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Report

Industrial Excess Heat Recovery – Status of the Norwegian Industry

Report within the framework of SINTEF's participation in IEA IETS Annex XV

Authors

Alexis Sevault, Olaf Lehn Tranås and Marit Mazzetti

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SINTEF Energi AS
SINTEF Energy Research

Address:
Postboks 4761 Torgarden
NO-7465 Trondheim
NORWAY
Switchboard: +47 73597200

energy.research@sintef.no
www.sintef.no/energi
Enterprise /VAT No:
NO 939 350 675 MVA

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ABSTRACT
This report is a deliverable to International Energy Agency - Industry-related Energy and Technology Systems (IEA IETS) Annex XV, focusing of industrial excess heat recovery. SINTEF Energy Research represents Norway in the Annex XV. The associated deliverables for the subtasks defined in the Annex XV Task 2 are summarized in this report.

- Subtask 1: Evaluation and inventory of excess heat levels
  - Deliverable (Del) 1 - Inventory of projects implemented for excess heat utilization in Norwegian industry
- Subtask 2: Methodology for the practical inventory
  - Del.2 - Proposal for a standardized survey method for excess heat inventory from industrial plants
- Subtask 3: Possible policy instruments and the influence on future use of excess heat
  - Del.3 - Matrix of available policy instruments with their effects
- Subtask 4 Technology development (contributions from R&D)
  - Del.4 - Recent results from research projects in the field of novel high-temperature heat pumps.

PREPARED BY Alexis Sevault and Olaf Lehn Tranås	SIGNATURE
CHECKED BY Marit Mazzetti	SIGNATURE
APPROVED BY Petter Røkke	SIGNATURE

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Table of contents

1 Subtask 1 - Evaluation and inventory of excess heat levels

Prepared by Alexis Sevault (SINTEF Energy Research), reviewed by Marit Mazzetti (SINTEF Energy Research)

1.1 Introduction

The EU Energy Strategy demands a 40 % reduction in greenhouse gas emissions and a 27 % increase in energy efficiency by 2030 [1]. These requirements are expected to become even stricter in the near future after the agreement on a 2-degree increase limit of global warming at the Paris Climate Conference in December 2015 [2]. Several countries with high political influence have already ratified the agreement (e.g. France, Germany and China). All industrial sectors are therefore expected to face stronger efforts to meet these climate goals, especially by dramatically reducing the reliance on fossil fuel and by optimising their specific energy consumption. Nevertheless, reducing specific energy consumption also results in an equivalent reduction of operating costs.

In parallel, excess heat from industrial processes is estimated to reach up to 812 TWh/year in Europe (EU27) in 2010 [3]. Such figures are not systematically reported to international energy statistics; therefore they need to be estimated. In Norway, the last survey (from 2009 [4]) gathered data from 72 participating Norwegian industries, accounting for about 63 % (about 53 TWh/year) of the Norwegian industry energy use, revealed a reported excess heat of about 19 TWh in 2008. The reported excess heat corresponds to more than six times the net production of district heating in Norway in 2008 [5].

The excess heat is defined as the heat content of all streams, which are discharged from an industrial process at a given moment [6]. It generally takes the form of a stream of gas, liquid water, steam, air, and ranges from above ambient temperature to a few hundred degrees Celsius. The purity of these streams usually depends on the standards and regulations in place. Though economical, utilization of excess heat can become relatively complex, depending on the nature of the stream, the type of industry and processes available, the distance to other industrial clusters or urban areas.

There exists various ways to make use of excess heat in the industry [6]:

- Internally, to realise primary energy savings
- At another industry site or other industries in an industrial cluster
- Between an industry / industrial cluster and a district heating system
- Between an industry/industrial cluster and e.g. greenhouses or for other low-temperature purposes
- As a heat source in refrigeration plants for industrial or district cooling

1.2 Aims and objectives

The objective of the present chapter is to investigate the most recent implementations of excess heat utilization in the Norwegian industry, considering the corresponding investment cost, their effect and the heat recovery method. The study focuses on cases where the implementation occurred after 2009, since most implementations occurred after ENOVA SF's 2008 inventory of excess heat from the Norwegian industry [4]and the consequent government support which started thereafter.

1.3 Participants

SINTEF Energy Research is the only representative of Norway within the IEA IETS Annex XV group. Senior Researcher Marit Mazzetti has led the task, assisted by Researcher Alexis Sevault and Senior Researcher Michael Bantle.

1.4 Budget

SINTEF Energy Research has been granted a budget by ENOVA SF to actively participate in the tasks carried out by the IEA IETS Annex XV and represent Norway. ENOVA SF is a governmental agency under the Norwegian Ministry of Climate and Environment and contributes to reduced greenhouse gas emissions, development of energy and climate technology and a strengthened security of supply. The budget for Subtask 1 was 150 KNOK for a duration of 18 months.

Main deliverable: *Inventory of projects implemented for excess heat utilization in Norwegian industry*

1.5 Methodology

1.5.1 Definition

In the present report we refer to excess heat as defined in the IEA Industrial Energy-Related Technologies and Systems Annex 15 [6], differentiating "excess heat" and "waste heat":

> *"**Excess heat** is the heat content of all streams (gas, water, air, etc.) which are discharged from an industrial process at a given moment. A part of that can be internally or externally **usable heat**, technically and economically. [...] **Non-usable excess heat** is the remaining part of the excess heat, when the internally and externally parts have been deducted. This part can be called **waste heat.** The often-used term true excess heat can be defined as white or green excess heat, depending on fossil or biomass origin."*

1.5.2 Inventory of excess heat in Norway

The Norwegian industry is characterised by a number of energy-intensive industries which are geographically distributed all over the country. Figure 1 shows the location of the largest energy-intensive industries in Norway. This scattered distribution constitutes a challenge when it comes to local re-use of excess heat, whereas industry clusters would allow trading excess heat between industries. Such clusters now exist in Norway, e.g., Mo Industripark [7] in Mo i Rana, and their number is expected to grow in the near future. However, today's geographical distribution of energy-intensive industries is linked to the access of dedicated hydroelectric power plants and has enabled a high number of stable jobs in locations far away from the major Norwegian cities.

The Norwegian agency ENOVA SF [8], owned by and operating for the Norwegian Ministry of Climate and Environment, commissioned an evaluation of the potential for excess heat utilization within the Norwegian industry. The investigation performed by Norsk Energi and NEPAS was published in 2009 [4] and presents data averaged from 72 participating Norwegian industries, accounting for about 63 % (ca. 53 TWh/year) of the Norwegian industry energy use. The total reported excess heat resources not utilized in 2008 have been accounted for into two different ways:

- By nature, within three categories: water/waste water, steam and exhaust gas
- By temperature range: 25-40 °C, 40-60 °C, 60-140 °C and > 140 °C

The geographical repartition of reported sources of excess heat in the Norwegian industry for temperature above 140 °C is shown in Figure 2.

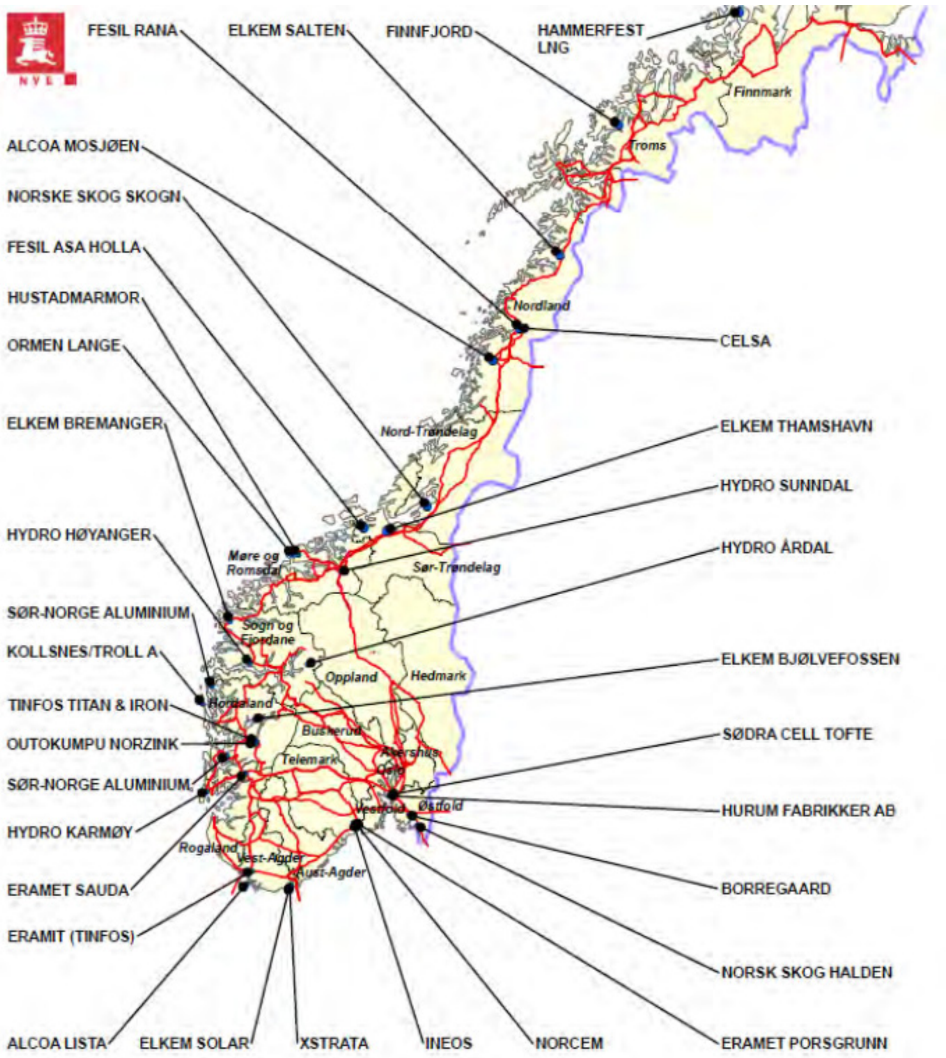
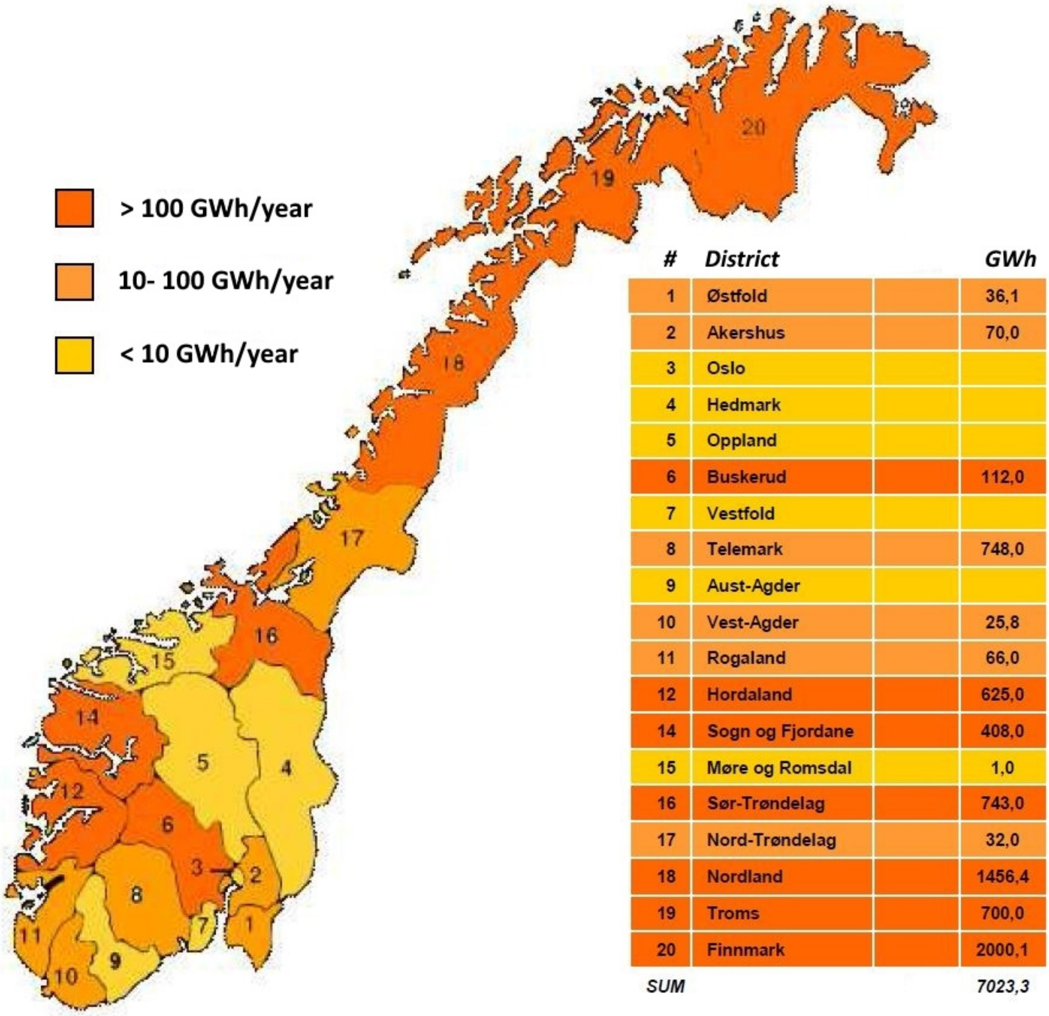


Figure 1: Location and name of the largest energy-intensive industries in Norway per 2012 [9].

An estimation of the heat demand by temperature levels has been presented in a recent study by Sevault at al. [10] and is shown in Figure 3. The figure highlights the temperature ranges in demand for most industry sectors in Norway. Though these estimates are based on an estimated 60 % of total energy use rather than on the actual total heat demand, they provide the order of magnitude of the heat demand for each temperature segment. From the results, it appears clearly that the chemical industry sector (including oil & gas sector), as well as the iron, steel and non-ferrous industry sector would be more prone to generate larger amount of excess heat than other industry sectors.

The methodology for this deliverable consisted in investigating the most recent implementations of excess heat utilization in the Norwegian industry, considering the corresponding investment cost, their effect and the heat recovery method. The study focused on cases where the implementation occurred after 2009, since most implementations took place after ENOVA SF's 2008 inventory of excess heat from the Norwegian industry and the government financial support which started thereafter.



#	District	GWh
1	Østfold	36,1
2	Akershus	70,0
3	Oslo	
4	Hedmark	
5	Oppland	
6	Buskerud	112,0
7	Vestfold	
8	Telemark	748,0
9	Aust-Agder	
10	Vest-Agder	25,8
11	Rogaland	66,0
12	Hordaland	625,0
14	Sogn og Fjordane	408,0
15	Møre og Romsdal	1,0
16	Sør-Trøndelag	743,0
17	Nord-Trøndelag	32,0
18	Nordland	1456,4
19	Troms	700,0
20	Finnmark	2000,1
SUM		*7023,3*

Figure 2: Reported excess heat sources with temperature above 140 °C in Norway [4].

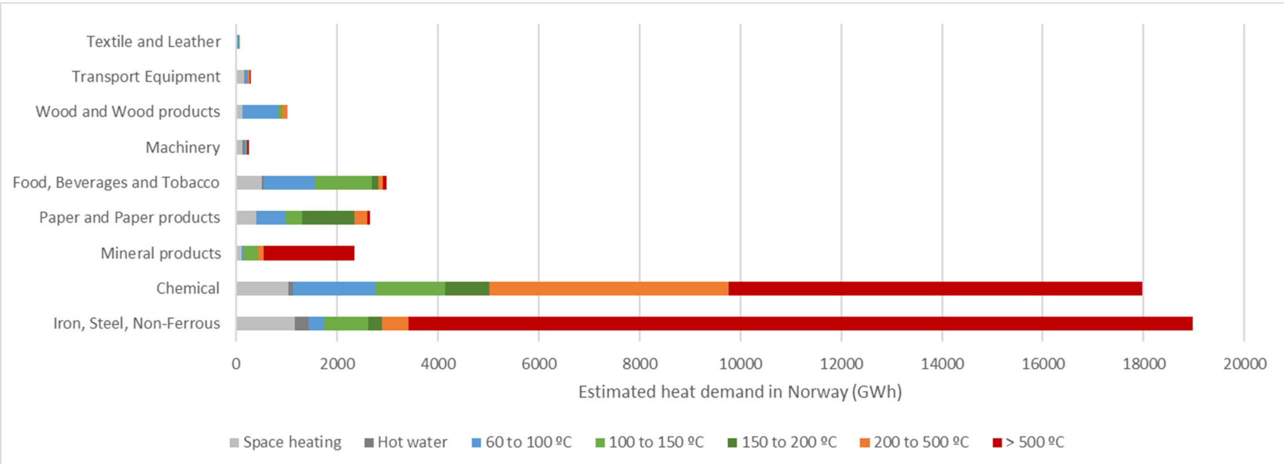


Figure 3: Estimates of the heat demand for the Norwegian industry per sector for 2016, based on [10] and considering that 60 % of the energy demand is for heating.

1.6 Results

In total, 27 examples of implementations of large-scale measures for utilization of excess heat have been studied within the following industrial sectors:

- Biorefinery (1)
- Food & beverages (8)
- Heat production & District heating (4)
- Metal industry (8)
- Mineral products (2)
- Non-residential buildings (1)
- Oil & gas (1)
- Wood and wood products (2)

One example per sector is described for each industrial sector and additional examples are given in tables. The following information is given in each case:

- Company name and location
- Year of implementation of the excess heat utilization measure
- Main activities
- Process of interest
- Technical solution
- Amount of energy recovered (if available)
- Effect of technical solution
- Implementation cost (if available)

1.6.1 Biorefinery

1.6.1.1 Borregaard AS – Sarpsborg (NO)

Year: 2010
Products: Biofuels

Figure 4: Steam accumulator installed in Sarpsborg (NO) – Photos: Borregaard AS / Sarpsborg Avfallsenergi AS.

Borregaard operates a biorefinery in Sarpsborg (NO). Borregaard and the district heating company Sarpsborg Avfallsenergi AS (originally under Hafslund Miljøenergi) installed a steam accumulator on the steam network linking the biorefinery to a waste-to-energy plant.

The **230 m^3 steam accumulator** weighs 160 tons and is filled up with 15-30 bar hot water to flash steam at 6 bars. The accumulator has the capacity to deliver **20-30 tons steam within 15-20 minutes** to the steam network.

The accumulator has several important purposes. It will stabilize the steam pressure in the plant by compensating for rapid changes in steam consumption by filling or draining the accumulator with steam. Previously, the network was regulated by the oil or electric boilers, but that solution provided slower regulation and unwanted pressure variations in the nets.

Including a new Waste-to-Energy (WtE) plant, the total investment was of 500 MNOK, incl. 82 MNOK of financial support from ENOVA SF.

Company involved: Sarpsborg Avfallsenergi AS

References: [11, 12]

1.6.2 Food & beverages

1.6.2.1 Tine SA – Ålesund (NO)

Year: 2015
Products: Ultra-pasteurized dairy

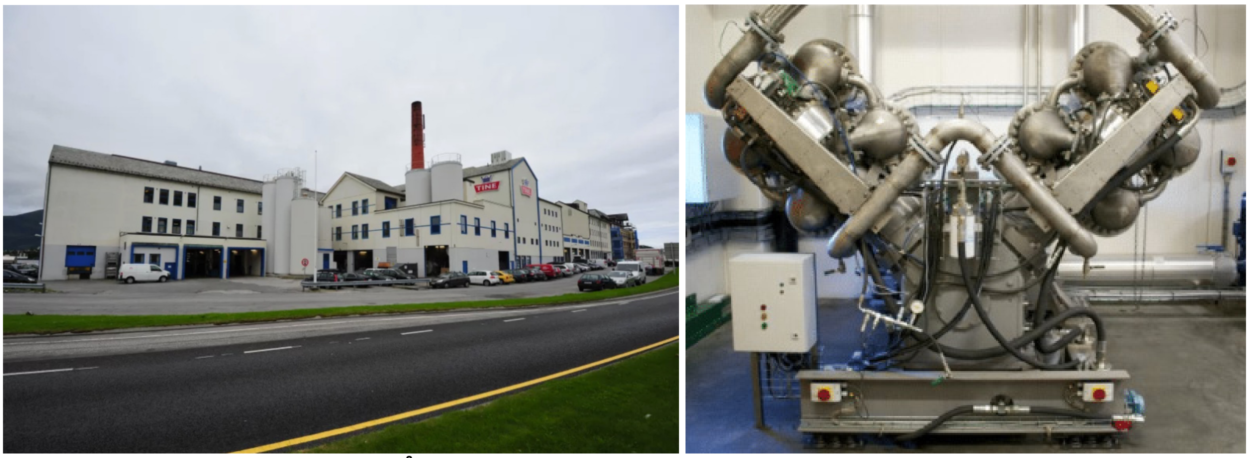


Figure 5: (Left) Tine facilities in Ålesund (NO); (Right) HTHP unit from Single Phase Power – Photos: Tine SA.

Tine is the largest milk processing actor in Norway, processing the milk from 10 000 farms. The production facility at Ålesund produces UHT (Ultra-High Temperature) dairy products.

Previously, a natural gas fired turbine produced 12 GWh/y on site, with a uniform use for about 51 weeks per year. Innovative high temperature heat pumps (HTHP) based on a Stirling cycle (Norwegian technology, produced by **Single Phase Power**) were installed. This innovative high temperature heat pump harvests heat from district heating (90 °C) and yields a temperature lift up to 180-190 °C.

The implementation of 3 Single Phase Power HighLift 104-6 high-temperature heat pumps yields an **energy delivery of 9.6 GWh/y**. In addition, about 5.2 GWh/y is harvested from the district heating network.

The combination of HTHP and district heating replaces the use of natural gas and electricity, which reduces the plant's CO_2 emissions by 66 %. This single measure yields a 5 % reduction in TINE's total CO_2 emissions. ENOVA SF provided 5.8 MNOK as financial support to install the new technology. The total investment cost is not available but should account for at least twice the ENOVA financial support.

Company involved: Single Phase Power AS.

References: [13-16]

1.6.2.2 Additional examples

Year	*Company*	*Process of interest*	*Technical solution*	*Energy recovered*	*Effect of technical solution*	*Implementation cost*
2013	Tine SA, Byrkjelo (NO) *[Dairy products]*	Various processes	High temperature heat pump with 200 kW compressor, providing cooling at 0-5 °C and heating at 120 °C.	1.4 GWh/y	Heat pump provides 200 kW cooling and 400 kW heating	
2013	Tine SA, Frya - Ringebu (NO) *[Dairy products]*	Dairy processes	High temperature heat pump	3.2 GWh/y	Additional 430 kW heating capacity	
2013	Rema 1000 AS, Kroppanmarka - Trondheim (NO) *[Grocery store]*	Ventilation, heating and cooling	Integration of ventilation, heating and cooling in addition to four boreholes for heat storage.	123.75 MWh/y saving (all measures included, not only heat recovery)	Excess heat from cooling system is stored in water tanks and reused later for ventilative heating and floor heating in the store. Boreholes provide cooling in summer and resource for heat pumping in winter. The grocery store consumes no electricity for heating and achieves 30 % lower total energy consumption than other stores.	
2014	Lerøy Seafood AS, Skjervøy (NO) *[Salmon products]*	Ammonia refrigeration plant	Recovery of superheated gas to produce hot water + ammonia heat pump for cooling/heating	0.491 GWh/y	Hot water + free cooling and heating, which corresponds to ca. 5 % saving on the plant's energy consumption	
2014	Fatland Jæren, Hommersåk (NO) *[Slaughter house, meat]*	Ammonia refrigeration system	Ammonia heat pump to recover excess heat from refrigeration condenser and produce hot water		The amount of fossil energy used to produce hot water dropped from 60 to 10 %	
2014	Skretting Fish Feed, Stokmarknes (NO) *[fish feed]*	Drying processes	1600 kW Hybrid heat pump	5 GWh/y	Upgrading of excess heat from 27-42 °C to 85 °C	
2015	Scanbio Ingredients AS, Bjugn (NO) *[fish proteins concentrates and fish oils]*	Drying process of fish peptides	Regeneration of electricity	19 GWh/y energy saving including all measures, not only heat recovery	Reduced use of heating from fossil fuel	11.35 MNOK from ENOVA for all measures

References: [13, 17-19]

1.6.3 District heating

1.6.3.1 Eidsiva Bioenergi AS – Hamar (NO)

Year: 2016
Products: Hot water for district heating

Figure 6: Eidsiva Bioenergi's Trehjørningen facilities in Hamar (NO) – Photo: Eidsiva Bioenergi AS.

Eidsiva built up in 2016 a **6000-m^3 accumulation tank** for hot water in its **Waste-to-Energy plant** in Hamar (NO). The goal is to store the excess hot water (e.g. produced at night) and release it at peak times throughout the day to prevent the use of fossil fuel-based boilers for peak loads and to ensure more stability in the waste incineration line.

The tank is 35 m high, weighs 86 tons and can take slightly pressurized water up to 115 °C for a total energy **storage capacity of 280 MWh**. This infrastructure will allow peak shaving and can secure hot water delivery for up to 10 hours.

The system entails an annual reduction in energy produced in other Hamar heating plants of **approximately 6 GWh.**

The total investment cost amounts to 38 MNOK (including 8.8 MNOK of financial support from ENOVA SF).

References: [20, 21]

1.6.3.2 Additional examples

Year	*Company*	*Process of interest*	*Technical solution*	*Energy recovered*	*Effect of technical solution*	*Implementation cost*
2011	Akershus EnergiPark, Lillestrøm (NO) *[District heating]*	Solar thermal production for district heating	1200 m^3 unpressurized hot water accumulator tank with feed temperature from solar thermal panel ca. 75-95 °C		Production peak shaving, Supply heat to district heating	
2015	Vardar Varme AS, Follum (NO) *[District heating]*	Bio-boilers	Power production from excess heat from low-pressure vapour from bio-boilers by using an expander and turbine	5 GWh/y El	1.5 MW El	6.5 MNOK received from ENOVA as financial support
2016	Statkraft Varme AS, Heimdal (NO) *[WtE - District heating]*	Hot water for district heating	5000 m^3 hot water (up to 120 °C) accumulator tank	8 GWh/y	Production peak shaving, Supply heat to district heating	

References: [19, 22-24]

1.6.4 Metal industry

1.6.4.1 Finnfjord AS – Finnsnes (NO)

Year: 2012
Product: Ferrosilicon

Figure 7: Finnfjord facilities in Finnsnes (NO) – Photo: MAN Energy Solutions.

One of the major land-based industries in Norway is metal production. One of the largest producers is Finnfjord AS, which produces 100 000 tons ferrosilicon and 20 000 tons micro silica dust per year. This major producer (15 % of European demand for steel industry) is located in Finnsnes in northern Norway.

Ferrosilicon production is extremely energy-intensive and vast amounts of energy are lost as heat in the exhaust gas from the furnaces. This exhaust gas exits the furnaces at **high temperature above 600 °C**. The gas is laden with silica dust which makes energy recovery challenging.

Excess heat was recovered from **3 FeSi-furnaces**, using **two newly designed water tube boilers** for heat recovery of the flue gas and a **40.5-MW steam turbine**. The power production started in October 2012. The total heat recovery reaches ca. **115 MW** with a production capacity up to **340 GWh EL per year**.

Finnfjord was in 2012 the world's most energy-efficient ferro-alloy plant due to their investment in energy recovery. Thanks to their 800 MNOK (100 MEUR) investment, Finnfjord has lowered the power consumption of producing ferrosilicon with up to 40 %.

Companies involved: Norsk Energi AS, MAN Energy Solutions.

References: [17, 25-27]

1.6.4.2 Additional examples

Year	*Company*	*Process of interest*	*Technical solution*	*Energy recovered*	*Effect of technical solution*	*Implementation cost*
2012	Elkem ASA, Thamshavn (NO) *[Silicon products]*	Melting ovens	Steam turbine	165 GWh/y EL + 30 GWh/y hot water (2012 was an extension from 90 to 165 GWh/y)	Local production of 30% of electricity consumed on site + hot water for district heating	39 MNOK as financial support from ENOVA, possibly 78 MNOK total - Includes measures to reduce dust emissions by 50% and lower noise
2012	Elkem ASA, Mo i Rana (NO) (previously Fesil Rana Metall) *[FeSi]*	2 FeSi furnaces	10 MW + 12 MW Shell boilers, producing saturated steam, using flue gas (600 °C down to 250 °C to enter filters)	75-85 GWh/y	Supply heat to district heating (Mo Fjernvarme AS)	25 MNOK for the 12 MW boiler facility
2013	Elkem ASA, Carbon Fiskaa - Kristiansand (NO) *[Carbon products]*	Anthracite ovens	Recovery of hot gas from anthracite ovens to oil heat exchanger and sent to pitch heating	34 GWh/y	Local re-utilization of heat enables electricity saving of the same order of magnitude	39 MNOK as financial support from ENOVA, possibly 78 MNOK total
2015	Tizir Titanium & Iron AS, Tyssedal (NO) *[Titanium products]*	New furnace technology in titanium oxide production	Water-cooled copper-ceramic roof and a system for controlled heat balance in the melting furnace	22 GWh/y energy saving including all measures, not only heat	Large energy savings and up to 23 000 tons CO_2 avoided per year	123 MNOK from ENOVA for all measures
2016	Elkem ASA, Bjølvefossen (NO) *[Ferrosilicon and magnesium silicon]*	Foundry / ovens	Steam turbine	77 GWh/y EL + heat	Local production of electricity consumed on site	54 MNOK (from ENOVA), possibly 116 MNOK total (to extend from 50 GWh/y to 77 GWh/y from 2016)
2017	Glencore Nikkelverk AS, Kristiansand (NO) *[Copper production]*	Copper demonstration plant - energy-efficient one-stage electrowinning process for production of copper	High temperature heat pump (and many other measures not directly related to utilization of excess heat)	35 GWh/yr including all measures	The new concept will reduce the energy use for the production of copper by 35 % and enable technology transfer to other plants worldwide	380 MNOK from ENOVA
2020	Elkem ASA, Salten (NO) *[Silicon products]*	Foundry /ovens	Steam turbine - Funding received in 2012 from ENOVA, solution to be operational in 2020	275 GWh/y EL	Local re-utilization of heat enables electricity saving of the same order of magnitude in heating processes + local heating network	350 (ENOVA), possibly 1000 MNOK total

References: [13, 17, 19, 25, 28-33]

1.6.5 Mineral products

1.6.5.1 AS Rockwool – Trondheim and Moss (NO)

Year: 2016
Products: Insulation materials

Figure 8: AS Rockwool facilities – Photo: AS Rockwool.

The ROCKWOOL Group is a world-leading provider of innovative solutions based on non-combustible rock wool. ROCKWOOL has more than 10 000 employees in more than 35 countries. In Norway, AS ROCKWOOL manufactures and sells environmentally sound insulation for the construction industry.

The excess heat from the Rockwool plants in Trondheim and Moss is to be supplied to Statkraft Varme for district heating (2018).

3.5 GWh is recovered for district heating in Trondheim and **4 GWh** in Moss (corresponds to ca. 500 houses). ENOVA SF partly supported the project with 1.1 MNOK.

Company involved: Statkraft Varme AS

References: [22, 34, 35]

1.6.5.2 Additional example

Year	Company	Process of interest	Technical solution	Energy recovered	Effect of technical solution	Implementation cost
2016	Norcem AS, Brevik (NO) *[Cement]*	Exhaust gas	Heat recovery from exhaust gas of the cement oven for production of low pressure steam required for CO_2 capture process by amines		Sufficient local energy recovery to steam to prevent use of new local power plant to sustain to capture of 400 000 tons CO_2/year	360 MNOK (incl. 70 MNOK support from Gassnova) to develop the concept and detailed planning of a full-scale CO_2 capture facility relying of local utilization of excess heat from exhaust gas

Reference: [22]

1.6.6 Non-residential buildings

1.6.6.1 Posten Norge AS – Trondheim (NO)

Year: 2017
Products: Logistics centre, warehouse (incl. cold products such as fish)

The Norwegian postal service, Posten Norge AS, aims at reducing its overall CO_2 emissions by 40 % by 2020. The company installed innovative equipment in their new logistic centre in Trondheim, including the ability to run the cold storage of fish and other fresh products more efficiently.

The process of interest is the **refrigeration of products at different temperatures** (-22 °C, 1 °C, 2 °C and 8 °C). The company relied on a **CO_2-booster refrigeration system** and an **excess heat trade** to/from Torgård Energi. The new system yields a lower energy consumption for different refrigeration temperatures than in previous logistic centre thanks to the recovery of excess heat and production of electricity and heating.

In addition, a partnership was established with neighboring companies Rema 1000, Brødrene Dahl and Optimera under a new local company Torgård Energi, which sells and buys excess heat from/to the mentioned participants. Excess heat is stored in boreholes in the meantime.

The energy recovered is estimated to **3 GWh/y energy saving** including all energy efficiency measures, not only heat recovery. The implementation cost was 28.4 MNOK total for the full energy system (incl. 14 MNOK financial support from ENOVA SF).

Company involved: Torgård Energi AS, Rema 1000 AS, Brødrene Dahl AS, Optimera AS.

References: [19, 36, 37]

1.6.7 Oil & Gas

1.6.7.1 Equinor ASA (Statoil) - Oseberg Platform (NO)

Year: 2014
Products: Oil & gas

Figure 9: Oseberg field centre (NO) – Photo: Harald Pettersen / Equinor ASA.

Offshore power production for oil and gas production platforms is one of the main emitters of CO_2 in Norway, contributing to 26 % of the emissions. However, due to an offshore CO_2 tax in Norway, the oil and gas industry operating on the Norwegian Continental Shelf (NCS) has adopted high standards for energy efficiency and is among the cleanest in the world measured in CO_2 emitted per barrel of oil produced.

On the Oseberg platform, a **Waste Heat Recovery Unit** (WHRU) is installed on two 25 MW gas turbines. The steam turbine skid is placed in the utility area of the platform. The WHRU-SG and the steam turbine skid are connected by a 400-m main steam pipe.

At the design point, the steam turbine **produces 15.8 MW**. Reduced fuel consumption on the generator sets is about 36 MSm^3/year leading to reduced CO_2 emissions of 80 000 tons/year.

Reference: [17]

There are more than 50 excess-heat recovery units installed on the NCS, recovering excess heat from the gas turbine for use in the oil and gas processing, as illustrated with Oseberg platform. In addition, three platforms have bottoming cycles installed for power production from excess heat. More information about the bottoming cycles can be found in recommended literature [38, 39].

1.6.8 Wood and wood products

1.6.8.1 Arba Follum AS – Follum (NO)

Year: 2018 (Not yet in operation)
Products: Bio-coal

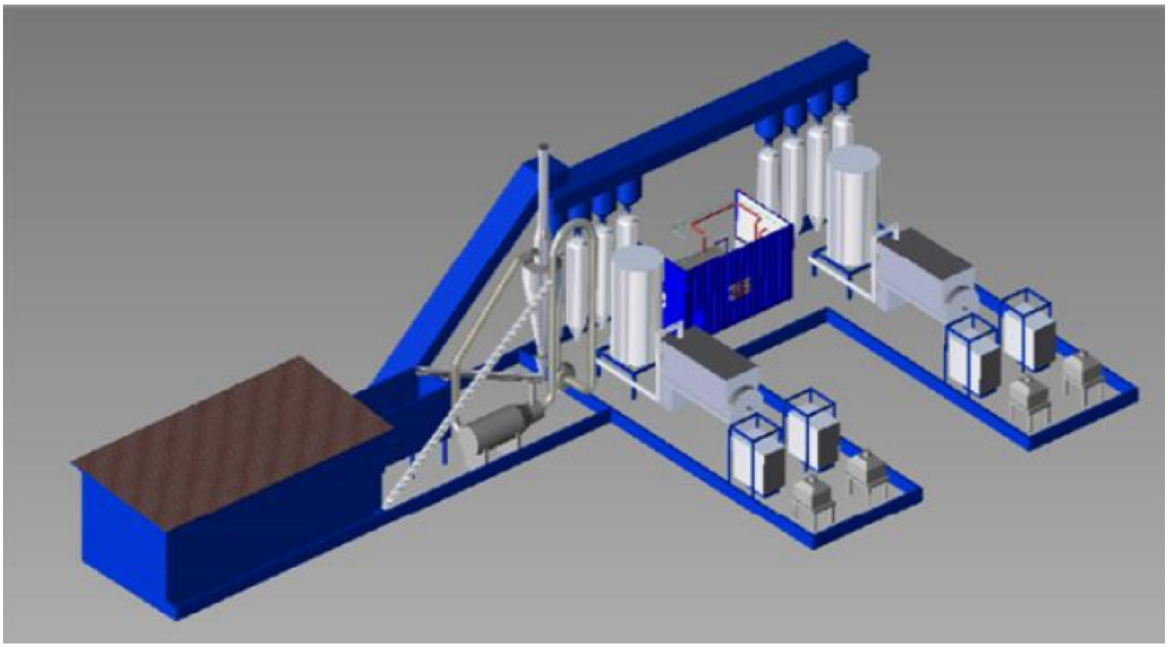


Figure 10: Overview of Arba Follum's new facility – Credit: Arba Follum AS.

The Arba Follum company was founded with the purpose of establishing demonstration plants for production of bio-based substitutes for fossil coal. The company has based its process on a patent from the company Arbaflame for an advanced wood pellet which can replace regular coal in coal-fired plants with a minimal cost for transition at the plant level.

The new plant in Follum aims at producing **200 000 tons of bio-coal per year** which is estimated to contribute to a CO_2 avoidance of 400 000 tons per year at the coal-fired plants.

The technological solutions for direct utilization of excess heat consist of:

- **Thermal integration and heat exchange** in pellet production
- **Heat recovery from process condensate** with high organic content
- **Integrated process** for production and use of biogas

The total investment cost for the new plant is 400 MNOK, including 138 MNOK financial support received from ENOVA SF.

Company involved: Arbaflame AS

References: [40, 41]

1.6.8.2 Additional example

Year	Company	Process of interest	Technical solution	Energy recovered	Effect of technical solution	Implementation cost
2014	Berry Alloc AS, Lyngdal (NO) *[Laminate wall and parquet, packaging]*	Laminate production	Excess heat recovered to district heating	3.7 MW	Excess heat recovered to district heating distributed by Sør-Energi AS, used for heating hospital, school, swimming pool, shopping mall	2.6 MNOK from ENOVA (possibly 5.2 MNOK total or more)

Reference: [42]

1.7 Conclusions

The mentioned examples give an overview of the large-scale implementations of excess heat utilization in the Norwegian industry since 2009. Both direct and indirect utilization of excess heat have been used, depending first on the heat demand profiles at the plant level and on the heat demand for space heating in the surroundings. When the temperature levels of excess heat were sufficiently high, electricity generation was made possible, as with Finnfjord AS, with self-consumption. Otherwise, heat pumps were used to lift temperatures up. Several companies specialized in high-temperature heat pumps flourished during this time period and the perspectives to see more and more implementations of this technologies are promising. Thermal energy storage, using large water tanks for the district heating or steam accumulator for industrial processes, still counts only a few implementations by now.

The majority of the mentioned implementations received support from the Norwegian Agency ENOVA SF following a national strategy to improve energy efficiency and reduce CO_2 emissions from the industry. Most of the current financial support tools effectively impacting the utilization of industrial excess heat in Norway were put in place after ENOVA SF's 2008 inventory of excess heat within the Norwegian industry. Another key factor to effectively impact the utilization of industrial heat has probably the communication of ENOVA SF around the implementations measures for each supported company to democratise this transition in industrial practice. In contrast, detailed examples of implementations of utilization of excess heat in the oil & gas sector (not covered by ENOVA SF) are not often made available publicly, though offshore platforms have widely implemented measures, for example.

1.8 Further work

Thermal energy storage is not yet widespread in the Norwegian industry and would have a great potential with regards to peak shaving, decrease in maximum power demand from network and overall energy efficiency. The potential for CO_2 emissions avoidance can be large as well when processes rely on fossil fuel combustion. The effort to democratize thermal energy storage technologies should be sustained and increased in the Task 3 of the IEA IETS Annex XV. The development of standardised methods to evaluate their potential within given processes could be an example of deliverable within Task 3.

2 Subtask 2 – Methodology for the practical inventory

Prepared by Alexis Sevault (SINTEF Energy Research), reviewed by Marit Mazzetti (SINTEF Energy Research)

2.1 Introduction

Several participants to the IEA IETS Annex XV have reported about planned national projects of inventory of industrial excess heat and expressed a high interest to compare and exchange experiences, both in the planning and performing phases. This Subtask therefore deals with results and experience from earlier inventories at national level, as well as recommendations regarding upcoming industrial excess heat inventories at national levels.

The largest national inventory of industrial excess heat in Norway was performed in 2008. The Norwegian agency ENOVA SF [43], owned by and operating for the Norwegian Ministry of Climate and Environment, commissioned an evaluation of the potential for excess heat utilization within the Norwegian industry. The investigation performed by Norsk Energi and NEPAS was published in 2009 [4] and presented data averaged from 72 participating Norwegian industries, accounting for about 63 % (ca. 53 TWh/year) of the Norwegian industry energy use. The total reported excess heat resources not utilized in 2008 reached 19 TWh and were accounted for into two different ways:

- By nature, within three categories: water/waste water, steam and exhaust gas
- By temperature range: 25-40 °C, 40-60 °C, 60-140 °C and > 140 °C

2.2 Aims and objectives

The objective of the present chapter is to share the lessons learnt from ENOVA SF's 2008 inventory of industrial excess heat [4] as well as a number of key recommendations from the analysis of the inventory's results presented in a recent study by Sevault at al. [10]. This will form the basis to draft a proposal for a standardized survey method for excess heat inventory from industrial plants.

2.3 Participants

SINTEF Energy Research is the only representative of Norway within the IEA IETS Annex XV group. Senior Researcher Marit Mazzetti has led the task, assisted by Researcher Alexis Sevault and Senior Researcher Michael Bantle.

2.4 Budget

SINTEF Energy Research has been granted a budget by ENOVA SF to actively participate in the tasks carried out by the IEA IETS Annex XV and represent Norway. ENOVA SF is a governmental agency under the Norwegian Ministry of Climate and Environment and contributes to reduced greenhouse gas emissions, development of energy and climate technology and a strengthened security of supply. The budget for Subtask 2 was 100 KNOK for a duration of 18 months.

Main deliverable: *Proposal for a standardized survey method for excess heat inventory from industrial plants*

2.5 Methodology

Feedbacks were collected from a key actor of the 2008 survey [4] regarding the methods used at that time and her own recommendations. The original survey template was also reviewed. In addition, a number of key results from the analysis of the inventory's results presented in a recent study by Sevault at al. [10] were reported. The main idea is to consider both the point of view of the survey makers as well as the one of the users of the results.

Note that the main deliverable of this subtask is a proposal for a standardized survey method which will take into account the feedbacks and experience reports from other participating countries in IEA IETS Annex XV. This deliverable is due in November 2018.

2.6 Results

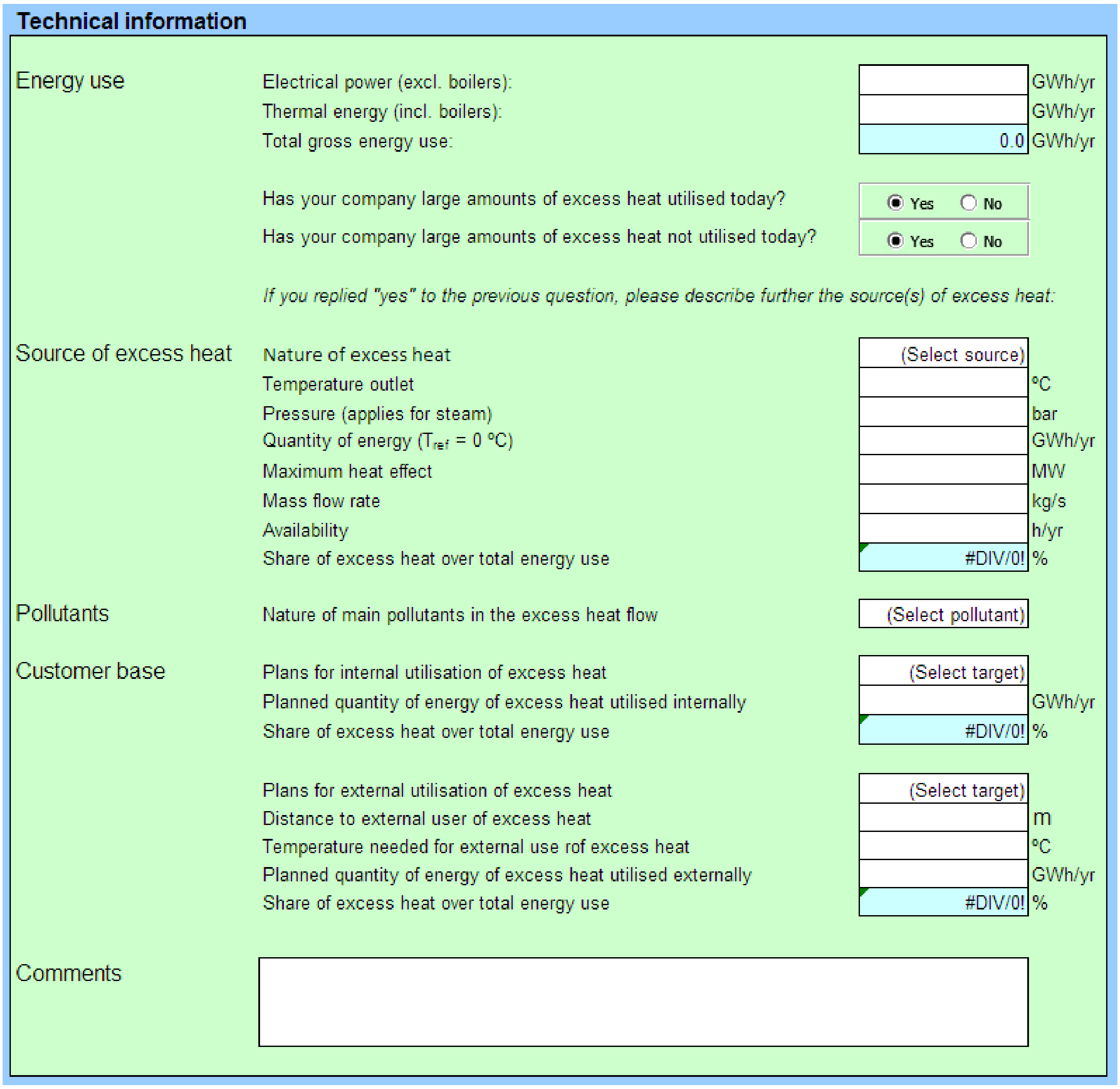
2.6.1 Feedback from the survey makers' perspective

The template used for ENOVA SF's 2008 survey [4] is shown in Figure 11 and Figure 12, translated into English. In Part 2 shown in Figure 12, the overall energy use at plant level is a key question to identify the profile of energy use of the surveyed company. Further, one or several sources of excess heat can be described and quantified in terms of outlet temperature, pressure (for steam), energy quantity, maximum heat effect, mass flow rate and availability over the year. Associated pollutants to the source of excess heat can also be described. At last, questions are made regarding on-going plans to utilize the excess heat, whether internally or externally, and to which extent.

General information

Company	Name:	VAT number:
Sector	Name: (Choose sector)	NACE: -
Contact person	Name:	Office phone:
	Email:	Mobile phone:
City	Name: Trondheim	Postcode:
Region/State	Name:	Number:

Figure 11: Survey template used for ENOVA SF's 2008 inventory of industrial excess heat, Part 1.



Technical information

Energy use	Electrical power (excl. boilers):		GWh/yr
	Thermal energy (incl. boilers):		GWh/yr
	Total gross energy use:	0.0	GWh/yr
	Has your company large amounts of excess heat utilised today?	Yes / No	
	Has your company large amounts of excess heat not utilised today?	Yes / No	
	If you replied "yes" to the previous question, please describe further the source(s) of excess heat:		
Source of excess heat	Nature of excess heat	(Select source)	
	Temperature outlet		°C
	Pressure (applies for steam)		bar
	Quantity of energy (T_{ref} = 0 °C)		GWh/yr
	Maximum heat effect		MW
	Mass flow rate		kg/s
	Availability		h/yr
	Share of excess heat over total energy use	#DIV/0!	%
Pollutants	Nature of main pollutants in the excess heat flow	(Select pollutant)	
Customer base	Plans for internal utilisation of excess heat	(Select target)	
	Planned quantity of energy of excess heat utilised internally		GWh/yr
	Share of excess heat over total energy use	#DIV/0!	%
	Plans for external utilisation of excess heat	(Select target)	
	Distance to external user of excess heat		m
	Temperature needed for external use rof excess heat		°C
	Planned quantity of energy of excess heat utilised externally		GWh/yr
	Share of excess heat over total energy use	#DIV/0!	%
Comments			

Figure 12: Survey template used for ENOVA SF's 2008 inventory of industrial excess heat, Part 2.

The first feedback received from the survey makers is that the response rate would be very low if the survey was sent by post or email and thus if industries had to fill it in themselves. To ensure a high response rate and successful survey, it was essential to take first contact by phone to find the relevant contact persons in the industry and then to organize an interview, by phone or face-to-face. On-site visits should always be considered if time allows, since trained eyes may identify excess heat sources that might otherwise be ignored.

This leads to the second feedback: it is very likely that not all sources of excess heat within the responding companies were reported. Not in order to hide anything but rather by lack of time, data or knowledge to identify such a source. Therefore, the overall levels of available excess heat are expectedly underestimated.

A third feedback is that companies with energy managers had a much better overview of their energy use and the quantity of available excess heat, certainly because they had already made plans for their utilization. The appointment of energy managers is crucial for energy-intensive industries and it is essential to show that their training to accurately measure and report data can only benefit their employers in the long term.

Such national survey occurs only occasionally. A more systematic reporting of excess heat sources for each industry to the authority, similarly to the annual reporting on energy use, would raise awareness about the excess energy to harvest and certainly stimulate excess heat utilization.

2.6.2 Feedback from the survey users' perspective

To maximize the impact of an excess heat inventory, the collected data, their display and the extent of their availability should be carefully considered. Despite the data aggregation for discretion purposes, the direct exploitation of the results by scholars and researchers might highlight new potential for utilization of industrial excess heat. In a recent study by Sevault at al. [10], a number of recommendations were issued for a next national survey of industrial excess heat, and are further developed in the next paragraphs.

Regarding the collected data, the source of excess heat may happen to be less obvious to measure than with regular flow, as for example, with a large room of chemical reactors constantly ventilated with colder outside air coming in. It may occur that, hot surfaces and, especially, heat exchangers using river or sea water as heat sink, might not be regarded as source of excess heat even though their energy content is tremendous. During the survey, providing examples of sources of excess heat as well as corresponding assessment methods would both help to identify and quantify such less obvious sources.

Though present in the survey, pressure data for the various inventoried sources of excess heat were not reported, certainly for discretion purposes. A statistical indication of pressure, at least by type of stream (exhaust gas, steam, hot water) would be of high interest. The indication of existing recovery for the expansion work associated to the reported sources could also add value to the reported results. Similarly, the information about pollutants in the sources of excess heat could be reported statistically by type of source stream. A promising technology for utilization of excess heat is for example the re-generation of steam for food processing, with was the object of the study by Sevault et al. [10], part of the research project KPN HeatUP [44] led by SINTEF. However, the contamination of excess steam by pollutants is crucial to apply this technology.

The collected data were aggregated by industry sectors for discretion purposes, to avoid displaying a direct link between reported excess heat sources and any individual company. This condition is essential to involve the industry without exposing sensitive information. However, it would be interesting to explore further ways to report about the collected data to get more out of the dataset while respecting this constraint.

The results were also aggregated according to their geographical repartition, providing a great overview of the degree of scattering of the available excess heat over the national territory. An example of reported sources of excess heat in the Norwegian industry for temperature above 140 °C is shown in Figure 2.

In Norway, most of the heat demand and consequently most of the excess heat originates from the chemical industry sector (incl. oil & gas) and the iron, steel and non-ferrous industry sector [10], see Figure 3. To ensure the highest relevance and impact, it is essential that a national survey of industrial excess heat strives for a high response rate in particular on these sectors.

In general, opening access to the gathered data, at least in an aggregated manner, would open the possibilities for further academic work around the utilization of excess heat as well as potentially generate opportunities for innovative technologies and companies to acquire a reliable picture of the industry needs. The dataset could be made available on the SSB website (Norwegian Statistics Bureau, www.ssb.no) in conjunction with the data on industrial energy use already available and regularly updated.

2.7 Conclusions

The national survey of industrial excess heat commissioned by ENOVA SF in 2008 had a deep impact in raising awareness in Norway and taking measures to utilize excess heat in the industry. A number of feedbacks have been gathered to support the design of the next national survey in Norway. These feedbacks added to those from other IEA IETS Annex XV participants will provide a strong basis for a standardized survey method.

2.8 Further work

The IEA IETS Annex XV could issue an international recommendation to, at least participating countries and eventually more, to carry out an updated inventory of industrial excess heat at national level, based on a survey method agreed upon by the Annex XV members. Finalizing the standardized survey method could be a pillar of IEA IETS Annex XV's Task 3.

3 Subtask 3 – Possible policy instruments and the influence on future use of excess heat

Prepared by Alexis Sevault (SINTEF Energy Research), reviewed by Marit Mazzetti (SINTEF Energy Research)

3.1 Introduction

Relatively to its number of inhabitants, Norway hosts a large number of energy-intensive industries, producing, e.g., aluminium, silicium, manganese, generally attracted by the relatively low-priced, low-carbon energy. In an early effort to reduce CO_2-equivalent emissions at national level, the Norwegian government implemented policy instruments in 1975 supporting the electrification of energy-intensive processes. This successful effort was then followed by an increasing focus on the energy efficiency in the industry. What makes Norway unique in this respect, is that most of the supportive mechanisms have been implemented earlier than those at European level and have generally generated a deeper impact on the energy use in the industry than the policy instruments at European level.

One of the specific impacts of the implemented national policy instruments has been the utilization of industrial excess heat in Norway. ENOVA SF [43] commissioned an exhaustive study in 2008 on the potential for utilization of industrial excess heat in Norway [4]. Beyond quantifying the available excess heat, the study pointed out some key barriers associated to the harvest of this untapped resource:

- Economic challenges, both in terms of profitability and capital investment
- Technical challenges, e.g., low temperature levels of excess heat, duration, pollutants within source flow
- Technical limitations, e.g., availability of key components, interest in Norway as a market
- Geographical distance between excess heat sources and potential heat sinks (e.g. district heating)
- Organizational challenges, e.g., difficulties to implement new and unconventional technologies, culture and interest in efficient energy utilization
- Missing political incentives and financial support.

Thereafter, the government, and especially through ENOVA SF, implemented a number of new instruments addressing directly all the above-mentioned barriers, effectively impacting the utilization of industrial excess heat in Norway. Incentives can take the forms of financial support, additional taxes or counselling for example. Inventories of existing policy instruments with an impact on utilization of industrial excess heat have been previously carried out in research projects involving SINTEF and/or other Norwegian research partners, such as KPN INTERACT[1], H2020 WaterWatt[2], FME HighEFF[3] and H2020 ODYSSEE-MURE[4].

3.2 Aims and objectives

The objective of the present chapter is to show the various policy instruments available in Norway that have an effect on the utilization of industrial excess heat. A secondary goal is to determine the extent of this effect to determine what policy measurements are the most suitable to promote the utilization of industrial excess heat in a sustainable manner.

[1] Research project KPN INTERACT (2014-2017), supported by the Research Council of Norway under grant #228656/E20
[2] H2020 research project WaterWatt, funded by the European Commission under grant agreement #695820.
[3] FME HighEFF (2016-2024), centre for environment-friendly energy research, supported by the Research Council of Norway
[4] H2020 research project ODYSSEE-MURE, funded by the European Commission

3.3 Participants

SINTEF Energy Research is the only representative of Norway within the IEA IETS Annex XV group. Senior Researcher Marit Mazzetti has led the task, assisted by Researcher Alexis Sevault and Senior Researcher Michael Bantle.

3.4 Budget

SINTEF Energy Research has been granted a budget by ENOVA SF to actively participate in the tasks carried out by the IEA IETS Annex XV and represent Norway. ENOVA SF is a governmental agency under the Norwegian Ministry of Climate and Environment and contributes to reduced greenhouse gas emissions, development of energy and climate technology and a strengthened security of supply. The budget for Subtask 3 was 150 KNOK for a duration of 18 months.

Main deliverable: *Matrix of available policy instruments with their effects*

3.5 Methodology

To make an inventory the existing policy instruments with an impact on utilization of industrial excess heat, this task could count on previous works carried out in research projects involving SINTEF and/or other Norwegian research partners, such as KPN INTERACT [45], H2020 Water Watt [46], FME HighEFF [47] and H2020 ODYSSEE-MURE [48]. A short description of each policy instrument is included, as well as some relevant facts and a qualitative evaluation of their relative impact of the utilization of industrial excess heat in Norway.

Since the Norwegian agency ENOVA SF supports the transition of Norway towards a low-emissions society, by promoting more sustainable energy technologies, it administers many of the listed policy instruments. Information about such measures are generally accessible and exhaustive on the ENOVA website.

3.6 Results

The current policy instruments in Norway impacting the utilization of industrial excess heat are listed below.

SINTEF

#	Type of policy instrument	Name of instrument	First year applied	Operator	Impact on excess heat	Description of policy instrument	Relevant facts	Ref.
I.1	Taxes	Energy and environmental taxes on energy	1975	Department of Finance / Energy fund	Medium	The energy taxes apply to electricity and fossil fuels. They have evolved through time and are dependent on energy carrier, end use and geographical location of the user. CO_2 taxes and sulphur taxes were introduced in 1991, as well as and NOx taxes in 2008.		[1], [2]
I.1.1	Taxes	Electricity taxes	1975	Department of Finance / Energy Fund	Low	There is a specific tax on all electrical power supplied in Norway, also for the power that the network companies or manufacturers make for their own use. The rates for 2018 are 16.58 øre (0.017 EUR) per kWh and 0.48 øre (0.00050 EUR) per kWh when the reduced rate applies. The main tax rate applies to households, non-industrial business activities and administrative buildings in industry. The reduced rate applies to industrial and mining production, production of district heating, all business activities in Finnmark and some municipalities in North Troms, data centers with outputs over 0.5 MW and shipping industry. There is an electricity tax exemption for power delivered to given power-intensive processes, greenhouse industry, propulsion of rail transport and households and public administration in Finnmark and some municipalities in northern Troms.	The electricity taxes were rather low until 2000 after the "Energy Commission" worked on the "the energy and power balance to 2020" and recommended a dramatic increase in electricity taxes to stabilise the electricity use. Since a number of locations and energy-intensive industry sectors are exempted and the tax levels are relatively low for the industry, especially compared to the rest of Europe, the electricity taxes are considered to have little impact on excess heat use in the industry.	[1], [2]
I.1.2	Taxes	CO_2 taxes (in addition to CO_2 EU ETS)	1991	Norwegian Environment Agency	High	Norway was one of the first countries in the world to implement in the oil & gas sector a specific tax on emissions from fossil fuels combustion. The rate for 2018 for the CO_2 tax is 1.06 NOK (0.11 EUR) per Sm^3 gas or liter oil. For combustion of natural gas, this corresponds to 453 NOK (47.36 EUR) per ton of CO_2. For methane emitted to the air, the rate is 7.16 NOK (0.75 EUR) per Sm^3 of methane. The oil & gas sector represents about a quarter of Norway's CO_2eq emissions. Norway kept the CO_2 tax for oil & gas sector also after the sector was finally included in the CO_2 EU ETS in 2008, maintaining overall CO_2 tax rates as high as before.	Approximately 50 % of Norwegian emissions are included in the EU Emission Trading Scheme. The following sectors of industry are included: pulp & paper, district heating, gas power plants, gas terminals, offshore oil & gas production, refineries, non-metallic minerals, steel production, aluminium production, ferroalloys, chemical industry. In total, 137 companies were included in the system in 2016. Impact evaluation: The Norwegian GHG emissions from enterprises in the EU ETS system were reduced by 0.5 million tons from 2015 to 2016, especially due to lower emissions from petroleum activities, oil refineries and production of fertilizers. The emissions were 25.15 million tons in 2016 which is at the same level as in 2014.	[1], [2], [3]
I.1.3	Taxes	Sulphur and NOx taxes	1991/2008	Norwegian Environment Agency	Low	Sulphur and NOx taxes have been introduced in 1991 and 2008, respectively. The NOx taxes are collected to form the NOx Fund, which has granted support to over 1000 applications to NOx-reducing measures with about 4000 MNOK (420 MEUR) total. A new NOx Agreement for the period 2018-2025 will further reduce Norway's NOx emissions.	Sulphur and NOx taxes have greatly contributed to lower both SO_2 and NOx emissions, however they had little effect on the level of excess heat in the industry. For example, only about 13% of the reported NOx-reductions are due to energy efficiency measures.	[4], [5], [6]
I.2	Financial, Information/ Education/ Training	Norwegian industrial energy efficiency network	1989 (-2002)	Norwegian Water Resources and Energy Directorate (NVE)	Medium	The Norwegian Industrial Energy Efficiency Network (IEEN) is an industry-driven energy efficiency programme financed by the Norwegian Water Resources and Energy Directorate (NVE), and membership is free to companies. Companies can get the following membership benefits: • Technical and financial support to initiate energy efficiency measures. • Investment support for purchasing equipment necessary for energy monitoring. • Information on current news and results of efficient energy use from Norway and abroad. • Energy statistics to allow comparison of own energy use with that of others in the same industry sector.	As of 1 January 2002, the IEEN had in total 786 industry members, representing a total energy use of ca. 40 TWh in 2001, which is approximately half of industry's total energy use in Norway.	[1]
I.3	Investment support scheme / Information	ENOVA SF	2001	ENOVA SF	High	Enova SF is owned by the Norwegian Ministry of Climate and Environment and contributes to reduced greenhouse gas emissions, development of energy and climate technology and a strengthened security of supply. Enova SF contributes with up to 50 % CAPEX to stimulate the implementation of relevant projects. In 2015, Enova has set new goals to accomplish its mission: • More efficient and flexible use of energy • Increased use of energy carriers other than electricity, natural gas and fuel oil for heating • Increased use of new energy resources, including energy re-utilization and bioenergy • Introduction and development of new energy and climate-technologies and solutions in the market • Well-functioning markets for efficient and environmentally friendly energy solutions • Increased general knowledge in society regarding the possibilities for utilizing efficient and environmentally friendly energy solutions • Reduced emissions in the transport sector. Enova plays a key role in achieving Norway's energy policy goals, through the promotion of financial instruments and incentives to stimulate the stakeholders and the development of energy savings measures to households and private sector. Enova administrates the Energy Fund levied from the mandatory energy taxes.	Each year, Enova SF invests more than 2000 MNOK (210 MEUR) of public resources in solutions that help build a green Norway for tomorrow. Since its establishment in 2001, ENOVA has supported more than 7000 projects (including private households) representing more than 22 TWh in energy savings.	[7], [8]
I3.1	Information	ENOVA's industry network	2001	ENOVA SF	Low	The industry network is a national network for Norwegian industry. The network provides the background for reference energy measurements and different analyses which again provide the basis for reporting, advising, best practice and effective basis of comparison. Any industry company can become a member of the network and have access to anonymous benchmark analyses for different business sectors, as well as company reports.		[1], [7]
I3.2	Information / Investment support scheme	Energy management - companies in networks	2003	ENOVA SF	High	The energy management program aims at small and medium sized companies with an annual energy consumption of at least 0.5 GWh. Companies or concerns working in project networks can apply for support to energy audits and energy management systems. The grant is individually evaluated and will not exceed 50 % of total approved project costs. The projects have to result in an energy saving of at least 10 % of the total energy consumption or conversion to new renewable energy sources. The companies have to sign a contract with a quantified energy saving/conversion.	This programme is a follow up of "Norwegian industrial energy efficiency network".	[1], [7]

I3.3	Investment support scheme	Support for introduction of new technology for renewable heating and cooling plants	2001	ENOVA SF	High	The program aims at supporting: • Establishment of infrastructure and associated power plant based on renewable energy sources. • Extension and reduction of existing district heating plants and district cooling plants. • Conversion to renewable energy production in existing heating plant based on non-renewable energy sources. Infrastructure for district heating and district cooling includes transmission facilities and distribution facilities up to the measurement point for heat and / or cooling. Any heat exchangers, power lines and customer centers can be included.	2139 MNOK (223.5 MEUR) were allocated to projects since 2001 for a total contractual energy result of 4.2 TWh.	[9]
I3.4	Investment support scheme	Support for introduction of new technology for renewable power plants	2001	ENOVA SF	High	The program aims at supporting: • Establishment of infrastructure and associated power plant based on renewable energy sources. • Conversion to renewable power production in existing power plant based on non-renewable energy sources	2511 MNOK (262.4 MEUR) were allocated to projects since 2001 for a total contractual energy result of 3.3 TWh.	[10]
I3.5	Investment support scheme	Energy and climate measures in industry and facilities	2003	ENOVA SF	High	The program is aimed at Norwegian industry and at process-related industrial installations (e.g. aquaculture, water and sewers, swimming-pool and ice skating halls, energy recovery plants). Companies can get support for physical installations for: (1) Energy measures affecting power use: efficiency, energy recovery, conversion and production; (2) Climate measures to either reduce CO_2 emissions through reduced use of fossil fuels or measures that reduce greenhouse gases other than CO_2. The project must result in reduced energy consumption, use of surplus energy and / or conversion to renewable energy of at least 100 MWh / year. Alternatively greenhouse gas emissions equivalent to at least 30 tons CO_2 equivalents per year.	21 projects were supported for the period 2012-2016 for a total contractual support of 2795 MNOK (292 MEUR) and contractual energy result of 497 GWh saved.	[1], [10], [11]
I3.6	Investment support scheme	Pre-project support for new energy and climate technology	2011	ENOVA SF	Low	The program is aimed at established companies that conduct industrial production in Norway and / or in the Norwegian economic zone. The applicant should be the one who will make use of the measure. The company can receive support for the investigation of a concrete energy measure that is already known. The investment project will have an expected energy output of 5 GWh or more per year, due to efficient energy use, efficient and renewable energy production, energy recovery or use of energy sources other than electricity, natural gas and oil for heating purposes. The aid may amount to up to 50 % of approved documented costs, but is limited to 1 MNOK (100 KEUR).	Only 7 projects were supported for the period 2012-2016.	[12]
I3.7	Investment support scheme	Support for introduction of new technology in industry	2011 (-201	ENOVA SF	Low	The program is aimed at established companies that conduct industrial production in Norway and / or in the Norwegian economic zone. The applicant should be the one who will make use of the new technology and aim at significant energy savings.	Only 9 projects were supported for the period 2012-2016.	[10]
I3.8	Investment/loan support scheme	Pilot, demonstration and full-scale innovative energy and climate technologies	2016	ENOVA SF	N/A	Enova can provide financial support to test, demonstrate at pilot or full-scale innovative technology for industry's manufacturing processes or improve energy or climate performance compared to existing solutions. The results and experiences of such a pilot will contribute to further development and to reduce the risk of using the technology at full-scale. The technology or solution must be innovative and must have a significant and realistic potential for being able to be used even outside the company. This measure consists of several programmes addressed either to established industries, technology developers or entrepreneurs. The support could be financial as an investment grant or an advantageous loan up to 60 % of the project's approved costs.	Most of these measures have been implemented since 2016 and their impact cannot be yet established.	[13]
I3.9	Information/Education	Support to the introduction of energy management in industry and equipment	2012	ENOVA SF	High	ENOVA SF can provide financial support for analysis and establishment of action lists in industry and construction companies. The support is aimed at small and medium-sized energy users using 1-50 GWh per year. ENOVA SF can provide financial support for mapping, studies and analysis, including the introduction of measurement equipment and tools necessary for the establishment of action lists and a systematic follow-up of the company's energy use. Projects must be anchored in the management of the applicant and have the ambition to contract a minimum energy target of 10 % related to specific energy use.	139 projects were supported in 2016 for a total contractual support of 68 MNOK (7.1 MEUR) and about 2 TWh of contractual energy saving.	[14]
I4	**Co-operative measures, fiscal/tariffs**	**Energy efficiency in industry (Program for energieffektivisering i energiintensiv industri)**	**2004 (-2014)**	**Norwegian Water Resources and Energy Directorate (NVE)**	**Medium**	**The programme was in operation for 10 years, from 2004 to 2014. Energy-intensive companies within the pulp and paper industry, chemical reduction processes, metallurgical processes and cement production could apply for participation in a programme for energy efficiency and the approved companies would be given a full exemption (i.e. a zero tax rate) from the electricity tax. These energy intensive companies were offered the possibility to participate in a five-year programme, which required that certain energy efficiency obligations should be fulfilled, and stipulated penalty arrangements in case the obligations were not fulfilled. These commitments were considered to replace the steering effect of the electricity tax, and the companies were therefore granted a full exemption from the electricity tax used in the industrial production process during the programme period.** **To qualify as an energy intensive company, the following conditions were to be fulfilled:** **• The purchasing costs for energy products and electricity amount to at least 3 % of the company's production value in the baseline year, or** **• Energy, CO_2 and sulphur dioxide taxes on the energy products and electricity used by the company in the baseline year amount to at least 0.5 % of the company's added value in the same period.** **The main obligations within two years were:** **• To implement a standardised energy management system that was certified by an accredited certification body.** **• To carry out an energy audit and identify electricity reducing measures and within five years.** **• To implement the identified electricity-efficient measures in the production process with a payback time of less than 3 years.**	**In total 18 pulp and paper companies participated in the programme. Due to close down of factories or other reasons, several companies have withdrawn from the programme and at the end in 2014 there were 10 companies participating. Total electricity savings were about 525 GWh (1900 TJ) and the total savings of the final 10 companies were about 271 MNOK (28.3 MEUR). In total the tax exemption was ca. 182 MNOK (19 MEUR) and the average cost of electricity savings became 0.35 NOK/kWh (0.037 EUR/kWh).**	**[1]**
I5	**R&D support**	**Funding for external R&D support**	**1946**	**Research Council of Norway**	**High**	**The Research Council of Norway serves as the chief advisory body for the government authorities on research policy issues, and distributes about nine billion NOK to research and innovation activities each year. The Research Council works to promote international cooperation and increase participation in the EU framework programme on research and innovation. The Research Council creates meeting places and provides a platform for dialogue between researchers, users of research and research funders.**		**[15]**

I5.1	R&D support	EnergiX research funding programme	2013	Research Council of Norway	High	ENERGIX is a large research-funding programme of the Research Council of Norway focusing on renewable energy, energy efficiency, energy systems and energy regulations. The programme started in 2013 and will run for 10 years. The ENERGIX programme continues the activities of the Clean Energy for the Future (RENERGI) programme, concluded in 2013. The ENERGIX programme contributes to achieve key energy and industrial policy objectives and is an important instrument in the implementation of the national Energi21 R&D strategy. The programme lays the foundation for a wide range of research activities to open the door to new thinking and innovative concepts. The programme is targeted towards Norwegian companies and research and educational institutions. Projects should enhance long-term competence-building that will further the development of the energy industry and related industries, such as the energy processing industry and the supplier industry.	The largest research project project of EnergiX and whole Norway is HighEFF - Centre for an Energy Efficient and Competitive Industry for the Future, with a budget of 480 MNOK (50.2 MEUR) over 8 years. HighEFF is a Centre for Environment-friendly Energy Research (known as FME in Norway), funded by the Research Council of Norway and industry partners.	[16], [17]
I5.2	R&D support	CLIMIT R&D funding programme	2004	Gassnova SF and Research Council of Norway	Medium	CLIMIT is a programme for research, development and demonstration of carbon capture and storage (CCS) technologies. The programme is carried out in cooperation between the Research Council of Norway, which handles CLIMIT R&D, and Gassnova, which handles CLIMIT Demo. The programme has a joint secretariat and Programme Board. Gassnova SF and the Research Council of Norway collaborate on the programme which grants in excess of 200 MNOK (21 MEUR) per year to the best CCS projects.	Though not primarily intended to reduce levels of excess heat in the industry, the programme has contributed to this goal through the process integration of CO_2 capture in industrial processes.	[18]
I5.3	R&D support	Regional research funds	2010	Research Council of Norway	Medium	The regional research funds are intended to increased R&D efforts and strengthen research for regional innovation and development. The research funds support the region's priority areas and contribute to long-term, basic competence building in relevant research environments. The goal is to develop effective and competitive research environments in all regions. The funds meet the R&D needs of the region through supporting R&D projects initiated by companies, public enterprises, including universities, colleges and research communities. Regional Research Fund aims to: • Strengthen research for regional innovation and regional development • Mobilize for increased R&D efforts in the regions • Contribute to increased research quality and development of good and competitive R&D environments in the regions • Create development and learning arenas where regional experiences can be discussed in relation to national and international knowledge and activities • Ensure close interaction between activities in the regions and their relationships with other national and international programs and activities.	A considerable number of companies seem to use the regional funding possibility as a starting point for their research-based innovation processes. All in all, about four out of ten applications were submitted by industry. The evaluation shows that even the projects established by universities and other research institutions have a relatively strong relevance for industrial development and normally involve companies or public institutions as active partners.	[19], [20]
I5.4	Investment support scheme	Innovation Norway	2004	Innovation Norway	Low	Innovation Norway is the Norwegian Government's instrument for innovation and development of Norwegian enterprises and industry. Innovation Norway supports companies in developing their competitive advantage and to enhance innovation.	A number of innovations supported by Innovation Norway have contributed to a reduction or better utilisation of excess heat in the industry. However, this is not the specific goal of Innovation Norway.	[21]
I.6	**Financial/ Trading scheme**	**Electricity certificate market**	**2012**	**Norwegian Water Resources and Energy Directorate (NVE)**	**Low**	**Since 1 January 2012, Sweden and Norway have a common electricity certificate market. The goal of the two countries is to stimulate the development of energy production based on renewable energy sources amounting to 28.4 TWh by the end of 2020. Sweden will finance 15.2 TWh and Norway 13.2 TWh.** **The Electricity Certificate System is a market-based support system for renewable electricity production. The system is based on the Swedish electricity certificate market started in 2003. Electricity producers receive one electricity certificate unit for each megawatt-hour (MWh) of electricity produced from renewable energy sources (biomass, solar photovoltaic, small-scale hydropower, wind) or from peat.**	**Studies of the common electricity certificate market between Sweden and Norway evaluated that its impact on industrial excess heat is not as straightforward as expected. For example, an increase in electricity certificate quota favours CHP plants rather than utilizing industrial excess heat.**	**[22], [23]**
I.7	**National energy strategy**	**Energi21**	**2011**	**Ministry of Petroleum and Energy**	**High**	**Energi21 is the Norwegian national strategy for research, development, demonstration and commercialisation of new energy technology. It is the Ministry of Petroleum and Energy's permanent strategic body for research, development and demonstration in the energy sector.** **The main purpose of the Energi21 strategy reports is to provide the Ministry of Petroleum and Energy with recommendations on future strategic priority areas for efforts to develop new climate-friendly, environment-friendly solutions in the energy sphere. The Energi21 strategy documents are drawn up in cooperation with trade and industry, academia and the relevant authorities.**	**High impact on energy efficiency in industry through implementations through research programme ENERGIX managed by Research Council of Norway.**	**[24], [25]**

Prepared by:
Alexis Sevault (SINTEF Energy Research)
Marit Mazzetti (SINTEF Energy Research)

Note:
Values in EUR were converted from NOK with valid rate for 2018-05-15

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3.6.1 Policy instruments with high impact on utilization of industrial excess heat

3.6.1.1 CO_2 taxes, in addition to EU CO_2 Emission Trading Scheme (ETS)

Norway was one of the first countries in the world to implement in the oil & gas sector a specific tax on emissions from fossil fuels combustion. The rate for 2018 for the CO_2 tax is 1.06 NOK (0.11 EUR) per Sm^3 gas or liter oil. For combustion of natural gas, this corresponds to 453 NOK (~47 EUR) per ton of CO_2. For methane emitted to the air, the rate is 7.16 NOK (0.75 EUR) per Sm^3 of methane. The oil & gas sector represents about a quarter of Norway's CO_{2eq} emissions. Norway kept the CO_2 tax for oil & gas sector also after the sector was finally included in the EU CO_2 ETS in 2008, maintaining overall CO_2 tax rates as high as before.

Approximately 50 % of Norwegian emissions are included in the EU CO_2 ETS. The following sectors of industry are included: pulp & paper, district heating, gas power plants, gas terminals, offshore oil & gas production, refineries, non-metallic minerals, steel production, aluminium production, ferroalloys, chemical industry. In total, 137 companies were included in the system in 2016. The Norwegian GHG emissions from industries in the EU CO_2 ETS system were reduced by 0.5 million tons from 2015 to 2016, especially due to lower emissions from petroleum activities, oil refineries and production of fertilizers. The emissions were 25.15 million tons in 2016 which is at the same level as in 2014.

References: *[48-50]*

3.6.1.2 ENOVA SF

Each year, ENOVA SF invests more than 2000 MNOK (210 MEUR) of public resources in solutions that help build a green Norway for tomorrow. Since its establishment in 2001, ENOVA SF has supported more than 7000 projects (including private households) representing more than 22 TWh in energy savings. Generally, the grants do not exceed 50 % of total approved project costs and the companies sign a contractual engagement to a quantified energy saving/conversion. A number of effective measures enhancing the utilization of industrial excess heat are listed below:

- **Energy management - companies in networks:** Addressed to small- and medium-sized companies with an annual energy consumption of at least 0.5 GWh. Companies working in project networks can apply for support for energy audits and energy management systems.
- **Support for introduction of new technology for renewable heating and cooling plants:** (1) Establishment of infrastructure and associated power plant based on renewable energy sources; (2) Extension and reduction of existing district heating plants and district cooling plants; (3) Conversion to renewable energy production in existing heating plant.
- **Support for introduction of new technology for renewable power plants:** (1) Establishment of infrastructure and associated power plant based on renewable energy sources; (2) Conversion to renewable power production in existing power plant.
- **Energy and climate measures in industry and facilities:** Addressed to process-related industrial installations (e.g. aquaculture, water and sewers, swimming-pool and ice-skating halls, energy recovery plants). Companies can get support for installations regarding (1) Energy measures affecting power use: efficiency, energy recovery, conversion and production; (2) Climate measures to either reduce CO_2 emissions through reduced use of fossil fuels or measures that reduce greenhouse gases other than CO_2.

- **Pilot, demonstration and full-scale innovative energy and climate technologies:** Financial support to test, demonstrate at pilot or full-scale innovative technologies for industry's processes or improve energy or climate performance compared to existing solutions.
- **Support to the introduction of energy management in industry and equipment:** (1) Financial support for analysis and establishment of action lists in industry and construction companies. (2) Financial support for mapping, studies and analysis, including the introduction of measurement equipment and tools necessary for the establishment of action lists and a systematic follow-up of the company's energy use.

References: [51-56]

3.6.1.3 Funding for external R&D support

The Research Council of Norway (RCN) serves as the chief advisory body for the government authorities on research policy issues and distributes about nine billion NOK to research and innovation activities each year. ENERGIX is a large research-funding programme of the RCN focusing on renewable energy, energy efficiency, energy systems and energy regulations. ENERGIX started in 2013 and targets Norwegian companies and research and educational institutions. ENERGIX contributes to achieve key energy and industrial policy objectives and is an important instrument in the implementation of the national ENERGI21 R&D strategy. Projects should enhance long-term competence-building that will further the development of the energy industry and related industries, such as the energy processing industry and the supplier industry. The largest research project of ENERGIX and of Norway is FME HighEFF - *Centre for an Energy Efficient and Competitive Industry for the Future*, with a budget of 480 MNOK (50.2 MEUR) over 8 years. FME HighEFF is a *Centre for Environment-friendly Energy Research* (FME), funded by the RCN and industry partners.

ENERGI21 is the Norwegian national strategy for research, development, demonstration and commercialization of new energy technology. It is the Ministry of Petroleum and Energy’s permanent strategic body for research, development and demonstration in the energy sector. The main purpose of the ENERGI21 strategy reports is to provide the Ministry of Petroleum and Energy with recommendations on future strategic priority areas for efforts to develop new climate-friendly, environment-friendly solutions in the energy sphere. The ENERGI21 strategy documents are drawn up in cooperation with trade and industry, academia and the relevant authorities.

References: [57-60]

3.7 Conclusions

There is a wide range of policy instruments impacting the utilization of industrial excess heat in Norway. A number of them were identified as successful due to their higher impact, especially within the measures managed by the Norwegian agency ENOVA SF. The policy instruments in place, and especially the financial support of ENOVA SF, led to a high number of technology implementations to utilize available excess heat in the industry, either internally or externally. Part of the success is due to the contractual requirement of ENOVA SF to account for the spared energy after implementations and to match the figures presented in the funding application. Another part of the success of these measures is the possibility to monetize the external utilization of excess heat for district heating, whose market has significantly grown in the last decade in Norway. Research projects focusing on utilization of industrial excess heat have also greatly contributed to raise awareness in the industry.

3.8 Further work

To raise awareness in the industry, FME HighEFF [47] has had an original approach that could be followed in other countries. FME HighEFF introduced the concept of “industry dating” to identify potential matches between producers of low-temperature excess energy and potential users of such energy. This approach allows the different industry sectors to talk to each other and identify business cases, following in a way the approach of "speed dating". Resulting synergies between the industrial sectors and ideas for low-temperature excess energy integration can be found in Figure 13.

More information: https://blog.sintef.com/sintefenergy/waste-heat/

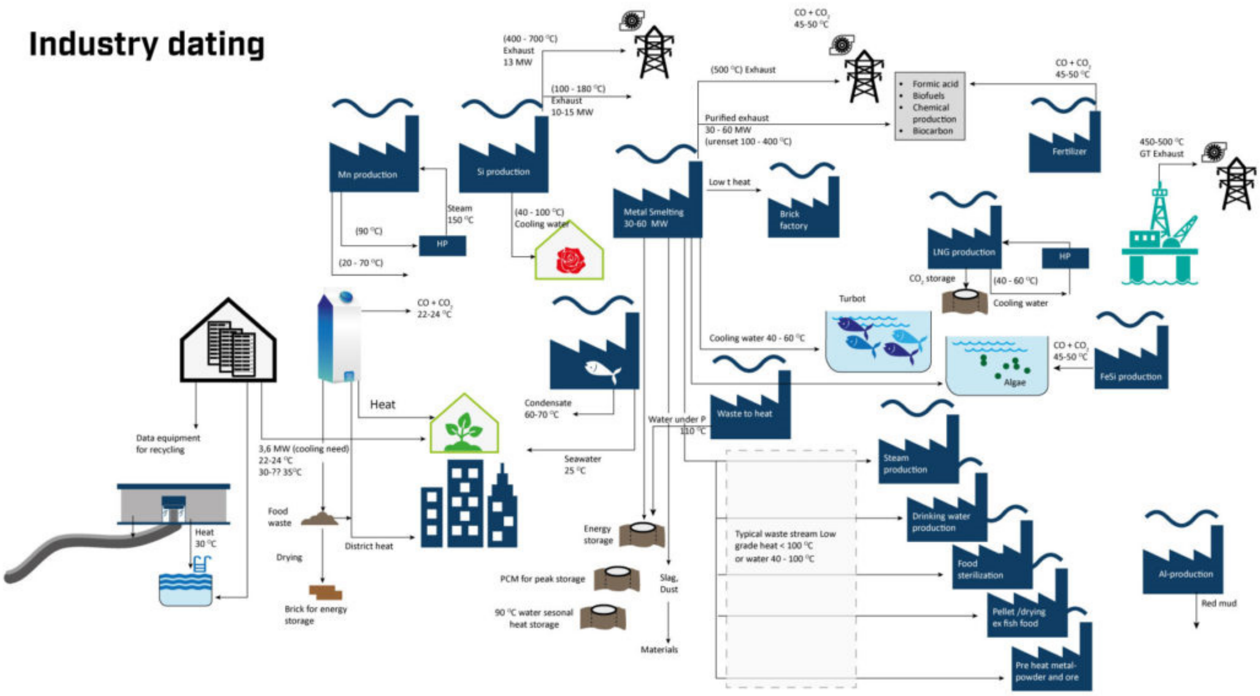

Figure 13: Illustration of possible match-making for industry sectors for excess heat utilization. Credit: SINTEF/HighEFF.

4 Subtask 4 – Technology development (contributions from R&D)

Prepared by Alexis Sevault (SINTEF Energy Research) and Olaf Lehn Tranås (SINTEF Energy Research), and reviewed by Marit Mazzetti (SINTEF Energy Research)

4.1 Introduction

The increasing demand for solutions to utilize industrial excess heat has led to the development of a wide range of technologies. Beyond heat-to-power solutions, mostly based on high-temperature steam turbines and bottoming cycle in Norway, SINTEF has focused more recently on the development of high-temperature heat pumps (HTHP). By increasing the temperature of the low-temperature excess heat, this energy can be utilized also in places where district heating is not a viable option. The work on HTHPs at SINTEF has mostly focused on three main pillars:

- Extend the maximum operational temperature above 200 °C
- Utilize natural working fluids with low or zero global warming potential
- Integrate turbo-compressors in HTHPs to reduce significantly overall implementation cost

4.2 Aims and objectives

The aim of the present chapter is to give an overview of a selection of research projects at SINTEF focusing on developing technologies to utilize industrial excess heat. There is a specific focus is on HTHPs for internal utilization of industrial excess heat since this technology is innovative, and SINTEF has made valuable technological breakthroughs.

4.3 Participants

SINTEF Energy Research is the only representative of Norway within the IEA IETS Annex XV group. Senior Researcher Marit Mazzetti has led the task, assisted by Researcher Alexis Sevault, Researcher Olaf Lehn Tranås and Senior Researcher Michael Bantle.

4.4 Budget

SINTEF Energy Research has been granted a budget by ENOVA SF to actively participate in the tasks carried out by the IEA IETS Annex XV and represent Norway. ENOVA SF is a governmental agency under the Norwegian Ministry of Climate and Environment and contributes to reduced greenhouse gas emissions, development of energy and climate technology and a strengthened security of supply. The budget for Subtask 4 was 100 KNOK for a duration of 18 months.

Main deliverable: *Recent results from research projects in the field of novel high-temperature heat pumps.*

4.5 Methodology

A selection of current research projects at SINTEF focusing on HTHPs for industrial excess heat recovery are presented. Application range, contact person, industry partners and project goals are detailed for each project. Technical results are also shown when publicly available. Corresponding publications have also been indicated for further detailed reading. First the projects focusing on the development of HTHP technology are presented, followed by the large research project HighEFF on industrial energy efficiency and its laboratory infrastructure including state-of-the-art HTHPs. Then three spin-off applied projects are presented where the focus is rather on the application of the technology.

4.6 Results

4.6.1 High-temperature heat pump technologies

4.6.1.1 KPN HeatUp

Contact person: Christian Schlemminger – Christian.Schlemminger@sintef.no

Partners:

- Statoil ASA (Oil & Gas)
- Statkraft Varme AS (District Heating)
- Hydro Aluminum AS (Metal)
- Vedde AS, member of TripleNine Group (Aquaculture/Feed)
- Tine SA (Diary products)
- Mars GmbH (Petfood)

KPN HeatUp [44] aims at developing high temperature heat pumps (HTHP) for utilisation of low temperature excess heat from industrial processes. Heat pumps have the possibility to efficiently produce thermal energy from only a fractional amount of electrical energy input. Current temperature limits are around 80 °C, which greatly restricts applications in the industry. The aim of KPN HeatUp is to extend the temperature range for heat pumps beyond 200 °C by using natural working fluids like butane, ammonia (NH_3) and water (H_2O), as these fluids have a global warming potential (GWP) close or equal to zero.

KPN HeatUp is financed by the Research Council of Norway and participating industry partners. The project started in 2015 with a project period of 4 years and a total budget of 16 MNOK. KPN HeatUp is also financing one PhD student who is addressing the topic of effective compressor designs for high-temperature heat pumps based on natural working fluids.

A turbo-compressor for use in a Mechanical Vapour Recompression (MVR) system has been tested. The first tests yielded promising results, with a system COP of 11.5 for a temperature lift of 24 °C, and an isentropic efficiency of 72 % for the compressor [61]. The potential specific energy saving compared to conventional steam dryers can be as high as 80 %. A number of challenges remain, as for instance the lubricant cooling of the gearbox under high temperatures.

Furthermore, using only commercially available components, SINTEF researchers set up a test rig for a 20 kW HTHP to test the potential for a high temperature lift for production of hot water for industrial processes. Using a cascade cycle with propane as the working fluid in the low temperature cycle and butane in the high temperature cycle, they managed to lift the temperature of waste heat by ca. 80 °C, from roughly 30 °C to 110 °C [62]. The COP was found to be up in the range 2.0 - 2.5 for the heating process and 3.1 - 4.0 for the combined heating and cooling, while the average total compressor efficiency was 71 %.

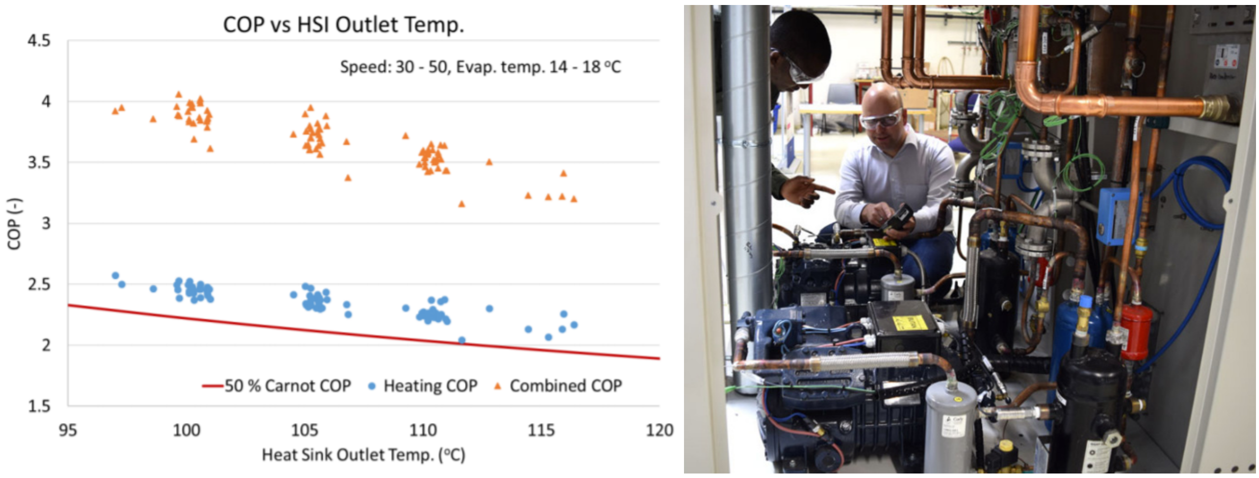

Figure 14: COP as function of Heat Sink Outlet Temp. as given in Bamigbetan et al. 2018 [62] (left). SINTEF Senior Research Scientist Michael Bantle and NTNU PhD student Opeyemi Bambigbetan are monitoring the first start-up of the prototype compressors of the HTHP (right).

4.6.1.2 DryFiciency

Contact person: Michael Bantle – Michael.Bantle@sintef.no

Partners:

- *Australian Institute of Technology (AIT)*
- *Wienerberger (brick production)*
- *Mars (pet food)*
- *Rotrex*
- *Agrana (food)*
- *Chemours*
- *Epcon*
- *RTDS*
- *Fuchs (lubricants)*
- *Ehpa*
- *Biben*

DryFiciency [63] is a project within the EU Horizon 2020 (H2020) programme, coordinated by AIT (Austrian Institute of Technology GmbH). The goal is to increase the efficiency in energy intensive industry and thus reduce the fossil carbon emissions, increase competitiveness and improve energy security by means of recovery and reuse of waste heat from industrial processes. The project addresses three sectors, namely brick, pet food and food industry, though the results are of major importance to other energy intensive industries. The ultimate goal is to elaborate technically and viable solutions for upgrading excess heat streams available at high temperatures up to 160 °C. The aim is to develop two industrial HTHP systems that are expected to:

- Save up to 80 % of energy in industrial drying processes
- Reduce carbon emissions by 57-73 %
- Reduce specific production cost by 20 % per kilogram.

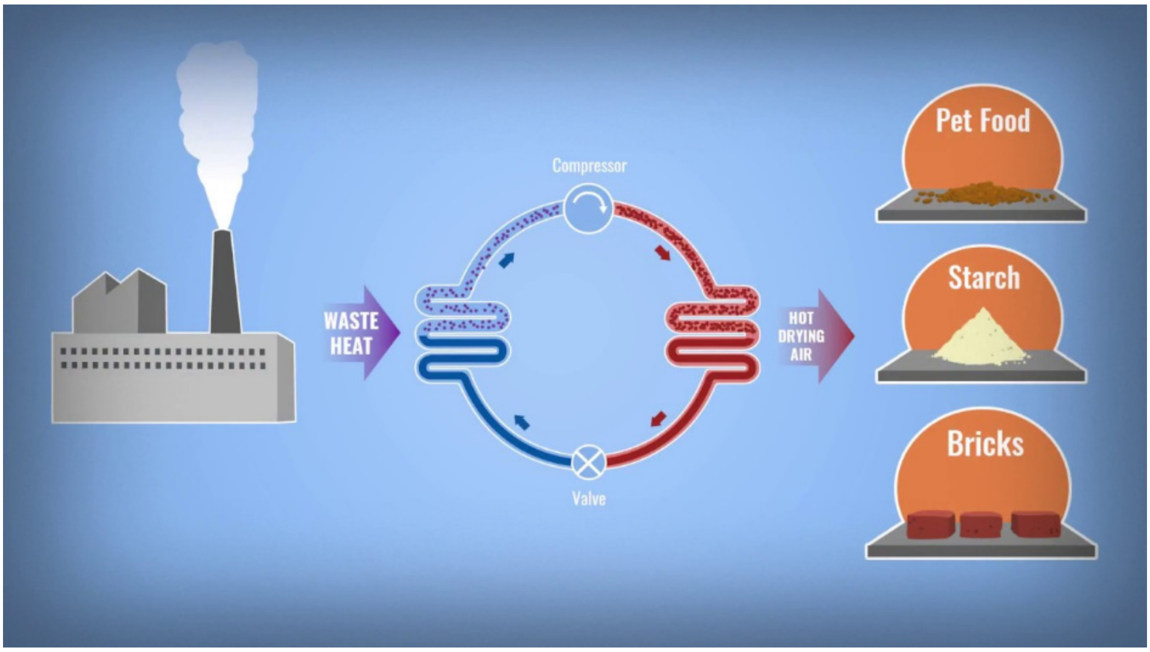

Figure 15: Illustration of the main focus of DryFiciency.

The research work has focused on an open loop MVR heat pump system using wasted steam from drying processes (see Figure 15). SINTEF Energy Research has carried out research on the use of a turbo-compression system using steam (R718) as the working fluid. More details are available in an informative video on the DryFiciency project website [63] and in a selected publication [64]. The activities on MVR within DryFiciency can be seen as a spin-off activity from the research performed in KPN HeatUP project.

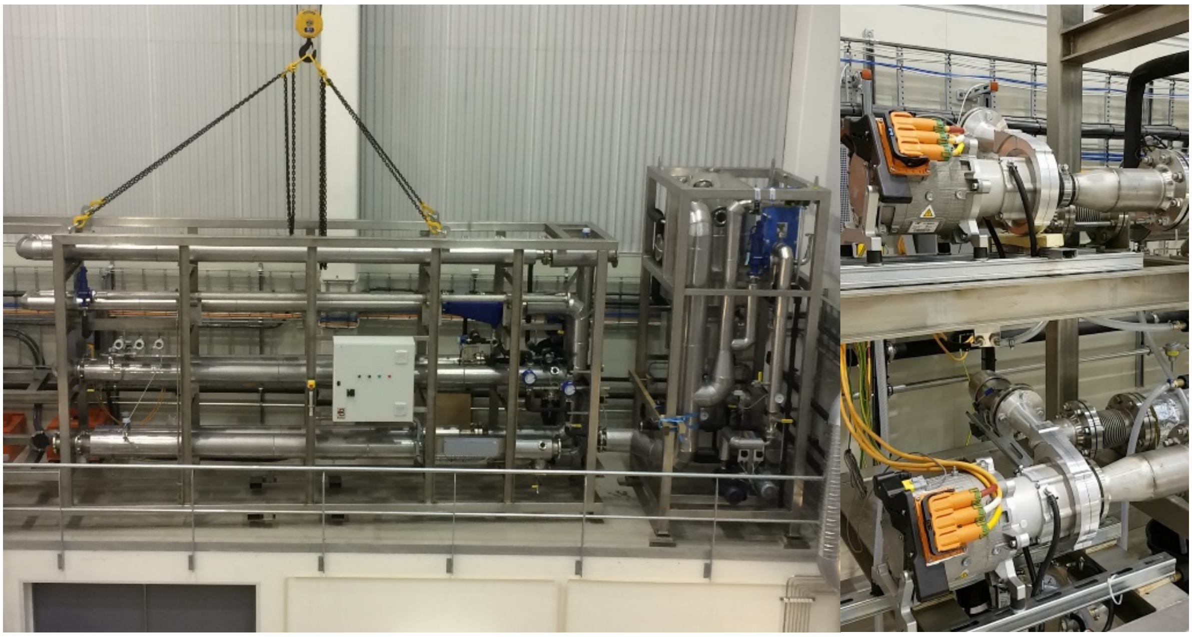
Figure 16: Installation of two-stage compressor for DryF in Trondheim (NO)

4.6.2 FME HighEFF

Project coordinator: Petter E. Røkke – petter.e.rokke@sintef.no

Budget: 42.7 MEUR

FME HighEFF [47] is a centre for an Energy Efficient and Competitive Industry for the future, led by SINTEF Energy Research. The project has a duration of 8 years, from 2016 to 2024 and has a budget of 42.7 million euros. A total of 45 partners (including 32 user partners) take part in FME HighEFF, along with 21 PhD students and Post. docs.

The goal of FME HighEFF is to reduce the specific energy use in the industry by 20 – 30 % and 10 % of the greenhouse gas emissions through implementation of the developed technologies and solutions. Research topics are divided into six *Research Areas* (RA), which a special focus on case studies in RA6 where measurable results from the implementation of FME HighEFF technologies are obtained. Figure 17 outlines the topics of each of the six RAs.

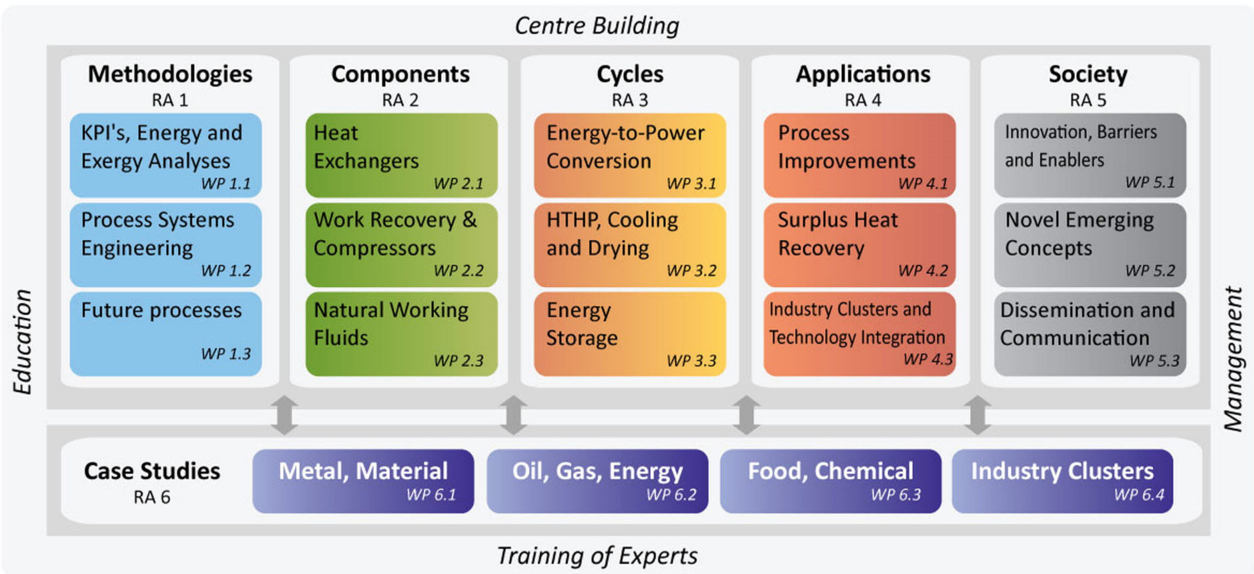

Figure 17: Overview of the Research Areas of FME HighEFF.

4.6.2.1 HighEff Lab

Contact person: Ingrid Camilla Claussen – IngridCamilla.C.Claussen@sintef.no

Budget: ca. 5 MEUR

In June 2017, the National Laboratories for an Energy Efficient Industry, HighEff Lab, was granted 50 MNOK from the Research Council of Norway to upgrade and invest in research infrastructure for the technological development needed to reach the goals of FME HighEff. The purpose of the lab is to research energy efficient utilization of excess heat from the industry, and it is run in cooperation between SINTEF and

NTNU. The lab should not only be used for research directly connected to HighEff but is available for other research tasks as well. Installations include:

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

Figure 18 shows the different Work Packages (WPs) and their time span. Among other activities, five new industrial HTHPs will be tested in the HighEFF Lab. In Figure 19, some of the equipment already installed can be seen, such as a CO_2 heat pump.

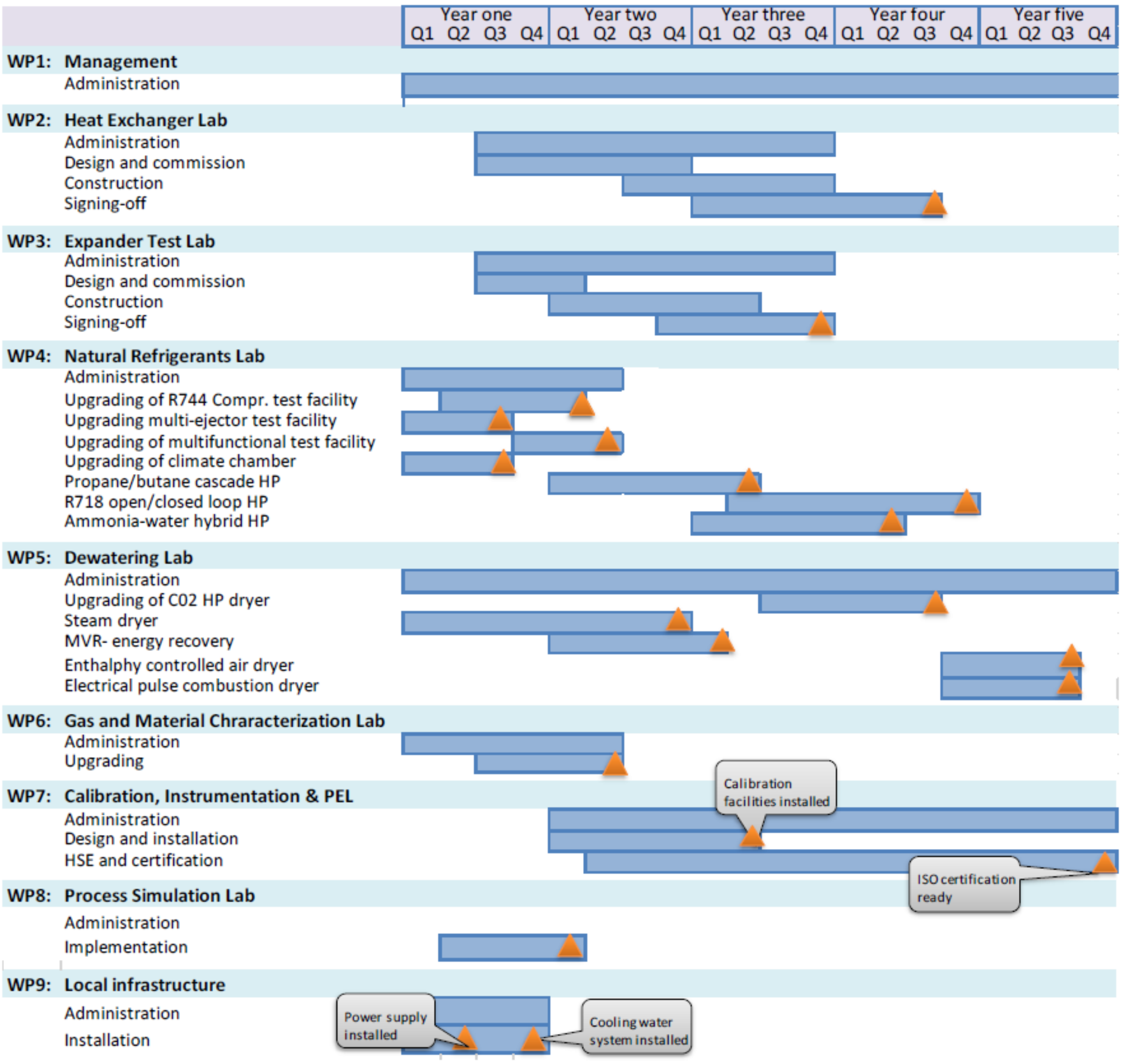

Figure 18: The different WPs of HighEFF Lab and their time span.

Figure 19: Some of the equipment installed in the HighEFF Lab: CO_2 heat pump facility (left) and propane & butane compressors (right).

4.6.2.2 RA6 Example – Tine Case study

As part of FME HighEFF RA6, a case study was carried out in 2017 to evaluate several energy system solutions for a new diary plant for TINE in Bergen (NO). The suggested HighEFF concept was to use an integrated heat pump system. It uses the heat extracted from the cooling process as heat source for a HTHP which can deliver high temperature heat to the production process.

The study included comparison of six different, innovative solutions – all using the surplus heat of the cooling process, but in different ways. The chosen solution provided good results, as shown in Figure 20. The project was granted funding by ENOVA and the full-scale system is expected to be commissioned by the end of 2019.

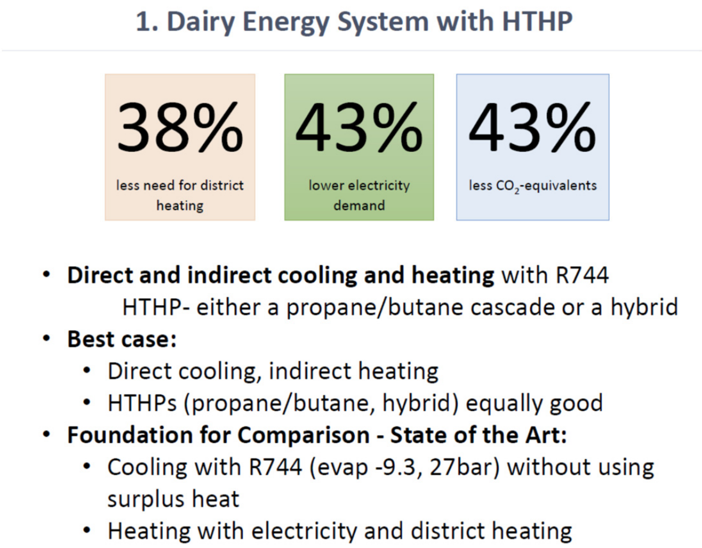

Figure 20: Key results from the Tine case study by FME HighEFF.

4.6.3 Spin-off Industry Projects

4.6.3.1 IPN CleanTex

Contact person: Ingrid Camilla Clausen - IngridCamilla.C.Claussen@sintef.no

Partners:

- *Nor Tekstil AS*
- *Epcon AS*
- *NTNU*

Budget: 10 MNOK

IPN CleanTex aims at developing a concept for a climate neutral laundry facility by using an energy- and cost-efficient heat pump technology to enable replacement of fossil fuels with clean energy. The goal is to demonstrate technical feasibility of a mechanical vapour turbo-compressor from excess heat available at Nor Tekstil AS – the user partner in the project. Figure 21 illustrates the main ideas of IPN CleanTex, while Figure 22 illustrates the main process of interest for the laundry facility. The duration is 2 years, from 2018 to 2019, and it has a total budget of 10 MNOK.

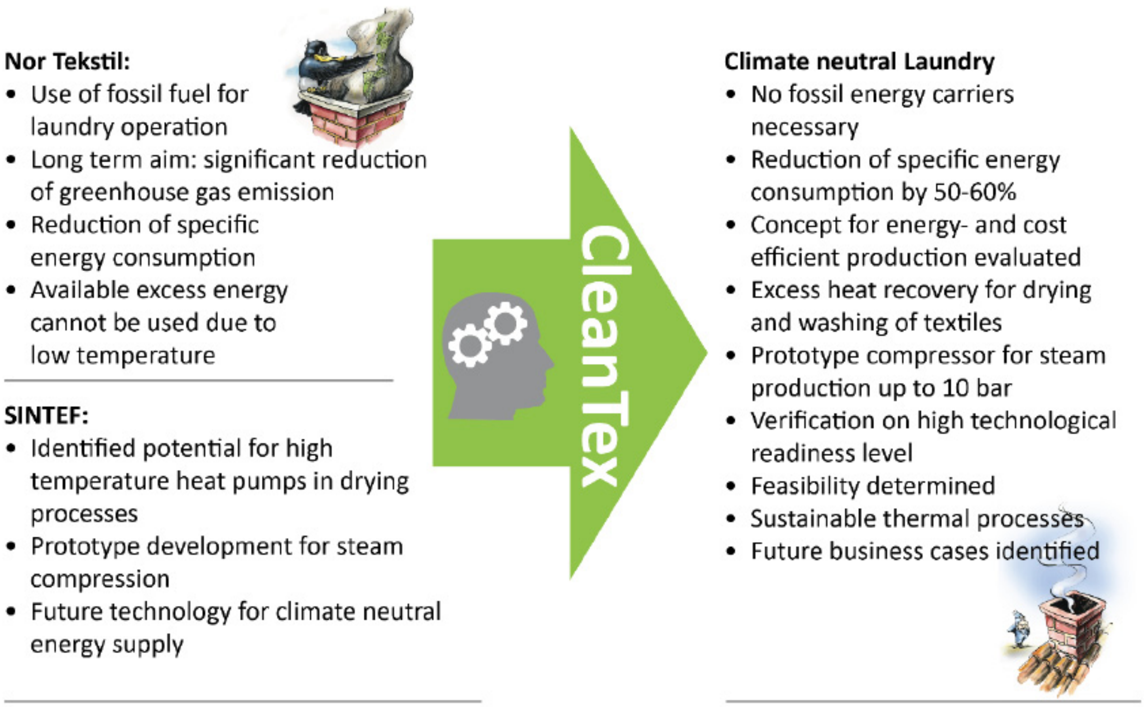

Figure 21: Illustration of the challenges, methods and goals for IPN CleanTex.

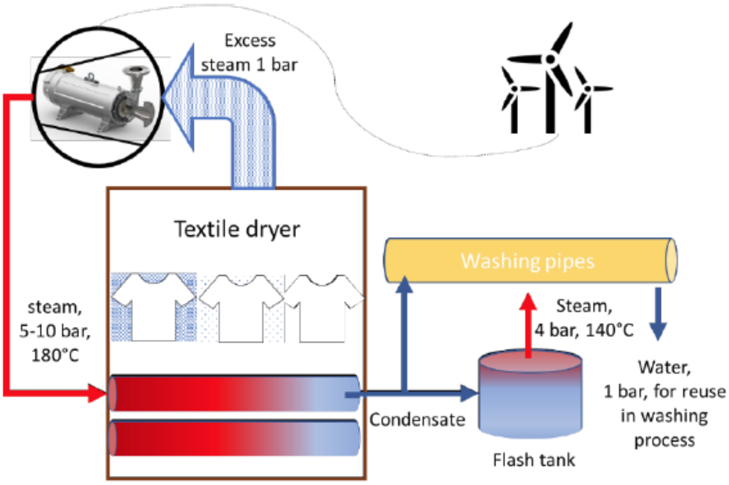

Figure 22: Illustration of the process of interest in IPN CleanTex.

4.6.3.2 IPN Free2Heat

Contact person: Michael Bantle – Michael.Bantle@sintef.no

Partners:

- *ToCircle AS*
- *NTNU*

Budget: 19.9 MNOK

IPN Free2Heat aims to develop an energy- and cost-efficient HTHP system for production of steam from excess heat and thus replace steam production from fossil fuels. With the collaboration of ToCircle AS, leading industry actor in HTHP, the project aims at saving up to 10-14 TWh in Norway and 172 TWh in Europe. This corresponds to a potential for value creation of ca. 13 – 35 000 MNOK for ToCircle. The duration is 3 years, from 2018 to 2021, and the total budget is 19.9 MNOK.

The challenges to overcome for this project evolve around:

- Fossil fuel used to produce low-temperature heat
- Excess heat available, but at too low temperature
- Flow rate of excess heat cannot be used today in heat pumps
- Compressor technology is not cost-efficient
- Today's technology does not match industry needs

An essential part of the project is the development, testing and evaluation of a two-phase compressor prototype for a two-phase HTHP system.

4.6.4 Snow for the Future

Contact person: Sverre Stefanussen Foslie – sverrestefanussen.foslie@sintef.no

Partners (Phase 1):

- *Norwegian Ministry of Culture*
- *Trondheim Municipality*
- *Ski Federation of Norway*
- *Biathlon Federation of Norway*
- *NTNU*

Snow for the Future is a project aiming at developing an energy-efficient solution for temperature independent production of snow. Figure 23 shows the structure of the different phases of the project, where Phase 1 has been completed in 2018.

During Phase 1, the main focus has been to begin development of novel technology for efficient and environmentally friendly production of snow. A review of the current state of the art technology within snow production has been carried out, along with two different master theses on snow production. The review showed that current technologies for temperature independent snow production have low energy efficiency and the potential for improvements is large. Furthermore, a modelling tool for evaluation and comparison of different approaches for fulfilling the need for snow production for a given facility has been developed.

Also, as part of Phase 1, work has been carried out to build an international research- and business network, *Centre of Snow Expertise,* for development and exploitation of technologies for *Snow for the Future.* In this regard, a workshop has been arranged in Trondheim (NO), and relations with major international business partners have been developed which will continue into Phase 2 of the project.

Furthermore, a research project with Statkraft Varme AS, a district heating supplier in Trondheim, has been carried out to investigate the possibilities of producing snow from surplus heat from district heating. The results are promising, and Statkraft Varme AS sees interest in continued work towards Granåsen skiing facility in Trondheim (NO).

Development of systems with higher efficiencies, as well as models for planning of skiing facilities will be the main focuses for the further work (Phase 2). This will be done in close cooperation with the industry.

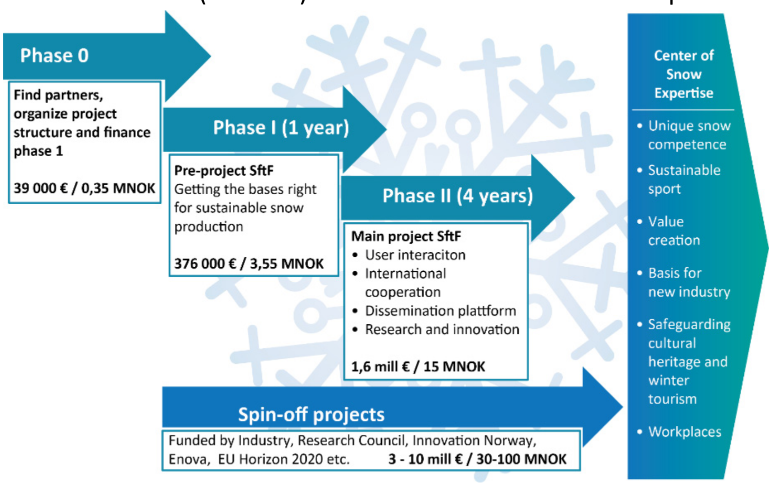

Figure 23: Overview of the different Phases of *Snow for the Future.*

4.7 Conclusions

The extent of research activities on industrial HTHPs for heat recovery has gained a lot of momentum the last years due to a higher awareness of benefits for the industry and a higher technological maturity for the companies delivering industrial heat pumps.

Additional research activities on industrial heat recovery take place at SINTEF Energy Research, such as bottoming-cycles for offshore platform, organic Rankine cycles with low-temperature excess heat for industrial processes as well as heat recovery for the process integration of CO_2 capture in various combustion and chemical processes. Thermal energy storage is also gaining momentum in the industry and dedicated research activities for heat and cold storage are on-going, especially within FME HighEFF [47] and project PCM-Eff [65], where thermal energy storage technologies using phase change materials (PCM) are in focus.

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