practical implementation is required. ***Energy storage concepts*** play a crucial role in increasing energy efficiency and the renewable energy share of the industry by acting as a peak shaving device and balancing any mismatch in production and demand of heating or cooling[31]. Thermal energy storage (TES) technologies, adapted to different temperature levels, can be utilized locally or at a systems level, i.e. in components, processes, industrial plants or clusters. Slurries of water and ice are relatively popular for cold storage, and concepts using other fluids, such as CO_2, enable storage at low temperatures[32]. In addition to storing thermal energy, cost-efficient solutions to handle the fluctuations in availability of electric power are needed as the share of wind and solar power is growing. When transfer capacity in the electric grid is limited, the options are to convert electric energy to a storable form of heat for later re-conversion, or to use excess energy for local industrial production. Alternative concepts, such as reversible gas compression/expansion and reversible heat pump/power cycles, are currently being investigated[33].

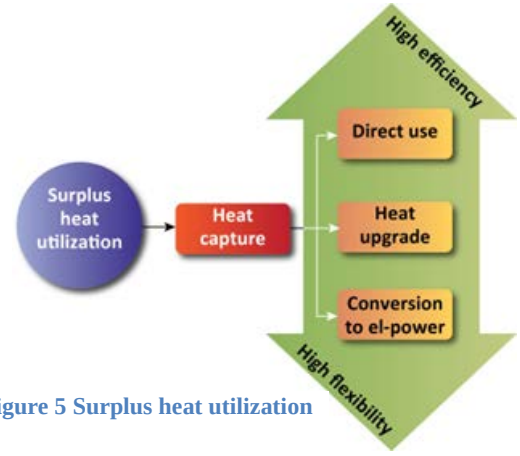

Figure 5 Surplus heat utilization

Applications: ***Process improvements*** are an important option for reducing specific power consumption. This can be illustrated by an example from the ferroalloy industry; by shifting from open to semi-closed furnaces, the exhaust gas flow has been reduced by 60%, thereby increasing the exhaust gas temperature from 200 to 800°C and improving possibilities for efficient heat-to-power conversion. Important R&D tasks remain, such as capturing and controlling the heat from top covers of the furnaces for heat-to-power conversion and advancing the steps towards closing the furnaces. Another example is development of alternative furnace feed designs for Mn and Si production to

[26] Watt & Crook (1994) Profiting for low grade heat. IEE energy series 7, ISBN 0 85296 835
[27] DiPippo (2005) Geothermal power plants. Principles applications, and case studies. IBSN 1856174743; Obernberger et al (2003) State of the art and future develop. regarding small scale biomass CHP systems with a special focus on ORC and Stirling engine technologies. Int. Nordic Bioenergy conf.
[28] The Alaska Center for Energy & Power: RSA 0925 Task one final report, 2009
[29] S Tønseth (2014). Drastic cut in electricity bill for supermarket. http://gemini.no/en/2014/06/drastic-cut-in-electricity-bill-for-supermarket/
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[31] KPN-application: SuperSmart-TES sent to the EnergiX –call of the RCN
[32] Hafner,Nordtvedt,Rumpf (2011). Energy saving potent. in freezing appl.by appl cold therm. energy storage with solid CO2. Proc Food Sc., 1. 448-454.
[33] Hemrle, J., et al (2011). Thermoelectric Energy Storage based on transcritical CO_2 cycle. Supercritical CO_2 power Cycle Symposium, Boulder, CO

reduce carbon consumption and CO emissions. Within the food industry, improvements can be made by implementing heat pumps to replace or reduce fossil fuel and electricity use in e.g. steam-based processes. ***Surplus heat capture*** is a prerequisite for all direct and indirect utilization of waste heat. Heat capture is limited by equipment cost, size, and efficiency; heat source composition; and potential detrimental effects such as fouling. Even large scale systems using low to moderate temperature heat sources typically capture only part of the available heat. New concepts are being developed to exploit various heat sources, such as hot, often particle-laden gases and liquids; equipment and infrastructure surfaces[34]; as well as slag and product casting. The spread of production units over a large area represents a challenge for efficient heat capture in some industries, such as the aluminium industry. Heat capture technologies often have high investment and high maintenance costs. They are, however, crucial to improve process energy efficiency and for controlling purposes, which highlights the importance of developing novel cost-efficient concepts. ***Integration of energy efficiency technology*** into the core industrial processes is crucial and might require redesign of existing systems. Important aspects include plant-specific physical constraints (space, weight), influence on the main/upstream process, and optimum interface for maximum efficiency and cost-effectiveness. Space and weight are particularly important for offshore oil and gas platforms, and ongoing and past projects have started developing more compact and lightweight bottoming cycles for offshore oil and gas industries[35,36]. ***Industrial cluster*** is defined as an assembly of several independent companies with agreements on the exchange of material and energy flows, such that the cluster as a whole is operating as close as possible to the optimum regarding material and energy flows and the economy. A prime example is Mo Industripark, where for instance CO and hydrogen are exchanged within the cluster, and heat from ferrosilicon smelters is utilized in fish farming and district heating. CO gas has a considerable potential for internal or external utilization, for instance through the water-gas shift reaction to hydrogen; through combustion to increase exhaust gas temperature for higher heat-to-power yield; for prereduction of Mn-ores; and to run a pelletizing unit for filter dust or wet scrubber sludges in a reducing atmosphere. Further, natural gas can be an important input factor both for power production and as a raw material, or a common carbon capture and storage plant (CCS) could be installed. Clustering of industries can hence benefit all parties in terms of reduced costs and improved energy efficiency. This will become even more relevant in a world with an increasing level of urbanization and as a way to ensure green growth. ***Local thermal grids*** are needed for optimal utilization of industrial surplus heat. Examples include utilizing the excess heat from a refrigeration system in a grocery store or dairy in nearby facilities or residential areas, or the placement of a data storage centre close to a city where the excess heat can be utilized for district heating. Implementation of local (smart) thermal grids with lower distribution temperatures than in the district heating grid will also allow for increased integration of renewable energy sources[37]. The share of renewable energy used for thermal purposes in industry was approximately 8% in Norway in 2014[38]. Local thermal grids and TES are the main approaches to increase this share.

Society: ***Innovation*** is a central driving force behind company performance and profitability[39], yet many companies find it difficult to develop innovations[40]. Universities and research institutions are considered to be key sources for innovations, giving companies the possibility to access fundamental knowledge and to conduct high quality research[41]. Although companies have recognized the importance of collaborating with public research organizations (PROs) in innovation development, identifying and assimilating relevant external knowledge sources is difficult[42]. In-depth understanding

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[36] Mazzetti, M (2015). Recovering Heat to shrink emissions. Chronicle in Norwegian Newspaper Dagens Næringsliv.
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[40] Katila & Ahuja (2002). A longitudinal study of search behavior and new product introduction. Academy of management J, 45(6), 1183-1194.
[41] Hussler, C., Picard, F., & Tang, M. F. (2010). Taking the ivory from the tower to coat the economic world: regional strategies to make science useful. Technovation, 30(9), 508-518.
[42] Laursen K, Salter A (2004). Searching high and low: what types of firms use universities as a source of innovation? Research policy, 33(8), 1201-1215.

of the organizational dynamics underlying these relationships[43], and the factors that reduce collaborative barriers over time are needed[44]. Finally, investments in energy efficiency measures will have to compete with alternative investments in the industry. Research is therefore needed on ***barriers and enablers*** for realization of the concepts and technologies developed in *HighEFF*.

2. **Benefits to Society and Industry:** Industrial energy efficiency addresses two important global issues: resource scarcity and climate change. By addressing the former, energy can be made available for other important demands. The latter is one of the most crucial challenges of our time, and immediate action is needed. While addressing these critical tasks, the research and innovations in *HighEFF* will bring added value to the public and the industry in many different areas:

   a) Reduced Environmental Impact: The role of industry on reducing the global environmental impact was highlighted in the introduction. Energy efficiency in industry has the advantage of involving a limited number of large energy consumers compared to the transport and building sectors consisting of millions of individual units. Energy efficiency measures are also less costly and can be implemented more rapidly than renewable energy and CCS. Through increased process efficiency and utilization of surplus heat developed in *HighEFF*, a reduction in specific energy use of **20-30%** can be expected. Shifting to natural working fluids and reducing the fossil fuels consumption can allow **10%** reduction in emissions.

   b) Reduced Energy Scarcity: The global energy demand is expected to grow with 37% by 2040 according to the IEA[3]. Energy scarcity and security are major concerns. Energy efficiency is therefore critical to relieve pressure on energy supply, and can also mitigate the competitive impacts of price disparities between regions. There is additionally a huge potential for utilization of industrial waste heat: 750 TWh, corresponding to 23% of the total heat demand in the EU in 2010[45]. In Norway, industrial waste heat amounts to approximately 20 TWh, but this resource is hardly utilized.

   c) Platform for Innovation: Innovation and new ideas are best created at the interface between different research communities, industrial end-users and vendors. *HighEFF* will create this dynamic interface, and thereby contribute to innovation and value creation. Innovation Norway and Enova will participate in the Centre with their resources to further stimulate the innovation process and bridge the gap between market and state-of-the-art technology.

   d) Network for Knowledge Building and Transfer: The Centre will become an international platform for knowledge building and exchange between industries and research organizations, and ensure publicity for the advances within energy efficient technologies. Through the established contacts and education of energy efficiency experts from participating research institutes and universities, the *HighEFF* network will remain and can be extended beyond the eight-year period of the Centre.

   e) Significance to the Industry: While being crucial for climate change mitigation, efficient energy use is also a decisive *competitive* factor for the energy-intensive industry[6]. Improved energy efficiency will lead to reduced fuel costs, and where applicable reduced CO_2 taxes (e.g. offshore oil and gas) or allowances in the EU Emissions Trading System. As a result, energy efficiency projects may have a short payback time on invested capital. Another focus will be to produce more compact products using less energy in the manufacturing process. All this may lead to increased productivity through better utilization of the energy and materials resources. The Centre will further increase the level of R&D activities in industry, creating new "green" jobs (5% increase), and new technology developments (ca. 30) and innovations (ca. 15) can be introduced to the international market.

   f) Value Creation Potentials for industrial and research partners are described in Table 1. The table indicates the interest for different RAs and WPs, as well as the cross-sectoral interests among the partners. The in-kind contribution from the industry and utilization of their research infrastructure will form a valuable basis for the work to be performed.

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[44] Bruneel, d'Este P, Salter A (2010). Investigating the factors that diminish the barriers to university–industry collaboration. Res. Policy 39(7), 858-868.
[45] Aalborg University, Halmstad University, Ecofys Germany, PlanEnergi and Euroheat & Power (2013). Heat Roadmap Europe: Second pre-study.

Oil, Gas & Energy	<u>*Oil & gas industry (Statoil, Lundin, Gassco)*</u>: Other regions have learned from the Norwegian oil and gas industry being an international leader in energy efficient production with low CO_2 emissions. This has created an opportunity for the export of green technology for the vendors, which should be fully exploited through increased technological development. Continuous improvement is important to reduce operational costs by reducing fuel consumption and future CO_2 emission costs. Emission reductions are important also to secure a license to operate in the future. (RAs 1, 2, 3 & 4; WPs 4.2, 4.3, 5.1, 5.2, 6.2) <u>*Energy companies (Statkraft Varme, Mo Fjernvarme, Hydro Energi)*</u>: Requirements of district heating (DH) customers will change in the future due to new building standards. Advanced heat pumping systems, new concepts for local low-temperature thermal grids and improved utilization of industrial waste heat developed in *HighEFF* will enable DH providers to supply CO_2-neutral heating and cooling. (RA 1; WPs 2.1, 3.3, 3.4, 4.2, 4.3, 4.4, 6.2, 6.4)
Metal & Materials	<u>*Aluminium industry*</u> *(Hydro Aluminium, Alcoa):* The energy needed to produce aluminium in Norway, 13-14 kWh/kg Al, is already among the lowest values obtained in plants world-wide[46,47]. Power production from surplus heat is the main option for significant further reductions in specific power consumption, and also represents a large potential for value creation. Heat recovery for proper utilization of different heat sources is however far from large scale implementation. Technological development is required on e.g. heat exchanger concepts and development of cost efficient heat-to-power plants. The potential energy saving is large, 0.9 kWh/kg Al produced, adding up to 1.06 TWH/y with the current Norwegian production (1.18 Mt in 2014)[48]. Further, new cooling concepts, e.g. Al-electrolysis off-gas cooling, give unique opportunities for improved plant operation. (RAs 1, 2 & 4; WPs 3.1, 3.4, 5.1, 5.2, 6.1) <u>*Ferro-alloy industry*</u> *(Elkem, Fesil Group, Eramet Norway, Finnfjord, Wacker Chemie, Glencore Manganese Norway-FFF)*: The electrometallurgical industry in Norway is advanced with mature process technologies. Energy efficiency improvements and value creation are related to improvements in the overall plant energy flows and heat transfer/exchange technologies. New technologies are needed to improve furnace efficiency and to recover the heat in slag and metal. Glencore Manganese has a 4% lower energy use due to more optimal oven design. New transformers can result in 5-10% reduction in energy consumption. Improved energy efficiency studies must include focus on surplus heat. Efficient furnace cooling systems including new heat transfer fluids and thermoelectric devices for cooling and power production are interesting. Smart utilization of CO is better used as a chemical raw material (reductant) than for combustion and power production. (RAs 1,2,4,5; WPs 3.1,3.2,3.4, 6.1,6.4) <u>*Glencore Nikkelverk:*</u> Value creation through application of improved and new technologies for copper and nickel electro winning, resulting in lower energy consumption, less emission and waste, reduced costs, improved competitiveness and strengthened environmental standards. Additional values gained through *HighEFF* are general know-how and education of professionals. (RAs 1,2,4; WPs 3.1-3.4,4.2,4.3,5.1,5.2, 6.1)
Food & Chemical	<u>*Food industries (Orkla, MARS, Vedde, Marine Harvest, Rema Franchise)*</u>: The environmental impact of food production, processing, storage and distribution has to be reduced. Food resources are limited and with an increasing population the pressure on this sector is high. GHG emissions related to the food industry are also considerable. The R&D work in *HighEFF* will enable reductions in specific energy use in food processing, hence reducing the environmental impact of the products. Improving processes will also reduce food waste, which gives an indirect reduction in specific energy use. (RAs 1, 2, 3 & 4; 5.4, 6.3, 6.4) <u>*Chemical industry (Borregaard, Norfrakalk, Waterbox4Life)*</u>: Energy intensive due to the need of heat treatment of materials in addition to using chemical processing equipment. Heat recovery and integration as well as improved optimization of processing equipment is needed and has the potential of reducing energy consumption up to about 20%. Water filtration/membrane processes for clean water supply are energy demanding, typically a new desalination plant requires 3.6 kWh per m3 water processed. The impact of energy savings measures is significant. (RAs 1, 2, 3 & 4; WPs 4.2, 4.3, 4.4, 5.1, 5.2, 6.3, 6.4)
Vendors	<u>*GE Power ESC Norway, Alfa Laval, Dorin, Obrist Engineering, Danfoss, Mayekawa, Kuldeteknisk, Carrier, Epcon, HybridEnergy, SWEP, Goodtech, Viessmann, Cadio:*</u> Bringing together motivated vendors represents a unique opportunity to develop innovative solutions for next generation vapour compression units. Cooperation and interaction among the vendors within the WPs will allow increased market shares. *HighEFF* will also contribute to increased competence and thereby the competitiveness of the partners. (RAs: 1, 2 & 3, WPs: 4.2, 4.3, 5.3)

[46] Kvande & Drabløs (2014). The Aluminum Smelting Proc and Innovative Alternative Techn. J of Occupational and Env.Medicine,56(5Suppl),S23–S32.
[47] Aalbu, J. (2015). Hydro Technology Update. http://www.hydro.com/upload/Documents/Presentations/Investor/Hydro%20Technology%20Update.pdf
[48] Ladam, Y., Solhiem, A. Segatz, M. and Lorentzen, O.-A (2011), Heat recovery from aluminium reduction cells, Light Metals 2011, pp. 393-398

Industry Parks	*Mo Industripark and Bulk Infrastructure*: Aim to become leaders in high efficiency exploitation of resources. Exploit great potential for increased energy and material exchange within the cluster. Through the interdisciplinary research in *HighEFF*, sustainable usage of natural resources and improved interaction and process efficiency are promoted, enabling value creation in the represented industries. Moreover, data centres are a rapidly growing industry with high energy demand (2% of the world's energy consumption), mainly due to cooling of the servers. This cooling demand could be covered with sorption cooling utilizing excess heat from the industries. *HighEFF* will also contribute to a lift in the R&D environment and the establishment of a new industrial sector in Helgeland and Agder. (RAs 1 & 4; WPs 3.3, 3.4, 4.2, 4.3, 4.4, 5.1, 5.2, 6.4)
Academia	*SINTEF Energy Research (SER), SINTEF Materials & Chemistry (SMK), SINTEF Fisheries & Aquaculture (SFA), NTNU, NTNU Society Research (NTNU SR), Tel-Tek, Senter for industriell forretningsutvikling (SIF), Kungelige Tekniska Høgskolen (KTH), Doshisha University (Doschisha), Massachusetts Institute of Technology (MIT), Carnegie Mellon University (CMU), University of Manchester (UoM), Shanghai Jiao Tong University (SJTU), Austrian Institute of Technology (AIT)*: Leading research groups in energy efficiency will collaborate to meet the challenge of reducing the energy consumption by close interaction with the industry. Each group has specialty areas where they are at the cutting edge of technology. The collaboration will have a great potential to produce innovative concepts in the interface between these experienced research groups, and will result in larger impact of the innovations as they can be applied in different areas of the world and in different industries. *HighEFF* will attract the best researchers on an international level, and thus contribute positively to the scientific quality of all the work. (RAs 1-6)

3. Research Areas (RA): 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. The research problems will be addressed within the six RAs described below, also including examples of innovations causing progress beyond state of the art.

RA1 Methodologies will extend existing and develop new methods that can be used to evaluate and improve the energy use in the industry. The success of technological improvements related to energy and resource efficiency will be measured by relevant KPIs. An exergy based KPI is suggested to evaluate industrial solutions from a resource efficiency point of view. Horizon 2020 is focusing on the reduction of costs of an energy service; however, this is insufficient as a technology driver. In *HighEFF*, a distinction is made between energy solutions that are economically more efficient and those that are thermodynamically more efficient. The former have shorter time frames for implementation, while the latter may serve as ideal targets that could be realised by changing boundary conditions, thus acting as technology drivers.

Objectives:

- Develop KPIs for e.g. energy efficiency, competitiveness, costs and GHG emissions
- Demonstrate the use and advantages of exergy as an objective metric for energy efficiency in order to create acceptance in an industrial setting
- Develop methods for improved energy efficiency using laws of thermodynamics at all process levels (equipment, plants, sites, and clusters) and all stages of design (conceptual to post-design)
- Develop methods for simultaneous heat and power considerations that will result in e.g. optimal work and heat exchange networks (WHENs)
- Explore the combined use of rigorous modelling and mathematical optimization in order to guide plant operation to maximize the utilization of invested equipment
- Define key framework parameters for future processing concepts and determine their influence on technologies for energy efficiency

Potential Innovations:

- Software system for innovative use of heating and cooling from compression and expansion
- Systematic methodology using exergy to guide conceptual design

RA2 Components will focus on efficient and adapted components and technologies meeting the needs of the industry to obtain cost efficient solutions for targeted applications. Compact components for heating, cooling and surplus heat utilization based on the use of environmentally friendly natural working fluids will be developed through multi-disciplinary research and collaboration. Examples are ultra-efficient heat exchangers, compressors and equipment for expansion work recovery.

Objectives:

- Develop components required for cost-effective implementation of heat pumping and conversion, including exploitation of novel technologies experimentally, e.g. utilizing additive 3D manufacturing
- Design rotating machinery suited for natural working fluids in new industrial application areas
- Develop methods and tools required for designing components and cycles with natural working fluid mixtures; thermodynamic properties, system optimization, and experimental development

Potential Innovations:

- Compressor concepts for targeted fluids, capacity ranges and operational conditions, e.g. semi-hermetic compressors able to operate at high suction temperatures and pressures
- Expander concepts for targeted fluids, capacity ranges and operational conditions
- Novel heat exchanger designs for power and heat pumping cycles
- Components for cycle enhancement, e.g. ejector concepts for off-design operation

RA3 Cycles will develop improved cycles and concepts for converting and upgrading energy sources, including power production from surplus heat, and heat upgrade using heat pumps. The main focus will be on vapour compression and expansion cycles. New and improved concepts will be developed for refrigeration and drying with energy recovery, furnace cooling and raw material pre-heating. The target will be high capacity applications for maximum impact on the energy consumption in Norwegian industry.

Objectives:

- Develop competitive concepts for utilization of surplus heat for widespread industrial implementation and significant impact on specific energy consumption
- Design heat-to-power cycles and HTHPs tailored to the surplus heat sources of different industries
- Develop optimized heating and cooling technology for demanding industrial and commercial applications
- Develop energy storage concepts for balancing mismatch in supply and demand

Potential Innovations:

- Competitive low and medium temperature power cycle concepts with cross-sectorial applicability
- High-efficient HTHP cycle concepts for upgrading surplus heat to steam, displacing fossil fuel use
- Integrated refrigeration units able to provide simultaneous heating/cooling/freezing/AC
- Lightweight bottoming cycle & heat exchanger technology improving offshore/marine energy efficiency
- New, enhanced technology concepts for large scale energy storage, crucial in future energy grids

RA4 Applications will integrate the components, cycles and concepts developed in RAs 2 and 3 into specific industry settings to generate more energy-efficient processes and improved heat capture and utilization concepts. With Mo Industripark as an example, this RA will also develop further the potential of "green" industry clusters and local thermal grids on a Nordic scale.

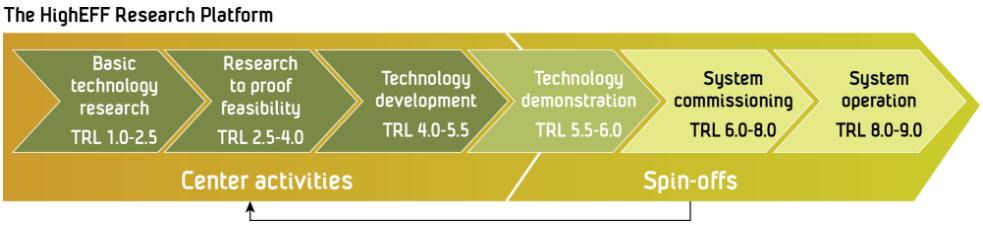
Objectives:

- Develop a metal furnace concept with at least 20% lower total energy use (carbon and power)
- Develop next generation concepts for surplus heat capture and utilization, including three new technologies for unconventional heat sources (solids, surfaces and radiative)
- Outline an industrial cluster consisting of processes or concepts familiar to the industrial partners; and identify the social, economic and environmental impacts and opportunities for sub-clusters
- Identify potential and concepts for use of process gas; such as CO in prereduction for Manganese

Potential Innovations:

- Novel business models for sharing energy and materials resources in closely located industries
- Methodology for optimizing cycle integration in plants and assessing the costs and benefits
- Develop self-cleaning dirty gas heat exchanger concepts in collaboration with SFI Metal Production and bring the technology further towards applications in heat-to-power conversion

RA5 Society will manage the innovation activities and handle dissemination, communication and general flow of information in the Centre. Innovation management will include research on internal and external interaction, as well as on the barriers and enablers for innovation and realization of *HighEFF* technologies and concepts. Contextual organizational preconditions will be studied by following the different industrial cases to gain insight into the innovation processes and to identify barriers and enablers. A culture of innovation will be facilitated by arranging 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. Potential novel emerging concepts that were not foreseen at the planning stage will be actively looked for. Effective communication of research results and technology innovations from the Centre to legislators and to the general public will be pursued.



Objectives:
- Develop innovation strategies and technology roadmaps for each sector, updated every second year
- Communicate centre activities and results internally, to stakeholders, legislators and the general public
- Enhance knowledge on barriers and enablers for collaborative innovation processes
- Allocate funding for at least one novel emerging concept each year

Potential Innovations:
- New business concepts for energy utilization between industries
- Novel concepts for effective interaction between businesses and researchers
- Methodologies for parametric evaluation of technical and sociotechnical barriers and enablers for the realisation of *HighEFF* concepts
- Concrete recommendations for policy framework conditions that promote *HighEFF* concepts

RA6 Case Studies will be performed to obtain measurable results from the implementation of *HighEFF* technologies in the different industry sectors. Sector-based workshops will be 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 will give input to the innovation strategies and roadmaps in RA 5 as well as to the concepts studied in RAs 2-4. Some partners have already suggested initial case studies, and these will be launched at the beginning of the Centre (see attached).

Objectives:
- Conduct 3-5 case studies for each industrial sector represented in *HighEFF*
- Develop a standard methodology for the case studies to obtain uniform results throughout the consortium

Potential Innovations:
- Novel power production cycles and heat pumping technologies for *HighEFF* industries
- Novel business methods for collaboration between industrial plants for reduction of energy use

4. Research Methods: The activities in *HighEFF* are divided into RAs and further into more specific work packages (WPs), as illustrated in Figure 2. There will be considerable collaboration and exchange of results across the RAs and WPs. Researchers from academia and research institutes will work closely with industrial experts to achieve the objectives outlined in Section 3. The research methods will 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 will be conducted for increased insight and competence building that could act as a catalyst to innovation. The international partners will participate in research and education activities, and through researcher exchange. The methodologies

and activities specific to the different RAs and WPs are outlined below (topics to be emphasised for the first 4 years of the Centre).

RA 1: Methodologies

WP 1.1 Key Performance Indicators:
- Determine KPIs to measure success of technological improvements in energy and resource efficiency
- Utilize exergy as a metric for energy efficiency
- Utilize specific energy consumption (energy per ton of product) as a common KPI for energy efficiency
- Define environmental KPIs using methodologies based on life-cycle analysis (LCA) and costs (LCC)
- Define economic KPIs (e.g. weight and volume) as well as different overall sector-specific KPIs

WP 1.2 Energy and Exergy Analyses:
- Further develop thermodynamics based pinch analysis methods to increase their industrial exploitation
- Further develop the methodology of exergy analysis for complex plants involving heat and power
- Perform pinch and exergy analyses in collaboration with industrial partners for selected plants to identify energy saving potentials and to provide feedback to methodology development
- Create Grand Composite Curves and Grassmann diagrams to obtain overviews of industrial processes

WP 1.3 Process Systems Engineering:
- Model, simulate, design, and optimize complex industrial processes (including operation and control)
- Build models for integration of novel components and cycles (RAs 2&3) in industrial processes. The models will be applied for technology integration in WP 4.3.
- Study industry clusters to improve energy value chains, material efficiency and reduce emissions

WP 1.4 Future Process Framework:
- Identify scenarios for future core process, related to e.g. increased off-gas temperatures in the metal industry
- Study and analyse incremental and step changes in historical process development in different industries
- Based on the analysis, identify prime opportunities for energy efficiency improvements for the next generation of industrial processes. The results will serve as input for the research work in the other RAs.

RA 2: Components

WP 2.1 Heat Exchangers:
- Further develop powerful in-house numerical tools for use in development of novel compact heat exchanger designs, including absorbers and desorbers for hybrid sorption cycles
- Test experimentally the efficiency and performance of selected concepts by manufacturing small-scale heat exchanger sections, e.g. by utilizing "3D printing" of metal alloys
- Compare the simulated and experimental results on efficiency and performance to high-performance commercial heat exchangers at equal external dimensions, weight and choice of material

WP 2.2 Expanders and Work Recovery:
- Use computational fluid dynamics (CFD) and other prediction methods to explore and design expander concepts for selected working fluid mixtures in the targeted temperature and capacity range
- Consider practical aspects (e.g. solutions for bearings and seals, need for lubrication) in design layouts
- Explore various types of ejectors and expanders to support the cycle development in RA 3

WP 2.3 Compressors and Pumps:

Adapt existing solutions and develop new ones for vapour compression/expansion cycles, including:
- Prototype design for compressors/pumps not commercially available, e.g. high temperature butane piston compressor, turbocompressors for steam, and wet-compression machines for resorption cycles
- Develop performance-boosted designs for technically mature solutions, e.g. mechanical/electrical design of scroll, screw and piston compressors, and high-efficiency compressor racks
- Prototype design of enhanced turbomachinery for power cycles, e.g. transcritical CO_2, Brayton and ORC
- Novel design of high-pressure pumps for semi-incompressible fluids
- The research work will cover simulations and experimental campaigns

WP 2.4 Natural Working Fluids:
- Identify promising natural working fluids and mixtures (hydrocarbons, CO_2, steam, ammonia and nitrogen)
- Target properties: profile matching of heat sources and sinks, cycle and component performance, and safety
- Establish models for heat transfer and pressure drop in compact heat exchanger geometries, focusing on the temperature and pressure ranges most relevant for power production systems and HTHPs.
- Close knowledge gaps on thermodynamic properties, safety and behaviour through experimental studies

RA 3: Cycles

WP 3.1 Heat-to-Power Conversion:

- Develop novel concepts to enable cost optimal heat-to-power conversion from low (LT) to medium (MT) temperature limited sensible heat sources, focusing on optimal utilization of the heat source
- Emphasis on different vapour expansion concepts, e.g. transcritical CO_2, fluid mixture Rankine cycles, and improved conventional ORC technology
- Study novel technologies for power conversion, e.g. TEGs, Phase Change Materials (PCM), Stirling engines and absorption cycles and benchmark these to the vapour expansion concepts
- Investigate concepts for power production utilizing intermittent heat sources, e.g. slag in metal industries
- Outline potential industrial demonstration activities and the need for large scale research infrastructure
- Investigate technical solutions for other potential industrial energy sources that are not utilized, such as pressure energy from well-streams in the oil and gas industry

WP 3.2 Heating, Cooling, and Drying:

- Feasibility studies of integrated refrigeration, cooling and heating processes to increase the overall efficiency
- Study new methods for cycle performance improvements for a range of industrial refrigeration and heat pump applications, including: ejector- and expander-supported mechanical vapour compression cycles, and high-efficiency vapour compression cycles e.g. with parallel compression
- Dimension components together with RA 2, design cycle architecture and optimize control strategies
- Set up experimental campaigns for novel heating, cooling and drying concepts

WP 3.3 High Temperature Heat Pumping:

- Investigate new HTHP concepts for different industrial applications, including: propane/butane cascade heat pump cycles, mechanical steam recompression cycles, multistage ammonia-water absorption cycles, and ammonia-water compression resorption cycles
- Optimize components, cycle architecture and control strategies, as in WP 3.2, and set up experimental campaigns for HTHP concepts

WP 3.4 Energy Storage:

- Investigate novel energy storage concepts through simulations and experiments, including latent heat storage (PCM) integrated in components and cycles; high-temperature TES for industry; and utilization of slurries for refrigeration applications
- Benchmark concepts for mitigation of large fluctuations of electric energy availability in future scenarios
- Further develop promising concepts, e.g. use of excess energy for hydrogen production; local energy conversion and thermodynamic storage, including compressed gas storage; and reversible heat pump/power cycles
- Study local conversion or round-trip efficiencies and compare them to grid transfer efficiency and efficiency of pumped hydroelectric storage

RA 4: Applications

WP 4.1 Process Improvements:

- Determine potentials of process improvements for reduction in specific energy consumption by systematic energy/exergy analyses and comparison of different system concepts
- Investigate new concepts for energy efficient process improvements, such as (i) new furnace concepts for Mn and Si production, in which the raw materials are fed into the furnace in separate trenches; (ii) implementation of HTHPs for thermal processes; (iii) dynamic process control especially for batch operations; and (iv) MVR for steam-based processes to substitute fossil fuels
- Investigate main selected concepts and components with focus on system robustness, acceptable return of investment and environmental impact

WP 4.2 Surplus Heat Recovery:

- Identify and develop effective approaches for heat capture from different industrial heat sources
- Establish physical interfaces and integration possibilities to industrial processes (linked to RA 1)
- Develop different heat capture solutions and efficient heat transferring fluids tailored to specific applications, depending on the nature, quality and quantity of the targeted heat sources, considering hazards of various fluids related to e.g. metal smelters

WP 4.3 Technology Integration:

- Study implementation of the developed components and cycles (RAs 2 and 3), and process improvements (WP 4.1) and into actual industrial processes utilizing PSE methodologies (WP 1.3)
- Develop concepts for utilization of surplus heat internally within a plant or in neighbouring plants, such as (i)

distributed heat recovery and power production; (ii) novel light-weight WHRUs and condensers developed in WP 2.1 for offshore applications; and (iii) use of surplus CO for prereduction of Mn-ore
- Concepts developed in WP4.3 will be applied in the case studies in RA 6

WP 4.4 Green Industry Clusters:
- Outline an industrial cluster consisting of processes familiar to the industrial partners. An example: high-temperature metal producing processes at one end and greenhouses or onshore fish farming units at the opposite end, and a number unit processes in parallel and series in between the endpoints.
- Optimize the cluster through detailed analysis and simulation of interaction between individual processes on various levels and under well-defined restrictions. Each process must be modelled with a suitable level of rigor, on a platform that can handle heat and mass transfer, fluid flow and chemical reactions.
- Benchmark the designed cluster towards Mo Industripark, with the aim of further development of the cluster
- Apply the concept towards modelling of local low-temperature thermal grids utilizing waste heat from data centres, supermarkets, or other industries

RA 5: Society

WP 5.1 Innovation and Roadmaps:
- Establish an Exploitation and Innovation Advisory Committee (EIAC) with representatives from industry and academia to assess main needs for future technology improvement and innovation
- Develop an innovation strategy with three focused levels: (1) generating 2-3 innovations each year from the project, (2) lifting innovations a higher TRL levels through IPN, DEMO and EU projects, and (3) commercialization together with Enova and Innovation Norway
- Support industry to write innovation roadmaps for energy efficiency for each industrial sector (including input from supporting organizations such as Innovation Norway and Enova)
- Update roadmaps biannually based on the Centre innovation processes and sociotechnical studies of the different industries

WP 5.2 Barriers and Enablers:
- Establish an expert team on interaction between industry partners and researchers to optimize innovation potential and elucidate barriers and enablers for innovation
- Establish a knowledge basis to understand internal and external barriers and enablers for innovation and realization of *HighEFF* technologies and concepts:
  - Internal company aspects: the influence of strategy, management, external knowledge integration as well as incremental and larger technological improvements
  - External conditions: effect of e.g. government regulations, market conditions (electricity and material cost)
- Develop a parametric methodology to estimate how barriers and enablers influence implementation of technologies for improved energy efficiency

WP 5.3 Novel Emerging Concepts:
- Evaluate novel emerging concepts suggested by researchers in all WPs and once a year fund the most cutting-edge concepts based on: idea, energy reduction/recovery potential, current state-of-the-art, technology choices, constraints and possibilities, risk evaluation and environmental impact based on LCA and LCC
- Apply rapidly the funded concept into new IPN or DEMO projects for further development
- Potential blue sky concepts with great impact on energy efficiency could be: (i) Thermal compression for selected fluids based on surplus heat, exploiting interaction of closed volume concepts and material sorption; (ii) Production of cooling from heat, applying compact vapour compression units driven by an expander; and (iii) Use of magnetic nanofluids for magnetically induced cooling concepts without moving parts

WP 5.4 Dissemination and Communication: The activities are explained in detail in Section 6.

RA 6: Case Studies

WP 6.0 Case Study Methodology and Tools:
- Utilize KPIs and tools from RA1 to develop a common methodology for the case studies
- Determine criteria and routines for activities such as data collection and reporting
- Identify cases with focus on energy-intensive processes and technologies, representative for different industrial environments

WP 6.1 Metal, Material: Potential case studies:
- Heat recovery from the pouring and forming of metals and slag, equipment, and metallurgical processes
- Increasing the degree of heat recovery from ovens through better cooling concept designs
- Recovery and utilization of process gases, e.g. CO

- Heat capture and utilization concepts for medium temperature heat in the aluminum industry
WP 6.2 Oil, Gas, Energy: Potential case studies: - Compact equipment for offshore bottoming cycles - Waste heat upgrading and heat production for future platforms that will be electrified - Evaluating implementation of different heat production technologies, particularly heat pumping concepts
WP 6.3 Food, Chemical: Potential case studies: - Cost efficient utilization of MVR for steam based process (e.g. drying) - Heat pump drying concepts to recover latent heat and upgrade it to be usable as drying energy - Substitution of fossil fuels by e.g. suitable HTHP systems in food and chemical sector - Low temperature thermal storage to reduce power demand for peak production requirements - Integrated concepts for high efficient commercial and industrial refrigeration systems
WP 6.4 Industry Clusters: Potential case studies: - Utilization of heat from metal production in Mo Industripark to produce cooling for a data storage centre - Development of innovative cooling solutions for data centre in Bulk industrial group

*See also attached Case Table

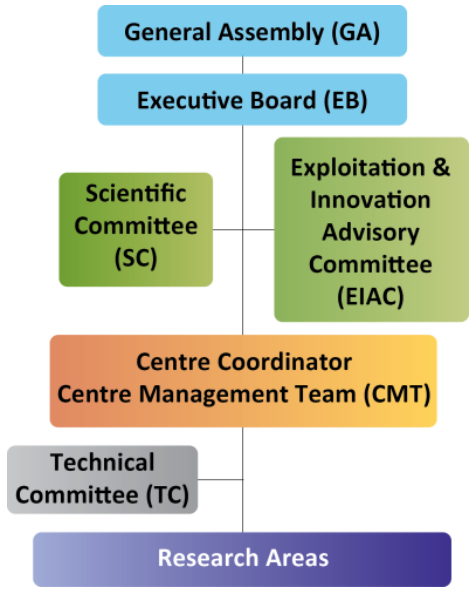
The HighEFF infrastructure includes the SINTEF/NTNU *CREATIV-laboratory*, set up for testing and verifying systems and components, and for validation of different models and control strategies within the field of energy and process technology. The laboratory consists of advanced equipment and infrastructure for the development and testing of: (i) heat pumping systems; (ii) surplus heat utilization concepts, including power generation from waste heat; (iii) air ventilation systems; and (iv) compact heat exchangers, compressors, and ejectors. *HighEFF* will also be supported by the laboratories at SMK, SFA, AIT Heat Pump Lab, Doshisha Energy Conversion Research Centre, KTH Energy Technology, Creative Thermal Solutions laboratories. Additional funding for HighEFF infrastructure will be applied for through the RCN Infrastructure Program. Active utilization of infrastructure of the industry partners will also be an important resource, as well as targeted use of in-kind contribution and user-partners infrastructure.

5. **Organization, Management and Centre Building** activities are organized as RA 0. *HighEFF* will build on the multi-collaborative competence building projects CREATIV, ROMA, INTERACT, HeatUp, Fume, EFFORT, and COMPACTS, all having a great impact on the understanding of energy efficiency in the industry. *HighEFF* has 50 partners; 15 academic and 35 industrial partners.

RA 0 Organization, Management and Centre Building
Management: A management and administrative system for ***smooth project execution*** will be established, including systems for overall project planning, co-ordination and proper progress reporting. SER will ***allocate resources*** to fulfil the coordination of *HighEFF*. The Centre Coordinator, scientific leaders and RA-managers will allocate necessary resources to lead the technical and operational performance.
Centre Building: The Centre management will establish and maintain a strong and well-considered Consortium and monitor that the project execution is in accordance with the Consortium Agreement and the proposal submitted to the RCN. Operational plans will be established. Continuous efforts will be made to serve the Consortium, safeguard the integration of partners and ensure that all partners operate in alignment with the common objectives of *HighEFF*.
Recruitment of new researchers and international cooperation and exchange will be emphasised.
Intellectual Property Rights will be administered by the Centre management as regards each partner's foreground, subcontracting and the invitation and integration of new partners.
Centre Funding distribution will be executed according to approved budgets and executive board (EB) decisions. Plans for continuous follow-up of activities, cost and work-performance will be established for the respective RAs and WPs. Eventual redistribution of funding may occur due to yearly reviews.
User Contribution and Industrial Relevance: Industry and sector specific seminars and cross-sectorial workshops will be arranged annually. Through these meetings, the industry partners will be actively involved in the planning and execution of research activities. Where possible, such events will be arranged in collaboration with relevant events for example in the SFI Metal production, or Enova Energy Conference. Synergies will be sought with other relevant FMEs and SFIs within topics such as energy-efficient buildings,

CCS, bioenergy and smart grids.
Research Infrastructure in the laboratories at NTNU and SINTEF will be made available and upgraded. The Centre will allow development of test laboratories and simulation tools to the benefit of the user partners. This will enable active participation of the industry partners, and ensure that their special competences and knowledge can be fully utilized. See also last section of Section 4.

Centre Management Structure:



GA: Representatives: All partners + EB chairman. Appoints the Executive Board (EB) and gives guidance to the EB in their decision-making on major project changes to consortium plans/budget. Annual meetings. Approve Background, and admit new partners.

EB: Lead: industry. Representatives: industry (majority), NTNU and SINTEF. Responsible to the financial contributors for the quality and progress of the work in the Centre. Discusses overall and annual work plans. Conflict resolution.

SC: Lead: Dr. Gundersen, NTNU. Representatives: all academic partners. Safeguard the scientific quality.
EIAC: Lead: industry. Representatives: all industry partners, selected research partners. Evaluate commercial potentials and identify spin-off projects. Advise EB on new research directions.

Centre Coordinator (Dr. Hemmingsen, SER): Day-to-day operation of the Centre and serve as main contact for RA leaders and above-mentioned organization bodies. The coordinator is supported by an experienced **Scientific Coordinator** (Dr. Nekså): Coordinates scientific activities between RAs and education program.
CMT: (Hemmingsen, Nekså, Gundersen, RA leaders): In charge of administrative, financial and legal tasks.

TC: Representatives: WP leaders, including industry representatives. Technical advisory committees will be established for specific R&D topics to ensure knowledge transfer between the Centre partners.

RA Coordinators: Assigned by RA partners and approved by EB. They are responsible for initiating and following up on all work package activities, and for organizing internal RA cooperation.

6. Dissemination and Communication activities are organized as WP 5.4.

WP 5.4 Dissemination and Communication
Dissemination: The scientific community will be addressed through publications in scientific journals and conferences; the goal is 100 publications in peer-reviewed journals and conference proceedings. For the widest possible sharing of project results, open access journals will be preferred when possible. Science communication to the public is important in order to have an impact on society and to participate in societal decisions about science and technology. SINTEF and NTNU researchers involved in the Centre have a long track record of publishing in the national media, and this will be even more emphasized in this FME. Public engagement is also essential to recruit students to work in research and industry.
Communication: Energy efficiency is one of the most significant technologies measured in terms of environmental impact, but it often does not generate the same attention as other new energy technologies. Thus, communicating the environmental potential of *HighEFF* is a key activity. Communication is a leadership responsibility, but researchers are individually responsible for communicating the results in close co-operation with the industry. In *HighEFF*, researchers as well as PhDs will be trained in science communication.
Main audience groups: (i) Industry: Communicating the importance and impact of research results is vital in order to bridge the gap between researchers and industry. Internal communication will be prioritized, and ensured through regular meetings and workshops as well as through an electronic workspace and newsletters. Industries outside the project consortium, in Norway and Europe, will also be addressed. (ii) Politicians and decision makers will be addressed to enable informed decision-making on the framework for energy efficient industry. (iii) Technology students and young talents will be addressed to recruit young talents to the industry

and to create commitment towards energy efficiency. (iv) The general public: Science communication and literacy are important in order to gain general support towards energy efficiency research.
Communication channels/platforms: (i) Scientific platforms: Journals and national and international conferences. (ii) *HighEFF* web-pages: Sharing of research results in a popular science format. (iii) Social media: Will be used to engage the audience, share results and achieve public participation through two-way communication. (iv) National and European media: Op-eds and popular scientific journals (e.g. GEMINI, ScienceNordic, alphagalileo.org, Aftenposten, Dagens Næringsliv and Teknisk Ukeblad). (v) *HighEFF* blog: Newsletters written in Norwegian and English will be regularly distributed to partners, industry, politicians and other interested stakeholders. (vi) Event activities and school talks through the Norwegian National Science Week and the role model program of the Norwegian Centre for Science Recruitment.

7. **International Collaboration:** *HighEFF* will facilitate industry and research collaboration across country borders and industrial sectors. It is strategically important for the Norwegian industry to have the opportunity to exchange knowledge with competent international actors. The research communities in *HighEFF* will similarly benefit from collaboration with national and international industrial companies and leading international universities. International collaboration on energy efficiency will stimulate coordinated efforts in developing political measures that promote reduced energy use. *International industry partners*: Most of the *HighEFF* industry partners are either international companies or have major activities internationally. *International academic partners:* Existing collaboration with MIT, CMU, UoM, UoD, SJTU, KTH, AIT will be continued and extended through being *HighEFF* academic partners with allocated funding from *HighEFF* and utilized to strengthen the knowledge base, increase the level of research, and reinforce the position of *HighEFF* partners on the international arena. The activities of the international partners will cover PhD education, research exchange, contribution in *HighEFF* workshops, publications. *Research exchange and PhDs* at MIT, CMU, KTH, and UoM are planned and budgeted for within *HighEFF*, replacing decades of informal contacts with these universities. To ensure true and tight collaboration, pairs of professors will be established between NTNU, MIT, KTH and the UoM, where each professor will have one PhD student. SINTEF and NTNU are actively involved in several *international networks*, such as: International Institute of Refrigeration (IIR), IEA, SPIRE (EU public-private partnetship on energy efficiency in process industry), EERA (joint program energy efficiency in industrial processes) and KIFEE (Norway-Japan network). A biennial *international conference* on industrial energy efficiency is planned for, as well as applying for arranging the biennial IIR- Gustav Lorentzen conference.

8. **Education, Researcher Training and Recruitment:** *An Education and Training Program* will be organized in *HighEFF*. It will recruit and train 20 PhD and 2 post.doc candidates (19 at NTNU, 1 at UoM, 1 at MIT, 1 at CM) and at least 50 MSc candidates (39 at NTNU, 3 at Doshisha, 2 at KTH, 2 at MIT, 2 at UoM, 2 at SJTU). The Master's and PhD students will be integral parts of the research teams working on methodologies an specific industrial cases, ensuring that new knowledge and technology will be efficiently available to our partners. The PhD students will be encouraged to spend at least 6 months at an international partner university. Through an annual *PhD forum*, dedicated to relevant selected topics, the students will have an opportunity to discuss, exchange information and establish personal networks. In addition, 30 new experts on energy efficiency from the industrial partners will be trained through *HighEFF*. *Industry seminars* will be held regularly to disseminate and discuss new knowledge developed. Another effective mechanism for training industrial experts are the numerous case studies that will be performed with the partner industries. An international *HighEFF summer school* will be arranged annually, attracting participants from around the world. About ten students will be recruited for *Summer Internships* yearly in collaboration with the industrial partners.

9. Milestones and Progress Plan:

RA 1: Methodologies	16 17 18 19 20 21 22 23 24	Milestones/deliverables
Key Performance Indicators		KPIs for overall system efficiency and CO2 footprint
Energy & Exergy Analyses		Toolbox for energy & exergy analyses per sector
Process Systems Engineering		Systematic approach to operational optimization*
Future Process Framework		Design procedure for heat and power integration (Y17), new process scenarios (Y17,19,21)
RA 2: Components		
Heat Exchangers		Novel concepts experimantally validated through additive manufacturing
Expanders & Work Recovery		Expander concepts for natural working fluid mixtures
Compressors & Pumps		Experimental verification of rotating machinery designs for novel applications
Natural Working Fluids		Fast & accurate formulation of properties for relevant natural fluid mixtures
RA 3: Cycles		
Heat to Power Conversion		Competitive heat-to-power technologies optimized per industry scenario
Heating, Cooling & Drying		System layouts for novel industrial heating, cooling and drying concepts
High Temperature Heat Pumping		Technology concepts for efficient HTHP systems
Energy Storage		System layouts for novel industrial internal energy storag econcepts
RA 4: Applications		
Process Improvements		Design (Y18) and specifications (Y24) for novel energy efficient process concepts
Surplus Heat Recovery		Novel concepts for surplus heat recovery systems/applications
Technology Integration		Designs for integrated energy efficient technologies for industrial use
Green Industry Clusters		Recommendations & concepts for novel industry clusters
RA 5: Society		
Innovation & Roadmaps		Innovation Strategy and Technology Roadmaps for each sector, updated every 2nd year.
Barriers & Enablers		3 white papers on framework conditions
Novel Emerging Concepts		One novel emerging concept funded per year. Future scenarios report (Y22).
Dissemination & Communication		a) 100 sc. Public. (Y24). b) Webpage & blog established (Y16), c) 20 Pop-sc. Public. (bY24)
RA 6: Cases		
		Methodology for case studies incl. KPI and framework conditions.
All industry sectors/clusters		Case study reports
★ Milestones/deliverables	● PhD dissertation, 3 years ● Post Docs finished, 2 years	* Many PhDs to match international collaboration, see Ch7

10: Budget, Expenses and Contributions:

A maximum budget frame from the RCN is applied for. This budget frame is needed to fulfill the scientific objectives of *HighEFF* and to be able to develop cost-efficient solutions for energy efficiency improvements applicable for the industry. *HighEFF* has many partners representing different sectors and company sizes, unified by our common goals. This variety in partners is a considerable strength, providing broad and deep insights from different perspectives, well worth the efforts needed to coordinate and run a large research Centre. The focus on technology development set in relevant industrial cases will increase the potential for innovations, but is also cost intensive.

	COSTS				FINANCING		
PARTNER	**Person/ indir**	**Equip**	**Other**	**Sum**	**Cash**	**inkind**	**Sum**
SINTEF ER	164 033	7 414	13 901	185 348	0	44 902	44 902
NTNU	80 837	3 654	6 851	91 341	0	23 829	22 128
SINTEF	55 976	2 530	4 744	63 250	0	15 323	15 323
TEL-TEK	4 625	0	375	5 000	0	1 211	1 211
Obrist	2 775	0	225	3 000	0	727	727
UiNordland	2 775	0	225	3 000	0	727	727
KTH	4 625	0	375	5 000	0	1 211	1 211
Doshisha	1 850	0	150	2 000	0	485	485
MIT	3 928	0	319	4 247	0	0	1 029
Carnegie Mel	3 923	0	318	4 241	0	1 027	1 027
UoManch.	2 568	0	208	2 776	0	0	673
Shanghai	0	0	0	0	0	0	0
AIT	2 775	0	225	3 000	0	727	727
SINTEF FA	6 013	0	488	6 500	0	1 575	1 575
NTNU Soci.	8 063	0	654	8 717	0	2 112	2 112
Un-allocated	18 500	0	1 500	20 000	0	4 845	4 845
Ind partners	65 322	0	7 258	72 580	68 720	72 580	141 300
RCN					240 000		240 000
SUM	**428 588**	**13 598**	**37 815**	**480 000**	**308 720**	**171 280**	**480 000**

	CONTRIBUTION		
Partner	**Cash**	**inkind**	**Sum**
Statoil	16000	4000	20000
FFF	12000	6000	18000
Hydro	8000	8000	16000
Alcoa	3200	3200	6400
MIP	3000	3000	6000
Lundin	3000	3000	6000
Rema	2000	2000	4000
Orkla Foods	2000	2000	4000
Marine Harv	2000	2000	4000
Glencore Ni	1600	1600	3200
Gassco	1920	1280	3200
Mars	1200	800	2000
Bulk N. park	1200	1200	2400
Norfrakalk	1200	1200	2400
Vedde	200	1400	1600
Borregård	0	400	400
Dorin	800	800	1600
Danfoss	0	6500	6500
GE Power	800	800	1600
Carrier	0	4000	4000
Goodtech	1200	1200	2400
Waterbox4	0	4000	4000
Viessmann	0	4000	4000
AlfaLaval	1600	1200	2800
Mayekawa	400	800	1200
Epcon	200	2200	2400
SWEP	0	2400	2400
Cadio	0	400	400
Kuldeteknisk	400	800	1200
HybridEnerg	0	800	800
Others*	4800	1600	6400
SUM	**68720**	**72580**	**141300**

*Considering *HighEFF* partnership: Statkraft Varme, Oil company, Food processing company, Chemical industry partner

BUDGET (kNOK)		2016	2017	2018	2019	2020	2021	2022	2023	2024	TOTAL
RA0	Centre building/organization	3415	5359	4911	4895	4830	5082	4997	5037	3973	42498
RA1	Methodology	2689	12317	12256	12545	10192	9008	8018	9721	4637	81383
RA2	Components	3461	8274	7910	8182	9439	8746	8612	8135	5648	68408
RA3	Cycles	5109	14095	13667	14154	14913	14409	13262	11994	7751	109353
RA4	Applications	2461	10157	9898	10536	10863	10651	10567	9850	4089	79073
RA5	Society	1835	4643	4322	3764	4450	5337	5405	5979	4551	40286
RA6	Case studies	1031	5154	4635	3524	2913	3566	5939	6085	6151	38999
	To-be-allocated	0	0	2400	2400	2400	3200	3200	3200	3200	20000
	SUM	**20000**	**60000**	**60000**	**60000**	**60000**	**60000**	**60000**	**60000**	**40000**	**480000**

11. Environmental Impact: The Centre will have a three-fold positive environmental impact, already highlighted in the introduction and in Section 2: increased energy efficiency, reduced GHG emissions and increased integration of renewable energy into industrial processes. The first-mentioned is vital for maintaining a competitive but also sustainable industry, and for reducing the demand for new power, as has been emphasized throughout the application. The second goal is bound to the first one; it is necessary in order to reach the climate mitigation goals set by Norway and EU, and thereby to limit the global temperature rise. The third goal is essential in a transition to a fossil-free society. In contrast to transport and household sectors, there is so far little focus on achieving a green energy shift for industries with high energy demand. Pioneering work is required to achieve this goal, and the collaboration between industries and research institutes facilitated by *HighEFF* is ideal for this effort.

12. Gender Aspects and Ethical Issues: The principle of equality between genders is deeply rooted in the ethical principles of SINTEF[49], and NTNU has a pragmatic action plan for recruitment of female employees[50]. *HighEFF* has a female coordinator. All parties of the consortium appreciate the importance of gender aspects. This focus will be emphasized at all levels of the consortium. 44% of the CMT are female; 36% including the WP management. The recruitment of PhDs and post docs will target a 50/50 gender balance. Female applications will be prioritized in case of equal qualifications. The project is not expected to raise specific ethical questions. Any health, safety, environmental and ethical issues will be dealt with according to procedures and principles of the organizations involved.

13. Out-phasing Strategy: This national funding programme constitutes an excellent opportunity to support the envisioned Centre and its objectives. However, *HighEFF* should be a durable operational initiative that gradually needs to advance towards self-sustainability beyond the current financial scope of the Centre. Therefore, an out-phasing strategy is needed from the inception of the Centre which will evaluate different continuous financial operational pathways and propose an action plan. To its end, *HighEFF* will establish a proactive out-phasing strategy group to ensure a successful pathway towards operational self-sustainability over a longer time period. This group will be strongly committed to and in close dialogue with many different stakeholders related to R&D&I financing. At the European level, EU programs constitute one of the possible strong financing pillars to extend the Centre activities. Many different instruments are already in place that cover competence building and innovation projects, the creation and operation of novel research infrastructures and funding mechanisms such as ERANET. An active presence and participation of the Centre members is crucial in initiatives like SPIRE PPP, which can constitute a support platform to establish reliable financing through EU public sources. On a national level, it is expected that support through the Research Council BIA, ENERGIX, PETROMAKS and other relevant programmes that will run concurrently with, and subsequent to, the proposed Centre and thus provide project-specific supplementary funding opportunities for Centre-related activities.

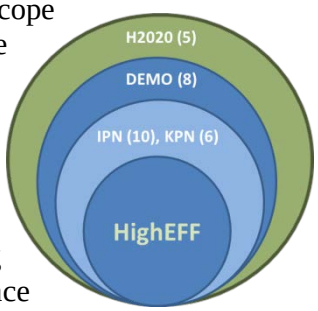


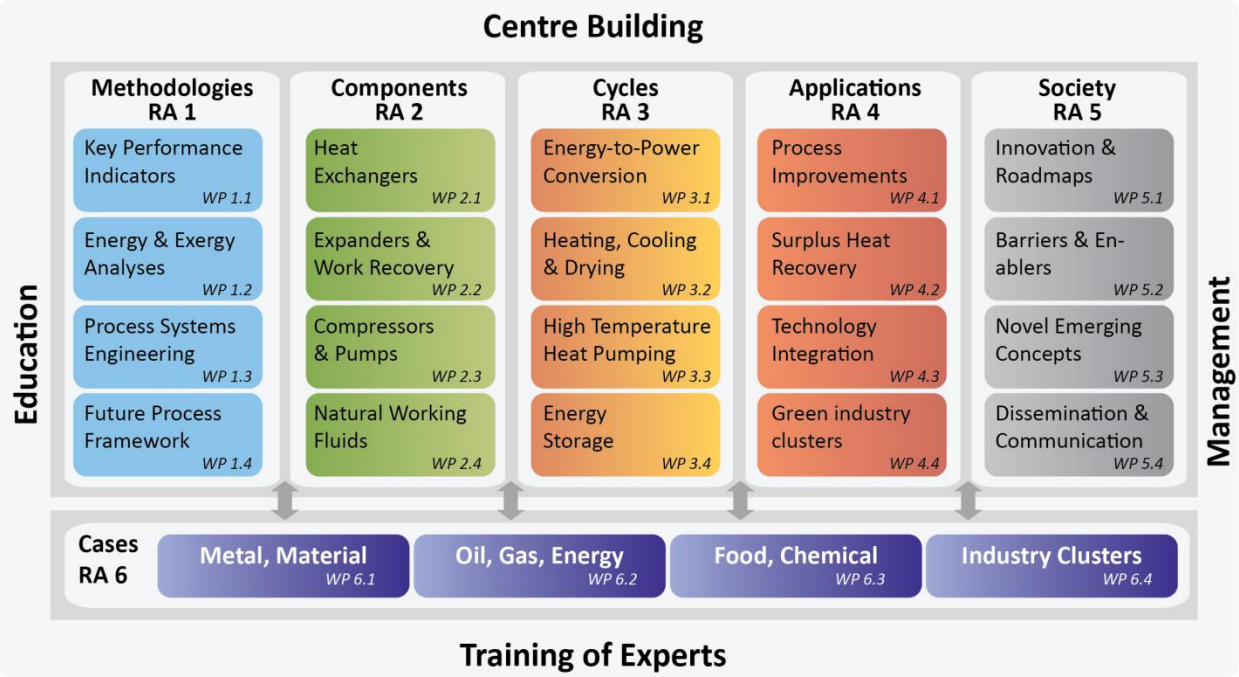
Figure 6 *HighEFF* spin-off potential

[49] Ethics in SINTEF (2013). http://www.sintef.no/globalassets/sintef-konsernstab/etikk-i-sintef/ethics/ethics_in_sintef_2013_hele.pdf?id=229931
[50] NTNU, Handlingsplan for bedre kjønnsbalanse 2014 – 2016 (2014). http://www.ntnu.no/likestilling

HighEFF Partners

Oil, gas and energy	Description	RAs	WPs
Statoil Petroleum AS	The Norwegian largest oil and gas company.	1, 2, 3, 4	4.2, 4.3, 5.1, 5.2, 6.2
Lundin Norway AS	Swedish independent oil and gas company working with finding, developing and producing oil and gas resources.		
Gassco AS	Operates the transport of natural gas from the Norwegian continental shelf to Continental Europe and Great Britain.		
Statkraft Varme AS**	District heating, renewable power , thermal grids		
Hydro Energi	The energy company of Hydro Aluminium.		
Industry parks			
Mo Industripark AS	Norway's and one of the world's most energy efficient industrial clusters.	1, 4	3.3, 3.4, 4.2, 4.3, 4.4, 5.1, 5.2, 6.4
Bulk Infrastructure AS	Industrial group with operations within real estate logistics, real estate data center, data center services and fiber infrastructure.		
Metal & materials			
Hydro Aluminium AS	Global vendor of aluminum and aluminum products.	1, 2, 4, 5	3.1,3.2,3.4, 6.1,6.4
Alcoa Norway ANS - Mosjøen	Producer of primary and fabricated aluminum.		
Elkem AS Technology (FFF)	Production of metal products and materials.		
FESIL RANA Metall AS (FFF)	Among the world leading producers of ferrosilicon.		
Eramet Norway AS (FFF)	Producer of manganese ore and manganese alloys.		
Finnfjord AS (FFF)	Manufacturer of ferrosilicon.		
Wacker Chemie AG (FFF)	Produces silicone rubbers, polymer products, polysilicon and wafers.		
Glencore Manganese Norway AS	Producer of manganese alloys.		
Glencore Nikkelverk AS	Large manufacturer of nickel, copper and cobalt.		
Food & Chemical			
Borregaard AS	Produces biochemicals, biomaterials and bioethanol.	1, 2, 3, 4	5.4, 6.3, 6.4
Norfrakalk AS	A mining company working with utilization of lime and dolomite.		
Orkla ASA	Supplier of branded consumer goods and concept solutions to grocery and out-of-home sectors.		
Marine Harvest ASA	Seafood company with primary interest in the production, processing and sale of farmed salmon.		
Vedde AS (Triple 9 Group)	Produces fish oil and fishmeal.		
Mars GmbH	One of the world's leading food manufacturers.		
REMA Franchise Norge AS	A multinational supermarket chain.		
Waterbox4Life Norway AS	Provides future solution for energy efficent water purificaton.	1,5	4.1, 6.3

Vendors			
GE Energy Power Conversion Norway AS	Works in transport, power and grid, and is a large environmental technology provider.		
Danfoss	Globally leading OEM in refrigeration, heating and control system.		
Officine Mario Dorin S.p.A.	Producer of compressors for refrigeration and air conditioning.		
Epcon Evaporation Technology AS	Evaporation plants for concentration and wastewater treatment.		
Goodtech Recovery Technology AS	Technology provider with core competences in electrical, automation, power, industrial and environmental engineering.		
Vissmann Refrigeration systems, Norpe Oy	One of the leading international manufacturers of heating, refrigeration and energy production systems.		
SWEP International AB	Producer of energy-efficient and compact brazed plate heat exchangers.		
Carrier Refrigeration Norway AS	Commercial refrigeration systems for e.g. supermarkets	1, 2, 3	4.2, 4.3, 5.3
Kuldeteknisk AS	Heatpumping technology, natural working fluides (CO2), domestic hot water with CO2 hp system, RSW systems		
Cadio AS	Produces and delivers refrigeration systems and heat pumps based on natural refrigerants.		
Hybrid Energi AS	High temperature heat pumps using compression-absorption concepts for utilisation of surplusheat in the temperature range of 30-65 ºC		
Alfa Laval Corporate AB*	Manufactures wide range of equipment, systems, and services for		
Mayekawa Mycom	Global supplier of heat pumping, freezing and compression technologies for industry		
Univerities and Research Institutes			
SINTEF Energy Research (ER)	RTD provider in energy efficiency, energy processes, gas technology, thermo- and fluid dynamics, combustion and thermo-chemical conversion processes.		
NTNU	Norway's leading technological university.		
SINTEF	*Materials and Chemistry* : Advanced materials, products, processes and new tools. *ICT* : Information and communication technology for industry and the public.		
SINTEF Fisheries and Acquaculture	Technological expertise and industry knowledge in the utilization of renewable marine resources.		
University of Manchester	A leading provider of methods for improved industrial energy efficiency.		
Massachuttes Inst. of Tech. (MIT)	Among the top technical universities in the world. Leading in Advanced Process Integration.		
Carnegie Mellon University (CMU)	A leading provider of methods for process optimisation.		
Tel-Tek	Reserch institute focusing on energy efficient processes and low emissions. (powder technology, CCS, smarter manufacturing, energy)		
Doshisha University (Reserach Center for energy Conversion System)	Expertise in refrigeration, heat pump systems and power engienes, emphasis on CO2 as working fluid.		
Shanghai Jiao Tong University	High efficient heatpump, thermal energy storage, energy efficient processes		
Royal Institute of Technology (KTH)	Expertise in refrigeration, heat pump systems and power engienes.		
Austrian Institute of Technology (AIT)	Expertise in e.g. high-temperature heat pumps and thermal storage, and thermal energy systems. Advanced laboratory facilities.		
OBRIST Engineering GmbH	Exhaust heat recovery and expansion machines for these cycles		
University of Nordland	Faculty of Social Science. Inteface between industry and research		
NTNU Social Research	Research related to innovation and industry clusters		
Assosiated partners			
Innovation Norway	The Norwegian Government's most important instrument for innovation and development of Norwegian enterprises and industry		
Enova	Promotes more efficient energy use and increased production of renewable energy, via targeted programmes and support schemes.		



Centre Management Team see enclosed CVs		
Name	**Title**	**Institute**
Anne K. T. Hemmingsen	Center Coordinator	SINTEF ER (SER)
Truls Gundersen	Scientific Committee Leader	NTNU
Petter Nekså	Scientific Coordinator	SER/NTNU
Egil Skybakmoen	RA 1 Leader	SINTEF MK (SMK)
Armin Hafner	RA 2 Leader	NTNU
Trond Andresen	RA 3 Leader	SER
Aud Wærnes	RA 4 Leader	SMK
Ingrid C. Claussen	RA 5 Leader	SER
Marit Mazetti	RA 6 Leader	SER

Work Package Leaders see enclosed CVs		
Eli Ringdalen	WP 1.1	SMK
Merete Tangstad	WP 1.2	NTNU
Sigurd Skogestad	WP 1.3	NTNU
Asbjørn Solheim	WP 1.4	SMK
Geir Skaugen	WP 2.1	SER
Krzysztof Banasiak	WP 2.2	SER
Armin Hafner	WP 2.3	NTNU
Trond Andresen	WP 2.4	SER
Trond Andresen	WP 3.1	SER
Michael Bantle	WP 3.2	SER
Michael Bantle	WP 3.3	SER
Hanne Kauko	WP 3.4	SER
Bernt Wittgens	WP 4.1	SMK
Petter Nekså	WP 4.2	SER
Truls Gundersen	WP 4.3	NTNU
Leiv Kolbeinsen	WP 4.4	NTNU
Per Morten Schiefloe	WP 5.1	NTNU Society Research (SR)
Jens Røyrvik	WP 5.2	NTNU SR
Egil Skybakmoen	WP 5.3	SMK
Ingrid Camilla Claussen	WP 5.4	SER
Aud Wærnes	WP 6.1	SMK
Marit Mazetti	WP 6.2	SER
Michael Bantle	WP 6.3	SER
Leiv Kolbeinsen	WP 6.4	NTNU

Curriculum Vitae

Name: **Anne Karin T. Hemmingsen, PhD**
Date of birth: 1971-08-16
Nationality: Norwegian
Present Position: Senior Research Scientist
Company: SINTEF Energy Research, *Thermal Energy*
E-mail: Anne.K.T.Hemmingsen@sintef.no

PROFILE

- Over 20 years experience in energy efficiency research & development, leading to product development and commercialization of technology.
- Extensive management experience as research director and team leader over many years and as project manager and coordinator for large multi-disciplinary projects and team leader, such as KPN CREATIV.
- Among the very best scores at the working environment examination among the research leaders and research directors in 2008, 2010, 2012, and 2014. Very high scores in all categories and especially regarding team motivation and quality.
- Additional skills: Strong strategic experience, and strong oral/written communication capabilities, and extensive member of board experience.
- Research experience: Energy efficiency in industry, power conversion and surplus heat utilization, heat pumping and energy efficient refrigeration technology, heat and mass transfer, food technology.
- Contract negotiation experience: Negotiation and description of large consortium agreements, Negotiation of agreements between NTNU and SINTEF
- Dissemination experience: Arrangement of large workshops with industry and research partners, publication activities, invited lectures. Demanded reviewer in the journal "Trends in Food Science &Technology", 10 media interviews.

EDUCATION & EMPLOYMENT

2002	PhD, Norwegian University of Science and Technology (NTNU), Department of Energy and Process Engineering, PhD-thesis: "Quality of fresh foods"
1997	NTNU, Department of Chemistry and Biology, Master thesis: "Drying of lactic acid bacteria"
1994	The University of Oslo, Preliminary examination
1991	Agder Regional Collage, Mathematics at the elementary level

2015-	Senior Research Scientist and Strategic Project Developer at the Thermal Efficiency Department at SINTEF Energy Research
2011-2014	Senior Research Scientist and Research Director of the Energy Efficiency Department at SINTEF Energy Research (SEfAS)
2006-2011	Research Scientist and Research Leader of the Energy Use group at (SEfAS), Dep. of Energy Processes. Senior Research Scientist from 2008

2015-	Member of Norsk Klimastiftelses Råd
2009-2011	Energy21 Energy Use Group, leader of the "chemical and petroleum group"
2009-2012	Member of board, Clean Tech Mid Norway
2009	Member of the Norwegian "Low energy committee" established by OED
2008-2013	Member of board, Nord Trøndelag Energiverk - Energi (NTE Energy)
2007-	Chairman of board, many RCN KPN and IPN KRAV project (Enabling small scale biomass)

2001-2006	TEKNA- P SEfAS
2004-2005	Head of Working Environment Committee at SEfAS
1998-	Responsible for co-ordination, supervision and censoring of various project and diploma Work of students at NTNU-SINTEF

PUBLICATIONS (2007-2015)

1. Hafner, Armin; **Hemmingsen**, Anne Karin: R744 Refrigeration Technologies for Supermarkets in warm Climates. Proceedings of the 24th International Congress of Refrigeration, Yokohama, Japan. International Institute of Refrigeration 2015
2. Kauko Hanne; Hafner, Armin; **Hemmingsen**, Anne Karin; Claussen, Ingrid Camilla. Integrated and efficient energy systems. RERC 2014; 2014-06-16 - 2014-06-17
3. Banasiak, Krzysztof; Hafner, Armin; **Hemmingsen,** Anne Karin. Influence of ejector performance on the overall efficiency of ammonia ejector refrigeration cycle. I: Ammonia Refrigeration Technology. Proceedings: Ohrid, Macedonia, May 9-11, 2013. International Institute of Refrigeration 2013 ISBN 9782913149984. ENERGISINT
4. Mazzetti, Marit Jagtoyen; Nekså, Petter; Walnum, Harald Taxt; **Hemmingsen**, Anne Karin. Novel Energy Efficiency Technologies for Reduction of Offshore CO2 Emissions. OTC 2013; 2013-05-06 - 2013-05-08. ENERGISINT NTNU
5. Mazzetti, Marit Jagtoyen; Nekså, Petter; Walnum, Harald Taxt**; Hemmingsen**, Anne Karin.
6. Novel energy efficiency technologies for reduction of offshore CO2 emissions. I: Offshore Technology Conference. Society of Petroleum Engineers 2013 ISBN 978-1-61399-241-8. ENERGISINT
7. Paul Rowley, Nick Doylend, Philip Leicester, Adam Thirkill1, Pablo Dolado, Peder Bacher, Henrik Madsen, Michael Hart, Anne **Hemmingsen**, Jan-Bleicke Eggers. Towards Smart, Sustainable Cities: the Application of Holistic, Adaptive Modelling Approaches. Abstract published to CISBAT Conference, Topic 9: Building and urban simulation (smart cities and buildings) (2013)
8. Indergård, Erlend; Nordtvedt, Tom Ståle; **Hemmingsen**, Anne Karin. Weightloss on whole salmon during freezing in tunnel with various product sizes and prosess parameters. I: Proceedings of the 23rd International Congress of Refrigeration. International Institute of Refrigeration 2011 ISBN 9782913149892.
9. Tangen, Grethe; **Hemmingsen**, Anne Karin; Lorentsen, Odd-Arne; Nekså, Petter. Energy efficiency in industry - a main path for increased value creation and sustainable energy use. I: Proceedings of the 23rd International Congress of Refrigeration. International Institute of Refrigeration 2011 ISBN 9782913149892.
10. Tangen, Grethe; **Hemmingsen**, Anne Karin; Nekså, Petter. CREATIV: Research-based innovation for industry energy efficiency. Applied Thermal Engineering 2011 ;Volum 31.(17-18) s. 3648-3652
11. Claussen, IC, **Hemmingsen**, AKT, Longva, KE, Strømmen, I, Kommisrud E (2011) *Characteristics of Bovine Spermatozoa after Immobilization by Dehydration.* In: Drying Technology, vol 29 (5), 480
12. **Hemmingsen**, AKT, Stevik AM, Claussen IC, Lundblad KK, Prestløkken E, Sørensen M, Eikevik TM (2008) *Water adsorption in Feed Ingredients for Animal Pellets at Different Temperatures, Particle Size, and Ingredient Combinations* In: Drying Technology vol 26, 738-748
13. Magnussen OM, **Hemmingsen** AKT, Hardarson V, Nordtvedt TS, Eikevik TM, (2008) Freezing of Fish, In: Frozen Food Science and Technology: 151-164. Blackwell publishing, ISBN: 978-1-45051-5478-9
14. Duun AS, **Hemmingsen** AKT, Haugland A, Rustad T. (2008) Quality changes during superchilled storage of pork roast. LWT Food Science and Technology.
15. Magnussen OM, Haugland AH, **Hemmingsen** AKT, Johansen S and Nordtvedt TS (2008) Advances in superchilling of food process characteristics and product quality. Trends in Food Science &Technology
16. Claussen IC, **Hemmingsen** AKT, Rustad T, Strømmen I (2007) *Relations between product structure, sorption characteristics and freezing point of atmospheric freeze dried foods* In: Drying Technology vol 25 (5), 22
17. Magnussen OM, Johansen S, Nordtvedt TS, Hardarson V, Haugland A and **Hemmingsen** AKT (2007): Advances in SUPERCHILLING. New Food Magazine, Issue 1 - 2007
18. Claussen IC, **Hemmingsen** AKT, Strømmen I, Rustad T, *Physiochemical properties of atmospheric freeze dried foods*, Proceedings, 2006 CIGR Section VI International Symposium in FUTURE OF FOOD ENGINEERING,

Warsaw, Poland
19. Claussen IC, **Hemmingsen** AKT, Strømmen I (2005) *Measurements of physical and quality parameters of Norwegian Stockfish* Proceedings, 3rd Nordic Drying Conference, Karlstad, Sweden, 9
20. **Torstveit** AK, Aune EJ, Opdahl IA, Nordtvedt TS, Magnussen OM (2001) Influence of modified atmospheric packaging on chilled fish products. Food Australia 54: 144-148
21. **Torstveit** AK, Magnussen OM (1998) Temperature conditions in refrigerated counters in Vest-Agder, Norway. In: Hygiene, Quality and Safety in the Cold Chain and Air-Conditioning, Refrigeration Science and Technology. Proceedings, IIR, Nantes: 237-248
22. Magnussen OM, Nordtvedt TS, **Torstveit AK** (1998) Use of partial freezing in the cold chain. IIR Conference, Sofia, Bulgaria.
23. Aune EJ, **Torstveit AK**, Magnussen OM, Nordtvedt TS (1999) The temperature course for MAP packed meat products through the chilling chain from producer to consumer, 10th World Congress of Food Science & Technology, Sydney, Australia.
24. **Torstveit AK**, Aune EJ, Nordtvedt TS, Magnussen OM (1999) Influence of modified atmosphere packaging on meat products. Proceedings, 20th International Congress of Refrigeration, IIR/IIF, Sydney, Australia.
25. **Torstveit AK**, Osvik AH, Stevik AM, Rustad T (2002) Quality of chilled and superchilled MA-packed salmon fillets, Proceedings 32nd WEFTA meeting Galway, Ireland
26. **Hemmingsen AKT** (2002) Quality of fresh foods. PhD Thesis 2002:137, NTNU, Trondheim.
27. **Torstveit AK** (2002) Matvaretrygghet – utfordringer i kuldekjeden. Kulde Skandinavia 2: 41
28. Haugland A, Aune EJ, **Hemmingsen AKT** (2005) *Superchilling – Innovative processing of fresh food.* Eurofreeze 2005: Individual Quick Freezing of Foods, Sofia, Bulgaria (silver price)
29. Eikevik, T.M., Strømmen, I., Alves Filho, O., **Hemmingsen, A.K.T**.; *Effect of Operating Conditions on Atmospheric Freeze Dried Cod Fish*, 3rd Inter-American Drying Conference, August 21-23, 2005, Montreal, Canada, ISBN 0-7717-0634-0
30. Eikevik TM, Strømmen I, Alves Filho O, **Hemmingsen AKT**, Effect of Operating Conditions on Atmospheric Freeze Dried Cod Fish, 3rd Inter-American Drying Conference, August 21-23, 2005, Montreal, Canada, ISBN 0-7717-0634-0
31. **Hemmingsen AKT**, Aune EJ, Magnussen OMM (2004) *Challenges in the distribution of fresh foods.* Scandinavian Refrigeration 5: 40-45
32. **Torstveit AK**, Magnussen OM, Nordtvedt TS, Aune EJ, Opdahl IA (1998) Influence of modified atmosphere packaging on fish products, 28th WEFTA meeting, Tromsø, Norway.
33. Alves-Filho O, Strømmen I, Aasprong A, **Torstveit AK**, Boman HC, Hovin W (1998) Heat pump fluidized bed drying for lactic acid suspensions using inert particles and freeze drying. IDS Conference, Tessaloniki, Greece.
34. **Torstveit** (1998) Temperaturforhold i kjøleinnretninger – betydning av internkontroll. Næringsmiddelindustrien 6: 42-43

Curriculum Vitae

Name: **Truls Gundersen**
Born: 4 October 1952
Nationality: Norwegian
E-mail: Truls.gundersen@ntnu.no

Present position: Professor

EDUCATION & EMPLOYMENT

1977 MSc in Physics, Norwegian University of Science and Technology (NTNU)
1982 PhD in Chemical Engineering, NTNU
1986 Professor II (Adjunct), NTNU, Chemical Engineering
1981 Norsk Hydro AS, Research Centre, Porsgrunn
1993 Professor, Telemark Institute of Technology, Dept. of Process Technology, Porsgrunn
1986 Professor, NTNU, Thermal Energy, later Energy and Process Engineering

MAIN FIELDS OF COMPETENCE

- Advanced Process Integration
- Pinch Analysis and Heat Exchanger Network Synthesis
- Thermodynamics and Exergy Analysis
- Mathematical Optimization (user, not developer)
- Low Temperature Processes (LNG, ASU)

EXPERIENCE

- 12 years industrial experience with Norsk Hydro working on processes from different branches such as petrochemicals (Ethylene), fertilizers (Ammonia and Nitric Acid), light metals (Magnesium and Aluminium) and Oil & Gas (Platform Separation processes), 1981-1993
- Industrial Sabbatical Year at Carnegie Mellon University, Pittsburgh, USA, 1987-1988
- Operating Agent for Annex I of the IEA Implementing Agreement on Process Integration, 1995-2002
- Nordic Research Professor, Process Integration Scientific Progr. of Nordic Energy Research, 2001-2002
- NTNU Coordinator for FME BIGCCS, 2009-2016
- Sabbatical Year at MIT, Boston, 2012
- Reviewer for 21 different international journals
- NTNU Coordinator for collaboration between MIT and NTNU since 2013

TEACHING, SUPERVISOR, CENSORSHIP

- Teaching experience since 1983 in MSc courses such as Process Simulation, Process Synthesis, Engineering Thermodynamics, Process Integration and a PhD course on Optimization
- Supervised 14 PhD students
- External examiner for 36 PhDs in 10 countries

COMMITTEE MEMBERSHIPS

- Member of Scientific Committee for 15 International Conferences
- Member of Scientific Advisory Board for the Swedish Energy Agency on Process Integration (PRISMA for the Iron & Steel industry, Swerea MEFOS, 2008, 2011 and 2015)
- Member of Scientific Advisory Board for Tekes, Finland (Efficient Energy End Use / CLEEN, 2014 and 2015)
- Member of International Evaluation Panel for Energy Market Authority, Singapore, 2014

AWARDS

- Fulbright Fellowship in Natural Science, 1987-1988
- Elected Member of the Norwegian Academy of Science and Technology (NTVA) since 1991
- Best Lecturer Award 2004 from students in Energy and Environment for TEP 4215 Process Integration
- Best Lecturer Award 2009 from students in Energy and Environment for TEP 4120 Thermodynamics 1
- Best Lecturer Award 2010 from students in Mechanical Engineering for TEP 4215 Process Integration

PUBLICATIONS

- About 100 international and national publications and 20 technical reports
- Numerous presentations in international and national meetings and conferences. The most prestigious and recent ones are (i) Plenary Speaker at the PRES Conference, Rhodes, Greece, October 2013, *Process Integration in Sub-ambient Processes*, (ii) Invited Speaker at the International Process Integration Jubilee Conference, Gothenburg, Sweden, March 2013, *What is Process Integration*, (iii) Invited Speaker at the International Process Integration Jubilee Conference, Gothenburg, Sweden, March 2013, *The Role of Process Integration in Sub-ambient Processes*, (iv) Invited Chemical Engineering Department Seminar, Carnegie Mellon University, Pittsburgh, USA, March 2012, *Thermodynamics and Innovative Design for Energy Efficiency and Carbon Capture*.
- Academic production according to Scopus: **h-index: 17, citations: 710, publications: 90**

SOME SELECTED PUBLICATIONS

- Gundersen T. and Naess L. "The Synthesis of Cost Optimal Heat Exchanger Networks - An Industrial Review of the State of the Art", ***Comput. and Chem. Engng.***, vol. 12, no. 6, pp. 503-530, 1988.
- Gundersen T. and Grossmann I.E. "Improved Optimization Strategies for Automated Heat Exchanger Networks through Physical Insights", ***Comput. and Chem. Engng.***, vol. 14, no. 9, pp. 925-944, 1990.
- Glemmestad B., Skogestad B. and Gundersen T. "Optimal Operation of Heat Exchanger Networks", ***Comput. and Chem. Engng.***, vol. 23, pp. 509-522, 1999.
- Anantharaman R., Abbas O.S. and Gundersen T. "Energy Level Composite Curves – A New Graphical Methodology for the Integration of Energy Intensive Processes", ***Applied Thermal Engineering***, vol. 26, pp. 1378-1384, 2006.
- Kaggerud K. H., Bolland O. and Gundersen T. "Chemical and Process Integration: Synergies in Co-Production of Power and Chemicals from Natural Gas with CO_2 Capture", ***Applied Thermal Engineering***, vol. 26, pp. 1345-1352, 2006.
- Aspelund A., Berstad D.O. and Gundersen T. "An Extended Pinch Analysis and Design Procedure utilizing Pressure based Exergy for Subambient Cooling", ***Applied Thermal Engineering***, vol. 27, No. 16, pp. 2633-2649, November 2007.
- Aspelund A. and Gundersen T. "A Liquefied Energy Chain for Transport and Utilization of Natural Gas for Power Production with CO_2 Capture and Storage – Part 1", ***Journal of Applied Energy***, vol. 86, pp. 781-792, 2009.
- Aspelund A. and Gundersen T. "A Liquefied Energy Chain for Transport and Utilization of Natural Gas for Power Production with CO_2 Capture and Storage – Part 2, The Offshore and the Onshore Processes", ***Journal of Applied Energy***, vol. 86, pp. 793-804, 2009.
- Anantharaman R., Nastad I., Nygreen B. and Gundersen T. "The Sequential Framework for Heat Exchanger Network Synthesis – The Minimum Number of Units Subproblem", ***Computers & Chemical Engineering***, vol. 34, pp. 1822-1830, 2010.
- Aspelund A., Gundersen T., Myklebust J., Nowak M.P. and Tomasgard A. "An Optimization-Simulation Model for a simple LNG Process", ***Computers & Chemical Engineering***, vol. 34, pp. 1606-1617, 2010.
- Wechsung A., Aspelund A., Gundersen T. and Barton P.I., "Synthesis of Heat Exchanger Networks at Sub-ambient Conditions with Compression and Expansion of Process Streams", ***AIChE Journal***, DOI: 10.1002/aic.12412, vol. 57, no. 8, pp. 2090-2108, August 2011.

- Fu C. and Gundersen T., "Using Exergy Analysis to reduce Power Consumption in Air Separation Units for Oxy-combustion Processes", ***Energy***, vol. 44, no. 1, pp. 60-68, August 2012.
- Marmolejo-Correa D. and Gundersen T., "A Comparison of Exergy Efficiency Definitions with Focus on Low Temperature Processes", ***Energy***, vol. 44, no. 1, pp. 477-489, August 2012.
- Fu C. and Gundersen T., "Recuperative Vapor Recompression Heat Pumps in Cryogenic Air Separation Processes", ***Energy***, vol. 59, pp. 708-718, 2013.
- Fu C. and Gundersen T., "Exergy Analysis and Heat Integration of a Coal-based Oxy-combustion Power Plant", ***Energy and Fuels***, vol. 27, No. 11, pp. 7138-7149 2013.
- Austbø B., Wahl P.E. and Gundersen T., "Constraint Handling in Stochastic Optimization Algorithms for Natural Gas Liquefaction Processes", ***Computer Aided Chemical Engineering***, vol. 32, pp. 445-450, 2013.
- Marmolejo-Correa D. and Gundersen T., "A new Graphical Representation of Exergy applied to Low Temperature Process Design" ***Ind. & Eng. Chem. Res.***, vol. 52, no. 22, pp. 7145-7156, 2013.
- Anantharaman R., Jordal K., Berstad D.O. and Gundersen T., "The Role of Process Synthesis in the Systematic Design of Energy Efficient Fossil Fuel Power Plants with CO_2 Capture", ***Chem. Engng. Trans.***, vol. 35, pp. 55-60, 2013.
- Soundararajan R. and Gundersen T., "Coal-based Power Plants using Oxy-combustion for CO_2 Capture: Pressurized Coal Combustion to reduce Capture Penalty", ***Applied Thermal Engineering***, vol. 61, no. 1, pp. 115-122, 2013.
- Marmolejo-Correa D. and Gundersen T., "A new Efficiency Parameter for Exergy Analysis in Low Temperature Processes", ***Intl. Jl. of Exergy***, vol. 17, no. 2, pp. 135-170, 2015.
- Austbø B., Løvseth S.W. and Gundersen T., "Annotated Bibliography – Use of Optimization in LNG Process Design and Operation", ***Comput. chem. Engng.***, vol. 71, 4 December, pp. 391-414, 2014.
- Austbø B. and Gundersen T., "Using Thermodynamic Insight in the Optimization of LNG Processes", ***Computer Aided Chemical Engineering***, vol. 33, pp. 1273-1278, 2014.
- Fu C. and Gundersen T., "N_2 Brayton Cycle in Oxy-combustion Power Plants", ***Chem. Engng. Trans.***, vol. 39, pp. 223-228, 2014.
- Zhang X., Singh B., He X., Gundersen T., Deng L. and Zhang S., "Post-combustion carbon capture technologies: Energetic analysis and life cycle assessment", ***Intl. Jl. of Greenhouse Gas Control***, vol. 27, pp. 289-298.
- Fu C., Anantharaman R. and Gundersen T., "Optimal integration of compression heat with regenerative steam Rankine cycles in oxy-combustion coal based power plants", ***Energy***, vol. 84, pp. 612-622, 2015.
- Fu C. and Gundersen T., "Integrating compressors into heat exchanger networks above ambient temperature", ***AIChE Jl.***, vol. 61, no. 11, pp. 3770-3785, 2015.
- Austbø B. and Gundersen T., "Optimization of a single expander LNG process", ***Energy Procedia***, vol. 64, issue C, pp. 63-72, 2015.
- Kim D. and Gundersen T., "Helium extraction from LNG end-flash", ***Chemical Engineering Transactions***, vol. 45, pp. 595-600, 2015.
- Fu C. and Gundersen T., "Integrating expanders into heat exchanger networks above ambient temperature", ***AIChE Jl.***, vol. 61, no. 10, pp. 3404-3422, 2015.
- Austbø B. and Gundersen T., "Optimal distribution of temperature driving forces in low-temperature heat transfer", ***AIChE Jl.***, vol. 61, no. 8, pp. 2447-2455, 2015.
- Fu C. and Gundersen T., "Sub-ambient heat exchanger network design including expanders", ***Chem. Eng. Sci.***, vol. 138, pp. 712-729, 2015.
- Fu C. and Gundersen T., "Sub-ambient heat exchanger network design including compressors", ***Chem. Eng. Sci.***, vol. 137, pp. 631-645, 2015.
- Fu C., Anantharaman R., Jordal K. and Gundersen T., "Thermal efficiency of coal-fired power plants: From theoretical to practical assessments", ***Energy conversion and Management***, vol. 105, pp. 530-544, 2015.

BOOK CHAPTERS

- Gundersen T. "Heat Integration: Targets and Heat Exchanger Network Design", in ***Handbook of Process Integration (PI)***, Klemes J.J. (ed.), Chapter 4, pp. 129-167, Woodhead Publishing Ltd., Oxford, 2013.

- Gundersen T. "Analysis and Design of Heat Recovery Systems for Grassroots and Retrofit Situations", in ***Handbook of Process Integration (PI)***, Klemes J.J. (ed.), Chapter 8, pp. 262-309, Woodhead Publishing Ltd., Oxford, 2013.
- Gundersen T. "Process Integration – Introduction to Key Concepts and Major Topics", in Gani R. et al. (eds.), ***Ullmann's Encyclopedia on Industrial Chemistry***, new Volume on "Process Systems Engineering", Chapter 3.1, pp. 12-26, Wiley-VCH Verlag GmbH & Co, KGaA, Weinheim, 2013.

PATENTS

- Fu C., Gundersen T. and Eimer D., "Air Separation", ***GB Patent***, Application number GB1112988.9, July 2011.

Curriculum Vitae

Dr. Petter Nekså
Current positions:
Chief Research Scientist at SINTEF Energy Research
Adjunct Professor, at NTNU, Dep. of Energy and Process Engineering
Visiting Professor, Doshisha University, Kyoto, Japan

Date of birth: 1960-09-17 Gender: Male Nationality: Norwegian
Present address: Parkveien 9, NO-7030 Trondheim, Norway
E-mail: Petter.Neksa@sintef.no

EDUCATION

1992 Dr.ing (Ph.D.) in Mechanical Engineering, Norwegian Institute of Technology (NTH), Refrigeration Engineering, Trondheim

1986 Siv.Ing. (M.Sc.) in Refrigeration Engineering/ Mechanical Engineering, Norwegian Institute of Technology (NTH), Refrigeration Engineering, Trondheim

MAIN FIELDS OF COMPETENCE

- Refrigeration and heat pump technology in general
- System design for refrigeration, air conditioning and heat pumps
- CO_2 technology for various applications
- Low temperature refrigeration, liquefaction and gas processing (LNG, LH2, LCO2…)
- Compressor and heat exchanger technology
- Working fluids, with emphasis on natural working fluids
- Power cycles for utilisation of low to medium temperature heat
- Low temperature processes for CO_2 capture, AGR and CCS
- Energy systems and energy efficiency related issues in general

EXPERIENCE

- Research Scientist at SINTEF Energy Research from 1986
- Experience from computer modelling and simulation, and experimental work in laboratory
- Project Manager for various projects (small to above 25 MNOK)
- Scientific Coordinator for various projects (small to above 40 MNOK)
- Steering Committee Member for various projects
- Assistant Research Manager for SINTEF Energy Research, Dep. *Refrig. and Air Cond.* 1996-1998
- Group Manager "Refrigeration Engineering" 1997-2008, except period in Italy, see below.
- Visiting Research Scientist at Consiglio Nationale delle Ricerche, Ist. per la Tecn. Del Freddo and at Universita di Padova, Dipartimento di Fisica Tecnica, 1999.08 – 2001.03
- Board member SINTEF Energy Research (2006-2008 observer, 2008-2014 perm., substitute at present)
- *Experience with emphasis on work related to innovation and business sector:* Project manager roles: CO_2 technology in RACHPs (2002-2006), Energy efficient hydrogen liquefaction processes (2005-2009), DECARBIt, SP Advanced air separation technologies (2008-2011), IDEALHY, EU-proj on liquefaction of hydrogen (2012-2013), Dev of Mini-LNG technology (2004-2014), A Green Sea, WP Low Temperature Acid Gas Removal (2010-2014). Scientific coord for several projects. Steering committee member, examples: Next Generation LNG Heat Exchangers (2003-2006), LUWS, Liquefaction of Unprocessed Well Streams (2007-2010), DECARBIt, General Assembly (2008-2011), A Green Sea (2010-2014). Innovation: Several components and system developments within Liquefaction technology and Refrigeration technology.

TEACHING, SUPERVISOR, CENSORSHIP

- Responsible for teaching the courses "Fundamental heat pump engineering" and "Advanced heat pump engineering" in the period 1993-1995

- Responsible for teaching the "Thermodynamic analysis" and "System analysis" parts of the course "Refrigeration engineering" in the period 1995-1996
- Responsible for co-ordination, supervision and censoring of various project and diploma work (MSc level) of the students at NTNU-SINTEF, and from other European universities
- Supervisor or co-supervisor for 7 PhD candidates, as well as many MSc candidates
- Member of evaluation committee as censor for 2 PhD defences of theses, and administrator for one

COMMITTEE MEMBERSHIPS

- Board of Norwegian Society of Refrigeration 2005-2007
- Intl. Inst. of Refrigeration (IIR), Commission E2 Secretary 1996-99, Vice Pres. 1999-07, Member
- UNEP-TEAP Technical Options Committee on Refrig., Air Cond. and Heat Pumps 2002-2016, member and author
- IPCC/TEAP, Lead Author of IPCC/TEAP Special report on "Safeguarding the ozone layer and the global climate systems: issues related to hydrofluorocarbons and perfluorocarbons" 2003-2005
- Member and President of Scientific- and Organising Committees for some conferences, e.g. IIR Gustav Lorentzen Conference on Natural Working Fluids, Oslo 1998 and Trondheim 2006
- International Journal of Refrigeration (Elsevier), International Advisory Board Member, (2007 – present)
- Participated in Energi21 development of a road map for energy efficiency within the industry in Norway (- 2012)

AWARDS

- Acknowledged recognition from the Nobel Prize Laureate (IPCC- 2007) for author role in the IPCC reports, 2007
- IEA Ritter Von Rittinger Award for the work on CO_2 technology, 2005

PUBLICATIONS

- About 150 international and national publications and 100 technical reports within the area of refrigeration and process engineering
- Numerous presentations in international and national meetings and conferences
- Co-author of 8 patents within CO_2 technology, heat recovery and liquefaction (LNG)
- Academic production according to Web of Science (URL: http://www.researcherid.com/rid/B-8825-2014): h-index: 8, citations: 422, publications: 129

SOME SELECTED PUBLICATIONS

International publications with referee:

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Fidorra, N; Hafner, Armin; Nekså, Petter; Köhler, Jürgen., Energy cost analysis of heat recovery in CO2 supermarket refrigeration systems". I: Ammonia and CO2 Refrigeration Technologies - Ohrid, Macedonia April 16-18, 2015 - Proceedings. International Institute of Refrigeration 2015 ISBN 978-2-36215-008-1.

Hu, Haitao; Eikevik, Trygve Magne; Nekså, Petter; Hafner, Armin; Ding, Guoliang; Huang, Qingnan; Ye, Jingjing., Performance analysis of a r744 ground source heat pump system with air-cooled and water-cooled gas coolers. International journal of refrigeration 2015

Iwamoto, Yuhiro; Yamasaki, Haruhiko; Niu, Xiao-Dong; Nekså, Petter; Yamaguchi, Hiroshi., Experimental study on system performance of ultra-low temperature cascade refrigeration system using Carbon Dioxide with tapped evaporator/sublimator. I: Proceedings of the 24th International Congress of Refrigeration. International Institute of Refrigeration 2015 ISBN 978-2-36215-012-8.

Jin, Zhequan; Eikevik, Trygve Magne; Nekså, Petter; Hafner, Armin; Ding, Guoliang., Energy performance of co2 hybrid ground-coupled heat pumping system for hotel application. I: Proceedings of the 24th Int. Congress of Refrigeration. International Institute of Refrigeration 2015 ISBN 978-2-36215-012-8.

Other international publications

Nekså, P. (2008): *Refrigeration: Perspectives, NH_3 and CO_2 as natural refrigerants,* Invited lecture at 2008 Refrigeration Year, AFF-IIR Centenary, 100 years at the service of the development of refrigeration and its applications, Paris, June 12, 2008

Walnum, H.T., Ladam, Y., Nekså, P. and Andresen, T. (2010): *Evaluation of Rankine cycles for power production from surplus heat at off-design conditions*, 9th Int. Conf. of Sustainable Energy Technologies, SET2010, Shanghai, August 24-27, 2010

Andresen, Trond; Ladam, Yves; Nekså, Petter (2011) *Simultaneous Optimization of Power Cycle & Heat Recovery Heat Exchanger Parameters*, Supercritical CO2 Power Cycle Symposium, Boulder, Colorado, May 24 - 25, 2011

Curriculum Vitae

Name: **Paul I. Barton**
Born: 3rd July 1966
Nationality: British
E-mail: pib@mit.edu

Present position: Lammot du Pont Professor

EDUCATION & EMPLOYMENT

1988 MEng Chemical Engineering, Imperial College, London
1992 PhD Chemical Engineering, Imperial College, London
1992 Assistant Professor of Chemical Engineering, MIT, Cambridge, MA
1999 Associate Professor of Chemical Engineering, MIT, Cambridge, MA
2005 Professor of Chemical Engineering, MIT, Cambridge, MA
2007 Lammot du Pont Professor of Chemical Engineering, MIT, Cambridge, MA

MAIN FIELDS OF COMPETENCE

- Global, mixed-integer and dynamic optimization theory and algorithms
- Hybrid discrete/continuous dynamic systems
- Numerical analysis of differential equations
- Sensitivity analysis and automatic differentiation
- Process modeling and optimization software
- Energy systems engineering
- Continuous pharmaceutical manufacturing
- Quantitative engineering of microbial consortia

EXPERIENCE

- Research Technican, BP Research Center, Sunbury-on-Thames, UK, 1983-1984
- Summer internships with Air Products, Walton-on-Thames, UK, 1985-1987
- Visiting Professor, CNRS-ENSIC, Nancy, France, 2000
- Visiting Professor, EPFL, Lausanne, Switzerland, 2006
- Consulting for Aspen Technology, Dow Chemical, Modell Environmental, Numerical Technology, Alstom Power

TEACHING, SUPERVISOR, CENSORSHIP

- Teaching experience since 1992 in undergraduate courses such as Batch Process Design, Continuous Process Design, and Process Simulation, and graduate courses in Systems Engineering, Numerical Methods, and Mixed-integer & Nonconvex Optimization
- Supervised 4 Master's students
- Supervised 37 PhD students
- Supervised 31 Postdoctoral students
- Member of thesis committee for numerous PhD students

PROFESSIONAL SERVICE

- Currently Associate Editor for *Journal of Optimization Theory & Applications* and *Journal of Global Optimization*
- Past editorial positions with *Chemical Engineering & Processing*, *Simulation: Transactions of the Society for Modeling and Simulation International*, and *Optimal Control Applications & Methods*.
- Editorial Advisory Board, *Industrial and Engineering Chemistry Research*, 2007-2009.
- Director (2001-2004) and Area 10C Programming Coordinator (1999-2001), AIChE CAST Division.

- Member of Scientific Committee for numerous international conferences
- Reviewer for a multitude of international journals in chemical engineering, optimization, applied mathematics and energy
- Proposal reviewer for numerous federal and international agencies

SELECTED AWARDS

- Research Collaboration Award, Council for Chemical Research, 2014 (member of winning team)
- Best Paper Award, *Journal of Global Optimization*, 2012
- Computing in Chemical Engineering Award, AIChE CAST Division, 2011
- Indo-American Frontiers of Engineering Award, National Academy of Engineering, 2008
- Best Paper Award, *Computers and Chemical Engineering*, 2004
- Outstanding Young Researcher Award, AIChE CAST Division, 2004
- IChemE's Hinchley Medal, 1988
- BOC/Dr. M.P. Schuftan Memorial Prize for Process Design, 1987

PUBLICATIONS

- 163 refereed journal articles, one edited book, 9 book chapters, 45 refereed conference proceedings.
- 77 keynote, plenary or invited papers. The most prestigious and recent ones are (i) Invited Speaker, 8th International Conference on Foundations of Computer-Aided Process Design, Cle Elum, WA, July 2014, (ii) Plenary Speaker, International Conference on Continuous Optimization, Caparica, Portugal, August 2013, (iii) Keynote Speaker, Spring Simulation Multiconference, Boston, MA, April 2011, (iv) Keynote Speaker, International Symposium on Process Systems Engineering, Salvador, Brazil, August 2009.
- 247 presented papers at international conferences.
- Academic production according to Scopus: **h-index: 36, citations: 3586, publications: 257.**

SOME SELECTED PUBLICATIONS

- Mitsos A. and P. I. Barton, editors, "Microfabricated Power Generation Devices: Design and Technology", Wiley-VCH, 2009.
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- Tan S. H. and P. I. Barton, "Optimal Dynamic Allocation of Mobile Plants to Monetize Associated or Stranded Natural Gas, part I: Bakken Shale Play Case Study", ***Energy***, vol. 93, no. 2, pp. 1581-1594, 2015.
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- Yang Y. and P. I. Barton, "Integrated Crude Selection and Refinery Optimization Under Uncertainty", In press: ***AIChE Journal***, October 2015.

PATENTS

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- Yang Y., P. Vayanos and P. I. Barton, "Systems and methods for improving petroleum fuels production", ***United States Patent application***, 17th November 2015.

Curriculum Vitae

Personal information

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Date of birth: 21/9/47

Work experience

1995 – present **Professor and Director of the Centre for Process Integration, The University of Manchester, UK**

Director for a Centre consisting of 2 readers, 2 senior lecturers, 1 lecturers, 1 Project Officer, 1 Computer Officer, 25 PhD students.

Managed the Process Integration Research Consortium (PIRC) of the Centre since 1994. This is a Consortium of international industrial companies that provide financial support to the research programme of the Centre. Activities include recruitment of companies, administration, development of the technical program and the dissemination of results to the members. Currently comprises 10 international organizations.Software packages developed in the Centre are used for teaching MSc students, both full-time and distance learning.

2007 – 2015 **Director of the BP Executive Training Programme on Engineering Management of The University of Manchester, UK**

The University of Manchester hosted the executive education programme for Engineering Management for BP engineering managers worldwide. The University of Manchester, along with MIT, provided the academic contribution to the BP Projects and Engineering College. Director of the programme since its inauguration in October 2007 with an annual budget of £1.25 million per year.

2007 – present **President, Process Integration Ltd**, **UK**

Process Integration Ltd (www.processint.com) is a spin-out company from the University of Manchester with offices in Manchester and Beijing. Established the company and started trading in October 2007. Currently 18 employees in the UK and 40 employees in PR China. Process Integration Ltd offers services in consultancy, software and training, specializing in improving energy technology and reducing greenhouse gas emissions in the process industries. The technology is based on the research output of the Centre for Process Integration.

2012 – present **Director, Process Asset Integration Management Ltd, UK**

Founder director of Process Asset Integration Management Ltd (ProAIM) (www.processaim.com), which is a spin-out company from the University of Manchester, with offices in Manchester and Hangzhou, PR China. The intellectual property is based on the research of two of my PhD students. PAIM offers services in consultancy, software and training, specializing in improving reliability, availability and maintainability in the process industries. Currently 3 full-time employees in the UK, and 7 full-time in China.

1981 - 1983 **Lecturer in Chemical Engineering, Chemical Engineering Department, University of Bradford, UK**

1977 - 1981 **Senior Research Engineer, ICI, UK**

Senior Research Engineer with responsibilities in computer-aided design and process integration. Company expert in distillation modeling and process integration. Provided support and development for ICI design activities worldwide. Member of the pioneering team that made the first industrial applications of process integration methods.

1975 - 1977 **Process Engineer, Rohm & Haas (UK) Ltd**

Process engineer with responsibilities in process investigation, production and process design.

Experience in fine and specialty chemical production from both continuous and batch operations.

Education and training

July 1976	PhD in Chemical Engineering, University of Bradford, UK
December 1972	MSc by Advanced Study in Chemical Engineering, University of Bradford, UK
December 1971	BTech, 1st Class Honours in Chemical Engineering, University of Bradford, UK

Professional Qualifications

Fellow of the Royal Academy of Engineering, FREng
Fellow of the Institution of Chemical Engineers, UK, FIChemE.
Chartered Engineer, CEng, Member of AIChE

Awards

Hanson Medal of the Institution of Chemical Engineers, UK 1992, for work on clean process technology

Research Activities

Current research projects include:

- Design of Heat Exchanger Networks
- Intensified Heat Transfer for Energy Saving in Process Industries
- Design and Optimization of Low Temperature Energy Systems
- Retrofit of Distillation Systems
- Design and Retrofit of Refinery Distillation Systems
- Energy Supply Integration
- Optimization of Utility Systems
- Process Integration for Waste Water Management

Research Impact

h-index: 43
Total citations: 8,337 (4,698 since 2010)
Highest cited paper : 992.
Citations for “Chemical process design and integration, R Smith”: 1278.
21 publications have been cited over 100 times.
Accumulated research of over 30 years exploited industrially by Process Integration Ltd and other competitive consultancy and engineering companies.
Research output from two PhD students commercialized by Process Asset Integration Management Ltd.

Recent Professional Activities

- Member of the editorial board of the Journal of Applied Thermal Engineering (1990 to present).
- Member of the Scientific Committee of the International Process Integration Jubilee Conference (Gothenburg, Sweden, March 2013)
- Member of Scientific Committee for PRES13 (Rhodes, Greece Sept 2013)
- Member of Scientific Committee for 8th Conference on Sustainable Development of Energy, Water and Environment Systems (Dubrovnik - Croatia Sept 2013)
- Member of Scientific Committee for ESCAPE22 (London, 2012).
- Member of the Scientific Committee of the First Annual Gas Processing Symposium, Gas Processing Center, Qatar, 2009 and the First Annual Gas Processing Symposium, Qatar, 2010.
- Member of Scientific Committees for PRES03 (Hamilton Ontario 2003), PRES04 (Prague 2004), PRES05 (Taormina, Italy, 2005), PRES06 (Prague, 2006), PRES07 (Ischia, Naples, Italy 2007) PRES08 (Prague, 2008), PRES09 (Rome 2009) and PRES10 (Prague, 2010), PRES11 (Florence, 2011), PRES12 (Prague 2012), PRES13 (Rhodes, Greece 2012), PRES14 (Prague 2012).
- Member of the editorial board of Transactions of IChemE (1996 to 2008).
- Lead Academic for North West Universities Association in the UK for the Chemical Sector to 2007 (one of two representatives for the region of the UK).
- Member of the Steering Committee of Chemicals Northwest (a lobby group for the chemical industry in the North West region of the UK) to 2007.
- Member of Scientific Panel for 7th World Congress of Chemical Engineering (Glasgow, 2005).
- Member of Scientific Committee for ESCAPE15 (Barcelona, 2005).
- Member of Scientific Committee of PSE 2003 Kunming, PR China.

Consulting Work

- Process integration for energy reduction carried out for Sinopec (PR China), Chinese Petroleum Corporation (Taiwan), Shell, BP, ExxonMobil, Total, BASF, Ciba Geigy, Whitbread Breweries, Ectona Fibres, Union Carbide, Express Foods Groups, Edward Hall, Chivas Regal, Gas Research Institute (Chicago, USA), Bass Breweries, Moosehead Breweries (Canada), British Gas (BG).
- Process integration for wastewater minimization and distributed effluent treatment carried out for Bayer, Exxon, DSM, Gulf Oil, Monsanto, Unilever, and Zeneca.
- Two surveys of effluent production from the chemical industry in the UK for the UK Environment Agency covering the petrochemical industries and specialty chemicals production. Surveys used as a basis for new regulations.
- Consulting work with UK Government Foreign and Commonwealth Office to promote actions against climate change in India.
- Studies on complex distillation carried out for UOP, BP, Total, Henkel, AspenTech and Sasol.
- Advisor in legal case in Northern Ireland

Professional Training

- In-house training courses on various aspects of Process Integration have been given for Shell (UK and the Netherlands), BP (UK), ExxonMobil (USA), Sasol (South Africa), Petro SA (South Africa), Huntsman Chemical (UK), Scientific Design Company (USA), ARCO (USA), Technip (Netherlands), Norsk Hydro (Norway), Dow (USA and the Netherlands), Dutch State Mines (Netherlands), MW Kellogg (UK), Olin Chemicals (USA), Ontario Hydro (Canada), and Eastman Chemical (USA), WS Atkins (UK), Johnson Matthey (UK).

- Public training courses on various aspects of Process Integration have been given in Manchester, Bahrain, Qatar, India, USA (Los Angeles, Washington DC and Houston) Frankfurt, The Netherlands, Finland, Singapore, Japan, Taiwan, Belgium, Australia and New Zealand.

Books

Smith R, December 1994, "Chemical Process Design", McGraw-Hill, pp 459. 211 cit

Smith R, January 2005, “Chemical Process Design and Integration”, John Wiley, pp 687. 238 cit (currently being revised for a 2nd Edition),

Edited Books

Klemeš J, Smith R and Kim J-K, “Handbook of Water and Energy Management in Food Processing”, Woodhead Publishing Limited, 2008.

Book Chapters

1. Smith R, Pan M and Bulatov I, 2013, “Heat transfer enhancement in heat exchanger networks” in Handbook of Process Integration, Woodhead Publishing Limited.
2. Kim J-K and Smith R, 2008, “Methods to Minimise Water Use in Food Processing in Handbook of Water and Energy Management in Food Processing”, Woodhead Publishing Limited.
3. Smith R, 2004, “Process Design” in “Kirk-Othmer Encyclopedia of Chemical Technology”, Wiley Inc.
4. Smith R and Kim J-K, 2003, “Pinch Analysis and Design” in “Encyclopedia of Chemical Processing”, Marcel Dekker Inc.
5. Alva-Argaez A, Kokossis AC and Smith R, 2001, “Process Integration, Synthesis, and Analysis for Cleaner Processes”, in Sikdar SK and El-Halwagi, MM, “Process Design Tools for the Environment”, Taylor & Francis.
6. Smith R, and Jobson, M, 1999, “Distillation”, in “Encyclopedia of Separation Science”, Academic Press.
7. Smith R, 1998, "Thermally Coupled Columns", in “Encyclopedia of Separation Science”, Academic Press.
8. Linnhoff B and Smith R, 1995, “Pinch Analysis for Heat Exchanger Network Design”, in “Heat Exchanger Design Handbook (HEDH)”, Begell House Inc.
9. Smith R, 1995, Chapter 8, “Wastewater Minimization”, in Rossiter, A., “Waste Minimization Through Process Design”, McGraw-Hill.
10. Dhole VR, Smith R and Linnhoff B, 1995, “Computer Applications for Energy Efficient Systems”, in “Encyclopedia of Energy Technology and the Environment”, John Wiley.

Publications

130 refereed publications

15 publications in professional journals
97 conference publications

Selected Publications from the last 10 years

1. Enríquez-Gutiérrez VM, Jobson M, Ochoa-Estopier LM, Smith R (2015) Retrofit of Heat-integrated Crude Oil Distillation Columns, *Chemical Engineering Research and Design*, 99, 185–198.
2. Zhang W, Binns M, Theodoropoulos C, Kim J-K, and Smith R (2015) Model Building Methodology for Complex Reaction Systems, *Ind Eng Chem Res*, 54, 4603−4615.
3. Ochoa-Estopier LM, Jobson M and Smith R (2014) The Use of Reduced Models for Design and Optimisation of Heat Integrated Crude Oil Distillation Systems, *Energy*, 75, 5-13.
4. Pan M, Bulatov I, and Smith R (2014) An Efficient Retrofitting Approach for Improving Heat Recovery in Heat Exchanger Networks with Heat Transfer Intensification. *Industrial & Engineering Chemistry Research*. 53(27), 11107-11120.
5. Jiang, N, Shelley, JD, Doyle S and Smith R (2014) Heat Exchanger Network Retrofit with a Fixed Network Structure, *Applied Energy*, 127, 25-33.
6. Pan, M., I. Bulatov and R. Smith (2013) New MILP-based Iterative Approach for Retrofitting Heat Exchanger Networks with Conventional Network Structure Modifications, *Chemical Engineering Science*, 104, 498-524.
7. Pan M, I. Bulatov and R. Smith (2013) A novel optimization approach of improving energy recovery in retrofitting heat exchanger network with exchanger details, *Energy*, 57,188-200
8. Ochoa-Estopier, Lluvia M., M. Jobson and R. Smith (2013) Operational optimization of crude oil distillation systems using artificial neural networks, *Computers & Chemical Engineering*, 59, 178-185.
9. Pan, M, Smith, R and Bulatov I, 2013, A novel optimization approach of improving energy recovery in retrofitting heat exchanger network with exchanger details. *Energy*, 57, pp 188–200.
10. Jain S, Kim J-K, and Smith R , 2013, Process Synthesis of Batch Distillation Systems, *Ind Eng Chem Res*, 52, 8272−8288.
11. Ooi EH, Foo DCY,Tan RR, Ng DKS,and SmithR, 2013, Carbon Constrained Energy Planning (CCEP) for Sustainable Power Generation Sector with Automated Targeting Model, *Ind Eng Chem Res*, 52, 9889-9896.
12. Pan M, Bulatov I and Smith, R, 2013, Exploiting tube inserts to intensify heat transfer for the retrofit of heat exchanger networks with considering fouling mitigation. *Ind Eng Chem Res*, 52, 2925-2943.
13. Lin Z, Zheng X, Smith R, and Yin, Q, 2012, Reliability Issues in The Design and Optimization of Process Utility Systems, *Theoretical Foundations of Chemical Engineering*, 46, 747–754.
14. Pan M, Bulatov I and Smith R, 2012, Retrofit procedure for intensifying heat transfer in heat exchanger networks prone to fouling deposition, *Chemical Engineering Transactions*, 29, 1423-1428.
15. Jain S, Kim J-K and Smith R ,2012, Operational Optimization of Batch Distillation Systems, *Ind Eng Chem Res*, 51, 5749-5761.
16. Wang Y, Pan M, Bulatov I, Smith R, Kim J-K, 2012, Application of intensified heat transfer for the retrofit of heat exchanger network, *Applied Energy*, 89(1) 45-59.
17. Soares Pinto F, Zemp R, Jobson M, Smith R, 2011, Thermodynamic Optimisation of Distillation Columns, *Chem Eng Sci*, 66, 2920-2934.
18. Smith R, Jobson M and Chen L, 2010, Recent Development in the Retrofit of Heat Exchanger Networks, *Applied Thermal Engineering*, 30, 2281-2289.
19. Del Nogal F, Kim J-K, Perry S, and Smith R, 2010, Synthesis of Mechanical Driver and Power Generation Configurations, Part 2: LNG Applications, *AIChE Journal*, 56, (9) 2377-2389.
20. Del Nogal F, Kim J-K, Perry S, and Smith R, 2010, Synthesis of Mechanical Driver and Power Generation Configurations, Part 1: Optimization Framework, *AIChE Journal*, 56, (9) 2356-2376.
21. Del Nogal F, Kim J-K, Perry S and Smith R, 2008, Optimal Design of Mixed Refrigerants, *Ind Eng Chem Res*, 47, 8724-8740.
22. Aguilar O, Perry S, Kim J-K and Smith R, 2008, Availability and Reliability Considerations in the Design and Optimization of Flexible Utility Systems, *Chem Eng Sci*, 63, 3569-3584.
23. Rodriguez C and Smith R, 2005, Optimisation of Operating Conditions for Mitigating Fouling in Heat Exchanger Networks, *Trans IChemE*, A86, 839-851.
24. Wang J and Smith R, 2005, Synthesis and Optimization of Low Temperature Gas Separation Processes, *Ind Eng Chem Res*, 44(8), 2856-2870.

Curriculum Vitae

Name: Aud Nina Wærnes
Born: 21021954
Nationality: Norwegian
E-mail: Aud.N.Warnes@sintef.no

Present position: Senior Business Developer

EDUCATION & EMPLOYMENT

MSc Chemistry 1978, NTH/University of Trondheim
Qualifying Continuing education course: Industrial Marketing

MAIN FIELDS OF COMPETENCE

- Project Management
- Process Metallurgy, Plasma Technology /High Temperature Process Development, and Silicon feedstock for Solar cells.

EXPERIENCE

- Research Director 2002 – 2004, SINTEF Material Technology
- Research Director 2004 – 2013, SINTEF Materials and Chemistry, Department of Metallurgy
  Head of department; Research Management, personnel responsibility for 50 employees, responsible for budgets, economy, purchasing of equipment, Health, Environment and Safety (HES), Competence and business strategy, system of agreements/Contracts, market analysis, industry contact and organisation, management of complex multidisciplinary projects.
- Member of the Board of Directors in SDC (Solsilc Development Company AS, 2008 – 2012).
  The aim of the company activities was to further develop a process for production of solar grade silicon based on a technology developed in three consecutive EU funded projects. I was participating in the process from idea/concept, through R&D and later the establishment of SDC. A license Agreement was later established between SDC and a Norwegian ferroalloy producer/FESIL AS
- Member of the board, Department of Materials Technology/NTNU, 2002 - 2005
- Leader of the Board, Department of Materials Technology/NTNU, 2006 – 2008
- Substitute member of the Board, Department of Materials Technology/NTNU, 2009 - 2013
- Coordinator/Manager of FFF (The Norwegian Ferroalloy Producers Research Association),
  Annual R&D-budget of appr. 25 – 30 mill NOK per year, 2003 and ongoing
  Responsible for management on a day to day basis, organize Board Meetings, Dissemination of R&D results to both industry and public authorities, arrange and implement strategy processes on R&D&I.
- Member of EERA steering Committee for JP-PV 2010 - 2012
- Coordinator of EU Foxy - Development of solar-grade silicon feedstock for crystalline wafers and cells by purification and crystallization, 2006 – 2008, 4.5 mill Euro
- Centre Director SFI Metal Production – Total budget of 250 mill NOK over 8 years starting from 2015.

PUBLICATIONS

- Numerous presentations in international and national meetings and conferences

SOME SELECTED PUBLICATIONS

Example of Dissemination to public sources
GEMINI våren 2009; "Golden Carbon"
http://www.ntnu.no/gemini/2009_spring/pictures/spring_09.pdf

Curriculum Vitae

Dr. Armin Hafner
Current position: Senior Research Scientist at
SINTEF Energy Research
Future position (2016): Professor in Refrigeration Technology at
NTNU, Trondheim
Date of birth: 1969-09-13
E-mail: Armin.Hafner@sintef.no

EDUCATION

2003 Dr.-Ing. (PhD), Norwegian University of Science and Technology (NTNU), Department of Energy and Process Engineering, Trondheim. Dr.-Ing. (PhD) thesis: "Compact Interior Heat Exchangers for CO_2 Mobile Heat Pumping Systems"

1996 Siv.Ing. (M.Sc.) in Refrigeration Engineering/ Mechanical Engineering, Norwegian Institute of Technology (NTH), Refrigeration Engineering, Trondheim. Master thesis: "Investigations on CO_2 car air-conditioning system"

1995 Dipl.Ing in Mechanical Engineering, FH-Karlsruhe, Germany, B-thesis: "Design and Build-up of a lab. refrigeration system for CO_2 and other natural working fluids""

MAIN FIELDS OF COMPETENCE

- Refrigeration and heat pump technology in general.
- CO_2 technology for various applications; supermarkets, industrial heat pumps, transport refrigeration.
- System design for refrigeration, air conditioning and heat pumps, (stationary and automotive).
- Compressor, Ejector and compact heat exchanger technology.
- Working fluids, with emphasis on natural working fluids, CO_2 NH_3 and hydrocarbons.
- Life Cycle Climate Performance of various energy systems.

EXPERIENCE

- Research Scientist at SINTEF Energy Research from 1997.
- Experience from computer modelling and simulation, and experimental work in laboratory.
- Project Manager for various projects (national and international).
- Supervisor or co-supervisor for several PhD candidates, as well as MSc candidates.

PUBLICATIONS

- About 100 international and national publications within the area of refrigeration and process engineering.
- Numerous presentations in international and national meetings and conferences.
- Co-author of 5 patents within CO_2 technology.
  Updated publication list at:
  http://www.cristin.no/as/WebObjects/cristin.woa/wa/personVis?type=PERSON&pnr=32301&la=en&instnr=7548

SOME SELECTED PUBLICATIONS

International publications with referee:

Hafner, Armin; Fredslund, Kristian and Banasiak, Krzysztof: *Next Generation R744 Refrigeration Technology for Supermarkets.* Proceedings of the 24th International Congress of Refrigeration, Yokohama, Japan. International Institute of Refrigeration 2015

Hafner, Armin; Hemmingsen, Anne Karin: *R744 Refrigeration Technologies for Supermarkets in warm Climates*. Proceedings of the 24th International Congress of Refrigeration, Yokohama, Japan. International Institute of Refrigeration 2015

Fidorra, Nikolas, Hafner, Armin; Minetto, Silvia; Köhler, Jürgen: *Low Temperature heat storage in CO_2 Supermarket Refrigeration systems*. Proceedings of the 24th International Congress of Refrigeration. International Institute of Refrigeration 2015

Hafner, Armin. *2020 perspectives for CO2 refrigeration and heat pump systems*. I: Ammonia and CO2 Refrigeration Technologies - Ohrid, Macedonia April 16-18, 2015 - Proceedings. International Institute of Refrigeration 2015 ISBN 978-2-36215-008-1.

Hafner, Armin; Nekså, Petter. *System configurations for supermarkets in warm climates applying R744 refrigeration technologies - case studies of selected cities*. I: 16th European Conference - Latest technologies in refrigeration and air conditioning, Milano 12th-13th June 2015 - Expo 2015. International Institute of Refrigeration 2015 ISBN 0-000-00001-9

Hafner, Armin; Försterling, Sven; Banasiak, Krzysztof. Multi-Ejector Concept for R-744 Supermarket Refrigeration. International journal of refrigeration 2014

Hafner, Armin; Schönenberger, Jonas; Banasiak, Krysztof; Girotto, Sergio. R744 Ejector supported parallel vapour compression system. Proceeding of the 3rd IIR Int. Conf. on Sustainability and the Cold Chain. London 2014.

Hafner, Armin; Henningsen, Anne Karin; Adinda Van de Ven. R744 Refrigeration system configurations for supermarkets in warm climates. Proceeding of the 3rd IIR Int. Conf. on Sustainability and the Cold Chain. London 2014.

Hafner, Armin; I.C. Claussen; F. Schmidt, R. Olsson, K. Fredslund, P.A. Eriksen, K.B. Madsen. Efficient and integrated Energy systems for supermarkets. Proceedings of 11th IIR Gustav Lorentzen Conference on Natural Refrigerants, Hangzhou, China, 2014

Hafner, Armin; Poppi, Stefano; Nekså, Petter; Minetto, Silvia; Eikevik, Trygve Magne. (2012) *Development of Commersial Refrigeration Systems with Heat Recovery for Supermaket Buildings*. Proc. of 10th IIR Gustav Lorentzen Conference

Hafner, Armin; Försterling, Sven; Banasiak, Krzysztof. (2012) *Multi-Ejektoren Konzept für R-744 Supermarkt-Kälteanlagen*. Deutsche Kälte-Klima-Tagung 2012 Würzburg. DKV - Deutscher Kälte- und Klimatechnischer Verein 2012 ISBN 978-3-932715-48-8.

Hafner, Armin; Schmälzle, Christian; Nekså, Petter; Obrist, Frank; Rekstad, Inge Håvard. (2012) *High efficient 100 kW el R744 compressor*. Proceedings of 10th IIR Gustav Lorentzen Conference, June 25 - 27 2012 Delft, the Netherlands.

Banasiak, Krzysztof; Hafner, Armin, Eikevik, Trygve Magne; Haddal Olav. CFC Case Study of R744 Ejectors. Proceedings of 11th IIR Gustav Lorentzen Conference on Natural Refrigerants, Hangzhou, China, 2014

Banasiak, Krzysztof; Hafner, Armin, Haddal Olav; Eikevik, Trygve Magne. Test facility for a multiejector R744 Refrigeration system. Proceedings of 11th IIR Gustav Lorentzen Conference on Natural Refrigerants, Hangzhou, China, 2014

Kauko, Hanne; Hafner, Armin; Henningsen, Anne Karin; Claussen, Ingrid Camilla. Integrated and efficient energy systems. RERC 2014; 2014-06-16 - 2014-06-17

Titze, Maren; Lemke, Nicholas; Nekså, Petter; Hafner, Armin; Köhler, Jürgen. (2012) *Dynamic modeling of a combined supermarket refrigeration and HVAC system*. Proceedings of 10th IIR Gustav Lorentzen Conference, June 25 - 27 2012 Delft, the Netherlands. IIR 2012 ISBN 978-2-913149-90-8.

Banasiak, Krzysztof; Hafner, Armin; Andresen, Trond. (2012) *Experimental and numerical investigation of the influence of the twophase ejector geometry on the performance of the R744 heat pump.* International Journal of Refrigeration 2012 ;Volum 35.(6) s.1617-1625.

Denecke, Julius; Hafner, Armin;; Ladam, Yves. (2012) *Heat Recovery Solutions for R744 Booster Commercial Refrigeration Systems.* Proceedings of 10th IIR Gustav Lorentzen Conference, June 25- 27 2012 Delft, the Netherlands. IIR 2012

Nordtvedt, Tom Ståle; Hafner, Armin. (2012) Integration of refrigeration and HVAC in supermarkets. I: Proceedings of 10th IIR Gustav Lorentzen Conference, June 25 - 27 2012 Delft, the Netherlands. International Institute of Refrigeration 2012

Rekstad, Inge Håvard; Hafner, Armin; Jenssen, Sigmund. (2012) *Energy efficient diary shed milk cooler and water heater using carbon dioxide as refrigerant.* Proceedings of 10th IIR Gustav Lorentzen Conference, June 25 - 27 2012 Delft, IIR2012

Wang, Chi-Chuan; Hafner, Armin; Kuo, Cheng-Shu; Hsieh, Wen-Der. (2012) *An overview of the effect of lubricant on the heat transfer performance on conventional refrigerants and natural refrigerant R-744*. Renewable & sustainable energy reviews 2012; Volume 16.(7) s.5071-5086

Hafner, Armin; Nekså, Petter; Ladam, Yves; Eikevik, Trygve Magne. (2011*) Oil-free R744 systems for industrial/commercial applications.* Proceedings of the 23rd International Congress of Refrigeration. International Institute of Refrigeration 2011

Banasiak, Krzysztof; Hafner, Armin; Andresen, Trond. (2011) *Experimental and numerical investigation on R744 ejector geometry.* Proceedings of the 23rd International Congress of Refrigeration. International Institute of Refrigeration 2011 ISBN 9782913149892.
Hafner, Armin. (2011) *Laboratory investigation of different ejector geometries for R744 transcritical systems*. International Journal of Air-Conditioning and Refrigeration 2011 ; Volume 19.(3) s.159-166

Nekså, P., Walnum, H.T. and Hafner, A. (2010): *CO_2 - A refrigerant from the past with prospects of being one of the main refrigerants in the future*, 9th IIR Gustav Lorentzen Conference 2010, Sydney, April 12-14, ISBN 978-2-913149-74-8

Hafner, A., Ladam Y., Andresen, T. and Nekså Petter (2010): *Experimental investigation of different ejector geometries for R-744 transcritical systems*, 9th IIR Gustav Lorentzen

Curriculum Vitae

Name: Egil Skybakmoen
Born: Norway
Nationality: Norwegian
E-mail: Egil.Skybakmoen@sintef.no
Present position: Research Manager,
Materials and Chemistry,
Dep. Electrolysis and High Temperature Materials

EDUCATION & EMPLOYMENT

1982 - 1984	Trondheim Ingeniørhøyskole (TIH), Engineer, metallurgy
1988 – 1991	Norges Tekniske Høyskole (NTH), MSc Electrochemistry
1984 – 1991	Engineer, SINTEF Metallurgy,partly 1988-91 (student)
1991 - 2002	Research Scientist, SINTEF Materials Technology
2002 - 2004	Senior Adviser, SINTEF Materials Technology
2004 - present	Research Manager, SINTEF Materials and chemistry, Dep. Electrolysis and High Temperature Materials

MAIN FIELDS OF COMPETENCE

- Molten salt electrochemistry and aqueous electrochemistry
- Aluminium electrolysis process,
- Development of test methods of materials (cathodes and sidelining materials) used in Al electrolysis.
- Test program of SiC based sidelining materials
- Cathode wear mechanism Al electrolysis cells
- Inert electrode technology
- Rare Earth Electrolysis and REE Recycling methods

EXPERIENCE

- Project Management and Scientific work in several projects financed by RCN and industrial partners: CarboMat (2002-2006), Thermotech (2006-2008, Hydro PI-HCD (2006-2010), Hydro HalUp Fundamentals (2010-2014), Duramat (2009-15), GADT (2012-15) and SHIFT Materials (2015-ongoing).

- Project leader for several projects for national and international customers.

COMMITTEE MEMBERSHIPS

- Member of TMS
- Session chair TMS Electrode materials (2013, 2015)

AWARDS

Best paper at the Reduction Technology Session at the XIII International Conference “Aluminium of Siberia-2007”, Krasnoyarsk, Russia, September 11-13, 2007.

PUBLICATIONS

- About 100 international and national publications and technical reports
- Numerous presentations in international and national meetings and conferences

SOME SELECTED PUBLICATIONS (2011-15)

Eick, Ingo; Klaveness, Arne; Rosenkilde, Christian; Segatz, Martin; Gudbrandsen, Henrik; Solheim, Asbjørn; Skybakmoen, Egil; Einarsrud, Kristian Etienne.
VOLTAGE AND BUBBLE RELEASE BEHAVIOUR IN A LABORATORY CELL AT LOW ANODE-CATHODE DISTANCE. 10th Australasian Aluminium Smelting Technology Conference; 2011-10-09

Haarberg, Geir Martin; Armoo, Joseph Prince; Gudbrandsen, Henrik; Skybakmoen, Egil; Solheim, Asbjørn; Jentoftsen, Trond Eirik.
Current efficiency for aluminium deposition from molten cryolite-alumina electrolytes in a laboratory cell. *Light Metals* 2011 s. 461-463

Kjos, Ole Sigmund; Aarhaug, Thor Anders; Skybakmoen, Egil; Solheim, Asbjørn; Gudbrandsen, Henrik. FUNDAMENTAL STUDIES OF PERFLUOROCARBON FORMATION. 10th Australasian Aluminium Smelting Technology Conference; 2011-10-09 - 2011-10-14

Osen, Karen Sende; Aarhaug, Thor Anders; Solheim, Asbjørn; Skybakmoen, Egil; Sommerseth, Camilla. HF measurements inside an aluminium electrolysis cell. *Light Metals* 2011

Skybakmoen, Egil; Rørvik, Stein; Solheim, Asbjørn; Holm, Knut Ragnar; Tiefenbach, Priska; Østrem, Øyvind. Measurement of cathode surface wear profiles by laser scanning. *Light Metals* 2011 s. 1061-1066

Skybakmoen, Egil; Rørvik, Stein; Solheim, Asbjørn; Østrem, Øyvind.
Investigations of cathode wear profiles obtained by the laser scanning method. 10th Australasian Aluminium Smelting Technology Conference; 2011-10-09 - 2011-10-14

Sommerseth, Camilla; Osen, Karen Sende; Aarhaug, Thor Anders; Skybakmoen, Egil; Solheim, Asbjørn; Rosenkilde, Christian; Ratvik, Arne Petter.
Correlation Between Moisture and HF Formation in the Aluminium Process. *Light Metals* 2011 s. 339-344

Tschöpe, Kati; Støre, Anne; Rørvik, Stein; Skybakmoen, Egil; Solheim, Asbjørn; Grande, Tor; Ratvik, Arne Petter. Cathode Wear Investigations in a Laboratory Test Cell. 50th Annual Conference of Metallurgists of CIM (COM 2011); 2011-10-02 - 2011-10-05

Kjos, Ole Sigmund; Aarhaug, Thor Anders; Skybakmoen, Egil; Solheim, Asbjørn.
STUDIES OF PERFLUOROCARBON FORMATION ON ANODES IN CRYOLITE MELTS. Light Metals 2012 s. 623-626

Martinez, Ana Maria Cuellar; Kjos, Ole Sigmund; Skybakmoen, Egil; Solheim, Asbjørn; Haarberg, Geir Martin. Extraction of rare earth metals from Nd-based scrap by electrolysis from molten salts. ECS Transactions 2012 ;Volum 50.(11) s. 453-461

Tschöpe, Kati; Støre, Anne; Rørvik, Stein; Skybakmoen, Egil; Solheim, Asbjørn; Grande, Tor; Ratvik, Arne Petter. Investigation of the cathode wear mechanism in a laboratory test cell. Light Metals 2012 s. 1349-1354

Wang, Zhaohui; Grande, Tor; Skybakmoen, Egil.
Thermal conductivity of porous Si3N4-bonded SiC sidewall materials in aluminium electrolysis cells. Journal of The American Ceramic Society 2012 ;Volum 95.(2) s. 730-738

Kjos, Ole Sigmund; Aarhaug, Thor Anders; Skybakmoen, Egil; Solheim, Asbjørn; Gudbrandsen, Henrik. Off-Gas Analysis of Laboratory-Scale Eletrolysis Experiments with Anodes of Various Compositions. *Light Metals* 2013 s. 899-903

Skybakmoen, Egil; Stoen, Lisbet I.; Kvello, Jannicke Hatlø; Darell, Ove.
Quality evaluation of nitride bonded silicon carbide sidelining materials. I: *Essential Readings in Light Metals. Volume 4 Electrode Technology for Aluminum Production*. John Wiley & Sons 2013 ISBN 978-1118-63663-3. s. 866-871

Solheim, Asbjørn; Rolseth, Sverre; Skybakmoen, Egil; Støen, Lisbet Irene Rønne.
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Tschöpe, Kati; Skybakmoen, Egil; Solheim, Asbjørn; Grande, Tor.
Cathode Wear in Hall-Héroult Cells. *Aluminium* 2013 ;Volum 89.(1/2) s. 95-98

Tschöpe, Kati; Støre, Anne; Skybakmoen, Egil; Solheim, Asbjørn; Grande, Tor; Ratvik, Arne Petter.
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Tschöpe, Kati; Støre, Anne; Solheim, Asbjørn; Skybakmoen, Egil; Grande, Tor; Ratvik, Arne Petter.
Electrochemical Wear of Carbon Cathodes in Electrowinning of Aluminium. *JOM: The Member Journal of TMS* 2013 ;Volum 65.(11) s. 1403-1410

A.Martinez, O. Kjos, E. Skybakmoen, A. Solheim, G.M. Haarberg: “Extraction of rare earth metals from Nd-based scrap by electrolysis from molten salts”, *ECS Trans.*, 50 (11), pp. 453-461 (2013).

Einarsrud, Kristian Etienne; Skybakmoen, Egil; Solheim, Asbjørn.
On the Influence of MHD Driven Convection on Cathode Wear. Light Metals 2014 s. 485-490

Wang, Zhaohui; Ratvik, Arne Petter; Skybakmoen, Egil; Grande, Tor.
Interaction of Sodium Vapor and Graphite Studied by Thermogravimetric Analysis. TMS Annual Meeting & Exhibition; 2014-02-16 - 2014-02-20

Wang, Zhaohui; Ratvik, Arne Petter; Skybakmoen, Egil; Grande, Tor.
Interaction of Sodium Vapor and Graphite Studied by Thermogravimetric Analysis. Light Metals 2014 s. 1239-1244

Skybakmoen, Egil; Wang, Zhaohui; Grande, Tor.
THE INFLUENCE OF MICROSTRUCTURE OF Si3N4-SiC SIDE-LINING MATERIALS ON CHEMICAL/OXIDATION RESISTANCE BEHAVIOUR TESTED IN LABORATORY SCALE. 11 th Australasian aluminium smelting technology conference; 2014-12-06 - 2014-12-11

Curriculum Vitae

Name: Ingrid Camilla Claussen
Born: 30.10.1974
Nationality: Norwegian
E-mail: Ingrid.C.Claussen@sintef.no

Present position: Research Manager, Energy Efficiency Group

EDUCATION & EMPLOYMENT

2014 -	Research Manager, SINTEF Energy Research, Thermal Energy
2011- 2014	Research Manager, SINTEF Energy Research, Energy Efficiency
2004-2006	Head Coach National Wheelchair Curling Team, 5th place in Worlds 2005; 4rd place in Paralympics (Torino, Italy), 2006
2002-2011	Research Scientist, SINTEF Energy Research, Energy Processes
01.08.96-09.01.98	DYNAL AS (Now: Invitrogen DYNAL AS)
01.08.94-31.01.95	Fellesmeieriet i Oslo – trainee

2004 – 2007	PhD	Norwegian University of Science and Technology (NTNU), Energy and Process Engineering
1998 – 2002	MSc	Norwegian University of Science and Technology (NTNU), Energy and Process Engineering
1996 – 1997	Cand.mag.	Oslo University College, Export Marketing
1993 – 1996	Engineer	HiST – Sør-Trøndelag University College, Faculty of Food Industry Studies

MAIN FIELDS OF COMPETENCE

Have extensive experience as project manager from large as well as smaller projects; As team-leader: among the very best scores of the team leaders in SINTEF 2012 and 2014 (the working environment examination). Very high scores regarding team motivation and quality.
Research experience: Heat pump drying technology; heat and mass transfer; Energy efficiency in Industryprocesses; Food chemistry and –technology; food quality; refrigeration and air conditioning

EXPERIENCE

- Project Manager for about 15 larger KPN, IPN and Industry projects
- Project Manager for the ongoing KPN INTERACT *Efficient interaction between energy demand, surplus heat/cool and thermal storage in building complexes*
- Chairman for the ongoing RCN projects KPN Drymeat and IPN DSTG
- WP leader of WP5 *Technology assessment* and task leader in WP4 *City-industry interaction* in SP4 urban Cityr realted Supply Technologies of the EERA JP Smart Cities
- Member of the FRISBEE International group

PUBLICATIONS

- About 40 international and national publications and numerouse technical reports
- Several presentations in international and national meetings and conferences
- 3 television/ radio publications
- One patent proposal (CA 2595129 A1)
- Academic production according to www.Scopus.com (2015) h-index: 6, citations: 151

SOME SELECTED PUBLICATIONS

1. Bantle, M., Tolstorebrov, I., Nordvedt, TS., Stavseth, O., **Claussen, IC**. (2015) *Heat pump drying: use of ambient air as energy source for cooling*. ICR 2015,Yokohama Japan

2. Kauko, H., Justo Alonso, M., Stavset, O, **Claussen, I.C.** (2014) *Case study on residential building renovation and its impact on the energy use and thermal comfort*, Energy Procedia
3. Stavset, O. Justo Alonso M., **Claussen I. C.** (2014)*Novel energy system for near Zero Energy houses*. 3rd IIR International Conference on Sustainability and the Cold Chain, London
4. Indergård, E., Nordtvedt, T.S., Bantle, M., **Claussen, I.C**., Chalco-Sandoval, W., Lagaron, J.M. (2014) *Use of Phase Change Materials (PCM) to keep superchilled temperatures in consumer packages through the cold chain.* Refrigeration Science and Technology, p 20-29 Code 108133
5. Kauko Hanne; Hafner, Armin; Hemmingsen, Anne Karin; **Claussen, Ingrid Camilla**. *Integrated and efficient energy systems*. RERC 2014; 2014-06-16 - 2014-06-17
6. The FRISBEE tool, a software for optimising the trade-off between food quality, energy use, and global warming impact of cold chains**,** in Journal of Food Engineering**.**
7. Gwanpua, S.G.,Verboven, P., Brown, T., Leducq, D., Verlinden, B.E., Evans, J., Van der Sluis, S., Wissink, E.B., Taoukis, P., Gogou, E., Stahl, V., El Jabri, M., Thuault,D. **Claussen, I.C**., Indergård, E. Nicolai, B.M., Alvarez, G., Geeraerd, A.H. (2014) *Towards sustainability in cold chains: Development of a Quality, Energy and Environmental Assessment Tool (QEEAT)*Proceedings, 3rd IIR International Conference on Sustainability and the Cold Chain
8. Alonso, M.J., Bantle, M., **Claussen, I.C.** (2014) *Simulation and evaluation of CO2 heat pump system with energy storage for ZEB.* Proceedings, 3rd IIR International Conference on Sustainability and the Cold Chain, London
9. Bantle M., Indergård E., **Claussen I.C**., Gullsvåg P.E., Magnussen O. M. (2013) *Case study on intermediate storage and mechanical stress treatment during drying of clipfish.* Nordic Drying Conference 2013, København
10. Bantle M., Eikevik T.M., **Claussen I.C**., Andresen T. (2013) *Dynamic process simulation of industrial heat pump drying of clipfish*. Nordic Drying Conference 2013, København
11. Widell, KN, Indergård, E, **Claussen, IC**, Laselle, S (2013) *Energy- and carbon footprint reduction in industrial production of hot water in abattoir by use of surplus heat and heat pump systems*. Proceedings, 2013, IIR Cold Chain Paris, France.
12. Tolstorebov, I, **Claussen IC,** Indergård, E, Eikevik TM (2013) *Frozen storage of Fish at Ultralow Temperatures: a Review.* Trends in Food Science
13. Hafner, A, **Claussen, IC**, Schmälzle, C, Obrist, F (2012) *Hocheffizienter 380cc R744 Verdichter*. Proceedings, DKV November 2012
14. **Claussen, IC,** Indergård, E, Magnussen, OM, Gullsvåg, PE (2011) *Factors Influencing the drying process of salted fish (Clipfish) of cod (Gadus Macrocephalus) and Saithe (Pollachius virens). Part B: Water removal rate from clipfish based on weight and drying air conditions.* Proceedings, 2011 Nordic Drying Conference, Helsinki, Finland. ISBN 978-82-92739-84-6
15. Indergård, E, **Claussen, IC**, Magnussen, OM (2011) *Heatpump drying of Clipfish: Increased energy efficiency and capacity by end-drying in separate storage facilities.* Proceedings, 2011 NDC Finland. ISBN 978-82-92739-84-6
16. **Claussen, IC,** Indergård, E, Grinde, M (2011) *Comparative Life Cycle Assessment (LCA) of Production and Transport of Chilled versus Superchilled Haddock (Melanogrammus aeglefinus) fillets from Norway to France.* Proceedings in iCEF11, Aten, Hellas. ISBN 978-960-89789-5-9
17. Stevik, AM**, Claussen, IC**, (2011) *Industrial superchilling, a Practical approach.* Proceedings in iCEF11, Aten, Hellas. ISBN 978-960-89789-5-9
18. **Claussen, IC,** (2011) *Superchilling concept enabling safe, high quality and long term storage of foods.* Proceedings in Refrigeration Innovations and Chill chain management FRISBEE Prosjekt Workshop at iCEF11, Aten, Hellas. ISBN 978-960-89789-5-9
19. **Claussen, IC,** Hemmingsen, AKT, Longva, KE, Strømmen, I, Kommisrud E (2011) *Characteristics of Bovine Spermatozoa after Immobilization by Dehydration.* In: Drying Technology, vol 29 (5), 480
20. Stevik AM**, Claussen IC,** Walde PM, Bjune M, Magnussen OM (2009) *Factors influencing the Drying Process of salted fish (clip fish) of Cod (Gadus macrocephalus) and Saithe (Pollachius virens). Part A: Initial trials.* Proceedings , 2009 Nordic Drying Conference, Island
21. **Claussen IC** (2008) *Lagring og lagringsforhold for klippfisk* Innspill til info hefte fra Bacalao Forum
22. **Claussen IC** (2008) *Tørkehastighet for klippfisk – Hvordan påvirkes denne?* Innspill til info hefte fra Bacalao Forum
23. Hemmingsen, AKT**,** Stevik AM, **Claussen IC**, Lundblad KK, Prestløkken E, Sørensen M, Eikevik TM (2008) *Water adsorption in Feed Ingredients for Animal Pellets at Different Temperatures, Particle Size, and Ingredient Combinations* In: Drying Technology vol 26, 738-748
24. Løkra S, Helland MH, **Claussen IC**, Strætkvern KO, Egelandsdal B (2008) *Chemical characterization and functional properties of a potatoe protein concentrate prepared by large scale expanded bed adsorption chromatography* In: LWT-Food Science and Technology vol 41, 1089-1099
25. **Claussen IC**, Andresen T, Eikevik TM, Strømmen I (2007) *Atmospheric Freeze Drying – Modeling and Simulation of a Tunnel Dryer* vol 25, 1959-1965
26. Strømmen I, Eikevik, TM**, Claussen, IC** (2007) *Atmospheric Freeze Drying with heat pumps – New possibilities in drying of biological materials* Key Note Lecture at the 5th Asia-Pasific Drying Conference, 13.-

15. August 2007, Hong Kong, China
27. **Claussen** ICC, Ustad, TS, Walde, PM, Strømmen I (2007) *Atmospheric Freeze Drying – A Review* In: Drying Technology vol 25 (6), 18
28. **Claussen** IC, Strætkvern KO, Egelandsdal B, Strømmen I (2007) *Effects of drying methods on functionality of a native potato protein concentrate* In: Drying Technology, Vol 25(12), pp.1959-1965
29. **Claussen** IC, Hemmingsen AKT, Rustad T, Strømmen I (2007) *Relations between product structure, sorption characteristics and freezing point of atmospheric freeze dried foods* In: Drying Technology vol 25 (5), 22
30. **Claussen** IC, Hemmingsen AKT, Strømmen I, Rustad T, *Physiochemical properties of atmospheric freeze dried foods*, Proceedings, 2006 CIGR Section VI International Symposium in FUTURE OF FOOD ENGINEERING, Warsaw, Poland
31. **Claussen** IC, Hemmingsen AKT, Strømmen I (2005) *Measurements of physical and quality parameters of Norwegian Stockfish* Proceedings, 3rd Nordic Drying Conference, Karlstad, Sweden, 9
32. Strømmen I, Alves-Filho O, Eikevik TM, **Claussen IC** (2004) *Physical properties in drying of food products with combined sublimation and evaporation* In: Chinese Journal of Chemical Engineering vol 12 (6), 4
33. Strømmen I, Alves-Filho O, Eikevik, TM, **Claussen IC** (2003?) *Physical Properties in drying of food products with combined sublimation and evaporation* Proceedings, International Drying Symposium, Bejing, China
34. **Claussen** IC, Schjøth Hansen H, Brenna E (1996) *Nordmenn spiser mindre fisk. Hvordan øke forbruket?* In: Norsk Fiskeoppdrett (15), 2

Curriculum Vitae

Name: DR. MARIT JAGTØYEN MAZZETTI
(Previous Name: Dr. Marit Jagtoyen)
Born: May 15, 1966
Nationality: Norwegian
E-mail: marit.mazzetti@sintef.no

Present position: Research scientist/Project Manager

EDUCATION & EMPLOYMENT

1989	M.Sc. (Siv.ing) in Chemcial Engineering, Norwegian Institute of Technology (NTH)
2006	Ph.D, Materials Science and Engineering, University of Kentucky, Lexington, KY, USA

MAIN FIELDS OF COMPETENCE

- Over 25 years of experience in energy and environmental research & development and innovation, leading to product development and commercialization of patented technology, 13 of which as head of research group and research manager.
- Areas of expertise: Offshore Energy Efficiency, Oil and Gas, CCS, Environmental, Air and Water Purification
- SINTEF Experience as Project Manager:
  -KMB COMPACTS, Project Manager, Originated project, main responsibility for proposal and consortium. Budget NOK 18.9 M, 2014-2018:
  -KMB EFFORT, Project Manager, Budget NOK 27M
  -NORDICCS WP1, WP1 Project Manager, Budget NOK 2M
  -Natural Gas Sweetening- Spin off from Nordiccs WP1 300K
  -Verdikjeden for videreforedling av naturgass, Budget NOK 300K
  - NORDICCS Summer School, Project Manager, Budget NOK 2.25 M
- Experience in small business start-up and growth through organic business development and M&A efforts. Originated US$7.1 M in SBIR and manufacturing contracts as well as $1.5M in licensing income from private industry in the period 1997-2006.
- Strong, innovative track-record: published eight (8) U.S. patents on activated carbon fiber composite and activated carbon synthesis and applications from 1995 through 2006. Extensively published in scientific trade and news publications.
- Additional skills include entrepreneurial attitude, strong managerial experience, pursuing and winning R&D grants, and strong oral/written communication capabilities.
- Experience in initiating, evaluating, marketing and licensing research discoveries from own firm LexCarb, LLC and Northwestern University's Technology Transfer Office (TTO).

EXPERIENCE

- 2011- Current: SINTEF Energy Research, Department of Energy Efficiency and Gas Technology Research Scientist and Project Manager for Large Energy Efficiency and CCS projects, budgets up to 3M€
- 2007-2009: Northwestern University TTO, Evanston, IL, USA (#1 producing US University TTO), Licensing Consultant and Licensing Associate
- 1997-2011: Founder, Principal, Manager. LexCarb, LLC, Lexington, KY, USA: A small, privately held R&D business specializing in the development of novel carbon materials and water and air

purification technologies, 3-5 employees.

- 1993-1997: **ADVANCED SEPARATION AND ADSORPTION PRODUCS, AS**, **USA**
  Co founder, Director, VP- Precursor to LexCarb
- 1990-1999: **Center for Applied Energy Research, UNIVERSITY OF KENTUCKY, USA**,

Head, Activated Carbon Research Group(1993-2001)

TEACHING, SUPERVISOR, CENSORSHIP

- Co-Supervisor for 2 Ph.D and MS Students at University of Kentucky

COMMITTEE MEMBERSHIPS

AWARDS

- Chair, Nordic CCS Summer School, 2015
- Invited speaker, ONS Centre Court 2014, Offshore Energy Efficiency, http://www.ons.no/2016/tv/centre-court-programme/
- Key-note Speaker,7th International Trondheim Conference on CCS, Trondheim, Norway, May 4-6, 2013
- Invited Speaker at Workshop "Drilling in Ice-Affected Regions", London, May 30th, 2013
- Invited Speaker at "Powering Offshore Oil and Gas fields", London, Jan 20-22. 2014, delayed
- Invited Speaker, Arctic Oil and Gas Conference, Oslo, Nov 2013.
- Technical Program Chair for "Carbon2001", the International Conference on Carbon, Lexington, KY July 2001.
- Topical Area Chair for "Adsorbent Carbons" at "Carbon'99", the International Conference on Carbon", Charleston, SC, July 1999.
- Organizer of "Workshops on Adsorbent Carbons", Lexington, KY,1993, 1995, 1997 and 1999.
- Chair, "Symposium on Carbon Materials for Environmental Applications", ACS Fall Meeting, Boston, MA, August 1998.
- Chair, "Materials and Chemicals Synthesis from Fossil Fuels and Biomass", Fuel Division, ACS Spring Meeting Anaheim, CA, April 1995.
- Chair, "Adsorption and Porous Carbons", 22nd Conference on Carbon, University of California at San Diego, San Diego, CA, July 1995.
- Best Poster Award, Gordon Conference on Hydrocarbon Materials, Hawaii, 1993.

PUBLICATIONS

- Author of 8 patents, 136 Publications of which 43 refereed publications, 3 book chapters, 6 news/radio publications.
- Over 100 presentations in international and national meetings and conferences: 1 key-note, 6 invited
- Academic production according to Web of Science: (For verification of numbers, search for both names Marit Jagtoyen and Marit Mazzetti)
  - **h-index: 13**
  - citations: 975
  - publications: 43

SOME SELECTED PUBLICATIONS AND NEWS ARTICLES (total # publications 131)

Radio &News articles

- Mazzetti, Marit, Interviewed on Norwegian National Radio, "Offshore Energy Efficiency", August 2015.https://radio.nrk.no/serie/distriktsprogram-troendelag/DKTL02017715/07-09-2015Item 13. Forskerpraten
- Mazzetti, M, Chronicle in Norwegian Newspaper Dagens Næringsliv, "Recovering Heat to shrink emissions, May 15, 2015http://www.dn.no/meninger/debatt/2015/05/14/2052/Teknologi/gjenvunnet-kraft-krymper-utslipp, http://gemini.no/2015/05/gjenvunnet-kraft-krymper-utslipp/
- Mazzetti, Interview Teknisk Ukeblad, May, 2015, http://www.tu.no/kraft/2015/06/04/slik-kan-supermaterialet-bedre-effektiviteten-i-dampturbiner
- Research Council of Norway publication on Energy Efficiency, http://www.forskningsradet.no/prognett-petromaks2/Forside/1253980921324
- Mazzetti, M. J, and Nekså, P, "Wasted heat regained", Chronicle in Norwegian Newspaper, Dagens Næringsliv, November 30th, 2012, 36-37; http://www.sintef.no/Projectweb/Effort/Presentations/Offshore-climate-cure1/
- Røkke, N., Mazzetti, M., "CO_2 rensing koster minst på sokkelen", TU; Nov , http://www.tu.no/forskning/2013/11/17/co2-rensing-koster-minst-pa-sokkelen
- "Alchemy in the Desert?", Article on LexCarb, LLC in Wall street journal, October 4th, 2005 p. A17
- "Converting Tailpipes into water fountains", Article on LexCarb, LLC in Popular Science Magazine, January 2006, p. 40
- "Army Tries Water From Vehicle Exhaust Fumes", October 5, 2005 http://www.military.com/NewsContent/0,13319,78169,00.html
- "Oil and Water", Military Logistics forum, Vol 6, Issue 10 http://www.military-logistics-forum.com/military-logistics-forum/83-mlf-2007-volume-1-issue-3/595-oil-and-water.html

Full papers in Conference Proceedings, 2013-15

- Mazzetti, M et. Al, Nordic CCS Roadmap, TCCS-8, Trondheim, Norway, June, 2015
- Mazzetti, M. et al, IMPACTS, TCCS-8, Trondheim, Norway, June, 2015
- Mazzetti, M, Kus, B., Walnum, H, Nekså, P, Skaugen, G, Hagen, B., Ladam, Y., "Flexible Combined Heat and Power Systems for Offshore Oil and Gas Facilities with CO_2 Bottoming Cycles". Skaugen, G, Walnum, H., T., Hagen, B., Kus, B., Clos, D., Mazzetti, M, Nekså, P, , Design And Optimization of Waste Heat Recovery Unit Using Carbon Dioxide As Cooling Fluid, .. CO_2 from Natural Gas Sweetening to Kick-Start EOR in the North Sea, oral presentation at GHGT, Houston, Oct 4th, 2014.
- Mazzetti, M, Eldrup, N.H, Anthonsen, K.L, Haugen, H.A, Onarheim, K., Bergmo, P., Johnson, F., Gislason, S. R., and Røkke, N.A, "Nordic CCS Roadmap", Proceedings of the 7th Trondheim CCS Conference (TCCS-7), June 4-6, 2013
- Mazzetti, M. J, Nekså, P, Walnum, Harald T. and Hemmingsen, A.K.T, Novel Energy Efficiency Technologies for Reduction of Offshore CO_2 Emissions, Proceedings, Offshore Technology Conference (OTC) 2013, May 6th, Houston, TX, USA.

PATENTS

US 7,000,409 Mazzetti, M. J. "Use of flow through capacitor in the recovery and purification of water from exhaust gases of internal combustion engines" Feb 21, 2006

US 6,852,224 Jagtoyen, M. et. al, "Carbon Fiber Filters", February 8, 2005

US 6,702,875 Jagtoyen, M. et. al, "Carbon Fiber Filters for air filtration", March 9, 2004

US 6,581,375 Jagtoyen, M. and G. Kimber" Apparatus and method for the recovery and purification of water from the exhaust gases of internal combustion engines", June 24, 2003

US 6,258,300 Burchell, T.D.; Weaver, C.E.; Chilcoat, B.R.; Derbyshire, F.; Jagtoyen, M. "Activated Carbon Fiber Composite Material and Method of Making"July 10, 2001.

US 6,057,262 Derbyshire, F. J. and Jagtoyen, M. "Activated carbon and process for making same ",May 2, 2000. (Ph.D work)

US 6,030,698 T. Burchell, C. E. Weaver, B. R. Chilcoat, F. Derbyshire, and M. Jagtoyen, "Activated Carbon Fiber Composite Material and Method of Making", Feb. 29, 2000.

US 5,721,186 M. Farcasiu, , P. Kaufman, F. Derbyshire and M. Jagtoyen, "Method for producing catalyst from coal", February 1998.

- BOOKS -

- Derbyshire, F. J. Jagtoyen, M, Andrews. R., Rao, A , Gullon I.M. and Grulke, E, " Carbon Materials in Environmental Applications", Chemistry and Physics of Carbon 27, L. Radovic, ed., New York: Marcel Dekker 2001, pp. 1-66..
- Derbyshire, F. J , Jagtoyen, M. and Thwaites, M. W. "Activated Carbon Production and Applications", in Porosity in Carbons (Ed. J. W. Patrick), Edward Arnold, UK, 1995, pp. 227-252.
- Derbyshire, F., Graham, U. , Fei, Y. Q , Robl, T. and Jagtoyen, M. "Oil shale as a feedstock for carbon materials", Composition, Geochemistry and Conversion of Oil Shales NATO ASI Series, Volume 455, 1995, pp 347-363

PUBLICATIONS IN SELECTED REFEREED JOURNALS

- Mazzetti, Marit J.; Skagestad, Ragnhild; Mathisen, Anette; et al."CO_2 from Natural Gas Sweetening to Kick-Start EOR in the North Sea" , Energy Procedia , 2015 , 63,MPP.7280-7289.
- Mazzetti, M. J, Nekså, P., Walnum, H. T., Hemmingsen, A.K.T, "Energy-Efficient Technologies for Reduction of Offshore CO_2 Emissions", Oil and Gas Facilities, February 2014, (3), 1, p.40-47
- Mazzetti, M, Eldrup, N.H, Anthonsen, K.L, Haugen, H.A, Onarheim, K., Bergmo, P., Johnson, F., Gislason, S. R., and Røkke, N.A, "Nordic CCS Roadmap", Energy Procedia, 51,pp. 1-13, 2014.
- Martin-Gullon, I.; Andrews, R.; Jagtoyen, M.; Derbyshire, F., "PAN-based activated carbon fiber composites for sulfur dioxide conversion: influence of fiber activation method". FUEL, 80(7), pp. 969-977, 2001
- Hilding, J.; Grulke, E.A.; Sinnott, S.B.; Quian, D.; Andrews, R.; Jagtoyen, M. "Sorption of Butane on Carbon Multiwall Nanotubes at Room Temperature", *Langmuir* **17**, 7540-7544 (2001).
- Derbyshire, F.; Andrews, R.; Jacques, D.; Jagtoyen, M.; Kimber, G.; Rantell, T., "Synthesis of isotropic carbon fibers and activated carbon fibers from pitch precursor". Fuel, 80(3), 345-356, 2001
- Powell, T; Brion, GM; Jagtoyen, M; Derbyshire, F, "Investigating the effect of carbon shape on virus adsorption", *ENV SCI TEC*, 34(13), 2000, pp. 2779-2783
- M. Jagtoyen and F. Derbyhire, "Activated Carbons from Yellow Poplar and White Oak by H_3PO_4 activation", Carbon, 36 (7-8), pp. 1085-1097, 1998.
- G. M. Kimber, M. Jagtoyen, Y.Q. Fei and F. J. Derbyshire, "Fabrication of Carbon Fibre Composites for Gas Separation", Gas. Sep. Purif., Vol. 10 (2), pp. 131-136, 1996.
- M. S. Solum, R. J. Pugmire, M. Jagtoyen and F. Derbyshire, "Evolution of Carbon Structure in Chemically Activated Wood", Carbon, 33 (9), 1247 - 1254, 1995.
- X-X. Bi, M. Jagtoyen, M. Endo, K. Das Chowdhury, R. Ochoa, F. J. Derbyshire, M. S. Dresselhaus and P. C. Eklund, "Nanoscale Carbon Blacks Produced by CO2 Laser Pyrolysis", J. Mater. Res., 10 (11), 2875-84, 1995.
- M. Jagtoyen, and F.J. Derbyshire, "Some Considerations of The Origins of Porosity in Carbons from Chemically Activated Wood". *Carbon,* Vol. 31, No.7, pp.1185-1192, 1993.
- M. Jagtoyen, J. Groppo and F. J. Derbyshire, "Activated Carbons from Bituminous Coals by Reaction with H3PO4: The Influence of Coal Cleaning", *Fuel Processing Technology* , 34(2), 85-96 1993.
- M. Jagtoyen, F. Derbyshire, S. Rimmer and R. Rathbone, "Relationship between Reflectance and Structure of High Surface Area Carbons", Fuel, 74 (4), pp. 610-614, 1995.
- V. Verheyen, R. Rathbone, M. Jagtoyen and F. Derbyshire, "Activated Extrudates by Oxidation and KOHactivation of Bituminous Coal", *Carbon*, 33(6), pp. 763-772, 1995.
- M. Jagtoyen, M. Thwaites, J. Stencel, B. McEnaney, and F. J. Derbyshire**, "**Adsorbent Carbon Synthesis from Coals by Phosphoric Acid Activation",*Carbon,* 30 (7), 1089-1096, 1992.
- H. A. Oye, M. Jagtoyen, T. Oksefjell and J. S. Wilkes, "Vapor Pressure and Thermodynamics of the System 1- Methyl - 3 - Ethyl – Imidazolium Chloride - Aluminum Chloride", Molten Salt Chemistry and

Curriculum Vitae

Name: Trond Andresen
Born: 1979-02-17
Nationality: Norwegian
E-mail: Trond.Andresen@sintef.no

Present position: Research Scientist, *Process Technology*

EDUCATION & EMPLOYMENT

2011-2015	Research Manager, *Surplus Heat Utilization*, SINTEF Energy Research
2002-	Research Scientist, SINTEF Energy Research
2009	PhD, Energy and Process Engineering, Norwegian University of Science and Technology (NTNU). Thesis: "Mathematical Modelling of CO_2 Based Heat Pumping Systems".
2002	MSc, Energy and Process Engineering, Norwegian University of Science and Technology

MAIN FIELDS OF COMPETENCE

- Project management
- Heat recovery and waste heat to power systems
- Heat exchanger design and optimization
- Energy efficiency in complex systems
- Numerical modelling of thermal cycles, heat exchangers and thermal processes
- Dynamic modelling
- Component and cycle development
- Techno-economic analyses and optimization
- Transcritical CO2 cycles
- Behaviour and properties of natural working fluids

EXPERIENCE

- Project management of competence building and innovation projects
- Modelling, simulation/optimization and experimental work
- Heat exchanger product development for clients
- Third party verification of novel technology concept designs for waste heat-to-power
- Personnel and project coordinator, main focus during period as research manager
- Worked in several research teams within SINTEF Energy; *Refrigeration Technology*, *Process Technology*, *Gas Technology*, *Energy Efficiency*, and *Surplus Heat Utilization*

TEACHING, SUPERVISOR, CENSORSHIP

- Supervision of various MSc-level project and diploma work at NTNU
- Censor of several diploma thesis and oral exams at NTNU
- PhD supervisor
- Lecturing in advanced course at NTNU; "Heat pumping processes and systems", 2006-2008

PUBLICATIONS

- About 30 international and national publications and 20 technical reports
- Numerous presentations in international and national meetings and conferences

SELECTED PUBLICATIONS

Walnum, H. T., Nekså, P., Nord, L.O., **Andresen, T.**: Modelling and simulation of CO2 (carbon dioxide) bottoming cycles for offshore oil and gas installations at design and off-design conditions. Energy, Vol 59, pp.513-520. http://dx.doi.org/10.1016/j.energy.2013.06.071

Rohde, D., Walnum, H.T., **Andresen, T.**, Nekså, P.: Heat recovery from export gas compression: Analyzing power cycles with detailed heat exchanger models. Applied Thermal Engineering, Vol 60 (1-2), 2013, pp. 1-6.

Banasiak, K.; Hafner, A.; **Andresen, T.**: Experimental and numerical investigation of the influence of the two-phase ejector geometry on the performance of the R744 heat pump. International journal of refrigeration, Vol 35(6) 2012, pp. 1617-1625

Walnum H. T.; **Andresen T**.; Widell, K. N.: Dynamic simulation of batch freezing tunnels for fish using Modelica. Procedia Food Science, Vol 1 (1) 2011, pp. 698–705.

Alonso, M. J.; **Andresen, T.**; Frydenlund, F.; Widell, K. N.: Improvements of air flow distribution in a freezing tunnel using Airpak. Procedia Food Science, Vol 1 (1) 2011, pp. 1231–1238

Walnum, H. T.; Ladam, Y.; Nekså, P.; **Andresen, T.:** Off-design operation of ORC and CO_2 power production cycles for low temperature surplus heat recovery. International Journal of Low-Carbon Technologies, Vol 6 (2) 2011, pp. 134-140

Claussen, I. C.; **Andresen, T.**; Eikevik, T. M.; Strømmen, I.: Atmospheric Freeze Drying - Modeling and Simulation of a Tunnel Dryer. Drying Technology, Vol 25 (12) 2007, pp. 1959-1965

Scientific papers in Conferences with peer review:

Rohde, D.; Bantle, M.; **Andresen, T.**; Nord, N. 2015. Documentation of an integrated thermal energy system for a building complex. The 24th IIR - International Congress of Refrigeration; 2015-08-16 - 2015-08-22, Yokohama, Japan

Bantle, M., Eikevik, T.M., Claussen, I.C., **Andresen, T**. 2013. Dynamic process simulation of industrial heat pump drying of clipfish. Nordic Drying Conference, Copenhagen, Denmark, June 5.-7

Andresen, T.; Ladam, Y.; Gilberg, A.F.; Rekstad, H.; Eikevik, T.M.: Improving energy efficiency in operation of CO_2 RSW system for fishing vessels. IIR-International Congress of Refrigeration 2011, August 21 – 26., Prague, Czech Republic

Banasiak, K.; Hafner, A.; **Andresen, T.**: Experimental and numerical investigation on R744 ejector geometry. IIR - International Congress of Refrigeration 2011, August 21 - 26 - Prague, Czech Republic

Walnum, H.T.; **Andresen, T.**; Widell, K.N.: Verification of a Modelica-based dynamic simulation model for batch freezing tunnels. IIR-International Congress of Refrigeration 2011, August 21 - 26 - Prague, Czech Republic

Hafner, A.; Ladam, Y.; **Andresen, T**.; Nekså, P.: Experimental investigation of different ejector geometries for R-744 transcritical systems. In proceedings: 9th IIR-Gustav Lorentzen Conference on Natural Working Fluids, Sydney 2010

Andresen, T.; Skaugen, G.: Advanced multipass heat exchanger model for use in simulation and optimization of transcritical CO2 heat pumping cycles. 8th IIR-Gustav Lorentzen Conference on Natural Working Fluids; Copenhagen, 2008

Andresen, T.; Skaugen, G.: Lookup tables based on Gibb's Free Energy for quick and accurate calculation of thermodynamic properties for CO2. 22nd IIR International Congress of Refrigeration, Beijing 2007

Stene, J.; Jakobsen, A.; **Andresen, T.**; Skiple, T.; Nekså, P.: CO2 Heat Pump for Combined Heating and Cooling of Non-Residential Buildings. 22nd IIR International Congress of Refrigeration, Beijing 2007

Stene, J.; Jakobsen, A.; **Andresen, T.**: CO2 Heat Pump System for Heating and Cooling of Non-Residential Buildings. 7th IIR/IIF Gustav Lorentzen Conference on Natural Working Fluids, Trondheim, Norway, 2006

Jakobsen, A.; Skaugen, G.; Skiple, T.; Nekså, P.; **Andresen, T.**: Development and Evaluation of a Reversible CO2 Residential Air Conditioning System Compared to State-of-the-Art R410A Unit. Natural Working Fluids - 6th Gustav Lorentzen Conference; Glasgow, Scotland, 2004

Other international conferences:

Justo Alonso, M., Ladam, Y., **Andresen, T.** Supercritical CO2 Rankine cycle test loop (ROMA) operation and initial results. ASME ORC 2013, 2nd international seminar on ORC power systems, Rotterdam, the Netherlands,7-8. October 2013

Andresen, T.; Ladam, Y.; Nekså, P.: Simultaneous optimization of cycle and heat recovery heat exchanger parameters**.** Supercritical CO_2 Power Cycle Symposium. Boulder, Colorado, 24-25. May 2011

Andresen, T.; Rohde, D.; Ladam, Y.; Nekså, P. Simultaneous optimization of cycle and heat exchanger parameters for waste heat to power conversion at aluminium plants. First International Seminar on ORC Power Systems, Delft, the Netherlands, 22-23. September 2011

Walnum, H. T., **Andresen, T**., Widell, K. 2011. Dynamic simulation of batch freezing tunnels for fish using Modelica. International Congress on Engineering and Food, Athens, Greece.

Alonso, M. J., **Andresen, T**., Frydenlund, F., Widell, K. 2011. Improvements of air flow distribution in a freezing tunnel using Airpak. International Congress on Engineering and Food, Athens, Greece.

Harald Taxt Walnum, Yves Ladam, Petter Nekså, **Trond Andresen:** Off-design operation of ORC and CO_2 power production cycles for low temperature surplus heat recovery. SET2010 - 9th International Conference on Sustainable Energy Technologies; Shanghai, China. 24-27 August, 2010

Curriculum vitae, Nov 2015

Name: Per-Gunnar Lundqvist, Date of birth: 1959-03-21
Citizenship: Swedish
Affiliation: KTH, School of Industrial engineering and Manage, Dept. Energy Technology, Div applied Thermodynamics and Refrigeration
Phone: 790 74 52, E-mail: per.lundqvist@energy.kth.se, Homepage: www.energy.kth.se

Professional preparation

1985, M.Sc. Mechanical Engineering, KTH, 1993, PhD Energy Technology

Appointments

1993 – 1996 ***Research associate.*** KTH, dept. of Energy Technology, Div. of Applied Thermodynamics and refrigeration
1997- ***Unversitetslektor (Assistant professor)***, KTH, Dept. of Energy Technology
1999 – ***Ämnesföreträdare, (Acting Professor),*** dept. of Energy Technology, Div. of Applied Thermodynamics and Refrigeration
1999- ***Director of Studies "Programansvarig"*** for the Mechanical Engineering Program
2005- ***Vice-Dean of Education,*** KTH School of Industrial Engineering and Management (on 60% time)
2007 – ***Professor in Energy Technology***, KTH

Commissions of trust

1994 - Member I-faculty, KTH
1995 - 97 Secretary, Swedish council for building research, Heat Pump Technical committee
1996 - 97 Member Dept. of Energy Strategy Group
1997 - Member of the Board Dept. of Energy Technology, KTH
1998 – Scientific working group for KTH research school in environmental management
1999 - Member of the Board KSIM (KTH School of Industrial Management)
1999 – Program chair for the Mechanical Engineering program at KTH
1999 - Vice president commission E2 within the IIR (International Institute of Refrigeration)
1999 – Co-chair Div. of Applied Thermodynamics and Refrigeration KTH
2002 - Member academic council KTH Energy Centre
2003 - Vice president commission E2 within the IIR, re-elected
2003 – 2006 Lead author for the IPCC report on safeguarding the ozone layer and the global climate system
2003 – 2005 Program chair for the Mechanical Engineering program at KTH
2005- Vice Dean of education for KTH School of Industrial Engineering and Management (approx 50% of time devoted to this since 2005)
2007 – 2015 President commission E2 within the IIR (International Institute of Refrigeration)
2007- 2015 Delegate of science and technology council of IIR
2007- 2015 Delegate of the management committé of the IIR
2008 – Member of Swedish Academy of Engineering Sciences (IVA, section 1)
2009- 2013 Delegate of energy and environment board of Swedish Academy of Engineering Sciences
2010 – 2013 KTH representative in international Sustainable campus Network, ISCN
2011- 2013 Member KTH Sustainability board

Tutoring experience

Number of examined PhDs: 11, Number of Licentiates: 5, PhD students in progress: 7

Doctoral students graduated:

2003, Anders Johansson, "Phase-out of refrigerant R22"
2004, Fredrik Lagergren, "Rethinking energy systems – an energy usage approach"
2005, Dimitra Sakellari, "Heat Pumps and Low temperature heating systems"
2005, Jaime Arias, "System Modelling For Energy Efficient Supermarkets"
2006, Wimolsiri Pridasawas, "Solar Cooling with ejector cycles"
2006, Vlasta Zanki, Energy efficiency and environmental impact from Hotels on the Croatian Adriatic Coast
2006, Tomas Persson, Solar energy and biomass in small scale energy systems
2007, Primal Fernando, Experimental Investigation of Refrigerant Charge Minimisation of a Small Capacity Heat Pump
2009, Marino Grosdek, Load Shifting and Storage of Cooling Energy through Ice bank or Ice Slurry Systems - modelling and experimental analysis
2011, Yang Chen, Thermodynamic Cycles using Carbon Dioxide as Working Fluid
2012, Hatef Madani, Capacity-controlled Ground Source Heat Pump Systems for Swedish single-family dwellings

Students Graduated With Licentiate Degree:

1997, Lars Herbe, CFC and HCFC Refrigerant retrofit, defended
2004, Tomas Persson, Elbesparing med pelletkaminer och solvärme i direktelvärmda småhus
2005, Cecilia Hägg, Ice slurry as secondary refrigerant,
2006, Yang Chen, Novel power cycles with CO2 as working fluid,
2013, Aleh Kliatsko, Energy Conservation and Service Efficiency in Buildings Explored as Situations of Opportunity for City Transformation

On-going Doctoral projects

Jonas Anund, Driving forces and hinders for Innovative Refurbishment of buildings
David Stolz, Creating and Understanding Innovation in EcoCities (working title)
Henrik Öhman, Power from waste heat (working title)
Omar Shafquat, Understanding energy saving limits in the built environment
Stefano Poppi, Integration of heat pumps and solar energy (at Dalarna University College)
Bengt Mölleryd, Innovation view – mastering disruptive innovation in technological systems for defence, security and energy
Luis Antonio Choque Campero, Biomass fired Stirling energy co-generation

Networks in academia and industry:

1989, Member ASME Heat Pump Technical Committee
1995 – 2001, Member Technical Committee the Swedish Refrigeration Society
1996, Member Nordic Stirling Group
1997, Development group for the NUTEK research programme Climate 21
2000, Member ASHRAE TC10.7
2006, Member Swedish National Team IEA Implementing Agreement for Heat Pumps
2007, Member Science and Technology Council International Institute of Refrigeration
2007, Members of the Management Committee International Institute of Refrigeration
2007, International Sustainable Campus Network, Member WG IV
2008, Member of Swedish Academy of Engineering Sciences

Publications (Jan 2005 – Dec 2014)

Publications in refereed international journals only

1. Arias, J., Lundqvist, P., 2005, "Modelling and experimental validation of advanced refrigeration systems in supermarkets", *J. Process Mech. Eng., Vol 219, Part E*
2. Sakellari, D., Lundqvist, P., 2005, "Modelling and Simulation Results for a Domestic Exhaust Heat Pump Heating System,. *Int. J Refrig. no 28, pp 1048 – 1056 (2005)*
3. Fernando, P., Lundqvist, P., 2005, "Refrigeration systems with minimized refrigerant charge system design and performance", *J. Process Mech. Eng., Vol 219, Part E*
4. Chen, Y., Lundqvist, P., Platell, P., 2005, "Theoretical Research of Carbon Dioxide Power Cycle Application in Automobile Industry to Reduce Vehicle's Fuel Consumption", *Appl. Thermal Eng. 25 (2005) 2041–2053*
5. Lundqvist, P., et.al., 2005, "Chapter four – refrigeration", IPCC-TEAP, Safeguarding the ozone layer and the Global Climate System, Cambridge, Univ. Press ISBN-13, 978-0-512-86336-01
6. Arias, J., Lundqvist, P., 2006, "Heat Recovery and Floating Condensation in Supermarkets", J. of Energy and Buildings, Vol. 38, Issue 2, Februari 2006, pp 73-81.
7. Sakellari, D., Forsén, M., Lundqvist, P, 2006, "Investigating control strategies for a domestic low-temperature heat pump heating system, Int. J Refrig. no 29, pp 547 – 555 (2006)
8. Y. Chen , P. Lundqvist, A. Johansson, P. Platell, "A comparative study of the Carbon Dioxide Transcritical Power Cycle compared with an Organic Rankine Cycle with R123 as working fluid in Waste Heat Recovery", Applied Thermal Engineering, 26 (2006) 2142–2147
9. Arias, J., Lundqvist, P., 2006, "Choisir entre récupération de chaleur ou pression de condesation flottante en froid commercial", *Revue J. du Froid* (2006), no 1066, pp 47-54
10. Pridasawas, W. and Lundqvist, P. (2007), "A Year-Round Dynamic Simulation of a Solar-Driven Ejector Refrigeration System with Iso-butane as a Refrigerant, *Int. J Refrig. no 30, pp 840 – 850 (2007)*
11. Fernando, P., Palm, B., Lundqvist, P., Granryd, E:, 2007, "Performance of a Single-Family Heat Pump at Different Working Conditions Using Small Quantity of Propane as Refrigerant", *J. Exp Heat Transfer, Volume 20, Issue 1 January 2007 , pages 57 – 71*
12. Hägg, C., Arias, J., Lundqvist, P., 2007, "Comparaison entre fluide secondaire monophasique et coulis de glace en supermarché" Rev. gén. Froid vol. 97; n. 1073; 47-54
13. Fernando, P., Palm, B., Ameel, T, Lundqvist, P., Granryd, E:, 2007, *A minichannel Aluminum Tube Heat Exchanger .- Part I: Evaluation of Single-pase heat transfer coefficients by the Wilson Plot method, Int. J Refrig, Volume 31, Issue 4, Pages 669–680*
14. *Fernando, P., Palm, B., Ameel, T, Lundqvist, P., Granryd, E:, 2007, A minchannel Aluminum Tube Heat Exchanger .- Part II: evaporator performance with propane, Int. J Refrig, Volume 31, Issue 4, Pages 681 – 695*

[1] Included here due to the tedious peer-review principles of the IPCC, The text has been through three extensive review systems in 2004 and 2005 with hundreds of reviewers.

15. *Fernando, P., Palm, B., Ameel, T, Lundqvist, P., Granryd, E:, 2008, A minichannel Aluminum Tube Heat Exchanger .- Part III: condenser performance with propane, Int. J Refrig Volume 31, Issue 4, Pages 696–708*
16. Grozdek, M., Khodabandeh, K., Lundqvist, P., 2009, *Experimental investigation of ice slurry heat transfer in horizontal tube. Int. J. Refrig. - Rev. int. vol. 32; n. 6; pp. 1310-1322*
17. Lundqvist, P, 2010, *Efficient refrigeration technologies - a prerequiste for sustainable development,* J, Industria Formazione, No 7, 2010 pp 18-21
18. Chen, Y., Pridasawas, W., Lundqvist, P., 2010, *Dynamic simulation of a solar-driven carbon dioxide transcritical power system for small scale combined heat and power production*, J. Solar Energy, Vol 84, Issue 7, July 2010, Pages 1103–1110
19. Madani, H.,Claesson, J., Lundqvist,P., 2011, *Capacity control in ground source heat pump systems: Part I: modeling and simulation*, Int. J. of Ref., Vol 34, Issue 6, Pages 1338-1347
20. Madani, H.,Claesson, J., Lundqvist, P., 2011*, Capacity control in ground source heat pump systems part II: Comparative analysis between on/off controlled and variable capacity systems, Int. J. of Ref., Vol. 34, Issue 8, pp. 1934-1942*
21. M.A. Marimón, J. Arias, P. Lundqvist, J. C. Bruno, A. Coronas, 2011, "Integration of trigeneration in an indirect cascade refrigeration system in supermarkets, Energy and Buildings 06/2011; 43(6):1427-1434.
22. Jonsson, D.K., Gustafsson, S., Wangel, J., Höjer, M., Lundqvist, P., Svane, Ö., 2011, *Energy at your service: highlighting energy usage systems in the context of energy efficiency analysis*, J. Energy Efficiency, DOI 10.1007/s12053-010-9103-5
23. Öhman, H., Lundqvist, P., 2012, *Theory and method for analysis of low temperature driven power cycles*. Applied Thermal Engineering, 37 (2012) 44-50
24. Hatef Madani, Joachim Claesson, Per Lundqvist, 2013, "A descriptive and comparative analysis of three common control techniques for an on/off controlled Ground Source Heat Pump (GSHP) system" Energy and Buildings 10/2013;
25. Henrik Öhman, Per Lundqvist, 2013, "Comparison and analysis of performance using Low Temperature Power Cycles", Applied Thermal Engineering 04/2013; 52(1):160–169.
26. Aleh Kliatsko, Per Lundqvist, 2013, A bottom-up approach for energy systems - a case study on energy and service efficiency explored by human activity system modelling, Int. J. of Strategic Engineering Asset Management 01/2013; 1(4):355 - 373.
27. Aleh Kliatsko, Per Lundqvist, 2013, "Transport, Energy Conservation and Energy Efficiency in Buildings Explored as Situations of Opportunity for City Transformation", International Journal of Environmental Science and Development 01/2013;
28. Henrik Öhman, Per Lundqvist, 2013, "Experimental investigation of a Lysholm Turbine operating with superheated, saturated and 2-phase inlet conditions", Applied Thermal Engineering 01/2013; 50(1):1211-1218.
29. David Stoltz, Omar Shafqat, Jaime Arias, Per Lundqvist, 2014, "On Holistic Planning in EcoCity Development: Today and in the Past", Energy Procedia 12/2014; 61:2192-2195.
30. Omar Shafqat, David Stoltz, Per Lundqvist, Jaime Arias, 2014, "Participatory Simulation for Energy Target Identification in EcoCities", Energy Procedia 12/2014; 61:2079-2082.
31. Henrik Öhman, Per Lundqvist, 2014, "Thermodynamic pre-determination of power generation potential in geothermal low-temperature applications" , Geothermal Energy 01/2014

Curriculum Vitae

Dr. Geir Skaugen
Current position: Research Scientist

Date of birth: 1961-08-03
E-mail: Geir.Skaugen@sintef.no

EDUCATION

2011 Advanced Course on Thermodynamic Models; Fundamentals and Computational Aspects, Centre for Energy Resource Engineering, Technical University of Denmark
2002 Dr.Ing (Ph.D) NTNU Faculty of Engineering Science and Technology, Department of Energy and Processes Engineering
1985 Siv.Ing (M.Sc), Mechanical engineering, Norwegian Institute of Technology (NTH)

MAIN FIELDS OF COMPETENCE

- General Refrigeration Technology
- CO2-Refrigeration Technology
- Trans-critical vapour compression cycles
- Microchannel heat exchangers
- Low temperature refrigerant systems
- System and process design and modelling
- Heat exchanger technology and modelling
- Computer modelling

EXPERIENCE

- 1986->present : Research Scientist at SINTEF Energy Research, Energy Processes
- 2007-2009 : Engaged by StatoilHydro ASA in the “Snøhvit Improvement Project”

PUBLICATIONS

Ibrahim, Mohamed; Skaugen, Geir; Ertesvåg, Ivar Ståle. An Extended Corresponding States Equation of State (EoS) for CCS Industry. *Chemical Engineering Science* 2015 ;Volum 137. s. 572-582

Berstad, David Olsson; Roussanaly, Simon; Skaugen, Geir; Anantharaman, Rahul; Nekså, Petter; Jordal, Kristin. Energy and cost evaluation of a low-temperature CO2 capture unit for IGCC plants.

Ibrahim, Mohamed; Skaugen, Geir; Ertesvåg, Ivar Ståle. Modelling CO2-water thermodynamics using SPUNG equation of state (EOS) concept with various reference fluids. Energy Procedia 2014 ;Volum 51. s. 353-362

Ibrahim, Mohamed; Skaugen, Geir; Ertesvåg, Ivar Ståle; Haug-Warberg, Tore. Modelling CO2 - water mixture thermodynamics using various equations of state (EoSs) with emphasis on the potential of the SPUNG EoS. Chemical Engineering Science 2014 ;Volum 113. s. 22-34

Løvseth, Sigurd Weidemann; Snustad, Ingrid; Brunsvold, Amy; Skaugen, Geir; Wahl, Per Eilif; Lervåg, Karl Yngve. From droplets to process: Multilevel research approach to reduce emissions from LNG processes. *Energy Procedia* 2015 ;Volum 64.(C) s. 3-12

Skaugen, Geir; Hammer, Morten; Gjennestad, Magnus Aashammer. Investigation of non-ideal behavior of plate-fin heat exchangers in LNG services using optimization technique. 3rd Trondheim Gas Technology Conference; 2014-06-04 - 2014-06-05, Published in: Energy Procedia 2015; Volum 64 p 13-22

Skaugen, Geir; Hammer, Morten; Wahl, Per Eilif; Wilhelmsen, Øivind. Constrained Non-Linear Optimisation of a Process for Liquefaction of Natural Gas Including a Geometrical and Thermo-Hydraulic Model of a Compact Heat Exchanger. Computers and Chemical Engineering 2014 ;Volum 73.(2) s. 102-115

Skaugen, Geir; Walnum, Harald Taxt; Hagen, Brede Andre Larsen; Clos, Daniel Perez; Mazzetti, Marit Jagtoyen; Nekså, Petter. Design and optimization of waste heat recovery unit using carbon dioxide as cooling fluid. I: ASME 2014 Power Conference - POWER 2014 - volume 1. ASME Press 2014 ISBN 978-079184608-7.

Curriculum Vitae

Name: Leiv Kolbeinsen
Born: July 15 1949
Nationality: Norwegian
E-mail: leiv.kolbeinsen@ntnu.no
Present position: Professor NTNU, Dep. Material Sci. and Eng.

EDUCATION & EMPLOYMENT

- MSc (1974), PhD (1982) both from NTNU, then known as NTH
- Professor in Materials Technology/Process metallurgy at NTNU since 2000; NTH: teaching assistant (1975-80) and SINTEF Metallurgy/Materials Technology: senior research scientist. Part time College lecturer at Trondheim College of Engineering (1984-1992) Visiting Scientist at Centre for Iron and Steel making Research (CISR) Carnegie Mellon University (CMU) (1996-1997). SINTEF Metallurgy/Materials Technology: senior research scientist (1997-2009).

MAIN FIELDS OF COMPETENCE

Head of an international MSc-program and teach courses in the following fields

- Extractive metallurgy/Process metallurgy Pyrometallurgical processes for Iron, steel and ferroalloys
- Resources, Enegy and the Environment
- Use of natural gas in metallurgical industry
- Chemical thermodynamics, Reaction kinetics and Transport processes in process metallurgy

EXPERIENCE

Some central research projects: CarboMat: Reactions of Carbon with gases and metallurgical liquids and solids. DISvaDRI: Direct Reduced Iron serving as grain refiner in steel. ROMA and FUME: Optimization of Raw Materials and Process Operation to Minimize Losses of Materials and Exergy. GasMat & GasFerroSil: Material producing clusters and use of natural gas in metallurgical industry.

TEACHING, SUPERVISOR, CENSORSHIP

Lectures, supervision and censorships in addition to those mentioned above at Luleå Technical University (Sweden), MEFOS (Sweden), The Royal Institute of Technology (Sweden), Helsinki University of Technology (Finland), University of Oulu (Finland), RWTH Achen (Germany), University of New South Wales (Australia), POSTECH Pohang University of Science and Technology (Korea), University of Missouri, Rolla (USA), University of British Columbia (Canada) and University of Alberta (Canada).

COMMITTEE MEMBERSHIPS

Board member – Norwegian Ferroalloy Producers Research Organization (FFF), Member of WG1 "Profit through Innovation" of European STeel Technology Platform (ESTEP). Various project steering committees and NTNU educational committees.

PUBLICATIONS

- About 60 international and national publications and 30 technical reports
- Numerous presentations in international and national meetings and conferences
- Academic production according to SCOPUS: h-index: 6, citations: 153, publications: 34

SOME SELECTED PUBLICATIONS

1) Børset, M.T., Kolbeinsen, L., Tveit, H., Kjelstrup, S.: "*Exergy based efficiency indicators for the silicon furnace*" [In press]; Published online March 12, 2015 **DOI:** 10.1016/j.energy.2015.07.010
2) Kolbeinsen, L., Lindstad, T., Tveit, H., Bruno,M. and Nygaard, L.: "*Energy Recovery in the Norwegian Ferro Alloy Industry*" INFACON 7, Trondheim, Norway, June 1995 Pages 165 - 177
3) Kolbeinsen, L. Nørstebø, V.S., Midthun, K.T., Bjørkvoll, T.H., Ødegård, J. "*Gas based industrial cluster for production of DRI, steel, methanol and carbon black; The technical and economic effects of natural gas with high CO_2 content*" 6th Int. Congr. on the Sci. and Tech. of Ironmaking 2012, ICSTI 2012 – Incl. Proc. from the 42nd Ironmaking and Raw Materials Sem., and the 13th Brazilian Symp. on Iron Ore Volume 4, 2012, Pages 2801-2813
4) Safarian, J., Kolbeinsen, L., Tangstad, M., Tranell, G.: "*Kinetics and mechanism of the simultaneous carbothermic reduction of FeO and MnO from high-carbon ferromanganese slag*" Metallurgical and Materials Transactions B: Process Metallurgy and Materials Processing Science Volume 40, Issue 6, December 2009, Pages 929-939
5) Kolbeinsen, L.: "*Modelling of DRI processes with two simultaneously active reducing gases*" Steel Research International Volume 81, Issue 10, October 2010, Pages 819-828

Curriculum Vitae

Name: Sigurd Skogestad
Born: 14 Aug. 1955
Nationality: Norwegian
E-mail: skoge@ntnu.no

Present position: Professor of Chemical Engineering at NTNU

Education
1978: M.S. (Siv.ing.) in Chemical Engineering at NTNU, Trondheim
1987: Ph.D. in Chemical Engineering at California Institute of Technology (Caltech).

Main fields
Process control, process design, optimal operation, distillation processes

Experience
1979: Military Service at Norwegian Defence Research Center (FFI).
1980-83: Research engineer at Norsk Hydro's Research Center in Porsgrunn, Norway.
1983-87: Ph. D. student and Research Assistant at California Institute of Technology
1987- present : Professor in Chemical Engineering at NTNU (Dept. Head 1999-2009)
1994-95: Visiting Professor at University of California, Berkeley (Departments of Chemical Engineering and Mechanical Engineering).
2001-02: Visiting Professor at University of California, Santa Barbara (5 months).

Supervision
37 completed PhD theses as main supervisor. Currently supervising 6 PhDs and 1 postdoc
160 completed MS theses as main supervisor.

Publications
About 200 international journal publications and 300 conference publications
H-index (ISI): 39 (2015).
H-index (Google scholar): 55 (2015)
Author of 2 international text books. (1) S. Skogestad and I. Postlethwaite, ``Multivariable feedback control - analysis and design,'' Wiley (1996); 2nd Edition (2005). (2) S. Skogestad, ``Chemical and energy process engineering'', CRC Press (2009).
No. of citations to book Multivariable Feedback control: 6174 (Google scholar, 2015)

Awards and Honors

- *Innstilling* awarded for the *Siv.ing.* degree (result communicated to Norwegian King), 1979.
- *Fullbright Fellowship* (travel grant) awarded for graduate studies at Caltech, 1983.
- *Utdanningsstipend* awarded from Univ. of Trondheim for graduate studies at Caltech, 1983.
- Elected member to *The Norwegian Academy of Technical Sciences* (NTVA), 1988.
- *Ted Peterson Best Paper Award* by the CAST division of AIChE (The American Institute of Chemical Engineers), 1989.
- *George S. Axelby Outstanding Paper Award* by the Control System Society of IEEE (The Institute of Electrical and Electronic Engineers), 1990.
- Elected member to *Det Kongelige Norske Vitenskapers Selskab*, 1991.
- *O. Hugo Schuck Best Paper Award* by the American Automatic Control Council, 1992.
- *Best paper award* for paper published in 2004 in *Computers and chemical engineering* (2006)
- Member of IFAC Technical Board, 2008-2014.
- Elected member of Process Automation Hall of Fame, , Delaware, USA, 23 May 2011
- Elected Fellow of American Institute of Chemical Engineers (AIChE), 2012.
- Elected Fellow of International Federation of Automatic Control (IFAC), 2014.
- Elected member to *The Norwegian Academy of Science and Letters*, Oslo, 2015.
- Honorary member of *Norwegian Society of Automatic Control,* 2015.

SINTEF

Curriculum Vitae

Name: Asbjørn Solheim
Born: 1952
Nationality: Norwegian
E-mail: asbjorn.solheim@sintef.no

Present position: Chief Scientist

EDUCATION & EMPLOYMENT

1985	Sivilingeniør (M.Sc.), Norges Tekniske Høgskole, Industrial Electrochemistry
1977	Ing. (Engineer, B.Sc), Tr.heim Tekniske Skole (Tr.heim Engineering College),Metallurgy
1977-1985	Engineer, SINTEF Metallurgy
1986-1993	Scientist, SINTEF Metallurgy
1993-2008	Senior Scientist, SINTEF Materials Technology
2008-	Chief Scientist, SINTEF Materials and Chemistry
1993-1997,	Part-time engagement as lecturer in Process Control, Høgskolen i Sør-
2000-2002	Trøndelag (Trondheim Engineering College)
2010-2011	Associate Prof. in Aluminium Electrolysis, Dep. of Materials Science and Eng., NTNU

MAIN FIELDS OF COMPETENCE

- Electrochemisty
- Aluminium electrolysis; in particular, modelling of electrolyte chemistry, transport processes, and themodynamics

COMMITTEE MEMBERSHIPS, AWARDS

- External examiner at NTNU, Department of Materials Science and Engineering (until 2010).
- Member of the Organizing Committee, Eleventh International Aluminium Symposium, 2001. Editor of Proceedin
- Member of the Organizing Committee, the International Jomar Thonstad Symposium, 2002. Editor of Proceedin Chairman.
- The Elf-Aquitaine prize, 1985
- Best paper at the Reduction Technology Session at the XIII International Conference "Aluminium of Siber 2007", Krasnoyarsk, Russia, September 11-13, 2007.
- Best paper at the Reduction Technology Session at the XIV International Conference "Aluminium of Siber 2008", Krasnoyarsk, Russia, September 10-12, 2008

PUBLICATIONS

- About 120 international and national publications, numerous technical reports
- Numerous presentations in international and national meetings and conferences

SOME SELECTED PUBLICATIONS

- O-J. Siljan, S. Slagnes, E. Furu, A. Sekkingstad, S. Aaram, and A. Solheim, "Lower Aluminium Production Cost through Refractory Material Selection", Light Metals 2010, pp. 865/70 (Proceedings, 139th TMS Annual Meeting, Seattle, Washington, February 14-18, 2010).
- Solheim, C. Schøning, and E. Skybakmoen, "Reactions in the Bottom Lining of Aluminium Reduction Cells", Light Metals 2010, pp. 877/82 (Proceedings, 139th TMS Annual Meeting, Seattle, Washington, February 14-18, 2010).
- G.M. Haarberg, Joseph P. Armoo, Henrik Gudbrandsen, Egil Skybakmoen, Asbjørn Solheim, and Trond Eirik Jentoftsen, "Current Efficiency for Aluminium Electrowinning from Cryolite-Alumina Melts in a Laboratory Cell", *ECS Transactions*, **33** (7), 175/79 (2010).
- Y. Ladam, A. Solheim, M. Segatz, and O.-A. Lorentsen, "Heat Recovery from Aluminium Reduction Cells", Light Metals 2011, pp. 393/98 (Proceedings, 140th TMS Annual Meeting, San Diego, California, February 27-March 3, 2011).
- Solheim, "Some Aspects of Heat Transfer between Bath and Sideledge in Aluminium Reduction Cells", Light Metals 2011, pp. 381/86 (Proceedings, 140th TMS Annual Meeting, San Diego, California, February 27-March 3, 2011).
- K.S. Osen, T. A. Aarhaug, A., E. Skybakmoen, and C. Sommerseth, "HF Measurements Inside an Aluminium Electrolysis Cell", Light Metals 2011, pp. 263/68 (Proceedings, 140th TMS Annual Meeting, San Diego, California, February 27-March 3, 2011).
- E. Skybakmoen, S. Rørvik, A. Solheim, K.R. Holm, P. Tiefenbach, and Ø. Østrem, "Measurement of Cathode Surface Wear Profiles by Laser Scanning", Light Metals 2011, pp. 1061/66 (Proceedings, 140th TMS Annual Meeting, San Diego, California, February 27-March 3, 2011).

Curriculum Vitae

Name: Krzysztof Banasiak
Born: 6th March 1978 in Tarnowskie Gory, Poland
Nationality: Polish
E-mail: Krzysztof.Banasiak@sintef.no

Present position: Researcher at SINTEF Energy Research

EDUCATION & EMPLOYMENT

Education: PhD in Refrigeration (2006); MSc in Mechanical Engineering (2002)
Employment: SINTEF Energy Research, Norway (since 2013); Silesian University of Technology, Poland (2003-2013); Energoprojekt Katowice SA, Poland (2002)

MAIN FIELDS OF COMPETENCE

- Design and operation of two-phase ejectors; CO_2 in refrigeration; modelling of absorption refrigerators; modelling of wet cooling towers; multilevel optimization of refrigeration systems

EXPERIENCE

- Team member (researcher) in 3 projects financed by the Research Council of Norway, 3 projects financed by the European Union, 2 projects financed by the Polish-Norwegian Research Programme, 5 projects financed by the Polish Ministry of Research and Higher Education, and a number of industry-founded commercial projects
- Reviewer activities for Appl. Th. Eng., Int. J. Ref., and Int. J.Th. Sc.
- Scientific experience at international centres: SINTEF Energy, Norway (visiting researcher in 2011-2012, 2010, 2007); National Technical University of Athens, Greece (FP6-founded two-week consultation in 2005); University of Ulster at Coleraine, UK (SOCRATES-ERASMUS MSc in 2002)

TEACHING, SUPERVISOR, CENSORSHIP

- 10-year experience in teaching activities at Silesian University of Technology (lectures, laboratory groups, supervising of BSc and MSc diplomas)
- 2-year experience as diploma consultant for international BSc and MSc students at SINTEF ER

PUBLICATIONS

- About 100 international and national publications and 20 technical reports
- Numerous presentations in international and national meetings and conferences
- Academic production according to Scopus: h-index: 6, citations: 84, publications: 22

SOME SELECTED PUBLICATIONS

[1] Banasiak, K., Hafner, A., Kriezi, E., Madsen, K., Birkelund, M., Fredslund, K., Olsson, R., Development and performance mapping of a multi-ejector expansion work recovery pack for R744 vapour compression units, Int. J. Ref. 57 (2015) 265-276.
[2] Banasiak K., Palacz M., Hafner A., Buliński Z., Smołka J., Nowak A.J., Fic A., A CFD-based investigation of the energy performance of two-phase R744 ejectors to recover the expansion work in refrigeration systems: An irreversibility analysis, Int. J. Ref. 40 (2014) 328-337.
[3] Banasiak, K., Hafner, A., Andresen, T., Experimental and numerical investigation of the influence of the two-phase ejector geometry on the performance of the R744 heat pump, Int. J. Ref. 35 (2012) 1617-1625.
[4] Banasiak, K., Hafner, A., 1D Computational model of a two-phase R744 ejector for expansion work recovery, Int. J Th. Sc. 50 (2011) 2235 - 2247.

Curriculum Vitae

Name: Bernd Wittgens
Born: Cologne
Nationality: German
E-mail: Bernd.Wittgens@sintef.no
Present position: Senior Adviser,
Materials and Chemistry,Dep.of Process Technology

EDUCATION & EMPLOYMENT

1982 - 1988	Mechanical Engineering / Process Engineering studies Rheinsch Westfälische Technische Hochschule Aachen, Germany
1988	NTH, Dep. of Industrial Chemistry, Diploma DEMINEX Scholarship
1989	Diploma Mechanical Engineering / Process Engineering studies Rheinsch Westfälische Technische Hochschule Aachen, Germany
1989	RWTH Aachen, Faculty of Mechanical Engineering, Internship Office
1990 - 1994	NTH, Dep. of Chemcial Engineering, DEMINEX – PhD scholarship holder
1995 - 1997	Scientific Assistant at Dep. of Chem. Eng. NTNU
1997 - 1998	Chief engineer at Dep. of Chem. Eng., NTNU
1998 - 2005	Senior research Engineer AITOS / Energos, Trondheim, 1998 – 20
2005 – 2011	Research Scientist, SINTEF Materials and Chemistry
2011	Senior Adviser, SINTEF Materials and Chemistry

MAIN FIELDS OF COMPETENCE

- Techno Economic Evaluation of chemical processes
- Design, engineering, optimization and operation of chemical process plants, separation systems, waste incineration, combustion technology, abatement systems and flue gas cleaning plants
- Energy efficiency
- Project and Innovation management
- Biofuel production: mass and energy balance and optimization
- Measurement and instrumentation for emission monitoring applied to flue gas cleaning systems
  Advanced gas analysis applied to industrial scale systems and measurements in interior and exterior environment

EXPERIENCE

- Business development especially in Biorefinery research and environmental technologies for landbased industries
- Project management of SINTEF internal Priority program: Biobased products from renewable sources (2013-2016)
- Project Manager/Scientific work in NFR projects Promiljø, FUME, SCORE
- Responsible for coordination Biorefinery activities in SINTEF Materials and Chemistry
- Technical and economical evaluation as tool for process design, research prioritation and decision tool for projects (2012)
- Emission monitoring instrumentation (2010)
- Energy production from Biogas (2010)
- Technical and economical evaluation of Biofuel production (2010)
- Design and Procurement High Pressure Membrane system for CO_2-removal (2009)
- Wood based biorefinery (2007)
- Microreactor for absorbtion processes (2006)
- Gas hydrate test loop at Kårstø (2006)
- Energos Waste incinerators design, procurement, start-up and operation of waste incinerators, flue gas cleaning and flue gas analytical system1998-2005
- Design, engineering and procurement of laboratory and pilot plant installations 1989 -1998

COMMITTEE MEMBERSHIPS

- Scientific advisory Board EcoChem Exhibition Basel
- Organizing committè Renewable Energy Conference (RERC) 2010
- Organizing committè Technoport/Renewable Energy Conference RERC 2012
- Member of SFFE (Senter for fornybar Energi) 2009 – 2013
- Organizing committè ESCAPE-1997, Trondheim

PUBLICATIONS

- About 70 international and national publications and technical reports
- Numerous presentations in international and national meetings and conferences

Curriculum Vitae

Name: Eli Ringdalen
Born: 05.04.1957
Nationality: Norwegian
E-mail: Eli.Ringdalen@sintef.no

Present position:
Senior research Scientist at Sintef Materials and Chemistry

Picture

EDUCATION & EMPLOYMENT

1979 MSc in Geology Norwegian University of Science and Technology (NTH), Trondheim Norway
1985 Economy:(1-year study) at The Norwegian School of Management, BI
1999 PhD in Metallurgy at Norwegian University of Science and Technology (NTNU), Trondheim, Norway. Ph.D. Thesis: The High Carbon Ferrochromium Process, Reduction Mechanisms.

MAIN FIELDS OF COMPETENCE

- Process Metallurgy
- Production of Ferroalloys and Si
- Project management
- Electric arc furnace operation
- Recycling of saw dust from sawing of Si-wafers
- Thermodynamics
- Iron ore geology and ore dressing
- Use of natural gas in metal production

EXPERIENCE

Employments
1980-1985: Mining geologist, Rana Gruber AS, Mo in Rana, Norway
1985-1990: Process engineer ore dressing and product development, Rana Gruber AS, Mo in Rana, Norway. Includes development, of Technology and start up of ColoRana pigment plant
1990-1993: Project manager for new waste treatment plant, Elkem Bremanger AS, Bremanger, Norway
1993-1995: Research manager, SINTEF Molab AS, Mo in Rana Norway, Responsible for surveillance of contaminated soil
1995–1999: Metallurgist (partly during PhD study), Elkem Rana AS, Ferrochromium plant, Mo in Rana Norway
1999-2002 : Metallurgist, Furnace operation and R&D, Elkem Rana AS, Mo in Rana Norway
2002-2003 : Project manager for R&D furnace project Elkem Thamshavn AS / Elkem Silicon division
2003-2006 : Process and technology manager, RDMN AS, a Vale company (now owned by Glencore Manganese), Mo in Rana Norway. Participated in sale to Vale and rebuilding of furnaces from HCFeCr to Mn-alloys
2006 -2008: Research scientist, SINTEF Materials and Chemistry, Trondheim Norway
2008-2010: Senior adviser, SINTEF Materials and Chemistry
2011 - : Senior Research Scientist, SINTEF Materials and Chemistry

- Extensive experience as Project manager for larger RCN funded projects such as KMB ROMA, KMB ROMAM, RaNaGass, IPN ESiP and IPN SiNG, in addition to several direct industrial Research projects at SINTEF (for Elkem, Eramet, Eramet Research in France, BHP in Australia/South Africa, Ferbasa in Brazil, Assmang in South Africa)

TEACHING, SUPERVISOR, CENSORSHIP

- Organising, Elkem University, Trondheim, Norway, 2003
- Censuring in course Metal production at NTNU, Trondheim, Norway
- Censuring Several MSc thesis in Process Metallurgy at NTNU, Trondheim, Norway,
- Co Supervisor for project and MSc at NTNU, Trondheim, Norway (2 students 2015-2016)
- Lecturing at 2 days Mn-course by SAIMN, Johannesburg, South Africa 2012
- Lecturing at Elkem University 1997, 2003, 2014
- Teaching at International Si-summer school in Norway 2012 and at Iceland 2014
- Teaching in Si and Mn as part of course Metal Production at NTNU, Trondheim, Norway,2015
-

PUBLICATIONS

- About 35 international and national publications and 20 technical reports , one patent
- Numerous presentations in international and national meetings and conferences
- Academic production according to Web of Science: citations: 10, publications: 5

Curriculum Vitae

Name: Hanne Kauko
Born: 30.12.1984
Nationality: Finnish
E-mail: hanne.kauko@sintef.no

Present position: Researcher, SINTEF Energy Research

EDUCATION

PhD	Physics, Norwegian University of Science and Technology (NTNU), Trondheim, 2009-2013.
MSc	Applied physics, Master's degree programme in Renewable Energy, University of Jyväskylä, Finland, 2006-2009.

MAIN FIELDS OF COMPETENCE

- Since 2014 focusing on energy efficiency in building complexes and industry, low-temperature thermal grids and industrial high-temperature heat pumps based on natural refrigerants
- Earlier work on solar photovoltaics (PV) and characterisation of solar cell materials

EXPERIENCE

2015-2017	Project leader for RCN project *DSTG – Development of Smart Thermal grids*
2014-2015	Group manager of the Energy Efficiency group, SINTEF Energy Research, Trondheim.
2007-2008	Internship on performance measurements of PV modules at the Joint Research Centre of the European Commission, Ispra, Italy.

TEACHING, SUPERVISOR, CENSORSHIP

2014-	Co-supervising and censoring of various project and diploma works of students at NTNU-SINTEF
2010-2013	Lab teacher in electron microscopy for the course Solid state physics at NTNU
2008	Course assistant for the course Technical thermodynamics at University of Jyväskylä

PUBLICATIONS

- J. Clauss, **H. Kauko**, A. Hafner, T. M. Eikevik. Wärmepumpen als Teil eines Smart Thermal Grids. DKV Tagung 2015, Dresden, Germany (2015).
- **H. Kauko**, O. Stavset, M. Bantle and N. Nord. Energy use in Norwegian non-residential buildings: building regulations, calculations and measurements. Cold Climate HVAC 2015, Dalian, China
- **H. Kauko**, M. J. Alonso, O. Stavset, I. C. Claussen. Case study on residential building renovation and its impact on the energy use and thermal comfort. Energy Procedia 58 160-165(2014).
- **H. Kauko**, A. Hafner, A. K. Hemmingsen, I. C. Claussen. Integrated and efficient energy systems. Renewable Energy Conference RERC 2014, Oslo, Norway (2014).
- **H. Kauko**, B. O. Fimland, T. Grieb, A. M. Munshi, K. Müller, A. Rosenauer, A. T. J. van Helvoort. Near-surface depletion of antimony during the growth of GaAsSb and GaAs/GaAsSb nanowires. Journal of Applied Physics 116(14) 144303 (2014).
- **H. Kauko**, C. L. Zheng, Y. Zhu, S. Glanvill, C. Dwyer, A. M. Munshi, B. O. Fimland, A. T. J. van Helvoort, J. Etheridge. Compositional analysis of GaAs/AlGaAs heterostructures using quantitative scanning transmission electron microscopy. Applied Physics Letters 103(23) 232111 (2013).
- **H. Kauko**, T. Grieb, R. Bjørge, M. Schowalter, A. M. Munshi, H. Weman, A. Rosenauer, A. T. J. van Helvoort. Compositional characterization of GaAs/GaAsSb nanowires by quantitative HAADF-STEM, Micron 44 254-260 (2013).
- G. Chinga-Carrasco, **H. Kauko**, M. Myllys, J. Timonen, B. Wang, M. Zhou, J. O. Fossum. New advances in the 3D characterization of mineral coating layers on paper, J. Microsc.-Oxf., 232(2) 212-224 (2008).

NTNU

Résumé of
Professor Merete Tangstad, Department of Material Science and Engineering
Norwegian University of Science and Technology, 2015

1984-1989	MSc- degree at The Norwegian Institute of Technology in Metallurgy.
1989 – 2000	Elkem Research, Research and developement
1992-1996	Dr. Ing. degree in Metallurgy, The Norwegian Institute of Technology, June 1996, Thesis: The High Carbon Ferromanganese Process – Coke Bed Relations.
1996-1997	Elkem Mangan Sauda (Main responsibilities: Operating no.12 furnace and training of operators)
2000-2004	Eramet Norway, Research and Developement (FeMn-production)
2004- today	Professor at Department of Material Science and Engineering, NTNU

Main fields:
*silicon and ferroalloy production including operation strategy, raw materials, thermodynamics, reaction mechanisms, and its thermodynamic- and kinetic- behaviour
* feedstock to solar grade silicon processes- methods, thermodynamic and kinetics

80 international publications , H-index = 9 and 221 citations

Supervisor on the following PhD thesis (cosupervising is not included)

1. *Andreas Westermoen, Modelling of dynamic arc behaviour in a plasme reactor, 2007*
2. Per Anders Eidem, Electrical resistivity of coke beds, 2008
3. Arjan Citja, Solar silicon refining; Inclusions, settling, filtration, wetting, 2009
4. Halvor Dalaker, Solubility of Carbon and Nitrogen in the Silicon Rich Part of the Si-C-N-B-System, 2009
5. Dmitriy Slizovkiy, Mn-waste materials, 2011
6. Michal Ksiazek, Thermal conductivity of Mn-ores", 2011
7. Sarina Bao, Al-filtration, 2011
8. Jeff Kline, Structures of CaO-SiO2, CaO-MgO-SiO2and CaO-Al2O3-SiO2slags and with the addition of B2O3: A Raman Spectroscopic Study, 2012
9. Lars Klemet Jakobsson, Distribution of boron between silicon and CaO-SiO_2, MgO-SiO_2, CaO-MgO-SiO_2 and CaO-Al_2O_3-SiO_2 slags at 1600 °C, 2013
10. Thomas Brynjulfsen, Reduction of manganese ore agglomerates, 2013
11. Joalet Steenkamp (cosupervisor)– Chemical wear of carbon-based refractory materials in a siliconmangnese furnace tap-hole, University of Pretoria
12. Øyvind Sunde Sortland, Boron removal from silicon by steam and hydrogen, 2015
14. Aslak Skjeldestad, Søderberg electrode segregation, 2015
16. Li Fei, SiO_2+C pellets: kinetics and reaction mechanism, 2017
17. Sethulakshmy Jayakumari, SiC crust formation in Si production, 2018
18. Pynghwa Kim, SiMn reaction mechanism, 2018
19. Xiang Li (PostDoc), Use of natural gas in Mn-production, 2017

Supervisor on PostDocs

1. Erlend Nordstrand, Refining to solar grade silicon
2. Jafar Safarian, Fundamentals within solar grade silicon production
3. Xiang Li, Use of natural gas in Mn-production

Books

- Production of manganese ferroalloys, S.Olsen, M.Tangstad, T.Lindstad, Tapir Forlag, 2007, ISBN-978-82-519-2191-6
- Crytal growth of Si for solar cells , K.Nakajima, N.Usami, Springer, ISBN 978-642-02043-8, contributed in 2 chapters with K.Tang, E.Øvrelid, G.Tranell, M.Tangstad, T.Engh
- Tangstad, M., 2013. Ferrosilicon and Silicon Technology. In: Gasik, M. (Ed.), Handbook of Ferroalloys: Theory and Technology. Elsevier Ltd., Butterworth-Heinemann, pp. 179–220.
  Tangstad, M., 2013. Manganese Ferroalloys Technology. In: Gasik, M. (Ed.), Handbook of Ferroalloys: Theory and Technology. Elsevier Ltd., Butterworth-Heinemann, pp. 221–266
- M.Tangstad (Ed.), Metal production in Norway, Akademika Forlag, 2013

Curriculum Vitae

Dr. Michael Bantle

Current position: PhD Research Scientist at SINTEF Energy Research
Year of Birth: 1977
Email: Michael.Bantle@sintef.no
Telefon: +47 41014024
Office Adress: Kolbjørn Hejes Vei 1D, 7465 Trondheim, Norway

EDUCATION

2011	PhD, Atmospheric Freeze Drying assisted by Ultrasound (2011:11), Norwegian University of Science and Technology, Department of Energy and Process Engineering, NO- Trondheim.
2007	Dipl. Ing. (FH), Process and Environmental Technology, University of Applied Science, Konstanz, Germany, 02/2007
1996	Education as bank officer (private sector), Sparkasse Villingen, Germany, 02/1996

MAIN FIELD OF COMPETENCE

- Refrigeration and Heat Pump Technology in general
- Energy Efficiency in Thermal Processes
- Energetic Analyses and Dynamic Modelling
- Life Cycle Climatic Performance of various energy systems

EXPERIENCE AND AWARDS

- Researcher and Project leader at SINTEF Energy Research, in the fields of food technology, heat pumps and energetic analyses, SINTEF (since 2012)
- Post-Doc, Energy efficient Drying systems, Norwegian University of Science and Technology (2011)
- PhD work, Norwegian University of Science and Technology, (2007-2011)
- Diploma-Thesis: Dimensioning of Drying System for Soybeans (2006)
- Bühler-Prize for best diploma, Bühler AG, Uzwil, Switzerland
- Hübner-Prize for best pre-degree, University of Applied Science, Konstanz, Germany
- Prize for best credentials during education, Sparkasse Villingen, Gemany

PUBLICATION

- About 40 international publications within the area of refrigeration, heat pumps and food technology
- Numerous presentations in international and national meetings and conferences

Some selected publications:

1. **Tolstorebrov, I., Bantle, M., Hafner, A., Kus, B., Eikevik, T.M.**, Energy efficiency by vapor compression in superheated steam drying systems, 11th Gustav Lorentzen Conference on Natural Refrigerants, 31. August – 2. September 2014, Hangzhou, China.
2. **Bantle, Michael; Eikevik, Trygve Magne.** A study of the energy efficiency of convective drying systems assisted by ultrasound in the production of clipfish. *Journal of Cleaner Production* 2013 Volum 65.(217) Suppl. 223.*http://www.sciencedirect.com/science/article/pii/S0959652613004770*
3. **Bantle, Michael; Gullsvåg, Per Egil; Nordtvedt, Tom Ståle; Indergård, Erlend; Tolstorebrov, Ignat.** Heat pump drying : simulation and evaluation of drying system for clipfish with main and storage drying. I: 3rd IIR International Conference on Sustainability and the Cold Chain 23rd 24th and 25th June 2014, St Mary's University, Twickenham, London, UK. International Institute of Refrigeration 2014 ISBN 978-2-36215-003-6 https://www.dropbox.com/sh/ykjqhbe801t6o6g/AAAB6Swl6PAx-YIslNByFm-ra
4. **Bantle, Michael; Petrova, Inna; Raiser, Jasmin; Eikevik, Trygve Magne.** Dynamic model and kinetics for convective drying of ham with different salt content. I: Proceedings of the 19th International Drying Symposium. Lyon, Frankrike: ESP Sciences 2014 ISBN 978-2-7598-1631-6. s. 1-8
5. **Tolstorebrov, Ignat; Eikevik, Trygve Magne; Bantle, Michael.** A DSC determination of phase transitions and liquid fraction in fish oils and mixtures of triacylglycerides. *Food Research International* 2014; Volum 58. s.132-140 http://www.sciencedirect.com/science/article/pii/S0963996914000817

More publications: http://www.sintef.no/ansattespublikasjoner/?empId=4503

CV (short version), 2015

Jens O. D. Røyrvik

Born: June 15th 1976
Phones: +47 73596264 (office), +47 94310996 (mobile)
e-mail: jens.royrvik@samfunn.ntnu.no

Current position:
Senior Researcher, NTNU Social Research – Studio Apertura
Head of the SA focus area *energy and environment*

Academic degrees:

- 2012 PhD Social Anthropology, NTNU
- 2005 Cand. Polit. Social Anthropology NTNU

Key qualifications:

- Anthropology of technology
- Practice and ontology
- Organization and society
- Off shore-industry, maritime sector, energy and environment

Professional experience

- 2012 - NTNU Social Research. Studio Apertura. *Senior Researcher*
- 2010 – 2012 NTNU Social Research. Studio Apertura. *Researcher*
- 2006 - 2010 NTNU - Department of Social Anthropology and Learning with ICT (LIKT) *Research for PhD, Lecturer, seminar leader*.
- 2002 - 2006 NTNU - Department of Engineering Design and Materials. *Researcher*
- 2000 - 2002 NTNU - Department of Social Anthropology. *Learning assistant.*

Projects related to energy and centre innovation

- Evaluation of Enovas program promoting passive houses (Enova 2014-15) Project Leader.
- INTERACT – Surplus heat and energy efficiency (NRC 2013 – ongoing) Headed by SINTEF Energy, WP leader.
- People@Statoil – Evaluation of the effects on openness (Statoil 2013). Project Leader.
- TRACULT – Translating HSE culture (NRC 2012 - ongoing) WP leader.
- SER – Societal and economical ripple effects of public investments in research centers (SIVA 2011), Researcher.
- BIGCCS - FME Centre, Centre building and innovation processes (NRC 2010- 2014 (center still ongoing)). Headed by SINTEF Energy, researcher and board member.
- CREATIV – program for energy efficiency (NRC 2010- 2013). Headed by SINTEF Energy, local Project leader.

Recent publications (2014 - 2015)

- Internationalization of Norwegian domestic traffic and safety (2015) Gyldendal Norsk Forlag, With Rolf Bye
- *Evaluating Enovas Passive house program (2015) ISBN 978-82-7570-412-0*
  With Sintef Byggforsk and Rambøll
- *Organizing Synergies in Integrated Energy Systems. (2014)* Energy Procedia
  With Jens Petter Johansen
- *Standardization, accountability and information infrastructures. The cultural logic of facts and figures* (2014); With Petter Almklov
- *Risk management in anchor-handling operations: the balance between control and autonomy* (2015) Safety and Reliability. With Kari Skarholt, Gunnar Lamvik, Jan Roald Jonassen
- *Culture as a tool and stumbling block for learning The function of "culture" in communications from regulatory authorities in the Norwegian petroleum sector* (2015) Safety science
  With Rolf Bye and Ragnar Rosness

CV 2015

Per Morten Schiefloe
Born: March 28th 1947
Phones: +47 73596323 (office), +47 90115516 (mobile), **e-mail**: perms@svt.ntnu.no

Current positions:
Professor, Dept. of Sociology and Political Science, Norwegian University of Science and Technology - NTNU
Research Director, NTNU Samfunnsforskning as – Studio Apertura

Academic degrees:

- 1973 M.A. in sociology (mag.art), University of Oslo
- 1987 Dr.philos in sociology, University of Trondheim

Key qualifications:

- General sociology
- Organizational studies (culture, change, innovation, safety, management)
- Network studies (personal networks, networks in organizations, social capital)

Selected research programs 1993-2015

- 1993-1997 *Program for Applied Coordination Technology.* Financed by Statoil and Telenor
- 1994-1995 *Evaluation project BRU* (Cheaper and faster development projects), Statoil
- 1997-2002 *BRA* (Better and faster administration): implementation of shared administrative data systems (SAP) and new administrative processes in Statoil
- 1998-2005 *Knowledge networks*, (Industry foundation for new ideas –NTNU)
- 2000-2004 *Management and organization in the new industry* (NRC)
- 2003-2006 *Identity, technology and organizational solutions in a mobile work environment (NRC)*
- 2007-2010 *Mobilizing social capital in ICT-based global organizations* (NRC)
- 2009-2011 *Understanding Success and Developing Management Leadership on International Mega-projects* (Statoil and University of California ,Berkeley)

Selected publications 2005-2015

- *Industriens rammebetingelser* (External conditions for industry) (2005) Oslo, Prosessindustriens landsforening – PIL-skolen (144 p)
- *Norge 2020. Industrielle og økonomiske fremtidsutsikter* (Norway 2020. Industrial and economic prospects) (with Gunnar Sand and Tone Merethe Berg Aasen) (2005) Bergen, Fagbokforlaget (205 p)
- ”The development, distribution and maintenance of trust in distributed work groups: a social network approach” (with Tom Erik Julsrud) *International Journal of Networking and Virtual Organisations* 4/2007 (351-368)
- “Dilemmaer i organisasjonsforskningen” (Dilemmas in research on organizations), in Irene Lorentzen
- “Oljelandet” (The Oil Country) (2010) in Lise Kjølsrød og Ivar Frønes (red) *Det norske samfunn* (The Norwegian Society) Oslo, Gyldendal Akademiske (19-40)
- “Sosial kapital: ressurs for organisasjoner og objekt for ledelse” (Social capital. Resource for organizations and object for management., in Elvegård, Lin Olderøien et al (eds) (2013) *Bedriftsledelse. Ulike perspektiver og tilnærminger til ledelse, økonomistyring og samfunnsansvar.* Trondheim, Akademika forlag (s 247-270)
- “Understanding project success through analysis of project management approach (with A. Rolstadås, I. Tommelein & G. Ballard) ” (2014) *International Journal of Managing Projects in Business*. 7/4 (638-660)
- *Sosiale landskap og sosial kapital. Nettverk og nettverksforskning*. (Social landscapes and social capital) (2015) Oslo: Universitetsforlaget (284 p)

Distribution of PhDs and Post.Docs within RAs and WPs of *HighEFF*

Strategic International Partnerships

- 2 PhDs for NTNU-MIT Collaboration
- 2 PhDs for NTNU-UoM Collaboration
- 2 PhDs for NTNU-KTH Collaboration
- 1 PhDs for NTNU-CMU Collaboration (CMU PhD funded 50% by CMU)

RA1 – Methodologies

- WP 1.1 – Key Performance Indicators (KPI): Signe Kjelstrup (NTNU) (including fundamental research on the use of Exergy for Energy Efficiency): ***1 PhD***
- WP 1.2 – Energy & Exergy Analyses: Truls Gundersen (NTNU) (Work and Heat Exchange Networks): ***1 PhD***
- WP 1.3 – Process Systems Engineering: Sigurd Skogestad (NTNU) and Robin Smith (UoM) (Operational Optimization for Energy Savings): ***2 PhDs***
- WP 1.3 – Process Systems Engineering: Truls Gundersen(NTNU) and Paul I. Barton (MIT) (Global Optimization for improved Energy Efficiency): ***2 PhDs***
- WP 1.4 – Future Process Framework: Ivar Ståle Ertesvåg (Use of Exergy for Energy Efficiency in new Offshore Frameworks): 1 PhD ***1 PhDs***

RA2 – Components

- WP 2.1 – Heat Exchangers: Erling Næss with Armin Hafner as co-supervisor (NTNU) (Compact Heat Exchangers): ***1 PhD***
- WP 2.2 – Expanders & Work Recovery Units: Armin Hafner (NTNU) (Expanders and Ejectors as Novel Components): ***1 PhD***
- WP 2.4 – Natural Working Fluids and Mixtures: Trygve Eikevik (NTNU) (Energy Efficient and Environmentally friendly Working Fluids in Heat Pumps and Refrigeration Cycles): ***1 PhD***

RA3 – Cycles

- WP 3.1 – Heat-to-Power Conversion: Lars Olof Nord (NTNU) (Compact and Efficient Bottoming Cycles for Offshore Power Production): ***1 PhD***
- WP 3.1 – Heat-to-Power Conversion: Supervisors: Petter Nekså (NTNU), and Per Lundquist (KTH) (Power Cycles Utilising Mixed Component Working Fluids): ***2PhDs***
- WP 3.3 – High Temperature Heat Pumping: Trygve Eikevik (NTNU) (Novel Components and Systems for High Temperature Heat Pumping): ***1 PhD***
- WP 3.4 – Energy Storage: Armin Hafner with Erling Næss as co-supervisor (NTNU) (Energy Storage for Integration of Renewables, etc.): ***1 PhD***
- WP 3.4 – Energy Storage: Sigurd Skogestad (NTNU) (Optimal Operation and Control of Energy Storage Systems): ***1 PhD***

RA4 – Applications

- WP 4.1 – Process Improvements: Supervisor: Gabriella Tranell (NTNU) (On the Way to Closed Furnaces in the Metallurgical Industry): ***1 PhD***
- WP 4.2 – Surplus Heat Recovery: Supervisors: Petter Nekså (NTNU) (Novel Energy Recovery Concepts): ***1 PhD***
- WP 4.3 – Technology Integration: Supervisors: Johannes Jäschke and Lorenz T. Biegler, (CMU) (Integration and Optimization of New Technologies in an existing Processing Plant): ***2 PhD*** (CMU PhD 50% funded by CMU)
- WP 4.4 – Industry Clusters/Grids: Supervisor: Leiv Kolbeinsen (NTNU) (Use of Smart Thermal Grids in Industrial Clusters for improved Energy Efficiency): ***1 PhD, 1 Post.doc***

5.5 RA5 – Society

- WP 5.1 & 5.2 – Innovation & Roadmaps, Barriers & Enablers: Supervisor: Per M. Schieflo (NTNU Society Research) (A study of Barriers & Enablers for improved Energy Efficiency while considering Innovation and Roadmaps):
  1 Post.doc

Case Studies

Possible case studies have been identified in discussions with the industrial partners as part of the HighEFF proposal development.

Case study definition together with partners will continue in Q1 2016. HighEFF will have annual workshops to select relevant and important industrial cases.

Potential Case Studies	**Partner**	**Description**	**Potential savings in energy use**	**Potential energy savings (%)**
Aluminium plant - surplus heat utilization	Hydro/Alcoa	Power conversion, heat utilization	To be described	To be described
Sverdrup – Boilers	Statoil	High temperature heat pumps for glycol regeneration	5-12 MW of 17 MW total	29-71%
Kollsnes - Heaters	Statoil	Heating	10-15 MW saved of 20 MW total	50-75%
The future energy optimal Thamshavn plant	FFF ELKEM	From best practice - to even better	To be described	To be described
Heat Recovery from pouring of metal/slag	FFF	Heat recovery from casting metal and slags	100 GWh/year. Explore novel casting methods to control solidification and recover energy. Result in both reduced specific energy consumption as well as improved product quality.	To be described
Energy optimal furnace	FFF	Future generation ultra-efficient furnaces will require novel heat management and new opportunities for heat recovery and conversion	To be described	To be described
CO as energy source for industrial clustering	FFF	Applied for preheating, prereduction of Mn-ore or applied for conversion to chemical and energy.	To be described	To be described
Waste heat for cooling of data centre/large building	Mo Industry Park/ Bulk Eiendom	Heat Recovery	All energy from waste heat (data centres make up 2% of worlds energy consumption)	100%
Overall plant efficiency	Glencore Nikkelverk	Surplus heat recovery and re-utilization and/or conversion	To be described	To be described
High Efficient Refrigeration processes	Rema/Marine Harvest/	Improved refrigeration technology, cycle improvements, process integration	To be described	To be described
Drying/Dehydration of foodstuffs,bricks	Vedde/ Orkla	Heat Pump for Drying	15-25 % of industrial energy use related to drying	75-80%
MVR Mechanical vapour recompression	Mars	Heat recovery for steam based processes e.g. superheated steam drying, evaporators	10-20%	80%

Proposed referees – HighEFF FME

Referee	Place of employ	Address
Professor Thore Berntsson	Chalmers Univ. of Technology, Sweden	Chalmers University of Technology, Department of Energy and Environment, SE-41296 Gothenburg, Sweden thore.berntsson@chalmers.se
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