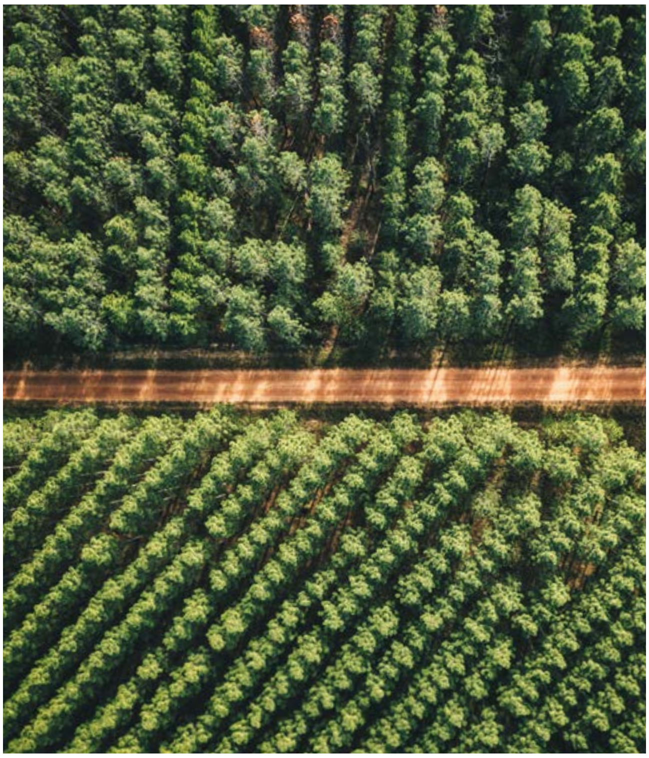
International technology scan

Alternative technologies for process heat

Energy Efficiency and Conservation Authority
Te Tari Tiaki Pūngao



Process Heat in New Zealand

New Zealand Government

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Executive summary

The goal of this report is to encourage users of industrial process heat, and their advisors, to consider a wider range of options for their process heat needs, and to adopt a long-term focus to complement the targeting of “quick wins” or business-as-usual options that only offer small incremental efficiency gains.

This report is the result of an international technology scan that identified an inventory of available technologies that could be of interest to New Zealand industry for energy efficiency and/or decarbonisation in process heat (i.e. reducing greenhouse gas emissions). It is also part of EECA’s 2018-2019 Statement of Performance Expectation (see Table 1 below).

Strategic focus area	Outcome	Action
Productive and low-emissions business Mobilise decision makers and technical experts to accelerate action.	EECA’s client businesses demonstrate best practices, continuously improve their energy and emissions productivity and motivate other businesses to take action	Identify new technologies to improve energy productivity and use of sustainable energy and then test their applicability in New Zealand

Table 1: Extract from EECA’s Statement of Performance Expectations: Productive and low-emissions businesses

The international technology scan also aligns with the Productivity Commission’s recommendation R6.3 in its “Low-emissions economy” report:

> *“The Government should investigate and implement any cost-effective institutional models that:*
>
> ✓ *scan new low-emissions technologies around the world to identify ones with promise for New Zealand but that may need adapting to suit local conditions; and*
>
> ✓ *help firms to improve their absorptive capacity for external knowledge, including new low-emissions technologies.”*

Key findings: international case studies

Primary products processing

- In terms of New Zealand’s large process heat users, key sectors that could benefit from technology changes are: **dairy, meat, food & beverage, pulp and paper, and wood**.
- The process steps consuming the most process heat in these sectors are: **drying, pasteurisation, sterilisation**, and **heating**.
- **Biogas** is an under-developed energy source for those sectors that both process plants or animals and produce organic waste, and require high temperature heat. The technology is mature and internationally there are many full-scale installations.

It is real, now.

- A range of **electro-technology alternatives to using heat are commercially available** and are already applied within key sectors of interest for New Zealand at industrial scale around the world.

Co-benefits are key

- Many of these alternative technologies offer valuable **co-benefits** (including productivity, quality, and shelf-life) which often exceed the energy and emissions savings.

Drying / evaporation

- **Heat recovery for existing assets:** If a process includes a drying operation and the existing equipment still has several years of remaining life then heat recovery should be considered. Drying enhancement technologies can also have short paybacks.
- **Asset replacement opportunity:** If a process includes a drying operation then equipment replacement should be planned early enough to allow serious consideration of low-emissions technologies and allow testing to confirm the technologies can be used.

Pasteurisation / sterilisation

- A wide range of alternative technologies are readily available.
- If a process uses heat for pasteurisation or sterilisation, switching to an alternative electro-technology could eliminate the need for high temperature, resulting in significant operating cost savings.

High temperature heat pumps

- **It's out there!** High-temperature heat pump technologies supplying >80°C heat are commercially available overseas, with numerous example installations in sectors relevant for New Zealand industries.
- **Performance is already good:** Coefficients of performance (COP) of three to five are readily achievable, even with significant temperature uplifts of 40°C to 60°C and supplying temperatures above 80°C.
- **It's improving!** 'State of the art' research projects currently supply temperatures of 120°C with a COP of up to six and an uplifts of 60°C to 90°C.

Key findings: technology-related policies scan

- Several countries (including UK, Germany, France and Japan) subsidise technical options that are proven to have positive cost-benefit outcomes from a public policy perspective.
- The subsidies are mostly available for energy-efficiency measures, crosscutting technologies [1] and renewable energy options. Those most relevant for the New Zealand context are: boiler systems optimisation, heat recovery, heat pumps, refrigeration optimisation, heating and cooling networks, thermal storage (heat and cold), space heating optimisation, biomass, electrification and biogas.
- Some technologies specific to critical sectors are also incentivised. Those targeting the agricultural sector (milk, livestock, and greenhouses) are of particular interest to New Zealand and could be future areas of focus to help each sector to reduce emissions.

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[1] Cross-cutting technology: A technology that has a wide array of applications. In this report, it means both cross-sectoral and cross-application.

1.0 Background and Main Findings

1.1 Introduction

This report provides an inventory of available technologies that could be of interest to New Zealand industry for energy efficiency and/or decarbonising in process heat.

Recognising the opportunity that exists in this area, the Ministry of Business, Innovation and Employment ('MBIE') is currently working with the Energy Efficiency and Conservation Authority ('EECA') on the Process Heat in New Zealand (PHiNZ) initiative that aims to identify the opportunities for, and address barriers to, improving the energy efficiency of process heat and increasing the input of renewable energy.

Why a focus on process heat?

Process heat offers one of New Zealand's largest opportunities to improve energy efficiency and reduce energy emissions.

Process heat is the energy used as heat mainly by the industrial and commercial sectors for industrial processes, manufacturing, and warming spaces. This is often in the form of steam, hot water or hot gases. Around half of New Zealand's process heat demand is currently met by burning coal or natural gas.

Using industrial energy use data from 2016, PHiNZ has identified that:

- process heat accounted for 35% of New Zealand's energy consumption
- around 55% of process heat demand was supplied by burning fossil fuels, mainly coal or natural gas
- around 68% of process heat was made using boiler systems
- the industrial sector (79%) was the largest user of process heat, including sawmills, pulp and paper mills, and food processing plants (including dairy)
- the commercial sector (10%) was the next largest user — mainly in shops and office buildings.

A full copy of the PHiNZ analysis of New Zealand's process heat current state can be found on MBIE's website.

Over a quarter of the energy used in New Zealand is for industrial heat processes

72%

of it comes from non-renewable energy sources.

By 2030 businesses could be saving $1.28 billion every year from energy efficiency.

EECA works with businesses that represent roughly 25% of New Zealand's energy use (excluding transport).

EECA's contribution to the SDGs through our work in productive and low-emissions business:

EECA STATEMENT OF INTENT 2018-2022

An international technology scan can help to address barriers

The PHiNZ initiative draws on qualitative research carried out by PwC (2018)[2] with nine large process heat users in New Zealand. This research found evidence that an energy efficiency gap exists for many process heat users in New Zealand, and that there are several key barriers, including:

- **Lack of information and/or aversion to new technologies**

  Organisations do not have perfect information, particularly about new or emerging technologies, and engineering consultants can have a bias towards proven technology (i.e. a preference for what they know has worked in the past).

  Firms and consultants tend to be risk averse with regards to new energy efficiency technologies. However, technology evolves over time while knowledge and/or perceptions may not; for example, microwave solutions today are vastly different from 20 years ago.
- **Hidden benefits of energy improvements**

  For large process heat users in New Zealand – where energy is often in their top three operating costs – energy savings are the main driver for investing in energy efficiency projects. However, in practice many energy efficiency projects also achieve significant co-benefits (such as increased production). Highlighting the co-benefits is therefore key when building the business cases of these projects.
- **Production disruption**

  A significant barrier to implementing process-heat energy-efficiency and renewable-energy projects is the fact that these technologies tend to be integral to the production process. This makes it difficult to implement projects without disrupting production.

  Consequently, to avoid missing opportunities to transition to better technologies it is crucial to take a long-term view and plan ahead when managing assets upgrades and replacement.

This international technology scan is one step in helping to address the barriers outlined above.

This technology scan provides an international perspective of the available alternatives to production processes currently using significant amounts of process heat. In identifying the alternatives, the scan has looked to answer the following key questions:

- what is the technology?
- is it real/commercialised?
- how advanced is it?
- who is using it and what are the reported outcomes?

Case studies

- This report contains:
- 21 case studies on innovative technologies
- 21 case studies on high temperature heat pumps
- 6 cases studies on biogas application on natural products processing sectors.

An increased focus on long-term thinking for low-carbon businesses

EECA is seeking to assist customers in taking a longer-term view of political and technological opportunities and risks for low carbon businesses, and to help them prepare for the future by capitalising on the energy and carbon saving opportunities that are in the pipeline now and through to 2030 and beyond.

This long-term thinking requires organisations to consider future production needs, and match the investment cycle of asset management with more radical technology change (rather than simple improvements of business-as-usual options). The worst outcome would be investments in outdated long-life assets where less emissions-intensive options could have been implemented.

The general approach used to define a transition pathway is described in diagram 1 below.

The purpose of this international technology scan therefore, is to clear the way for alternative technologies in New Zealand's key sectors of focus.

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[2] PwC (2018). Large process heat users and energy efficiency in New Zealand. Available at https://www.eeca.govt.nz/assets/Resources-Main/Large-process-heat-users-and-energy-efficiency-in-New-Zealand.pdf

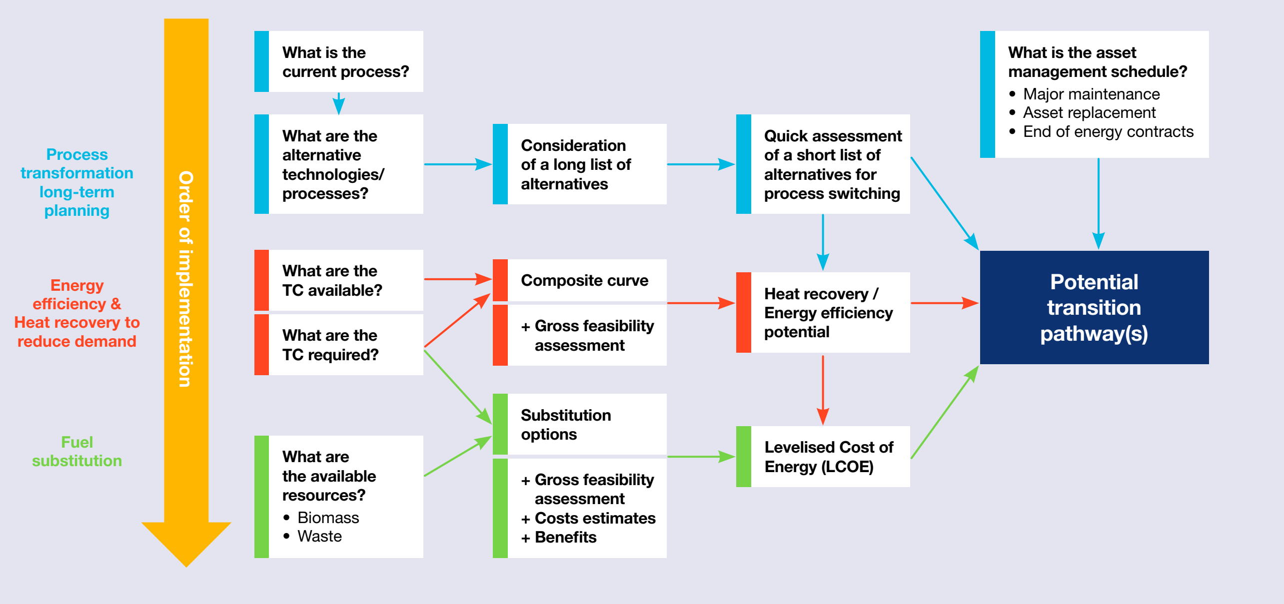

Diagram 1: Approach to define a transition pathway

Other related EECA publications

More technical details on some of the electro-technologies mentioned in this report can be found on EECA's website.

A PHiNZ technical paper has identified and explained the barriers to energy efficiency and GHG emissions reduction in process heat.

1.2 Purpose

This report provides an inventory of available technologies that could be of interest to New Zealand industry for energy efficiency and/or decarbonisation in process heat.

The goal has been defined as "identifying potential technological gaps between New Zealand and international practices in process heat".

This work will help to inform PHINZ, and identify new opportunities for both EECA and New Zealand industry.

1.3 Scope

The scope of this study has been defined to include process heat technologies that:

- are commercially available or near-commercially available: technology readiness level of 7 to 9 (see diagram 2 for the complete Technology Readiness Level scale)
- will reduce energy consumption and/or carbon emissions
- deliver reasonable payback periods
- offer potential for replication.

Diagram 2: Technology Readiness Level scale

Credits: CloudWATCH

www.cloudwatchhub.eu/exploitation/brief-refresher-technology-readiness-levels-trl

While the internationally used Technology Readiness Level scale may be relevant to help define the scope of this study, it may not be the best way to identify different technology maturity levels.

As highlighted in diagram 3 (below), some technologies can be commercialised but still in a fast improvement phase – a positive sign of the technology's vitality although early adopters may prefer to wait until the next generation of equipment.

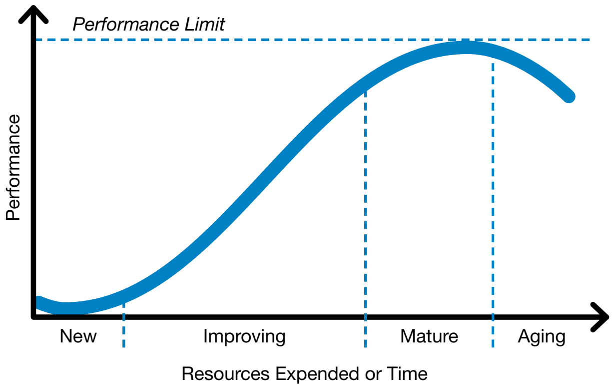

Diagram 3: Representation of the maturity cycle for a technology

Therefore, the evaluation used in this report is a qualitative mix of these two aspects. For example, while high temperature heat pumps are fully commercially available (TRL=9), the technology is still evolving and so performance falls within the 'improving' phase of the maturity curve. Therefore, high temperature heat pumps are adjusted at a rate of 8 in this report.

1.4 Approach

This international (process heat) technology scan focuses on:

1. benchmarking policies that incentivise the adoption of specific technologies in five leading countries: UK, Germany, France, Japan, Canada
2. screening international cases studies, guidelines and reports published by energy agencies or sectoral organisations, identifying those that could be of interest in a NZ context (i.e. targeting specific sectors and processes).

This international technology scan therefore provides:

- a review of publicly available international case studies
- an overview of available technologies that could potentially play a role in New-Zealand's transition to a low carbon economy.

Equally important is noting what this international technology scan does not provide:

- it does not endorse any technology or supplier mentioned in this report: each application/project is different and will need to undergo a full due diligence process
- new case studies
- New-Zealand case studies (these can be found on EECA's website)
- an exhaustive overview of all available technologies for sectors of New-Zealand's economy
- a list of "silver-bullet" technologies (i.e. solutions that address every problem that exists)
- a technically detailed analysis of each technology's potential for sector-specific applications.

1.5 Mainstream technologies available for energy and emissions savings

The technology-related policies scan carried out on several countries leading the way in terms of subsidizing and incentivising the transition to a low emission economy (i.e. UK, Germany, France, Japan, Canada) identified a long list of mainstream technologies (i.e. defined as immediately available and commercially mature) capable of playing a role in New Zealand's transition to a low-carbon economy.

The full list of identified technologies is provided in Appendix 1.

A high-level assessment of the complete list has identified the best potential opportunities for New Zealand industry, being:

- **Boiler optimisation systems:** offer good potential with well-identified actions but should be considered good practice rather than new technology so they have not been investigated further in this study.

- **Heat recovery:** good potential in New Zealand, although the challenges of integrating the technology into existing facilities is a well-known barrier.
  - Developing good case studies would help to bring insight on the economics of adopting the technology locally.
  - Pinch analysis is a powerful, yet under-utilised method to optimise heat recovery in a plant.
- **Air heat recovery:** good potential in New Zealand, especially in industries with large drying needs.
- **Heat pumps:** huge potential in New Zealand for the electrification of process heat applications.
  - This report has focused on a general overview of commercially available high temperature heat pumps – state of the art (performance and working fluid) and case studies.
- **Alternative energy sources:** offer good potential for New Zealand, although this obviously varies between energy sources. Alternative energy sources that offer greater potential in New Zealand for process heat are biomass, biogas or electricity.
  - **Biomass** combustion is well known in New Zealand. It involves technologies similar to coal combustion, allowing a transition to co-firing or full fuel switching (the main point to investigate for a particular application being the availability of the biomass in the area of consumption). More information is available on the BANZ website.
  - **Biogas** potential appears to be under-developed in New Zealand; it is relevant for applications requiring a high temperature energy source (e.g. steam, cooking drying, etc), or for easier fuel switching from natural gas. Most biogas projects are largely driven by the waste treatment benefit, energy production being a co-benefit. This report contains several case studies of biogas projects in the Wood, Paper, Meat, and Food & Beverage sectors. More information is available on the BANZ website.
  - **Electrification** is relevant in New Zealand considering the high level of renewables in the electricity generation mix. Some of the alternative technologies presented in this report allow electrification of processes. More technical details about electro-technologies can be found in EECA's factsheets.
  - **Geothermal** is an interesting option when a local opportunity is available. Given New Zealand's highly developed geothermal technologies, there is little benefit in scanning international technologies. It is, however, an option worth further consideration in the right circumstances.
  - **Solar thermal** could also be of interest for New Zealand. Commercial solutions are available abroad that are specifically targeted to process heat applications, although current economics are leading these solution providers to more obvious markets in countries with greater solar resource than New Zealand. However, considering the great solar resource of Australia and the strong links between Australian and New Zealand markets, there is a lesser risk of technological gap for solar thermal. For an overview of existing solar process heat installations around the world, see the IEA's task 49[3].
- **Refrigeration systems:** good economic potential for New Zealand although these systems use electricity which is already considered low emission due to the significant level of renewable generation here.
  - Like boiler optimisation systems, energy users require more information and a more exhaustive approach from energy service providers.
- **Heat and cold storage:** good potential for New Zealand.
  - Storage technologies are a way to facilitate heat recovery when production and consumption are not time-aligned.
  - For cold production especially, storage is a way to displace electricity consumption when it is cheaper and renewable.
  - On-site heat/cold storage capability is a cost-efficient way to optimise heat and/or cold production equipment capital cost and efficiency.
- **Space heating system optimisation:** offers potential for New Zealand in public buildings with central heating (e.g. hospitals, universities, prisons, etc) or warehouses.
- **Specific industrial machinery:** there is potential for New Zealand in this category, particularly in key industrial sectors of the local economy.
  - The second phase of this study will focus on specific technologies applicable to sectors and/or applications relevant to the New Zealand economy.
- **Specific systems for agriculture:** good potential for New Zealand.

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[3] http://task49.iea-shc.org/Data/Sites/1/publications/SHC-2014--Brunner--Solar-Heat-for-Industrial-Processes.pdf

- **Factory Energy Management System (FEMS)/Smart Factory:** offers potential for New Zealand's large energy users, although these solutions require a minimum complexity and scale in the manufacturing process to be economically relevant. In New Zealand, the technology could be applied to food processing.
- **Waste heat to electricity:** these options are of lesser interest in the New Zealand context (i.e. with a relatively low emissions network electricity and high emissions process heat).
- **CHP/Cogeneration:** again, these options are of lesser interest in the New Zealand context (i.e. with a relatively low emissions network electricity and high emissions process heat).
- **Heat and cold networks (mostly known in New Zealand as "district heating"):** no widespread adoption in New Zealand. No specific technology.
  - The technology does not fit within the purpose of this study, except to note that it is a solution that many countries heavily rely on, and is under-developed in New Zealand. The densification of population in specific areas could be an opportunity for future projects.

1.6 Innovative technologies applicable to New Zealand's "sectors of interest"

In this section we consider innovative technologies that are commercially available internationally but not yet mainstream applications in New Zealand.

In order to maximise the potential benefits of these technologies, it is necessary to also identify those industries (i.e. "sectors of interest") that could most benefit from them. These sectors have been identified using the following criteria:

- processes that contribute significant emission impact
- sectors with sufficient numbers of sites/plant to allow for replication.

Industries meeting these criteria are considered as "sectors of interest" and are summarised in table 2, sorted by order of total emissions. Industrial sectors with only a few plants have been excluded from this study; a bespoke approach being more relevant for them.

A high level assessment of the identified sectors, supported with international data available on energy consumption within these sectors, indicates the following process steps represent a significant share of New Zealand's total industrial process heat consumption (and will therefore form the basis of this technology scan):

- drying / evaporation
- sterilisation / pasteurisation
- heating (cooking / blanching / melting / reacting / etc)
- refrigeration.

		Energy Use				**Emissions**		
Sector	Plants	GWh	PJ	% of Process heat total	Rank	ton CO_2/y	% of Process heat total	Rank
Dairy - Milk Powder	50	8,688	31	14.1%	3	2,263,708	24.4%	1
Dairy - Other	30							
Meat	179	2,371	9	3.9%	5	659,640	7.1%	23
Food (other)	100+	2,739	10	4.4%	4	557,097	6.0%	3
Pulp & Paper	5	10,924	39	17.7%	1	427,790	4.6%	4
Wood	110	8,981	32	14.6%	2	288,826	3.1%	5

Table 2: Identified "Sectors of Interest"

It has been relevant to scan technologies by process step given many of them will be applicable to several sectors; even though the application of the technology (and therefore the level of commercial development) may vary between sectors.

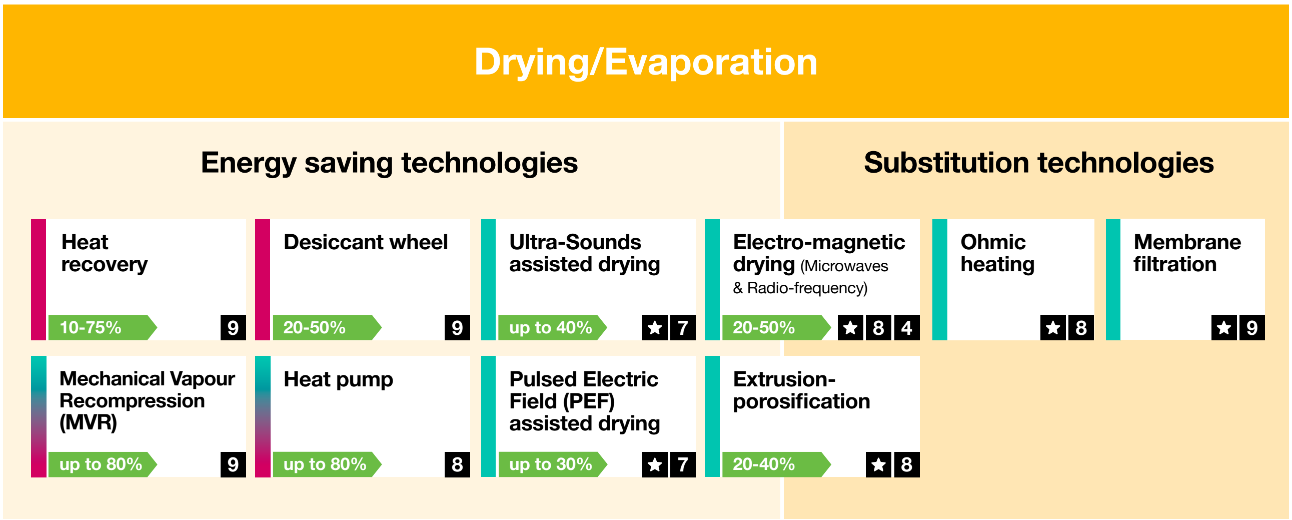
At many industrial sites, a process heat technology is applicable to different process steps throughout the site, so the diagrams below summarize the findings by process step.

Each diagram below summarizes the technologies identified and classifies them by category. Each technology is characterised by:

- a colour code to represent its thermal or / and electric nature
- a number illustrating its stage of development and maturity (see diagrams 2 and 3)
- a star to indicate if significant co-benefits (other than energy related) are reported
- an estimate of the level of indicative energy savings (based on savings reported in case studies).

Legend

Involve heat
Involve electricity
Both
★ Co-benefits
7 LTR (Level of Technology Readiness)
Energy savings



Drying/Evaporation

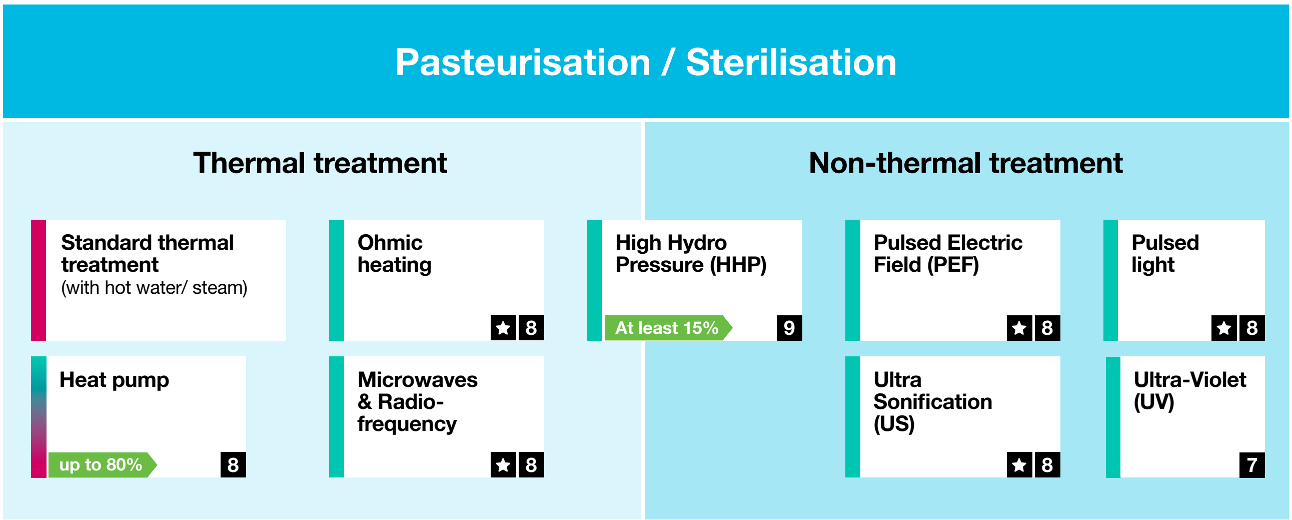
Energy saving technologies

Heat recovery	10-75%		9
Desiccant wheel	20-50%		9
Ultra-Sounds assisted drying	up to 40%	★	7
Electro-magnetic drying (Microwaves & Radio-frequency)	20-50%	★	8 4
Mechanical Vapour Recompression (MVR)	up to 80%		9
Heat pump	up to 80%		8
Pulsed Electric Field (PEF) assisted drying	up to 30%	★	7
Extrusion-porosification	20-40%	★	8

Substitution technologies

Ohmic heating		★	8
Membrane filtration		★	9

Diagram 4: Drying / evaporation



Pasteurisation / Sterilisation

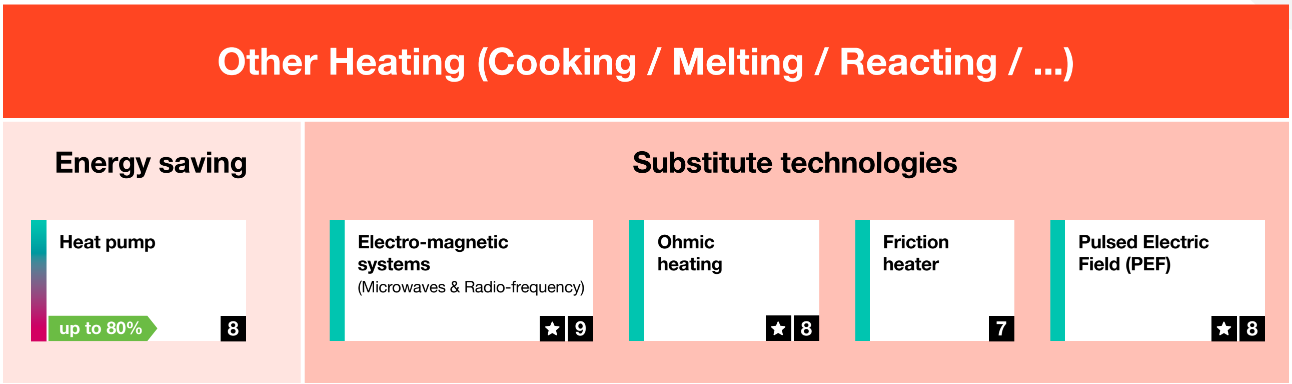
Thermal treatment

Standard thermal treatment (with hot water/ steam)			
Ohmic heating		★	8
Heat pump	up to 80%		8
Microwaves & Radio-frequency		★	8

Non-thermal treatment

High Hydro Pressure (HHP)	At least 15%		9
Pulsed Electric Field (PEF)		★	8
Pulsed light		★	8
Ultra Sonification (US)		★	8
Ultra-Violet (UV)			7

Diagram 5: Pasteurisation / sterilisation



Other Heating (Cooking / Melting / Reacting / ...)

Energy saving

Heat pump up to 80% 8

Substitute technologies

Electro-magnetic systems (Microwaves & Radio-frequency) ★ 9

Ohmic heating ★ 8

Friction heater 7

Pulsed Electric Field (PEF) ★ 8

Diagram 6: Other heating (cooking / melting / reacting / etc)

Table 3 provides an overview of the applicability of each technology for each of New Zealand's "sectors of interest".

Technology / Sector	Dairy	Meat	Food (other)	Pulp & Paper	Wood	Horti-culture	Chemical	Pharma	Ceramics
Heat recovery	●	●	●	●	●	●	●	●	●
High Temp. Heat pump	●	●	●	●	●	●	●	●	●
Desiccant system	●	●	●	●	●	●	●	●	●
MVR	●						●		
Ultra-sounds	●	●	●	●	●		●	●	
PEF (Pulsed Electric Field)	●	●	●	●			●	●	
Microwaves & RF	●	●	●	●	●		●	●	●
Extrusion porosification	●						●	●	
Ohmic heating	●	●	●				●	●	
Membrane filtration	●								
High Hydrostatic Pressure	●	●	●						
Pulsed light	●	●	●						
UV (Ultra Violet)	●	●	●						
Friction heater	●		●						

Table 3: Technology applicability by sector

Table 4 (below) lists applicable technologies for process steps with the most intensive use of process heat. For some of them, a relevant technical information document is available (as a link) as part of an EECA series.

Technology applicability by process step: What are the options?

Process step	Applicable technologies	Energy saving	Electrification
Drying / evaporation	Heat recovery	●	
	Dessicant wheel	●	
	Heat pumps (drying <90°C)	●	●
	Mechanical Vapor Recompression (MVR)	●	
	Ultra-sound (US) assisted drying	●	
	Pulsed Electric Field (PEF) assisted drying	●	
	Microwave & radio frequency		●
	Ohmic heating		●
	Extrusion porisification	●	
	Membrane filtration: MF / UF / NF / RO	●	●
	Infrared drying		●
Pasteurisation / sterilisation	Heat pumps	●	●
	Microwave & radio frequency		●
	Ohmic heating		●
	High Hydrostatic Pressure (HHP)	●	●
	Pulsed Electric Field (PEF)	●	●
	Ultra-sound (US)	●	●
	Pulsed light	●	●
	Ultra-Violet sterilisation	●	●
Other heating (cooking, melting, reacting, etc.)	Heat pumps	●	●
	Pulsed Electric Field (PEF) pre-treatment	●	●
	Microwave & radio frequency		●
	Ohmic heating		●
	Friction heater		●
	Infrared heating		●
	Induction heating		●
	Indirect electric resistance heating		●
Non-displaceable high temperature process heat (> 100°C: steam, direct heating…)	Small electric steam generators (local or punctual needs)		●
	Electro-boiler		●
	Biomass (biogas / solid biomass / etc.)		

Table 4: Technology applicability by process step

2.0 International Scan: Case Studies

2.1 Overview of energy quality required by sector or process step

Energy needs are often analysed quantitatively (in kWh or GJ), while the practical usability of an energy source depends mainly on its quality (i.e. density).

In the case of process heat, the main quality criteria will be the temperature level: the higher the temperature, the higher the value of the energy available.

Under this framework, using high temperature energy for low temperature applications is a form of wastage.

Electricity is also considered a valuable form of energy as it can be used to produce high temperature levels, perform mechanical work or produce radiation.

The following matrix (diagram 7) provides an example of the potential correspondence between form / source of energy and industrial sectors.

Table 5 (below) is a good example of the applicability of a technology (in this case, heat pumps) on various industrial sectors depending on the process step targeted and the level of temperature required.

These tables provide a template for how a sector and / or process step approach (e.g. drying, boiling, distillation, evaporation, sterilisation, etc) can be adopted, depending on the specific needs for New Zealand industry.

More importantly, table 5 shows that most applications requiring heat are at low temperatures (below 100°C) and could therefore be supplied by heat pumps and heat recovery.

As a result, this scan contains dedicated information on **high temperature heat pumps** and **heat recovery**.

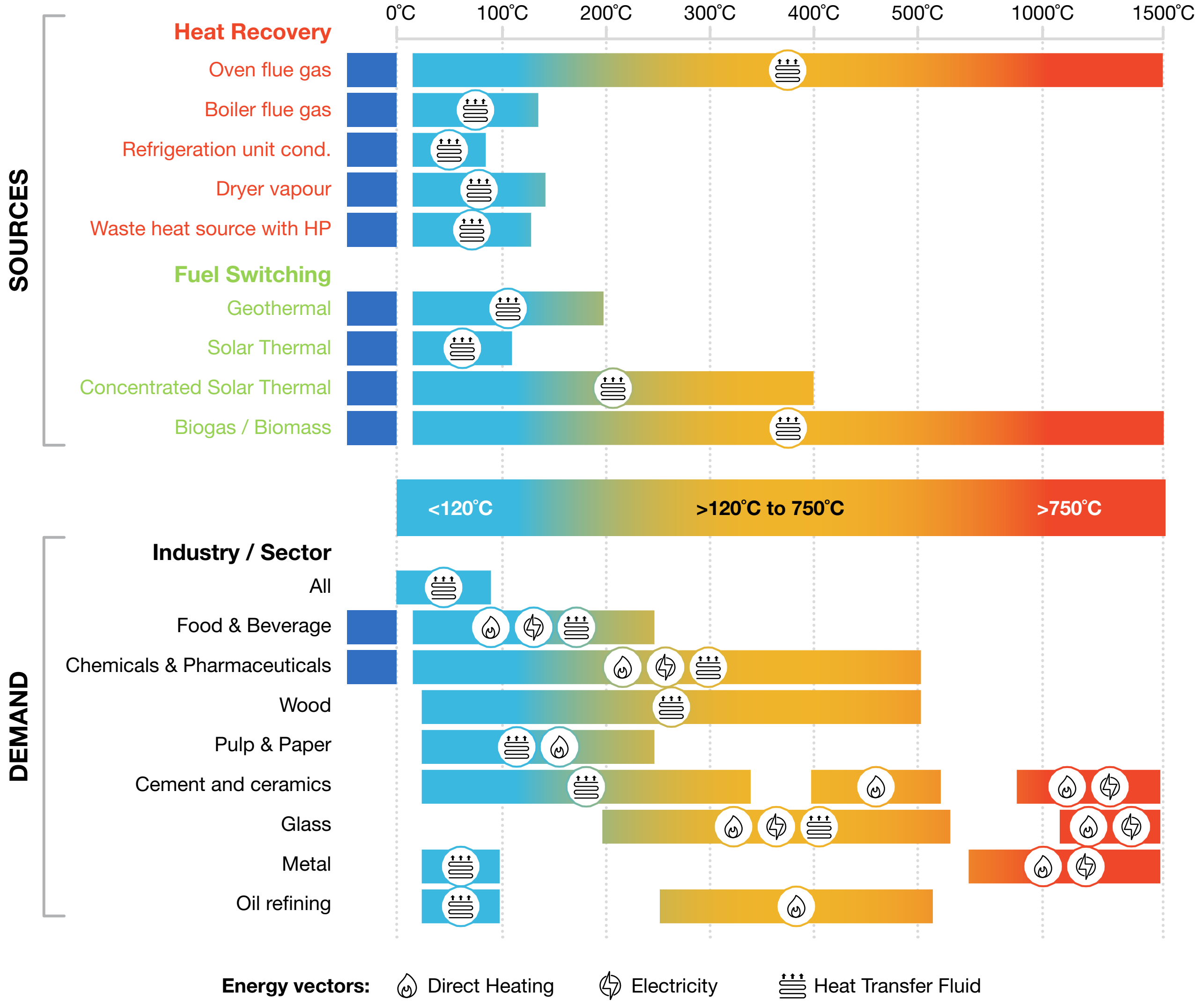
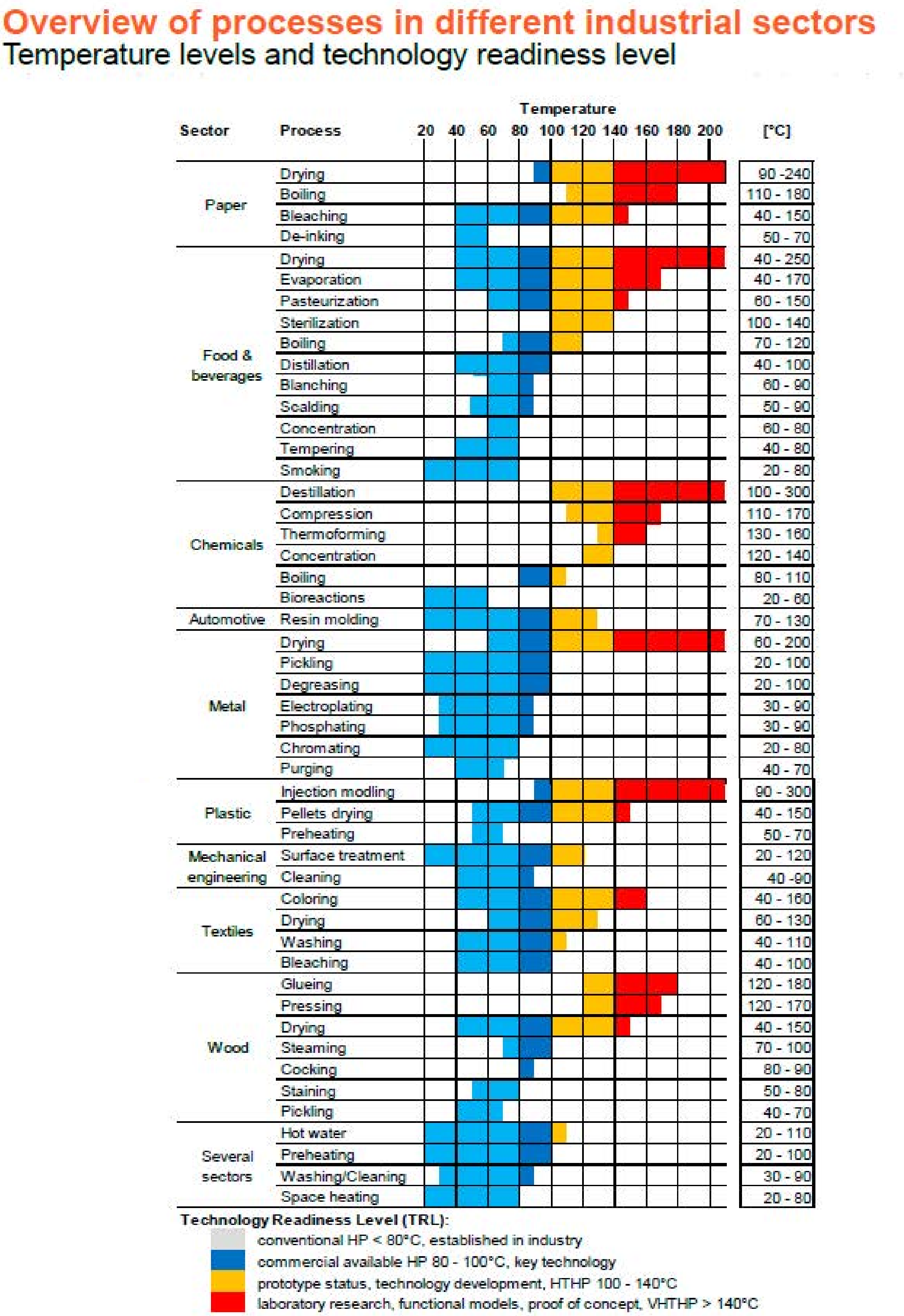


Diagram 7: Mapping of waste heat and renewable energy applicability to industrial sectors depending on temperature level and energy vector



Overview of processes in different industrial sectors

Temperature levels and technology readiness level

Sector	Process	[°C]
Paper	Drying	90 -240
	Boiling	110 - 180
	Bleaching	40 - 150
	De-inking	50 - 70
Food & beverages	Drying	40 - 250
	Evaporation	40 - 170
	Pasteurization	60 - 150
	Sterilization	100 - 140
	Boiling	70 - 120
	Distillation	40 - 100
	Blanching	60 - 90
	Scalding	50 - 90
	Concentration	60 - 80
	Tempering	40 - 80
	Smoking	20 - 80
Chemicals	Destillation	100 - 300
	Compression	110 - 170
	Thermoforming	130 - 160
	Concentration	120 - 140
	Boiling	80 - 110
	Bioreactions	20 - 60
Automotive	Resin molding	70 - 130
Metal	Drying	60 - 200
	Pickling	20 - 100
	Degreasing	20 - 100
	Electroplating	30 - 90
	Phosphating	30 - 90
	Chromating	20 - 80
	Purging	40 - 70
Plastic	Injection modling	90 - 300
	Pellets drying	40 - 150
	Preheating	50 - 70
Mechanical engineering	Surface treatment	20 - 120
	Cleaning	40 -90
Textiles	Coloring	40 - 160
	Drying	60 - 130
	Washing	40 - 110
	Bleaching	40 - 100
Wood	Glueing	120 - 180
	Pressing	120 - 170
	Drying	40 - 150
	Steaming	70 - 100
	Cocking	80 - 90
	Staining	50 - 80
	Pickling	40 - 70
Several sectors	Hot water	20 - 110
	Preheating	20 - 100
	Washing/Cleaning	30 - 90
	Space heating	20 - 80

Technology Readiness Level (TRL):

⬜ conventional HP < 80°C, established in industry
🟦 commercial available HP 80 - 100°C, key technology
🟨 prototype status, technology development, HTHP 100 - 140°C
🟥 laboratory research, functional models, proof of concept, VHTHP > 140°C

Data sources: Brunner et al. (2007), Hartl et al. (2015), IEA (2014), Kalogirou (2003), Lambauer et al. (2012), Lauterbach et al. (2012), Noack (2016), Ochsner (2015), Rieberer et al. (2015), Watanabe (2013), Weiss (2007, 2005), Wolf et al. (2014)

Table 5: Temperature requirements by sector and process step for industrial heat pumps

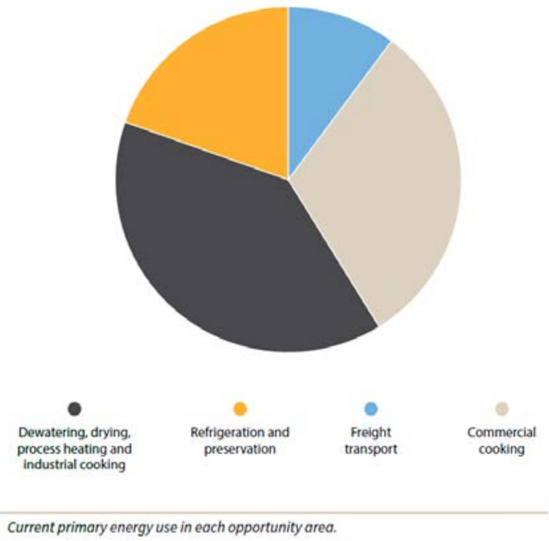
Credits: Cordin ARPAGAUS[1], FrédericBLESS[1], Jürg SCHIFFMANN[2], Stefan S. BERTSCH[1]

[1] NTB University of Applied Sciences of Technology Buchs, Switzerland

[2] Ecole Polytechnique Fédérale de Lausanne, Switzerland

A few processes that require higher temperatures would be challenging because they also require higher energy quality: drying, evaporation, distillation, boiling, bleaching, gluing, and pressing.

Currently, most of New Zealand's available energy consumption data is by sector or factory, and not by energy use (except for big category use, such as boilers); this makes technology targeting challenging. However, a general knowledge of an industry / sector is enough to target the most energy consuming process steps.



Current primary energy use in each opportunity area.[4]

Chart 1: Distribution of energy consumption within the food value chain

In addition, a few international studies give an estimate of the energy intensive process step for several sectors (see table 6 and chart 1 below).

Similarly, the pie chart below (Chart 1) issued by the 2xEP Australian programme 'Innovation to Improve Energy Productivity in the Food Value Chain' shows how primary energy consumption is distributed within the food value chain.

The underlying assumption is that processes in other countries are quite similar than those in New Zealand.

The "sectors of interest" for New Zealand industry are dairy, meat, other food & beverage, pulp & paper, and wood.

The data presented above (table 4, table 5 and chart 1) shows that the process steps requiring the higher energy quality, for these sectors are:

- drying / evaporation
- sterilisation / pasteurisation
- heating (cooking / blanching / melting / reacting / etc)
- refrigeration.
- As a result, this scan has specifically focused on these process steps.

In addition, case studies related to **biogas projects in the sectors** mentioned above have also been included.

		Heat energy demand					
Industry	**Total energy demand***	**Total heat demand****	**Chemical conversion, melting, casting, baking**	**Distilling, separation**	**Drying**	**Hot water***	**Other**
Chemical	279	~240	>110	~85	>15		
Refining	132	~111	n.a.	65		n.a.	n.a.
Base metal ferrous	40	~30	~30				
Base metal non-ferrous	11.3	3	3				
Metal products	21	12	12				
Feed and beverage	85	55	7	2.5	26	16	n.a.
Pulp and paper, board	23	18	2		14	1	6
Textile	3,7	3			3		0,7
Construction materials	24	19	19				
Other	53	12	n.a.	n.a.	n.a.	n.a.	n.a.
Total	672		>185	~150	~60	>17	n.a.

Table 6: Heat energy demand of energy intensive process steps by sectors in Holland

Source : http://www.ispt.eu/media/Electrification-in-the-Dutch-process-industry-final-report-DEF_LR.pdf

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[4] https://www.airah.org.au/Content_Files/Resources/Innovation-to-Improve-Energy-Productivity-Food-Value-Chain-2017.pdf

2.2 Drying / evaporation

Key insights

- **Heat recovery for existing assets:** If a process includes a drying operation and the existing equipment still has several years of remaining life then heat recovery should be considered. Drying enhancement technologies can also have short paybacks.
- **Asset replacement opportunity:** If a process includes a drying operation then equipment replacement should be planned early enough to allow serious consideration of low-emissions technologies and allow testing to confirm the technologies can be used.

Even if a drying operation consists of removing water from a product, the specific characteristics of a product (form, structure, thermal resistance, etc) and the specifications to which it needs to be put (water content, shelf-life, etc) make each drying application very specific.

Therefore, for each product, it is necessary to conduct specific testing when choosing individual drying equipment. This can add a barrier to the adoption of a new technology when former methods are already proven.

Nevertheless, the case studies below demonstrate how some companies are choosing to move toward innovative techniques. Most of the time, these changes are driven by the co-benefits these electro-technologies bring compared to former thermal solutions: energy savings are often a worthy co-benefit.

When a change of drying technology is not possible, it is important to know that heat recovery is likely to offer great savings.

Therefore, the case studies below provide examples of successfully implemented heat recovery projects on drying operations.

Diagram 8 below provides a summary of the technologies applicable to drying / evaporation operations presented in this section.

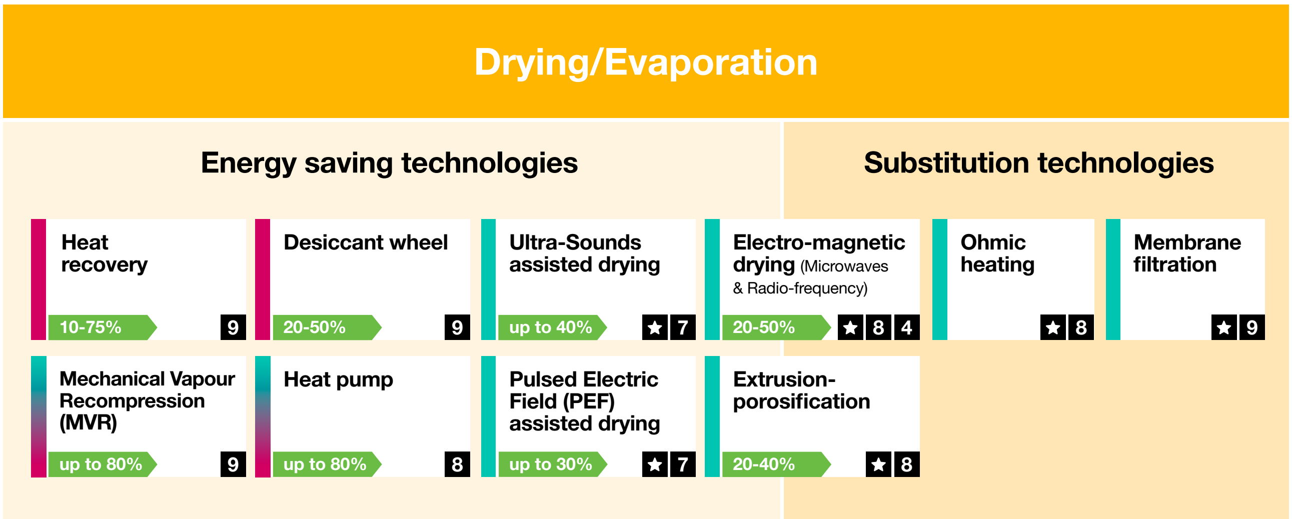


Diagram 8: Drying / Evaporation Technologies

2.2.1 Heat recovery

Heat recovery on drying processes

9	TRL level	**Energy recovery technology**
Sectors of applicability		
Energy savings reported		10% to 75%
Co-benefits reported		• reduced emissions (particles, pollutants, etc.) • reduction of product cooling time • containment of unpleasant odours • reduction of processing time (pre-heating of product)

Multiple fit-for-purpose solutions exist and are commercialised, so the technology (consisting of heat exchangers) can hardly be considered as new (although design innovation is occurring to manage specific constraints – for example, clogging caused by the product).

Case Study	**One**
Country:	France (page 92)
Sector:	Food / primary industry
Product:	Cereals
Technology:	Silo dryer
Improvement:	**Heat recovery with a cyclonic heat exchanger** The fouling of heat exchangers can be a barrier to the implementation of a heat recovery solution on an industrial site, in the presence of clogging effluents. The exhaust air resulting from drying is moist and charged with particles and can cause clogging; using a tube-fin type exchanger or a bag filter to treat it isn't feasible (both would be quickly rendered inoperable).  Credit: CLAUGER CLAUGER has installed a cyclonic heat exchanger, which simultaneously reduces the mass of particles emitted and recovers the energy contained in the "worn" air. This hot air is saturated with moisture, having served to dry the grain, and constitutes a fatal heat that represents a significant energy potential to recover. The exchanger, made of stainless steel, is installed at the top of the dryer and combines the effect of condensation and centrifugation. The body consists of two vertical cylinders concentric, between which are arranged spirals dense slats tubes conveying a coolant. The next step will be to use a heat pump to enhance the level of temperature of the recovery loop to 70°C / 80°C.
Energy savings:	20% to 30% (6 to 9 W/m3 of air)
Cost savings:	NC
Investment:	NC

Case Study	Two
Country:	France (page 94)
Sector:	Food / primary industry
Product:	Animal feed
Technology:	Rotating drum dryer

Improvement:

Pre-drying with a perforated endless conveyor belt dryer

PRODEVA produces alfalfa and dehydrated beet pulp for the sole purpose of animal feed.

The raw material (alfalfa and pulp) is dried, crushed, and then granulated. The moisture content of the product at the entrance of the dryer is between 55% and 75%.

Credits: PRODEVA - FAX 03 26 67 40 87

The company's site includes two drying lines, treating 45,000 tons/year of product, corresponding to a water evaporation of 40 tons/hour.

The product is dried in rotating drums in a stream of air, heated by pulverized coal boilers.

The improvement consists of a direct heat recovery on the hot air rejects of the rotating drum, which allows the product to be thermally pre-dried: it is deposited on a perforated strip, through which warm and wet air recovered from the rotating drum circulates.

The pre-dried product is then transported by screw to the rotary drum.

In view of the pre-drying operation, the drying temperature in the drum is lowered, which reduces the energy consumption of the dryer.

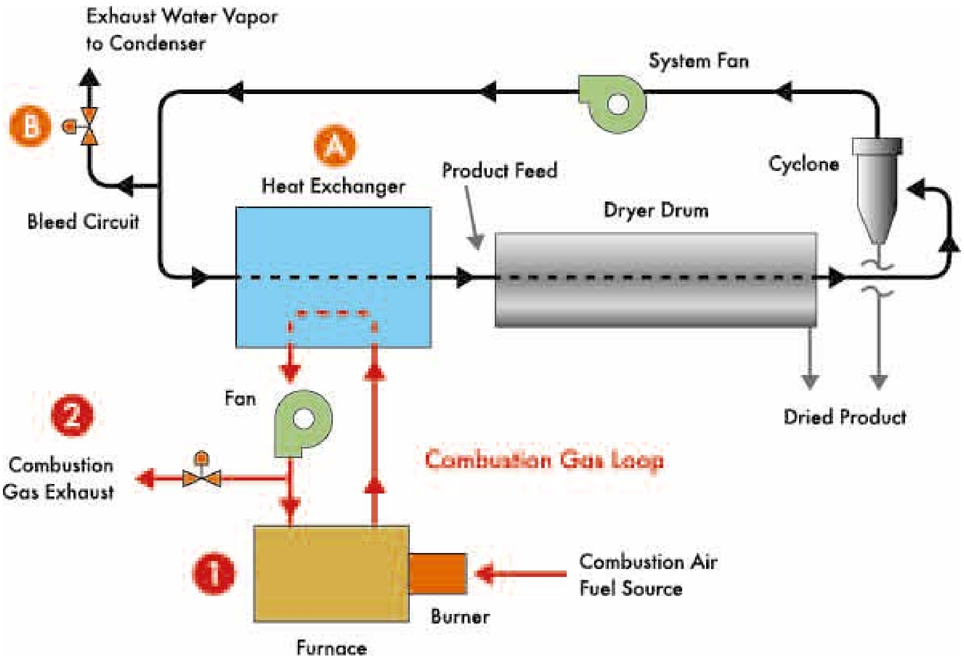
Another potential benefit of this recovery is to recycle the dust in the exhaust air extracted from the dryer and integrate it into the manufactured granules.

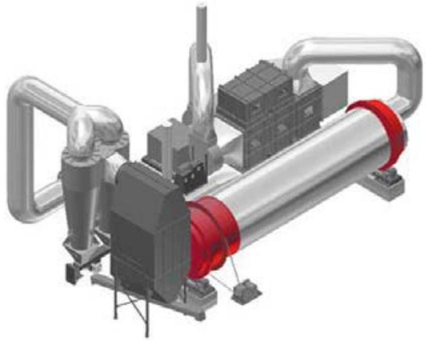
Energy savings:	10% = 1,100 tons of lignin / year (1,800 tons eq. CO2 / year)
Cost savings:	$190k / year
Investment:	$2,210k / year

Case Study	**Three**
Country:	France (page 98)
Sector:	Food
Product:	Sugar
Technology:	Rotating drum
Improvement:	**“Cold” drying (40°C) using latent heat from the hot product (70°C)** As it leaves the centrifuges, the sugar is still surrounded by a film of syrup that will have to be evaporated during the last drying step. Traditionally, the drying is done with a hot air flow (70°C-90°C) injected into the dryer. This requires a steam consumption of about 20 kg of steam per ton of sugar. In order to reduce energy consumption, the dryer has been designed and sized to use the sensible heat of sugar as the only energy intake to the drying process. As a result, the product comes out of the process upstream drying (about 70°C). During drying, the sugar will give up some of its heat which will be used to evaporate the water contained in the syrup film (about 1%). A limited amount of air is injected into the dryer (counter-current) to evacuate the evaporated water. This air, slightly warmed (about 40°C) to reduce its relative humidity, will cross the dryer and warm up again (slightly) once it comes into contact with the sugar. In the end, this principle of “cold” drying saves more than 75% of the steam compared to a traditional “hot” drier (i.e. about 15 kg of steam per ton of sugar). This type of dryer also pre-cools the sugar and thus reduces the energy consumption spent on cooling. Due to a significantly lower airflow, the overall power consumption of the ventilation system is reduced by about 50%.
Energy savings:	75% (2,690 tons of steam / year)
Cost savings:	$140 / k
Investment:	0 (cost is similar to rotating drum technology)

Case Study	**Four**
Country:	Sweden
Sector:	Food
Product:	Fish by-products to animal feed, fertiliser, oil, etc
Technology:	Rotary drum dryer
Improvement:	**Closed vacuum air circuit with heat recovery**

A three pass tubular heat exchanger with removable cores to facilitate cleaning, is used as an indirect gas fired heater during the drying process of the fishmeal. Recirculation of the process gas by the heat exchanger contains the unpleasant odour typically associated with this process.





Credits: MUNTERS

The system fan creates a circulating loop of water vapor. Heat is transferred from the Munters heat exchanger (A) to drive the evaporation of moisture from wet feed in the dryer drum. The water evaporated from the feed displaces air in the water vapor loop, creating the “airless” environment. To maintain atmospheric pressure in the dryer, a bleed circuit (B) is needed to exhaust water vapor. This water vapor can be treated with a conventional condensing system or used as a heat source for other processes.

Combustion gases from a conventional furnace (1) supply heat to the Munters heat exchanger.

Energy savings:	64% (21 MMBTU / HR)
Cost savings:	NC
Investment:	NC

Case Study	Five
Country:	USA
Sector:	Food
Product:	Fried potatoes
Technology:	Potatoes dryer and Regenerative Thermal Oxidizers (RTO)
Improvement:	**Heat recovery from RTO to dryer:** The RTO's were designed to control emissions from the potato frying portion of processing to meet local air regulations. Prior to the frying process, the potatoes must move through a number of steps to produce the quality and flavors desired in the product. The potato drying section of the process, just before the fryer, requires clean, indirectly heated air to remove about 15% of the moisture in the potato after they have been blanched. The waste energy from the RTO's could provide a suitable heat source to the dryer when coupled with an energy recovery unit (heat exchanger).  Credits: MUNTERS The air that is used in the dryer is a combination of recirculated air and fresh air from the atmosphere. Air that is brought in from the atmosphere passes through an air-to-air heat exchanger where the RTO exhaust air preheats the incoming fresh air. The air-to-air heat recovery is of a unique design where the two air streams never see each other or mix, eliminating the possibility of cross contamination between the two air streams.
Energy savings:	30%
Cost savings:	NC. Payback in less than a year
Investment:	NC

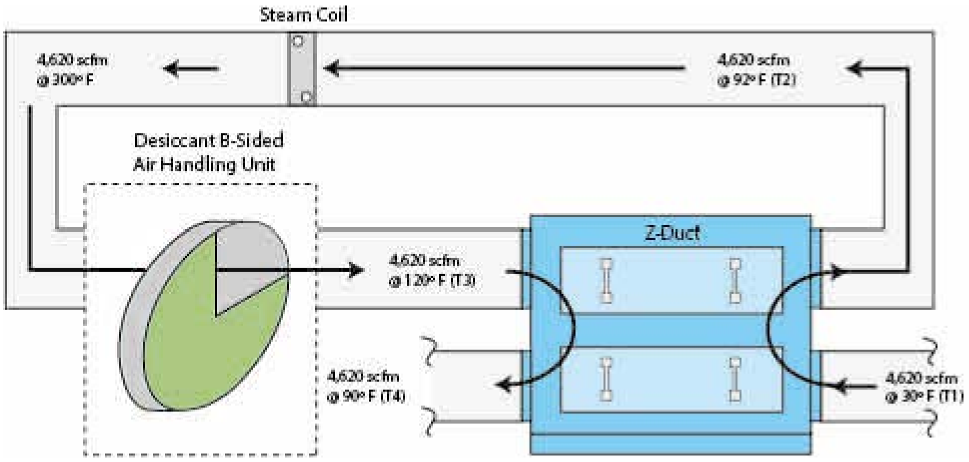
Case Study	Six
Country:	USA
Sector:	Pulp & paper
Product:	Printed paper
Technology:	Printer
Improvement:	**Air-to-air heat exchangers** In the Wisconsin plant, the web presses required approximately 40,000 m3 per hour of air to dry the ink on the printed material. Air from the plant was drawn into the presses, warmed by electric heaters in the presses to about 70°C, and exhausted to the outside. This wasted energy could have easily been captured to help increase production and profits. An air-to-air heat exchanger has been installed. Gas fired heaters that were needed to maintain temperatures in the plant were shut down, reducing gas consumption and reducing maintenance costs. A major part of the energy savings stems from the fact that the electric heaters in the press do not have to operate as frequently. On a typical winters day, the heat recovery system raises the 0°C outside air to 37°C and this preconditioned air is supplied directly to the presses.
Energy savings:	$80 / k / year
Cost savings:	NC
Investment:	NC

Case Study	**Seven**
Country:	NC
Sector:	Pharmaceutical
Product:	Drugs
Technology:	Desiccant wheel
Improvement:	**Air-to-air heat exchanger downstream of the desiccant wheel**

This production process is sensitive to moisture because in several phases, the drugs are in hydroscopic form, meaning they absorb moisture.

To maintain proper humidity levels in its manufacturing environment, the company installed an air-handling unit several years ago with a desiccant wheel for dehumidification. When the desiccant becomes saturated with moisture, hot air is run through it to regenerate the medium.

An air-to-air heat exchanger was placed downstream of the desiccant wheel to recover heat from the discharge during the regeneration cycle. The captured heat is then used to heat outside air coming into the reactivation side of the dehumidifier.



Credits: MUNTERS

Energy savings:	NC
Cost savings:	NC
Investment:	NC

2.2.2 Desiccant system (with heat recovery)

Desiccant system with heat recovery

9 **TRL level**	**Energy recovery technology**
Sectors of applicability	
Energy savings reported	25% to 50%
Co-benefits reported	• increased production capacity (reduction of drying time) • uniformity of process conditions • product preservation (reduction of temperature required) • reduction of risk of contamination (avoided condensation)

Many drying systems work with hot air, and the efficiency of the process depends on the ability of the air to capture water (from the product) to dry. Heating the air increases the quantity of water it can carry.

Consequently, the more humidity contained in the air at the entry to the dryer, the less effective the process is.

A preliminary dehumidification of the air reduces the energy need: either by requiring less air to be injected into the dryer or allowing this air to be heated at a lesser temperature.

A desiccant wheel works on the principle of sorption, which is the adsorption or the absorption process by which a desiccant removes water vapour directly from the air.

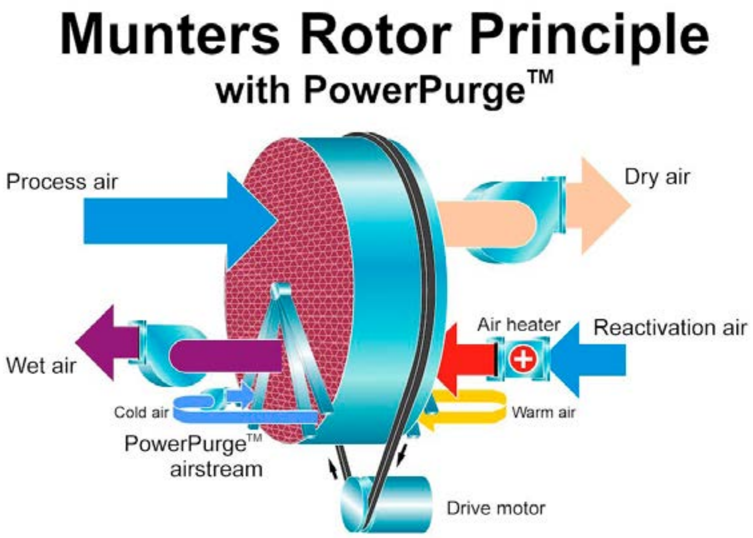
The air to be dried passes through the desiccant wheel and the desiccant removes the water vapour directly from the air and holds it while rotating.

As the moisture-laden desiccant passes through the regeneration sector, the water vapour is transferred to a heated airstream, which is exhausted to the outside.

The reactivation of the desiccant material requires heat (from 50°C to 80°C - the higher the temperature, the higher the efficiency of the wheel); in order to save energy overall, this system requires heat recovery from the outlet air and / or other source of waste heat.

The overall energy efficiency and / or emissions reductions of such systems depend heavily on the good integration of heat recovery and on the co-benefits on the rest of the production (for example, reduction of the drying temperature required).

Because it stabilises and improves the air characteristics entering the dryer, it allows either an increase in productivity or a reduction in the size (and capital) of the required dryer.



Credits: MUNTERS

Desiccant systems can therefore be utilised when hot air is used to dry, or when there is a need for chilling / freezing where condensation or frost needs to be avoided. However, in that second case, it is likely that only electricity would be saved, meaning less impact on emissions.

Here are a few examples of case studies:

Case Study	One
Country:	NC
Sector:	Dairy
Product:	Milk powder
Technology:	Spray drying
Improvement:	**Extra-drying of air with desiccant wheel to increase production** The performance of a spray tower is limited by the amount of energy that can be supplied by the hot air. If an increase in performance is required there are two possibilities: either the temperature of the injected air is increased, or the air humidity is decreased. For sensitive products such as milk or vitamins the injection temperature is reduced to 80°C to 100°C to maintain quality (i.e. production can only be increased by drier air). In this respect desiccant rotor systems provide high efficiency and uniform process conditions. Energy savings are achieved through energy recovery on the regeneration air of the wheel, reduction of temperature required, and reduction of the post-coolers energy consumption. The reduction in required temperature also facilitates heat recovery from waste heat at lower temperatures.
Energy savings:	30%
Cost savings:	Production increase 15% to 20%
Investment:	NC

Case Study	Two
Country:	Germany
Sector:	Manufacturing
Product:	Coating of optical lenses
Technology:	Desiccant wheel
Improvement:	**Retrofitting a desiccant wheel with an energy recovery system** The retrofitting system generates an additional partial flow of air through the regeneration sector of the rotor. This air flow is used for pre-heating the regeneration air and reduces the need for external energy regeneration.  Credits: MUNTERS The device collects waste heat off the hottest section of the desiccant wheel and uses it to help with the regeneration. This reduces the energy required for reactivation whilst also reducing the discharge temperature of the process air, resulting in lower energy costs for post cooling. This can also save on investment costs by reducing the size of the desiccant rotor without diminishing the dehumidification capacity whilst still seeing savings in energy costs.
Energy savings:	25% to 38%
Cost savings:	NC
Investment:	NC

Case Study	Three
Country:	Denmark
Sector:	Food
Product:	Chocolate and candy
Technology:	Hot air applications: colour, polish and dry
Improvement:	**Installation of dehumidification of process air in coating processes**  Credits: MUNTERS Carletti used an older ventilation system to supply hot air to processes where there was a need for dry air to colour, polish and dry products. Investing in four desiccant dehumidifiers has allowed the company to reduce energy consumption by up to 50%. While the process itself is slightly more expensive, production capacity has been increased by shortening the drying process from 19 hours to 12 hours for a batch of 4,500 kg chocolate lenses.
Energy savings:	50%
Cost savings:	NC. Reduction of drying time by 1/3.
Investment:	NC

Case Study	Four
Country:	South Africa
Sector:	Meat
Product:	Meat and poultry
Technology:	Cold storage
Improvement:	**Desiccant dehumidifiers** Through the dehumidification process, a desiccant system has enabled Chester Wholesale Meat to reduce the refrigeration plant load eleven times more effectively, rather than allowing the plant itself to dehumidify the air. This has resulted in significant savings and a reduction in power usage.
Energy savings:	NC
NC	NC
Investment:	NC

Case Study	**Five**
Country:	Belgium
Sector:	Food
Product:	Frozen vegetables
Technology:	Freezing tunnels
Improvement:	**Desiccant dehumidifier** Fresh vegetables cross in bulk through a tunnel in which the temperature borders 30°C. At the exit of the tunnel, the temperature is +10°C. The difference in temperatures caused condensation on the ceiling, ground, products and packing, with the resulting risk of contamination. Another problem was condensation forming on vegetables (peas) that froze again during storage in freezing rooms, causing them to weld together in blocks. “The advantages of the installation are obvious”, explains Koen Dejonghe, at Pinguin. “The ground is no longer slippery from condensation. We also increased the quality of the products. The vegetables no longer freeze together.”
Energy savings:	NC
Cost savings:	NC
Investment:	NC

2.2.3 Electro-magnetic drying: microwave and radio frequency

Electro-magnetic drying: microwave and radio-frequency

4 **8** **TRL level** (variable depending on application)	**Energy saving technology** **Electrification technology**
Sectors of applicability	
Usage	Drying / pasteurisation / sterilisation / blanching / heating / cooking / extraction
Energy savings reported	20% to 50%
Co-benefits reported	• increased production capacity (reduction of drying time) • increased reaction yields

Microwave / radio-frequency is a well-known technology, with industrial units commercially available since the 1960's, but it is still under-utilised compared to its application potential – the technology continues to evolve and offer solutions for a broader range of applications.

The technology is used for drying but can also be applied to any process application requiring heat transfer; as long as the product involved has charged and mobile particles.

Low costs units are available from manufacturers from India or China (also here), which shows the maturity of this technology for some applications.

Here are some examples of a microwave dryer commercialised for wood drying:

Credits: SAGA machinery Co.Ltd

www.bogengroup.com/e_productshow/?129-Wood-vacuum-Microwave-Dryer-129.html

www.maxindustrialmicrowave.com/industrial-microwave-system-for-wood-a-15.html

Credits: maxindustrialmicrowave

Depending on the product characteristics, this technology can be used either as a complete replacement of existing technologies or as a pre- or post-dryer to save energy. Retrofitting of existing installations is also possible.

Advantages and disadvantages of microwave technology are well described here.

Furthermore, it can be mixed with a humidity control solution (like a desiccant wheel) to increase overall energy efficiency gains.

Microwave heating / drying is already used in various industries like food (mushrooms, fruits, etc), wood, paper, latex and rubber, chemicals, ceramics (including metallurgy), pharmaceuticals, polymers, or textiles.

Vacuum impregnation and osmotic dehydration prior to hot air microwave in fruit preservation are becoming widespread for reducing energy consumption, improving the quality and extending the shelf life[5].

Many studies have been carried out on the energy savings from using microwaves, but not many of them are actual case studies on industrial sites. This is in part because microwave technology is generally chosen by industrial users for product quality or production capacity, with the energy saving being a co-benefit.

Case Study	One
Country:	United Kingdom
Sector:	Food industry
Product:	Sugar-rich products: chocolates, lollipops, fudges, hard-boiled sweets, candies, toffees, gums and jellies
Technology:	Steam stoves
Improvement:	Microwaves stoves
Energy savings:	Unclear (CO2 savings but in UK)
Cost savings:	NZD$60,000 + production benefits
Investment:	NZD$250,000, 10 units in the factory. Payback in 4 years.

Case Study	Two
Country:	USA
Sector:	Wood manufacturing
Product:	Wood strands
Technology:	Rotary drum dryer
Improvement:	Microwave dryer
Energy savings:	Up to 50%
Cost savings:	NC
Investment:	NC

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[5] (Ozkoc, Sumnu & Sahin 2014).

Case Study	**Three**
Country:	Belgium (page 10)
Sector:	Wood manufacturing
Product:	Wood joinery for doors and windows
Technology:	Drying room
Improvement:	Tunnel dryer with microwaves pre-drying, then hot air drying. Water droplets migrate to the surface during the microwave treatment and the hot air drying allows the evacuation of these droplets. This is a continuous process where the suspended frames are moving in the oven: each frame is pre-dried in the microwave for 90 seconds and then passes through the hot-air tunnel for 5 to 6 minutes (air heated by external heating batteries).
Energy savings:	2/3 of hot air consumption avoided
Cost savings:	NC
Investment:	NC
Supplier:	Giardina (page 14)

Case Study	**Four**
Country:	UK
Sector:	Chemical industry
Product:	NC
Technology:	Continuous flow microwaves reactor (pilot size of 1 ton/day)
Improvement:	As scale increases, the advantages of using microwaves compared to conventional methods can be lost. This is because the power generated from microwaves can dissipate rapidly as the distance the microwaves have to travel into the reaction mixture increases. Consequently, this can result in overheating at the surfaces, just as is the case with conventional heating.
Energy savings:	90% savings
Cost savings:	Significant increases in reaction yields (35% to 70%). Significant reductions in reaction time (8h to 3min) compared to conventional processes.
Investment:	NC

Future developments

A recent evolution in microwave technology is the commercialisation of solid-state generators to replace magnetrons for microwaves generation. The main presented advantages are:

- increased reliability with lower maintenance costs and fewer production stops required (i.e. the technology uses magnetrons with a rated lifetime of over 500,000 hours versus the 5,000 to 8,000 hours of typical magnetrons)
- use of safer low-voltage DC power instead of multi-kV power supplies
- the ability to change the operating frequency of the microwave power source, which has two major effects:
  1. it changes the coupling of the microwave energy to the load (by finding the frequency of optimal coupling using a software, this ensures maximum energy transfer to the load and usually eliminates the need for a costly and cumbersome mechanical tuner)
  2. when the operating frequency changes, the “hot” and “cold” spots in the applicator move around (by sweeping through the frequency range and moving the hot and cold spots, this effectively acts as method of “electronic stirring” that results in much better uniformity of heating).

Other developments have focused on microwaves drying in vacuum conditions (i.e. partnership ENWAVE/GEA) while, other improvements are oriented toward how microwaves are applied to allow even distribution of energy (e.g. CSIRO is developing an antenna).

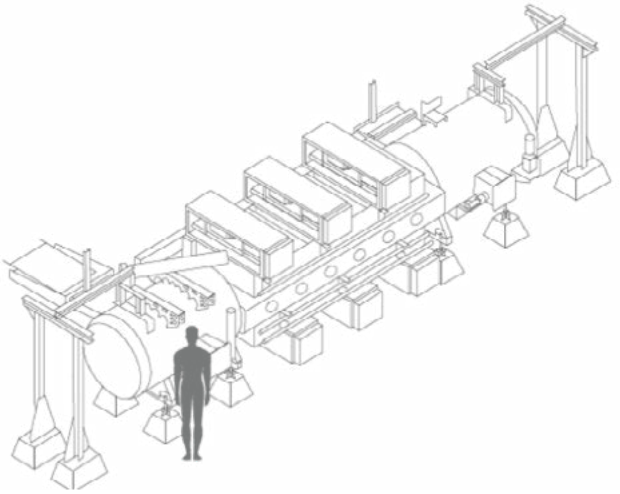


Diagram 9: Microwaves drying in vacuum conditions

Credits: ENWAVE

2.2.4 Membrane filtration

Membrane filtration

9	TRL level	Energy saving technology	Electrification technology
Sectors of applicability			
Usage	Pre-drying / de-watering / separation		
Energy savings reported	See case studies		
Co-benefits reported	• transport costs		

Membrane filtration is a mature solution that can be used for pre-concentration or separation. It is energy efficient and uses electricity instead of heat, allowing additional emissions savings in the specific context of New Zealand.

The overall cost efficiency will depend on the right balance between the extent of filtration and the thermal drying step.

Depending on the product and the expected final properties, membrane filtration can replace the entire thermal drying process in some instances.

Milk can be concentrated to 50% of its original volume without adversely affecting its quality, creating efficiencies in its storage, refrigeration and transportation. A further productivity benefit is a much lower energy requirement for drying milk at the processing plant, while a co-benefit is an increased availability of water on farm (in case of water shortage).

The economic feasibility has been demonstrated in Australia.

Case Study	**One**
Country:	Australia
Sector:	Dairy
Product:	Milk
Technology:	Reverse osmosis
Improvement:	When operational, the system produced 400 litres per hour of concentrated milk, as well as fresh water.
Energy savings:	NC
Cost savings:	Reduced transport costs to the processing plant were the greatest source of savings, worth about $30 per kilolitre. It is estimated that, for a 10,000 litre a day system, savings of AUD$48,483 per annum can be achieved with a simple payback of 2 years.
Investment:	AUD$100,000

Case Study	**Two**
Country:	France
Sector:	Dairy
Product:	Cheese
Technology:	Multi-effects evaporators
Improvement:	**Nano-filtration and reverse osmosis** For serum concentration, the use of two multi-effect evaporators was required. The first evaporator has three effects consuming 3.8 tons / h of steam for a serum flow of 22m3 / h. The second is an evaporator with mechanical vapor recompression consuming 150 kg / h of steam for an identical flow rate. To reduce the use of these energies, the company has replaced the concentration step of the serum manufacturing process using nano-filtration and reverse osmosis unit.
Energy savings:	Gas: 18.1 GWh / year Electricity: 1 GWh / year
Cost savings:	€588,000 (NZD$1,000,000)
Investment:	€1.815m (NZD$3.1m). TRI: 3.3 years

2.2.5 Extrusion Porosification Technology (EPT)

Extrusion – Porosification (mix of thermal and mechanical treatment)

8	**TRL level**	**Energy saving technology**	**Electrification technology**
Sectors of applicability			
Usage	Drying / concentration		
Energy savings reported	20% to 40%		
Co-benefits reported	• enhanced powders properties		

This is a proprietary solution jointly developed by a French company (Clextral) with New Zealand and Australian partners (INOVO, FIAL, CSIRO).

Credits: CLEXTRAL

It is presented as an economical, flexible and compact alternative to conventional powder drying technology such as spray drying, drum drying and freeze-drying.

The twin-screw extruder is configured to continuously process highly viscous and heat-sensitive products, using mechanical action adapted to the function (mixing, limited shearing, controlled residency time) and precise temperature control. EPT™ increases drying efficiency by accelerating material and heat transfers.

This enables the manufacturing of complex powders with homogenous features and interesting rehydration properties at a lower cost (in particular, through lower energy consumption during the concentration and drying phases).

Once again, the main commercial arguments are not the energy savings but the effects on the product (new properties or non-degradation of heat sensitive ingredients).

This technology is not limited to the food industry with trials currently underway in the pharmaceutical and chemical industries.

A pilot unit has demonstrated energy savings of between 20% and 40% compared to traditional atomisation drying.

2.2.6 Ultrasound-assisted drying

Ultra-sounds assisted drying

7 **TRL level**	**Energy saving technology**	**Electrification technology**
Sectors of applicability		
Energy savings reported	up to 40%	
Co-benefits reported	• increased drying rate • increased productivity (reduction of drying time) • reduction of the temperature required = thermal degradation of product avoided	

The aim of ultrasound-assisted drying is to overcome some of the limitations of traditional convective drying systems, by increasing drying rate without reducing quality attributes in a short period. Drying rate of a product depends on the factors such as composition of the product, intensity of ultrasound, time of exposure and environmental conditions.

When ultrasound passes through the product, mass transfer can be effectively achieved by cavitation phenomenon, which creates micro streaming channels in the food product (i.e. the mechanical forces created are higher than surface tension that withhold the moisture inside the capillaries of the food). This facilitates fast removal of bound water from the product to achieve effective drying.

The company Cavitus, with an office in Australia, is commercialising a product specifically designed to improve spray-drying.

Their case study (below) illustrates one of the highly specific energy saving opportunities of this versatile technology.

Case Study	**One**
Country:	Europe
Sector:	Food & beverage
Product:	Beer
Technology:	Beer canning line (5,000 ml cans at 80,000 cans per hour)
Improvement:	Operational performance of the line had required the beer to be chilled to 10°C to reduce foaming. Additionally, the beer was flash pasteurized and cooled before the filler. Then, additional energy was utilised to re-warm the can to ambient temperature to avoid condensation and quality issues. By applying the ultrasound foam control system, the beer filling temperature could be increased to ambient temperature, reducing the energy requirement for chilling and can re-warming. Installation of the system was completed within a few hours (no production disruption).
Energy savings:	Electricity: 411 MWh / year Steam: 8,317 GJ / year
Cost savings:	€88,246 (NZD$145,000)
Investment:	Around €65,000 (NZD$110,000) and a payback of less than 9 months

Energy efficiency

A thesis on the subject mentions 40% of energy savings compared to non-assisted traditional drying.

The technology still requires further demonstration at an industrial scale, but ultrasound-assisted drying has demonstrated its ability to reduce energy consumption in two ways:

1. reduction of drying time
2. reduction of the temperature required.

Other potential applications of ultrasound are detailed below in the “Sterilisation / pasteurisation” section.

2.2.7 Pulsed Electric Field (PEF) assisted drying

Pulsed Electric Field (PEF) technology is further developed in the Sterilisation / pasteurisation section. However, enhanced drying of several fruit and vegetable products after a PEF application has been demonstrated, allowing for a reduction of drying times of up to 30 percent for potato cubes.

Suppliers also report industrial applications of PEF for enhanced osmotic drying of fruits and pre-treatment of vegetables before drying.

Though the energy required for water evaporation will not be changed by a PEF application, significant energy savings can be expected due to faster moisture transportation and increased production capacities of existing lines.

Additionally, a pre-treatment by a PEF application could also be utilised to improve uptake of salt and nitrite / nitrate.

2.2.8 Mechanical Vapour Recompression (MVR)

When a process stream is available in vapour phase close to the partial pressure, direct Mechanical Vapour Recompression can be a viable alternative.

This technology is completely mature with many large-scale installations around the world. However, it is worth mentioning in this scan because:

- EECA’s work with large energy users has revealed several sites in New Zealand where MVR opportunities exist, especially in the dairy industry
- several improvement programmes to this technology are at a pilot stage (see below), which could increase the range of its potential application.

The principle of a MVR system is similar to compression heat pumps, but in an open cycle: in MVR, the working fluid is directly the vapour from the process stream.

The process therefore spends a small amount of electricity to reuse large amount of heat.

Theoretically, compared with a multi-effect evaporator, it can save 50% to 80% on energy consumption and 90% on cooling water.

The main advantage is it requires less thermodynamic work, and therefore allows higher efficiency. The main disadvantage is that working with process stream can feature very high specific volume or be particularly difficult (e.g. corrosion, fouling, etc), requiring large and expensive compressors.

The temperature lift is usually quite limited (around 10K) because it is cheaper to use blower compressors (fans) than specially designed compressors.

Milk and whey	**Citric Acid**	**Paper drying**
Fruit juice	**Sewage sludge**	**Saline water**
Sugar	**Liquid manure**	**Boiler feedwater**
Yeast	**Oil recycling**	**Blood plasma**
Bioethanol	**Seawater desalination**	**Electrolyte baths**
Gelatine	**Wood drying**	**Petrochemical industry**

Table 7: List of international applications of MVR

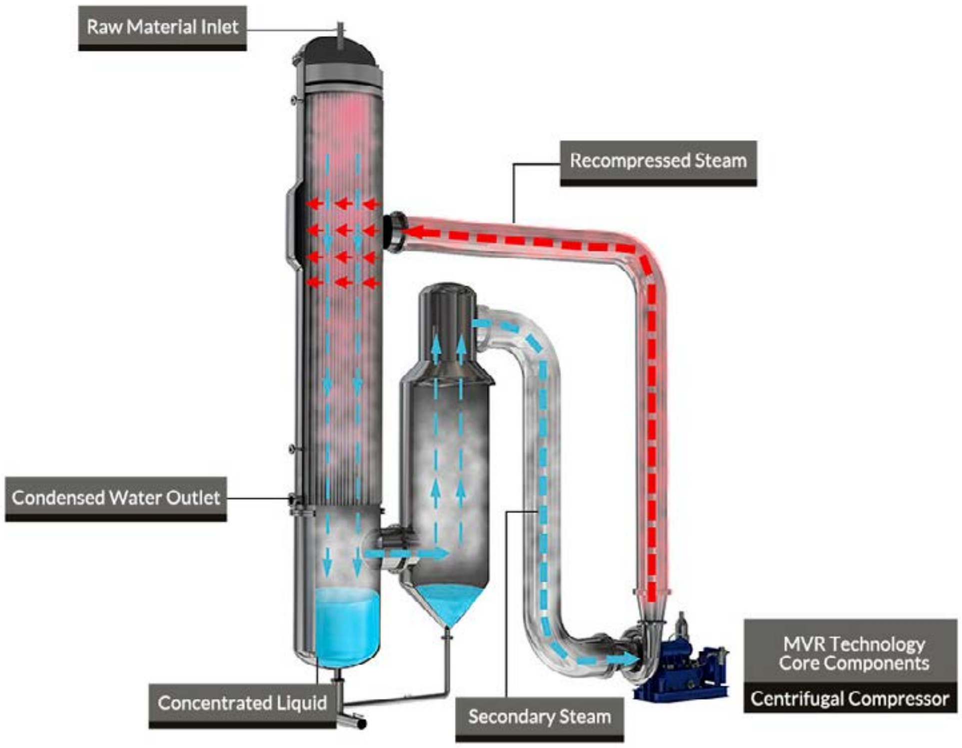


Diagram 10: Principle of an MVR system

Credits: LeHeng www.lhevaporator.com

Diagram 11 (below) from PILLER's blowers and compressors line of products shows the relatively low temperature increase achievable with such systems.

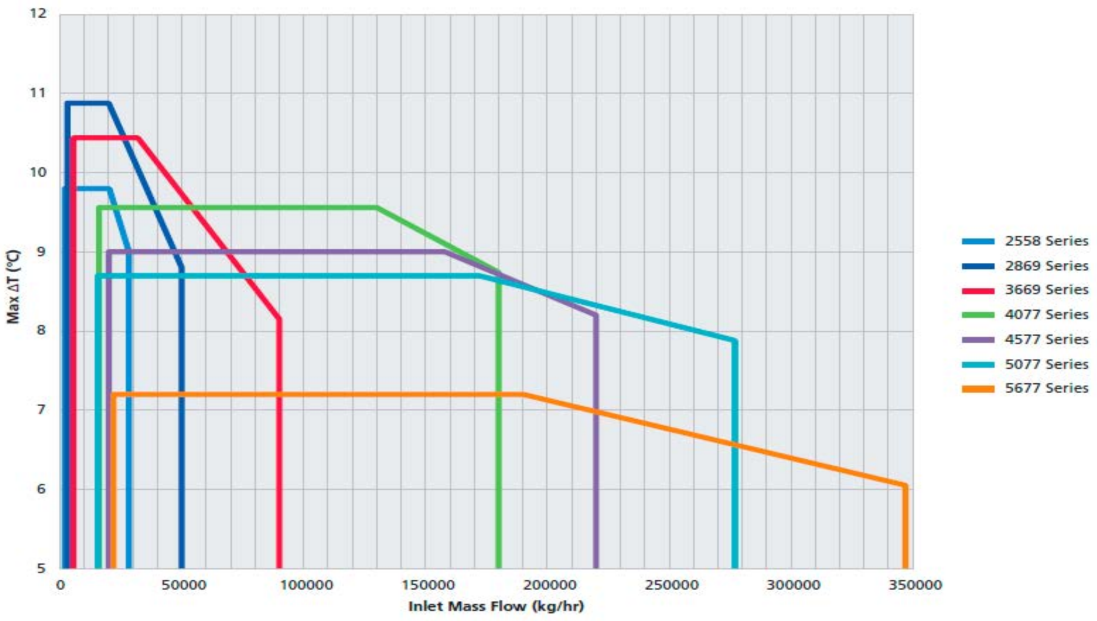


Diagram 11: PILLER's product line summary at 100°C (temperature lift)

Credits: PILLER

Chart 2 (below) shows the current limitations of these widely spread technologies.

A temperature lift of 50 Kelvin is achievable with expensive tailor-designed compressors, but the thermal capacity of the system should have a minimum of 5 MW. This is due to the high thermal energy in steam condensation, the (fixed) volume of the compressor and the significant volume reduction of steam during compression (especially important for multistage compression).

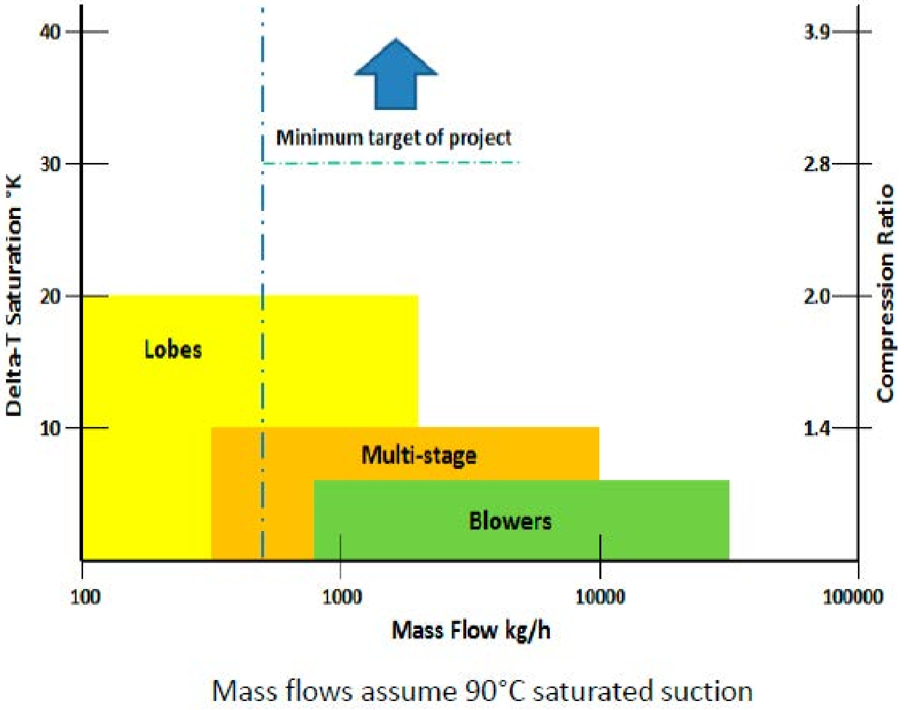
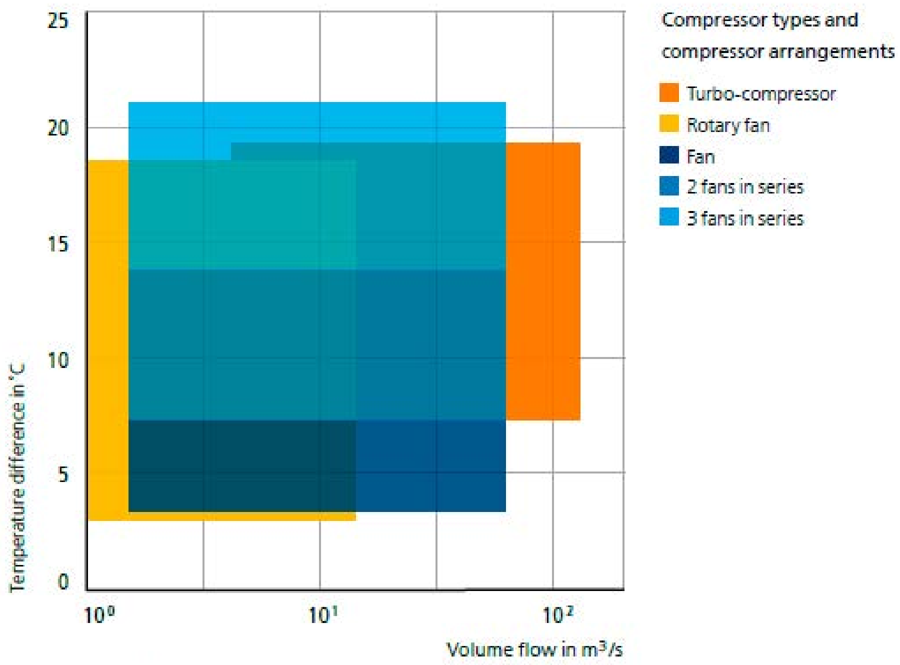


Chart 2: Range of applications for the three main MVR technologies



Applications of compressor types and arrangements depending on temperature difference and volume flow

Future developments

There are several technical options to optimize mechanical vapour recompression by increasing the achievable temperature lift (by increasing the compression ratio) in an economic way:

1. **PACO project (EDF / Johnson Controls): France:** Started in 2009 and successfully achieved in 2016.

   A two-stage centrifugal compressor with magnetic bearings with an ability to increase temperature of up to 40K, with a maximum temperature of 130°C at a COP >5. This project was specifically targeting heat need for the food and wood and paper industries. This development is not yet commercially available with Johnson Control currently looking for an industrial partner.

2. **Dryficiency:** EU project started in 2016 and running to 2020.

   The project is specifically targeting drying applications. It aims to achieve a TRL level of 7 at the end of the programme. One of the goals is to develop an open-loop heat pump able to reach a temperature of 150°C to 180°C. An industrial implementation is planned in a Mars factory (see diagram 12).

The technology used is based on a compressor technology from the automotive industry (Rotrex) with the expected following advantages:

- highly efficient steam compression (up to 75% aerodynamic)
- high pressure (PR > 6)
- extremely low cost maintenance – minimal system downtime <1h
- low cost investment – ROI less than 2 years.

However, this system isn't commercially available yet.

The above projects demonstrate that applied research is active in this field, meaning improvements can still be achieved despite the lack of commercially available new technology now.

Commercial availability can be expected within 5 years and, therefore, this kind of optimisation could be worth including in long term planning.

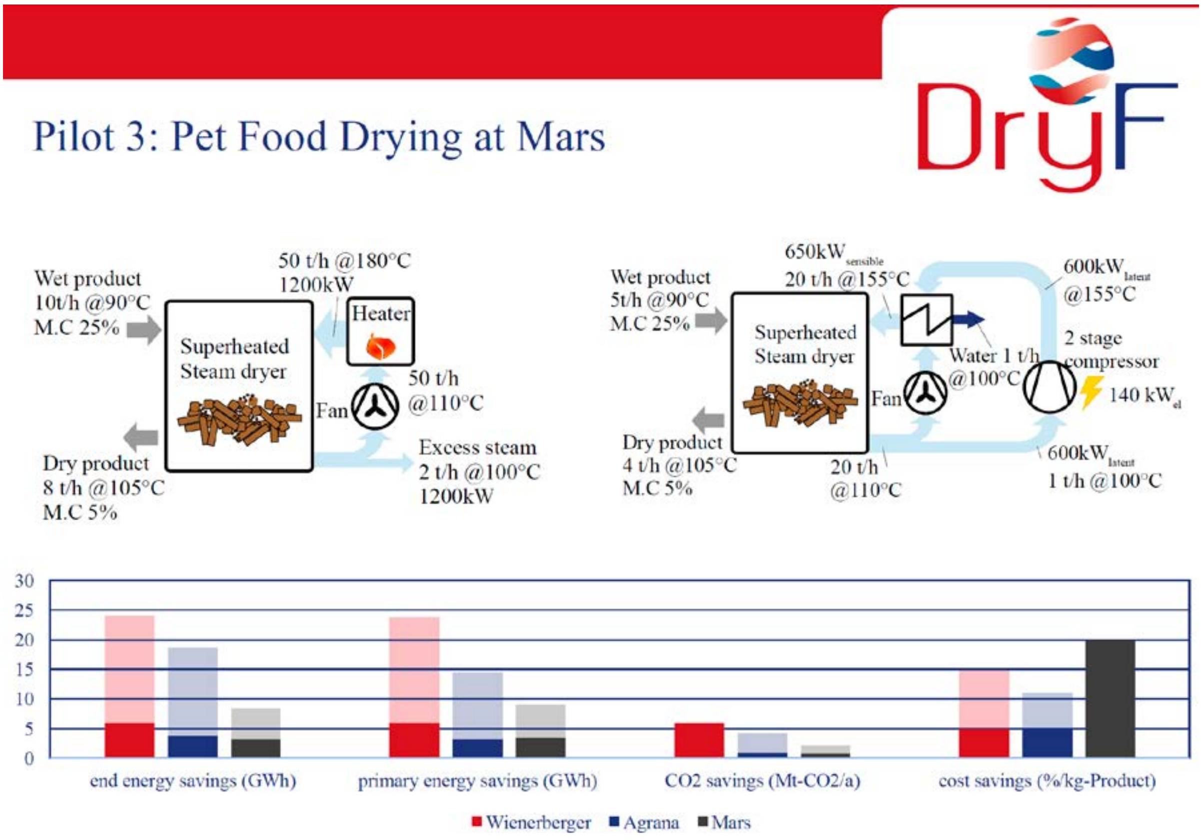

Pilot 3: Pet Food Drying at Mars

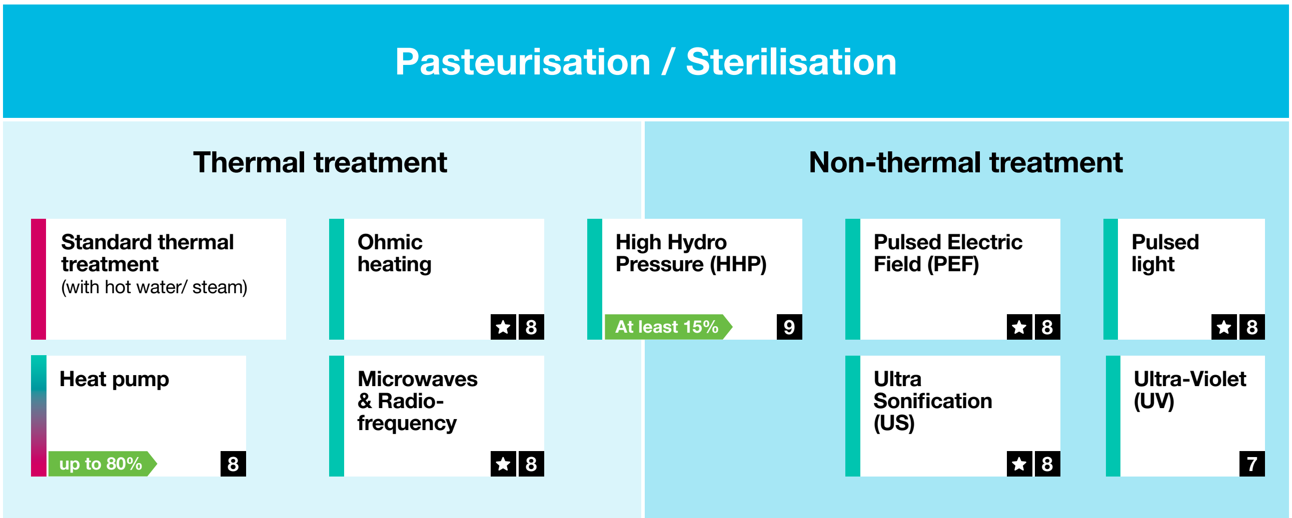
Diagram 12: Proposed pet drying application at Mars

Credits: Dry-F

2.3 Pasteurisation / sterilisation

Key insights

- A wide range of alternative technologies are readily available.
- If a process uses heat for pasteurisation or sterilisation, switching to an alternative electro-technology could eliminate the need for high temperature, resulting in significant operating cost savings.



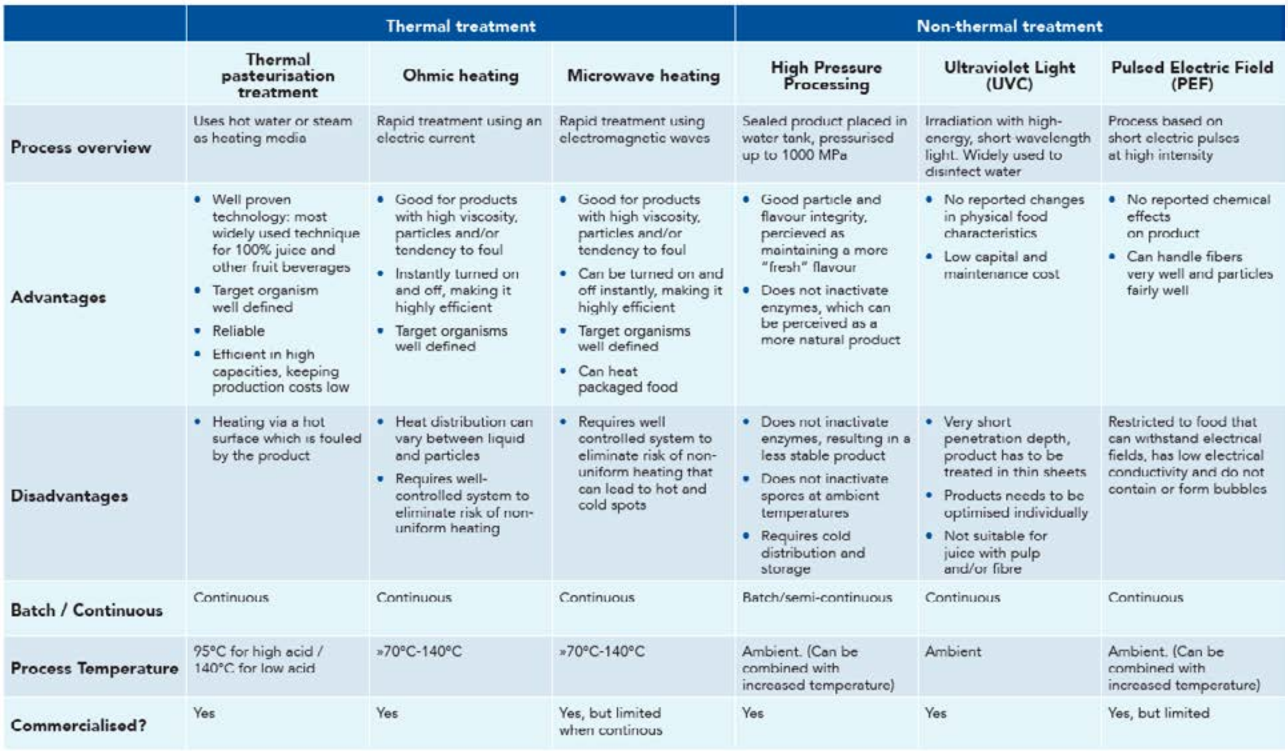
Pasteurisation and sterilisation still largely relies on thermal treatment. However, a wide range of technological alternatives, based on physical principles different from the thermal inactivation of pathogens, are available.

These solutions all consume electricity instead of heat, and most of them are much less energy intensive than thermal treatment.

This may eliminate the need for high temperature (steam) in some factories, and therefore remove the need to operate an emission intensive and costly to operate boiler.

These technologies allow stabilisation of perishable products, meaning they can also translate into energy savings in refrigeration.

Table 8 (below) summarises the various options available in food processing for preservation; while this relates specifically to juices it can be extended to other applications.



	Thermal treatment			Non-thermal treatment		
	Thermal pasteurisation treatment	**Ohmic heating**	**Microwave heating**	**High Pressure Processing**	**Ultraviolet Light (UVC)**	**Pulsed Electric Field (PEF)**
Process overview	Uses hot water or steam as heating media	Rapid treatment using an electric current	Rapid treatment using electromagnetic waves	Sealed product placed in water tank, pressurised up to 1000 MPa	Irradiation with high-energy, short wavelength light. Widely used to disinfect water	Process based on short electric pulses at high intensity
Advantages	• Well proven technology: most widely used technique for 100% juice and other fruit beverages • Target organism well defined • Reliable • Efficient in high capacities, keeping production costs low	• Good for products with high viscosity, particles and/or tendency to foul • Instantly turned on and off, making it highly efficient • Target organisms well defined	• Good for products with high viscosity, particles and/or tendency to foul • Can be turned on and off instantly, making it highly efficient • Target organisms well defined • Can heat packaged food	• Good particle and flavour integrity, percieved as maintaining a more "fresh" flavour • Does not inactivate enzymes, which can be perceived as a more natural product	• No reported changes in physical food characteristics • Low capital and maintenance cost	• No reported chemical effects on product • Can handle fibers very well and particles fairly well
Disadvantages	• Heating via a hot surface which is fouled by the product	• Heat distribution can vary between liquid and particles • Requires well-controlled system to eliminate risk of non-uniform heating	• Requires well controlled system to eliminate risk of non-uniform heating that can lead to hot and cold spots	• Does not inactivate enzymes, resulting in a less stable product • Does not inactivate spores at ambient temperatures • Requires cold distribution and storage	• Very short penetration depth, product has to be treated in thin sheets • Products needs to be optimised individually • Not suitable for juice with pulp and/or fibre	Restricted to food that can withstand electrical fields, has low electrical conductivity and do not contain or form bubbles
Batch / Continuous	Continuous	Continuous	Continuous	Batch/semi-continuous	Continuous	Continuous
Process Temperature	95°C for high acid / 140°C for low acid	»70°C-140°C	»70°C-140°C	Ambient. (Can be combined with increased temperature)	Ambient	Ambient. (Can be combined with increased temperature)
Commercialised?	Yes	Yes	Yes, but limited when continous	Yes	Yes	Yes, but limited

Table 8: Example of a comparison between disinfection options for the fruit juice industry

Credits: TETRA PAK assets.tetrapak.com/static/documents/processing/juice-processing-fact-sheet.pdf

Note the list in the above table is not exhaustive, as it does not mention pulsed light or ultrasonification. It is also just an example as the advantages and disadvantages of each technology will vary widely depending on the product and / or application.

2.3.1 High Hydrostatic Pressure treatment (HHP)

High Hydrostatic Pressure treatment (HHP)

9 TRL level	Energy saving technology Electrification technology
Sectors of applicability	
Usage	Pasteurisation / preservation
Energy savings reported	From 15%
Co-benefits reported	• preserved flavours • extended shelf life • eliminates the use of chemical preservatives (meat)

Probably the most developed and widely implemented of the listed new preservation technologies at an industrial level is High Hydrostatic Pressure (HHP).

This technology has demonstrated its capability for preserving sensory and nutritional qualities of foods while producing suitable levels of microbiological and enzyme inactivation.

HHP, also known as High Pressure Processing (HPP) or Ultra-High Pressure (UHP), is a non-thermal food processing technology applied when the food is subjected to high hydrostatic pressure commonly at or above 100 MPa.

However, treatments are optimized at a pressure level between 400 MPa and 600 MPa in combination with moderate heat.

The technique of HHP is currently successfully used in Japan, the United States and Europe for pasteurization of food products.

HHP is also in regular commercial use in Australia. Globally it has been applied to a wide range of products and, most recently, was extended to dairy with an HPP-treated milk.

The industrial application of HHP / HPP / UHP has been an increasing trend for the last decade, as is evidenced by increased numbers of equipment installations (see Charts 3 and 4 below). In 2012, HHP processes generated 350,000 tons of food.

This technology is fully commercialised, the main suppliers are listed in this document (refer to page 7).

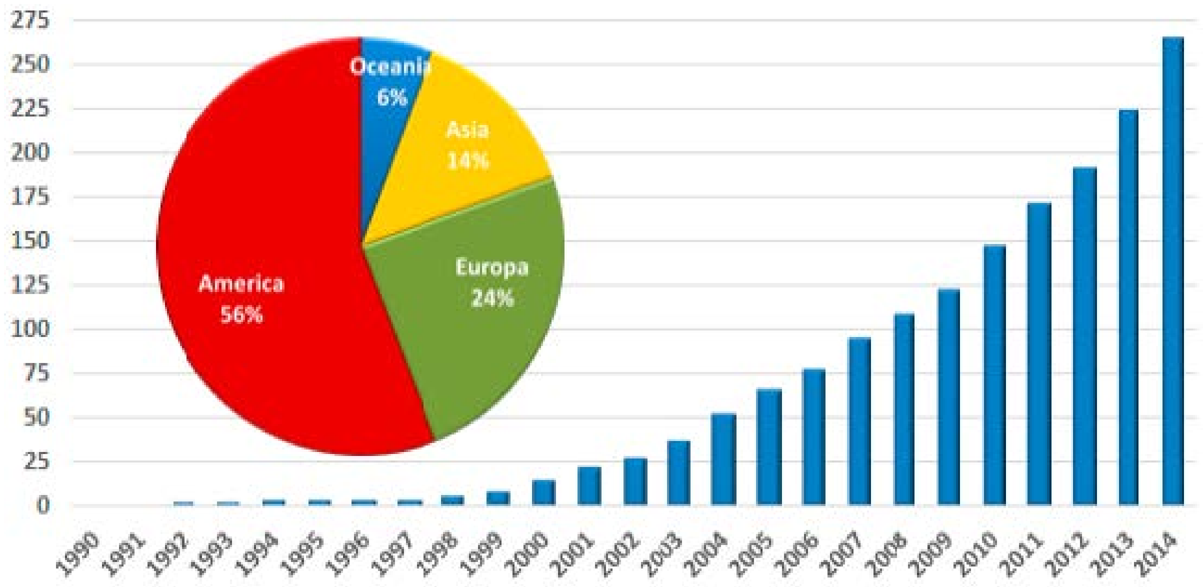


Chart 3: Adoption rate of HPP (total number of HPP industrial machines in production until 2014)

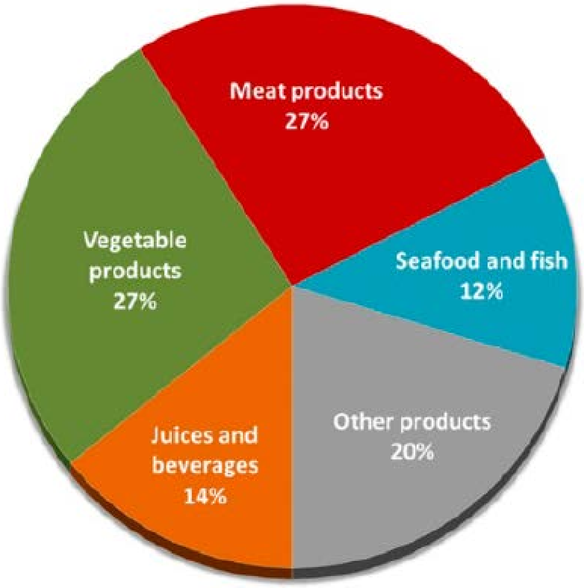


Chart 4: Worldwide HPP food production in 2014

Charts 3 and 4: High Pressure Processing Technology and Equipment Evolution: A Review

Wael M. Elamin, Johari B. Endan, Yus A. Yosuf, Rosnah Shamsudinand Anvarjon Ahmedov

jestr.org/downloads/Volume8Issue5/fulltext85112015.pdf

Here is an example of an industrial installation from HIPERBARIC:

Credits : HIPERBARIC (Hiperbaric 300)

The cost of a commercial-scale HPP unit ranges from USD$500,000 to over USD$2.5 million. The total cost includes the variable costs (labour, area, energy, utilities, maintenance and other) and the capital cost. Approximately 80% of the investment goes to the capital cost of the HPP system and installation.

The cost per amount of treated product is still high for HPP. The range is from USD$0.08 to USD$0.22 cents/L, where prices for traditional heat treatment may only be USD$0.02 to USD$0.04 cents/L.

There is a fast growing demand for HPP technology as a promising technique for increasing product shelf life and for delivering a healthy and quality food.

As demand grows, the cost of production as well as the HPP products themselves will fall further.

The main objective of any non-thermal technology is to maximize the freshness and flavour qualities of the foodstuffs while achieving the required level of food safety.

High hydrostatic pressure (HHP) meets with these requirements and is currently being incorporated in many companies as an alternative to conventional heat treatment procedures. Applications include the preservation of meat products, oysters, fruit jams, fruit juices, salad dressings, fresh calamari, rice cake, duck liver, jam, guacamole, and many ready-to-eat foods (including cheese).

Two examples from Australia involve the food and beverage (fruit juices: https://www.hiperbaric.com/en/preshafood) and meat industries (http://www.moiramacs.com.au/technology).

One application of HHP that has great appeal is the stabilisation of fresh cheese due to its global consumption and the increase in global production (3.5 million tons in the last 10 years). Cheese is characterized by special physical and chemical properties such as a near neutral pH, high water activity of 0.97, high relative humidity, and proneness to contamination from pathogens.

Energy efficiency

A thesis has compared the Life Cycle Analysis (LCA) of milk and fresh cheese production with Ultra-high Pressure Homogenisation (UHPH) and classic thermal treatment at Ultra-High Temperature (UHT). The results are mitigated because it compares UHPH lab scale equipment without energy recovery and industrial optimised UHT process. However, the impact is still in favour of UHPH by 14%.

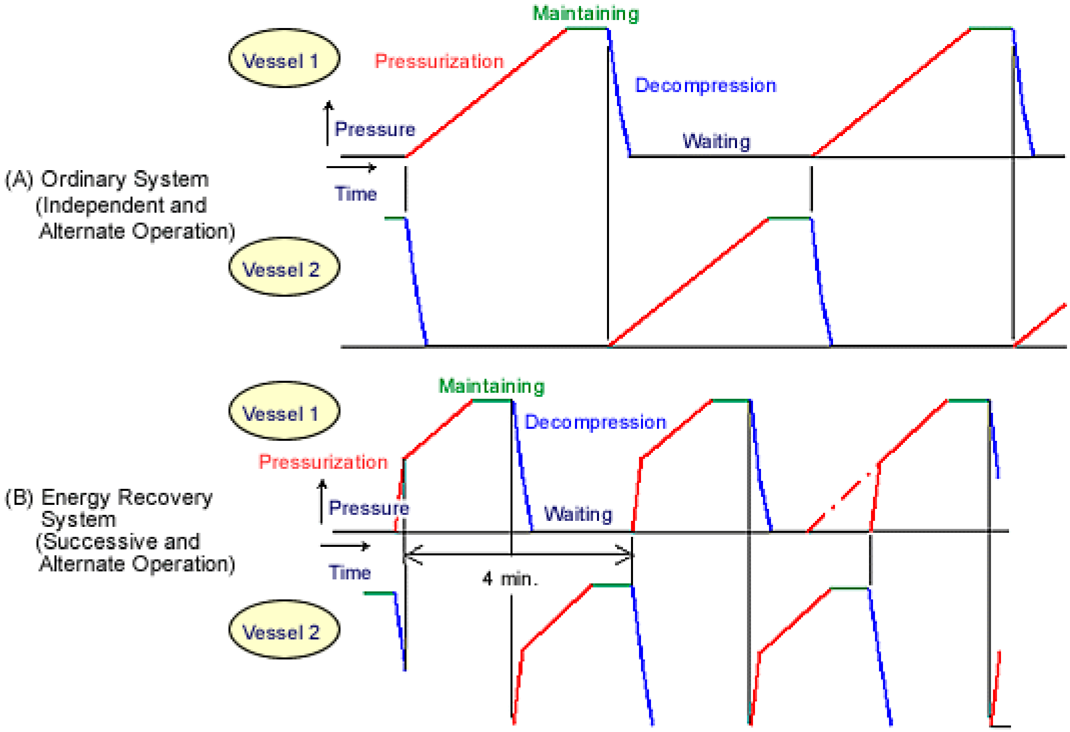
Some commercial suppliers of HHP systems are providing energy recovery:

However, no data about energy efficiency seems to be publicly available; the main commercial argument for energy recovery in such systems being the reduction in required pressurization time.

Future developments

The next step of the evolution in HHP treatment is multi-pulsed HHP treatment, which improves the efficiency of the treatment.

A European programme has also investigated High Pressure Thermal Sterilisation (HPTS) where products are pre-heated to 70°C to 90°C and pressurised up to 800 Mega-Pascal, reaching an actual temperature of (up to) 120°C.



Credits: KOBELCO

2.3.2 Ohmic heating

Ohmic heating

8 TRL level	Electrification technology
Sectors of applicability	
Usage	Pasteurisation / blanching / drying
Energy savings reported	Not the main benefit of the technology. High efficiency (>95%) though
Co-benefits reported	• see list below

Ohmic heating is based on the principle of the ‘Joule effect’. It takes place in a tubular cell equipped with three electrodes that are used to apply an alternating current to the product. The product acts as a resistance and heats up via the energy produced by Joule effect. The rise in temperature depends on the conductivity of the product.

When compared to microwave heating, for example, Ohmic heating presents advantages. In the former, heating is achieved only in a certain depth of the product while the latter heats the entire volume, no matter its size.

From an energy perspective, this is a highly efficient process, with energy efficiency >95%. Almost all the energy consumed is given to the product to heat. Hence, the energy saving benefits will depend on the efficiency of the previously used process.

Credit: ALFA LAVAL

The SterilOhm heating units from Alfa Laval.

Credit: EMMEPIEMME

www.emmepiemme-srl.com/ohmic-heating

Case Study	**One**
Country:	Germany and Switzerland
Sector:	Food
Product:	Fruits
Technology:	Ohmic pasteurization
Improvement:	Frutarom, a manufacturer of fruit preparations, operates two lines of ohmic pasteurization: one of 3,000 l/h in Switzerland and the other of 2,000 l/h in Germany. This technology allows producers to work with riper fruits that are richer in flavour. Gain of productivity provided by a homogeneous and ultrahigh volume heating (1 second to pass from 65°C to 100°C instead of 20 seconds in conventional technology). The fouling is lower, thus the downtimes for cleaning the line are reduced drastically. On aseptic lines production runs from 4–6 hours to 20 hours.
Energy savings:	NC
Cost savings:	NC
Investment:	NC, but more expensive than classic thermal treatment

European industrial companies claim to have developed readily available solutions specific to dairy products[6], although no case studies are currently publicly available.

Ohmic heating is most likely to be of interest when it translates into industrial benefits for the site and / or added value for the product. It is unlikely to be a process adapted to consumer milk products as manufacturers are primarily looking to optimise cost / volume.

However, there is several technological developments where this technology could be adopted for new applications such as viscous dairy products or infant milk powder.

Ohmic heating is also applicable to the chemical industry due to rapid heating (1,000°C/min), a highly uniform heat and extremely accurate control (helps with selection of reactions, yield and conversion efficiency).

The advantages of Ohmic heating can overcome the additional cost of energy but this must be assessed for each specific application. Advantages may include:

- direct volumetric heat generation within the product
- no external heat transfer required
- no hot surfaces involved
- rapid start-up and shutdown (and heating)
- highly precise temperature control
- high efficiency (>95%)
- ability to handle slurries with high solid contents (up to 80% solids)
- ability to process streams with large particulates
- ability to heat viscous products (e.g. to 100000 cP)
- low pressure drop, minimal shear, with large open flow channel
- low heater product volume with in-line heating
- reduced fouling and thermal degradation
- not limited by heat transfer area or low heat transfer coefficients.

The potential applications of this technique in the food industry are wide and include blanching, evaporation, dehydration, fermentation, pasteurisation and sterilisation.

The advantages discussed above make ohmic heating especially useful for very sticky (viscous) materials or fluids containing solid particles; it may also be used wherever non-uniform heating must be avoided or where mechanical agitation to improve heat transfer is not recommended.

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[6] https://www.rlf.fr/actualites/traitement-thermique-le-chauffage-ohmique-debarque-dans-le-secteur-laitier:QSNW9RQU.html

2.3.3 Pulsed Electric Field Processing (PEF)

Pulsed Electric Field Processing (PEF)

8	**TRL level**	**Energy saving technology**	**Electrification technology**
Sectors of applicability			
Usage		Pasteurisation / preservation / blanching / peeling / drying	
Energy savings reported		No clear figures yet, but expected to be significant (the physical principle is not energy intensive).	
Co-benefits reported		• shorter processing time • reduced capital cost • preserved flavours for food (ambient temperature) • allows extraction of valuable chemicals (pharmaceuticals, wine)	

Pulsed Electric Field (PEF) technology is a mild food processing technology, suitable for preserving liquid and semi-liquid food products.

The basic principle of PEF is the application of short pulses of high electric fields with duration of microseconds and intensity of 10-80 kV/cm to achieve microbial inactivation in food products while preserving the product's fresh characteristics.

When an electric field is applied, electric current flows into the liquid food and is transferred to each point in the liquid because of charged molecules present.

It creates a phenomenon called electroporation by which the cell wall is perforated and cytoplasmic contents leak out causing microorganisms' cell death.

Therefore, it is not ohmic heating, because the electrical field is not applied to produce heat.

PEF treatment intensity can be characterized based on:

- initial temperature
- energy delivery electrical field strength
- temperature after treatment.

Typically, the liquid flow is heated before the treatment to increase efficiency. After the treatment, the flow is cooled to stop quality-decreasing processes, such as enzyme reactions.

Process benefits are independent of product categories and could be of benefit to other industries such as the biotechnology and pharmaceutical industries where a reduced thermal intensity during pasteurization (media for fermentation, vaccines, etc) would also be beneficial.

This technology has been introduced in relatively recent times but is already commercialised at an industrial level for both liquid and solid food applications.

Credits: Elea GmbH, Germany

Credits: PUREPULSE / CoolWave Processing

Applications

The most common application of PEF has been focused on preservation of flowable foods, including fruit and vegetable juices, milk, beer, and liquid eggs. Wine making is also an area of interest.

PEF technology enhances yield in fruits by about 30% when exposed to low electric fields. There are also successful results for meat and fish (about 30% improvement in mass transfer) in reducing the residence time (i.e. red peppers from 360 minutes to 220 minutes). The energy use is about 10 KJ/kg.[7]

In New-Zealand, the University of Otago is running a pilot programme funded by MBIE (FIET - Food Industry Enabling Technology programme) that will test the technology for large-scale French fry production.

The electric field being pulsed through un-cut potatoes during processing alters their microstructure, which results in a more controlled release of sugar, more uniform colouration and reduced oil uptake. It also enhances processing as the softer texture makes the potatoes easier to cut (meaning less waste), allows for the development of new shapes (e.g. lattice cut), and increases knife durability (60%).

What are the barriers to a wider implementation of PEF?

Discussions with early adopters of this technology, as well as with enterprises that are open to innovation, have revealed that the lack of process guidelines with respect to complying with the relevant food legislation is one, if not the most dominant, factor hindering a broader application of PEF.

In general, processors require a HACCP (Hazard Analysis Critical Control Point) concept that identifies critical control points, process conditions and monitoring tools. As PEF is a technology with multiple process and operation parameters (electric field strength, pulse waveform, energy input, and temperature), there is no general dose concept available so far to describe and monitor the treatment intensity and its distribution. Present users of the technology have identified their own application-specific concepts for process monitoring, which requires a high level of technical and scientific background as well as case-by-case discussions with food authorities.

Future developments

PEF can also be coupled with ultrasound, which was the purpose of the SMARTMILK project funded by the EU for milk pasteurisation.

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[7] (Toepfl, Siemer, Heinz, 2014)

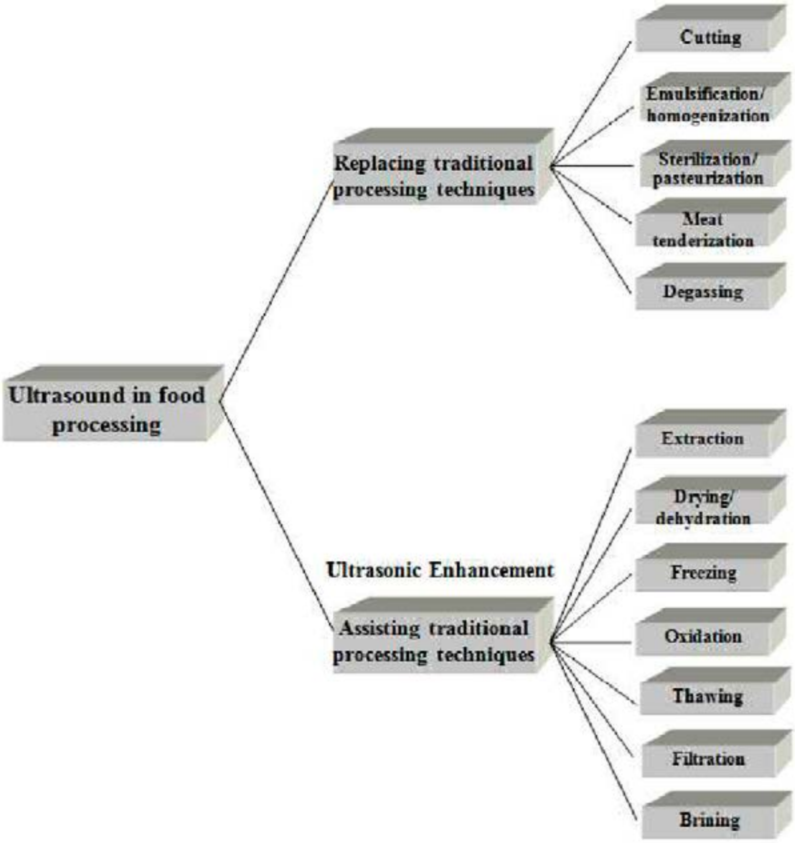
2.3.4 Ultrasonification

Ultrasonification

8 TRL level	Energy saving technology Electrification technology
Sectors of applicability	
Usage	Pasteurisation / sterilisation / drying / fermentation / extraction
Energy savings reported	Highly dependent on the application
Co-benefits reported	• effective mixing • increased mass transfer • reduced temperature • increased production rate

Ultrasound is a versatile and innovative technology due to its wide range of potential applications.

The application of ultrasound to liquid systems causes acoustic cavitation which is the phenomenon of generation, growing and eventual collapse of bubbles. As ultrasound waves propagate, the bubbles oscillate and collapse which causes the thermal, mechanical, and chemical effects.



[8]

Diagram 13: Applicability of ultrasound on food processes

Tao, Yang & Sun, Da-Wen. (2013). Enhancement of Food Processes by Ultrasound: A Review. Critical reviews in food science and nutrition. 10.1080/10408398.2012.667849.

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[8] Yang Tao, Da-Wen Sun: https://www.researchgate.net/publication/262976954_Enhancement_of_Food_Processes_by_Ultrasound_A_Review

Food processing:

In food processing, depending on its intensity, ultrasound is used for the activation or deactivation of enzymes, mixing and homogenisation, emulsification, dispersion, preservation, stabilisation, dissolution and crystallisation, hydrogenation, tenderisation of meat, ripening, ageing and oxidation, and as an adjuvant for solid-liquid extraction for maceration to accelerate and to improve the extraction of active ingredients from different matrices, as well as the degassing and atomisation of food preparations.

Due to the elimination of micro-organisms and enzymes without destroying nutrients of foods, ultrasound can be used as an alternative method to thermal treatments in the food preservation. Additionally, low power ultrasound is thought to be an attractive non-thermal method due to its ability to overcome problems that occur during heat treatments such as physical and chemical changes, nutritional loss and change in organoleptic properties.

Dairy:

Ultrasound treatment is applied in the dairy industry for the removal of fat from dairy wastewater using enzyme (Lipase z) as a catalyst. Ultrasound-assisted enzymatic pre-treatment of high fat content dairy wastewater, improvement in whey ultrafiltration, cutting of cheese blocks, crystallisation of ice and lactose, all alter the functionality of dairy proteins.

Ultrasonic processing of dairy products, cleaning of equipment, pasteurisation, and homogenisation (while involving minimum loss of flavour) can increase homogeneity and deliver energy savings.

Pasteurisation:

For pasteurisation purpose, ultrasound can also be applied jointly with other methods such as thermal-ultrasonification and ultrasonification under pressure, or even Manothermosonication (MTS: a combined method of heat, ultrasound and pressure), to circumvent the high resistance of certain enzymes and bacterial spores to ultrasound treatment.

The use of ultrasound in pasteurisation is of interest to the dairy industry. It has proved effective for the destruction of *E. coli*, *Pseudomonas fluorescens* and *Listeria monocytogenes* with no detrimental effect on the total protein or casein content of pasteurised milk[9].

Sterilisation:

One of the main and long-established industrial applications of power ultrasound is in surface cleaning as it has proven to be an extremely efficient technology. The particular advantage of ultrasonic cleaning in this context is that it can reach crevices that are not easily reached by conventional cleaning methods.

Ultrasonic sterilisation is used for medical application to clean instruments and tools, making its use relevant for knives cleaning in meat processing industry, for example.

As a rule, an ultrasonic power rating of 8 to 10 w/L of bath liquid ensures good cleaning results.

Credit: Fisa-Schall

Despite having many advantages, and apart from being a relatively new technology, some disadvantages to the use of ultrasound waves has been reported, including:

- free radicals formed during cavitation may cause harmful effects on the consumer
- may cause a physic-chemical effect which may be responsible for off-flavour, discoloration and degradation of components
- the frequency of ultrasound waves can impose resistance to mass transfer.

The versatility of ultrasound is likely its main barrier to a wider adoption: each application requires specific research, testing, and parameters tuning.

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[9] Impact of ultrasound on dairy spoilage microbes and milk components: https://link.springer.com/article/10.1051%2Fdst%2F2008037

2.3.5 Pulsed light

Pulsed light

8	**TRL level**	**Energy saving technology**	**Electrification technology**
Sectors of applicability			
Usage	Sterilisation		

UV treatment is widely used for disinfection purpose in industry; pulsed light sterilisation is an evolution of this principle.

While still a relatively new technology, it is already commercialised in some industries.

The basic principle of pulsed light sterilisation is to destroy micro-organisms using short, intense light flashes generated by xenon lamps.

The energy needed for product decontamination is accumulated in a capacitor. A high-voltage signal initiates the so-called "arc formation" (the arc comprises highly ionised gas with strong currents).

Xenon gas is used because of its capacity to convert electrical energy into light energy. This arc starts the flash of intense luminosity.

The peak power of one flash is around 1 megawatt (MW). The flashes present a continuous spectrum, rich in UV light, which lasts a few hundred microseconds. The housing of the lamp is made of quartz, so almost no optical energy is wasted. The flashes are controlled and concentrated by aluminium reflectors, specifically designed for each application.

Each flash produces an enormous amount of energy. For example, a lamp energy of 300J and a flash time of 0.3mS produces 1MW of energy (or 1kW per cm2 of the treated object).

The micro-organisms absorb all the energy – including those that exist in the far UV domain.

Pulsed light has a destructive effect on micro-organisms thanks to a combination of two effects:

1. the sterilising effect of UV: the DNA in the cells of micro-organisms absorb the UV rays - this ruptures the double strands of DNA and provokes the formation of abnormal single-strand bonds, preventing DNA replication (i.e. the micro-organism's protein production and cell metabolism is blocked and it dies)
2. the power of the flash: the intense energy delivered in a very short time increases this lethal effect.

The main limitation is that pulsed light is a surface treatment; the decontaminated areas are those which receive the light pulse, either by direct emission or by reflection or diffusion phenomena. The effects of shadows, connected with the shapes of the items treated, limit the technology.

However, the utilisation of reflectors surrounding the lamps, optimises the treatment and makes it possible to sterilise packaging items with complex shapes, which make the technology suitable for most packaging (e.g. caps, cups, lids, preforms, metal cans, etc); here is an example for infant milk powder cans.

Case Study	**One**
Country:	Saudi Arabia
Sector:	Food
Product:	Beverages
Technology:	Pulsed light treatment
Improvement:	Pulsed light treatment has replaced hot filling at 80°C to 85°C
Energy savings:	NC
Cost savings:	Mainly on process line optimization
Investment:	NC

2.3.6 Ultra-Violet (UV)

Ultra-Violet (UV)

8	**TRL level**	**Energy saving technology**	**Electrification technology**
Sectors of applicability			
Usage	Sterilisation		

As explained in the previous pulsed light section, the main limitation of UV treatment is that it is a surface treatment.

However, its application in the food industry as an alternative to steam sterilisation of tools and surfaces is used at scale in other countries, and presents a significant energy saving opportunity.

A significant application in New Zealand would be for the sterilisation of knives in the meat processing sector.

Credits: ELEGA

Examples of knives steriliser UV cabinets

However, a recent patent has been registered for sterilisation of milk with UV. In the patent “Method for sterilising gas dispersed liquids”, an Estonian company (Mikromasch Eesti) presents a novel method for sterilising food liquids such as milk, juice or water. The product is first treated to get rid of its impurities, then it is atomised (in air, nitrogen or an inert gas) to form a stable aerosol, which undergoes UV irradiation. The dispersed form of the product has a very low optical density that multiplies the ability of the radiation to penetrate the material. At the end of the treatment, a centrifugation or the passage in a cyclone makes it possible to recover the initial liquid in a homogeneous form.

A panel from the European Food Safety Authority (EFSA) has concluded that Ultra-Violet treated milk is safe for the general public.

2.3.7 Microwaves

Microwave technology is detailed above in the drying / evaporation section.

However, this section is about specific insights for sterilisation and pasteurisation operations.

Pasteurisation

The technology has been used on-and-off for over 30 years, mainly in the industries of yoghurt and milk.

Continuous flow microwave pasteurisation is used for apple cider and packaged acidified vegetables.

Pasteurisation processes with microwave technology has a special relevance for solid and semi-solid materials in terms of pasteurisation and sterilisation avoiding high levels of degradation.

Sterilisation

The technology enables an improved uniformity of heating for in-package sterilisation. A microwave power profile optimized for the package is possible.

There is a promising 915 MHz single mode sterilisation for processing packaged food. The food is immersed in pressurised hot water simultaneously heated by microwaves; 5-8 minute processing for safe and high quality food. This is especially good for non-homogeneous food[10].

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[10] (Ozkoc, Sumnu & Sahin 2014).

2.4 Other heating

Other Heating (Cooking / Melting / Reacting / ...)

Energy saving

- **Heat pump** up to 80% 8

Substitute technologies

- **Electro-magnetic systems** (Microwaves & Radio-frequency) ★ 9
- **Ohmic heating** ★ 8
- **Friction heater** 7
- **Pulsed Electric Field (PEF)** ★ 8

2.4.1 Friction heater

Friction heating is based on molecular rubbing, more precisely the same molecules of the product inside the heater are set in motion and the friction effect release heat. It is basically composed of an asynchronous motor driven by inverter - the rotor is connected to a special disk, rotating at a small distance from a stator disk.

Credits: EMMEPIEMME)

This heater can be used for any liquid (with any density and viscosity), but without suspended solid particles (although it will allow a small presence of suspended particles – sizes less than 0.2mm and less than 20% of volume).

After heating the appearance of such particles may appear completely different depending on their composition: normally they are amalgamated and there is no visible trace at the output of the heater, for this reason the heater can be used, if possible, to perform both the function of the heater and smoothing / homogenizer.

The friction heater has been designed primarily to allow ultra-fast heating without contact with “hot wall”, for products with no electrical conductivity, such as oil, margarine, butter, liquid chocolate, petroleum products (which cannot be heated in ohmic heaters).

It has a global efficiency of about 85% and is characterized by precision (+/- 0.1 ° C), uniformity and stability of temperature. On the other hand, it is a mechanical object with rotating and mechanical seals, so it presents all the maintenance problems typical of this type of equipment.

- Other product limitations are:
- maximum temperature gap of 50°C
- maximum outlet temperature of 145°C
- medium heating time of about 1.5 seconds.

https://www.emmepiemme-srl.com/friction-heater

2.4.2 Pulsed Electric Field Processing (PEF)

Pulsed Electric Field Processing (PEF)

8 TRL level	Energy saving technology Electrification technology
Sectors of applicability	MILK
Usage	Pasteurisation / preservation / blanching / peeling / drying
Energy savings reported	No clear figures yet but expected to be significant (the physical principle is not energy intensive).
Co-benefits reported	• shorter processing time • reduced capital cost • preserved flavours for food (ambient temperature) • allow extraction of valuable chemicals (pharmaceuticals, wine)

The Pulsed Electric Field (PEF) technology principle is further described in the section 2.3: Sterilisation / pasteurisation”.

In addition to its sterilisation potential for liquid or semi-liquid food, PEF can be used for solid food processing: tenderisation of meat, blanching, soaking (beans), sugar extraction, pre-treatment of animal fodder, etc.

Credits: Elea GmbH, Germany

Credits: PULSEMASTER

2.5 High temperature heat pumps[11]

This section focuses on electrically powered compression heat pump applications for industry (which implies both a minimum size and a higher level of temperature), commercially available products, and the current trends with this technology. Diagram 14 clarifies the types of heat pump technology targeted here.

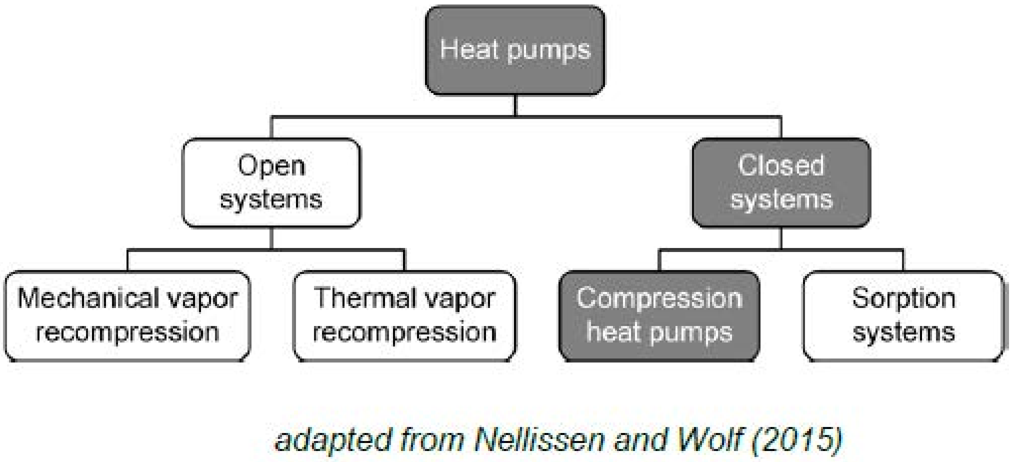

Diagram 14: Families of heat pump technologies

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[1] NTB University of Applied Sciences of Technology Buchs, Switzerland
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2.5.1 Temperature and pool of potential applications

Heat pumps are currently classified internationally according to the level of temperature they supply as shown in diagram 15.

Based on these classifications, heat pump technology can be broken into three groups:

- up to 80°C: considered to be well proven and the standard application
- from 80°C to 100°C: considered commercially available but more advanced and complex
- above 100°C: considered innovative (or even experimental).

No operational example of a heat pump operating at 80°C can be reported in New Zealand, highlighting the technology gap with observed international practices. Only one known planned project is reported to operate at 85°C (for the sterilisation of cleaning water).

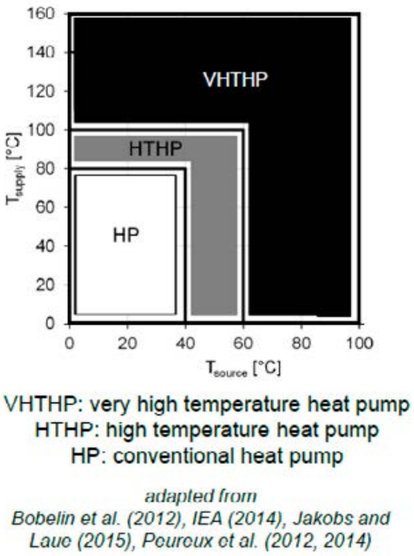

Diagram 15: Heat pump classifications by temperature

Adapted from Bobelin et al. (2012), IEA (2014), Jakobs and Laue (2015), Peureux et al. (2012, 2014)

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[11] Most of the information contained in this section come from publications available on the website of University of Applied Sciences of Technology Buchs, Switzerland: https://www.ntb.ch/projekt/hochtemperatur-waermepumpe

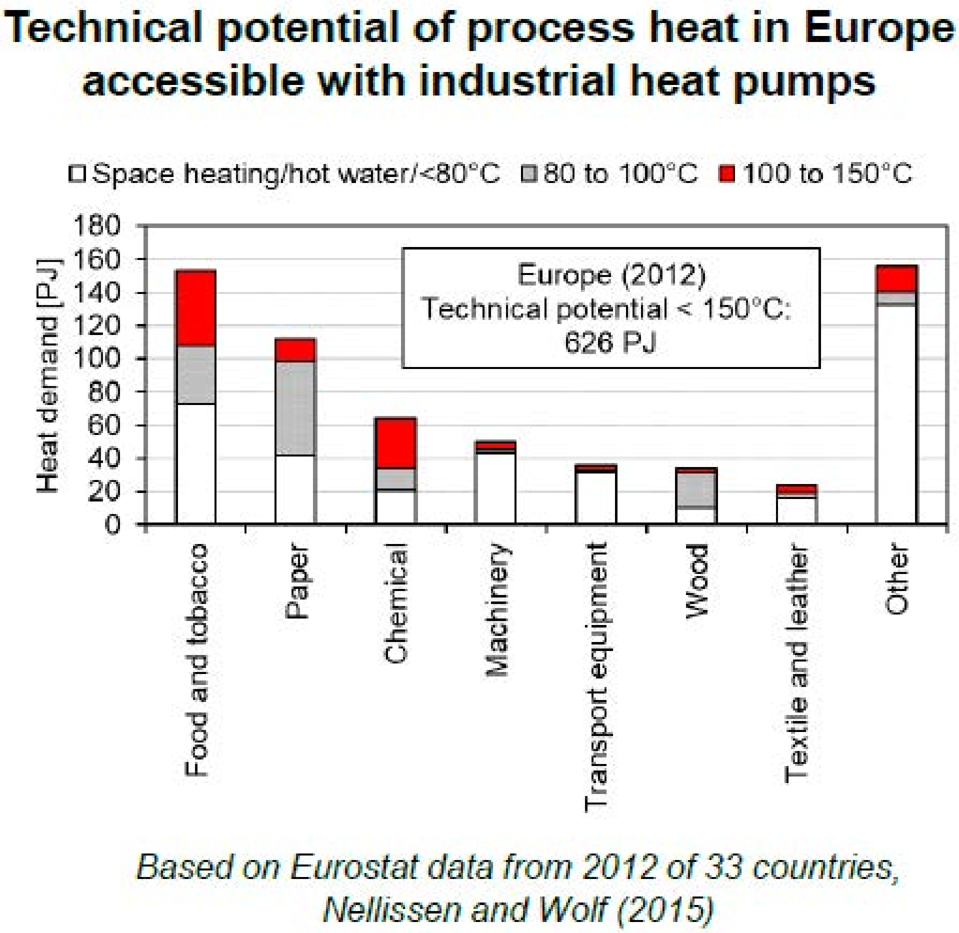
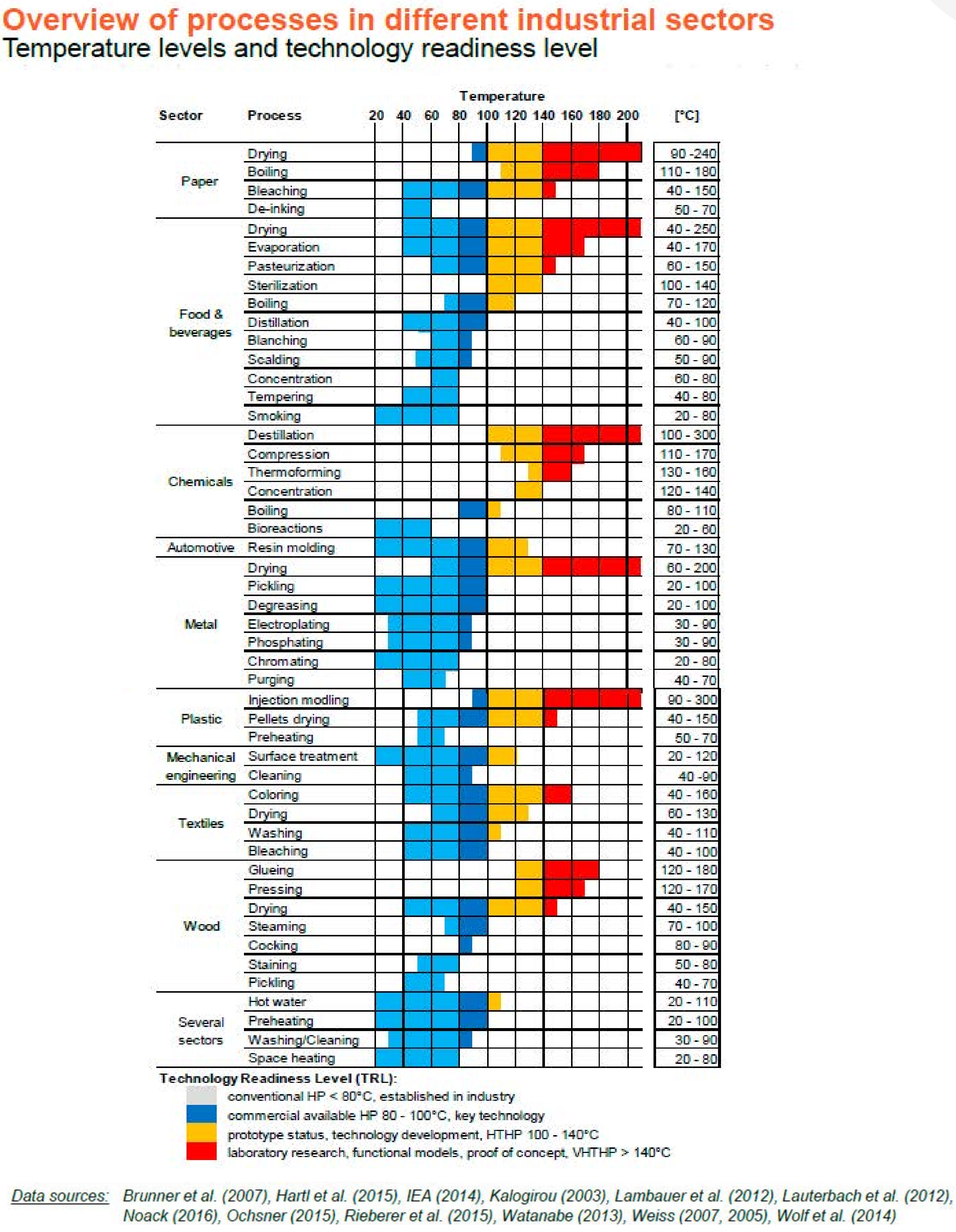


Chart 5: Technical potential of process heat in Europe accessible with industrial heat pumps

Based on Eurostats dat from 2012 of 33 countries (mainly Europeans). Nellissen and Wolf (2015)

These limits are also used to categorise the application pool in industries. The bar chart above (Chart 5) gives an overview of energy potential split within these categories.

Table 9 below provides a more detailed overview of temperature levels required for energy intensive processes within several industries. However, unlike chart 5, energy quantities are not represented.



Overview of processes in different industrial sectors

Temperature levels and technology readiness level

Sector	Process	[°C]
Paper	Drying	90 -240
	Boiling	110 - 180
	Bleaching	40 - 150
	De-inking	50 - 70
Food & beverages	Drying	40 - 250
	Evaporation	40 - 170
	Pasteurization	60 - 150
	Sterilization	100 - 140
	Boiling	70 - 120
	Distillation	40 - 100
	Blanching	60 - 90
	Scalding	50 - 90
	Concentration	60 - 80
	Tempering	40 - 80
	Smoking	20 - 80
Chemicals	Destillation	100 - 300
	Compression	110 - 170
	Thermoforming	130 - 160
	Concentration	120 - 140
	Boiling	80 - 110
	Bioreactions	20 - 60
Automotive	Resin molding	70 - 130
Metal	Drying	60 - 200
	Pickling	20 - 100
	Degreasing	20 - 100
	Electroplating	30 - 90
	Phosphating	30 - 90
	Chromating	20 - 80
	Purging	40 - 70
Plastic	Injection modling	90 - 300
	Pellets drying	40 - 150
	Preheating	50 - 70
Mechanical engineering	Surface treatment	20 - 120
	Cleaning	40 -90
Textiles	Coloring	40 - 160
	Drying	60 - 130
	Washing	40 - 110
	Bleaching	40 - 100
Wood	Glueing	120 - 180
	Pressing	120 - 170
	Drying	40 - 150
	Steaming	70 - 100
	Cocking	80 - 90
	Staining	50 - 80
	Pickling	40 - 70
Several sectors	Hot water	20 - 110
	Preheating	20 - 100
	Washing/Cleaning	30 - 90
	Space heating	20 - 80

Technology Readiness Level (TRL):

⬜ conventional HP < 80°C, established in industry

🟦 commercial available HP 80 - 100°C, key technology

🟨 prototype status, technology development, HTHP 100 - 140°C

🟥 laboratory research, functional models, proof of concept, VHTHP > 140°C

Data sources: *Brunner et al. (2007), Hartl et al. (2015), IEA (2014), Kalogirou (2003), Lambauer et al. (2012), Lauterbach et al. (2012), Noack (2016), Ochsner (2015), Rieberer et al. (2015), Watanabe (2013), Weiss (2007, 2005), Wolf et al. (2014)*

Table 9: Overview of processes in different industrial sectors with temperature levels and technology readiness

Credits: Cordin ARPAGAUS[1], FrédericBLESS[1], Jürg SCHIFFMANN[2], Stefan S. BERTSCH[1]

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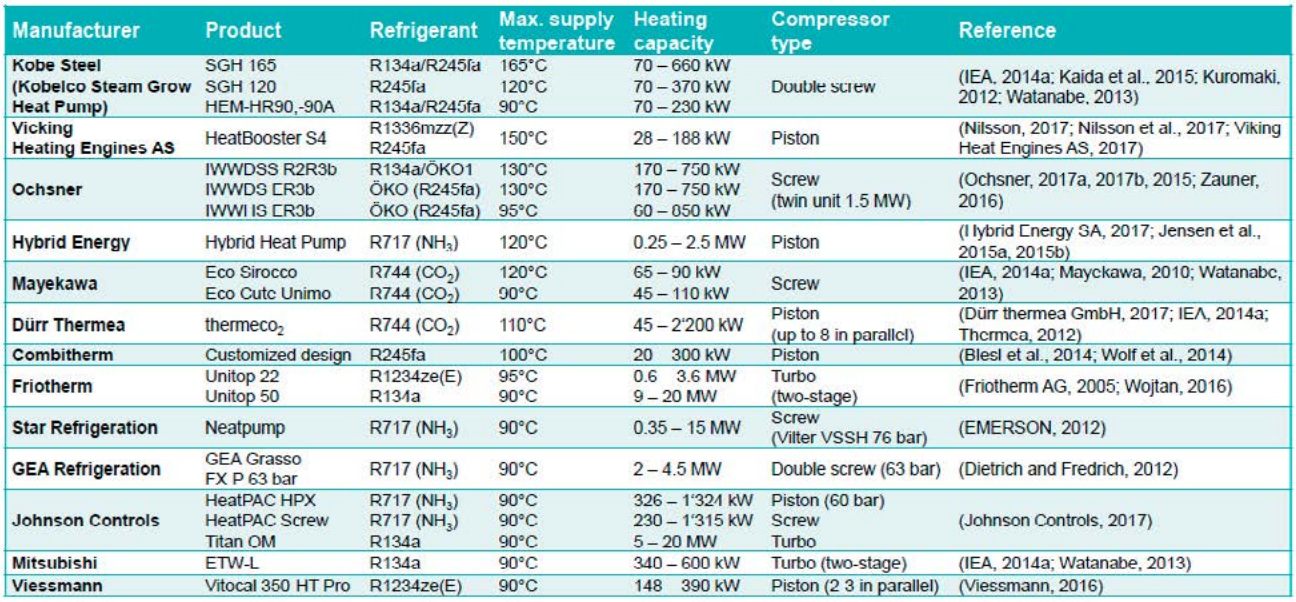
2.5.2 Commercial availability

High temperature heat pumps above 80°C are commercially available through a range of suppliers, as demonstrated in table 10.

For VHTHP, some products are commercially available, but the number of products is still limited (see diagram 16 below).

However, many of these high-end products are still in the “death valley” of innovation with available technology but few references (probably because of risk aversion from customers to unproven machinery).



Manufacturer	Product	Refrigerant	Max. supply temperature	Heating capacity	Compressor type	Reference
Kobe Steel (Kobelco Steam Grow Heat Pump)	SGH 165 SGH 120 HEM-HR90,-90A	R134a/R245fa R245fa R134a/R245fa	165°C 120°C 90°C	70 – 660 kW 70 – 370 kW 70 – 230 kW	Double screw	(IEA, 2014a; Kaida et al., 2015; Kuromaki, 2012; Watanabe, 2013)
Vicking Heating Engines AS	HeatBooster S4	R1336mzz(Z) R245fa	150°C	28 – 188 kW	Piston	(Nilsson, 2017; Nilsson et al., 2017; Viking Heat Engines AS, 2017)
Ochsner	IWWDSS R2R3b IWWDS ER3b IWWHS ER3b	R134a/ÖKO1 ÖKO (R245fa) ÖKO (R245fa)	130°C 130°C 95°C	170 – 750 kW 170 – 750 kW 60 – 050 kW	Screw (twin unit 1.5 MW)	(Ochsner, 2017a, 2017b, 2015; Zauner, 2016)
Hybrid Energy	Hybrid Heat Pump	R717 (NH_3)	120°C	0.25 – 2.5 MW	Piston	(Hybrid Energy SA, 2017; Jensen et al., 2015a, 2015b)
Mayekawa	Eco Sirocco Eco Cute Unimo	R744 (CO_2) R744 (CO_2)	120°C 90°C	65 – 90 kW 45 – 110 kW	Screw	(IEA, 2014a; Mayekawa, 2010; Watanabe, 2013)
Dürr Thermea	thermeco$_2$	R744 (CO_2)	110°C	45 – 2‘200 kW	Piston (up to 8 in parallel)	(Dürr thermea GmbH, 2017; IEA, 2014a; Thermea, 2012)
Combitherm	Customized design	R245fa	100°C	20 300 kW	Piston	(Blesl et al., 2014; Wolf et al., 2014)
Friotherm	Unitop 22 Unitop 50	R1234ze(E) R134a	95°C 90°C	0.6 3.6 MW 9 – 20 MW	Turbo (two-stage)	(Friotherm AG, 2005; Wojtan, 2016)
Star Refrigeration	Neatpump	R717 (NH_3)	90°C	0.35 – 15 MW	Screw (Vilter VSSH 76 bar)	(EMERSON, 2012)
GEA Refrigeration	GEA Grasso FX P 63 bar	R717 (NH_3)	90°C	2 – 4.5 MW	Double screw (63 bar)	(Dietrich and Fredrich, 2012)
Johnson Controls	HeatPAC HPX HeatPAC Screw Titan OM	R717 (NH_3) R717 (NH_3) R134a	90°C 90°C 90°C	326 – 1‘324 kW 230 – 1‘315 kW 5 – 20 MW	Piston (60 bar) Screw Turbo	(Johnson Controls, 2017)
Mitsubishi	ETW-L	R134a	90°C	340 – 600 kW	Turbo (two-stage)	(IEA, 2014a; Watanabe, 2013)
Viessmann	Vitocal 350 HT Pro	R1234ze(E)	90°C	148 390 kW	Piston (2 3 in parallel)	(Viessmann, 2016)

Table 10: Selection of industrial HTHPs with supply temperature ≥90°C

Source: European Heat Pump Summit 2017

Credits: Cordin ARPAGAUS[1], FrédericBLESS[1], Jürg SCHIFFMANN[2], Stefan S. BERTSCH[1]

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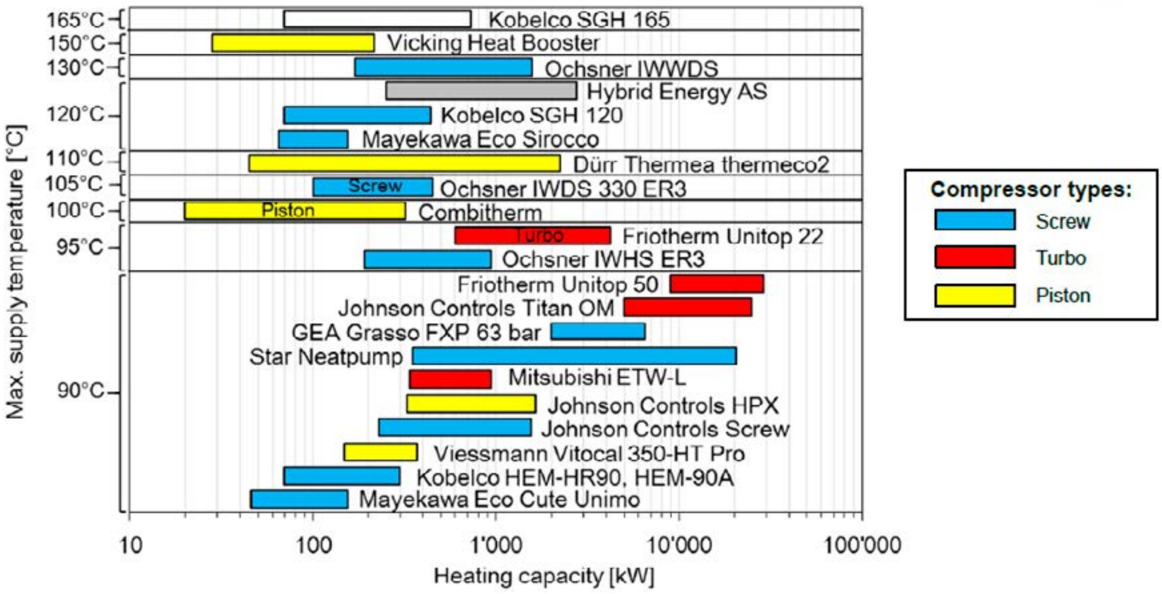

Diagram 16: Commercially available HTHPs sorted by maximum supply temperature and heating capacity

Source: European Heat Pump Summit 2017

Note: Durr Thermea ceased operations in December 2017.

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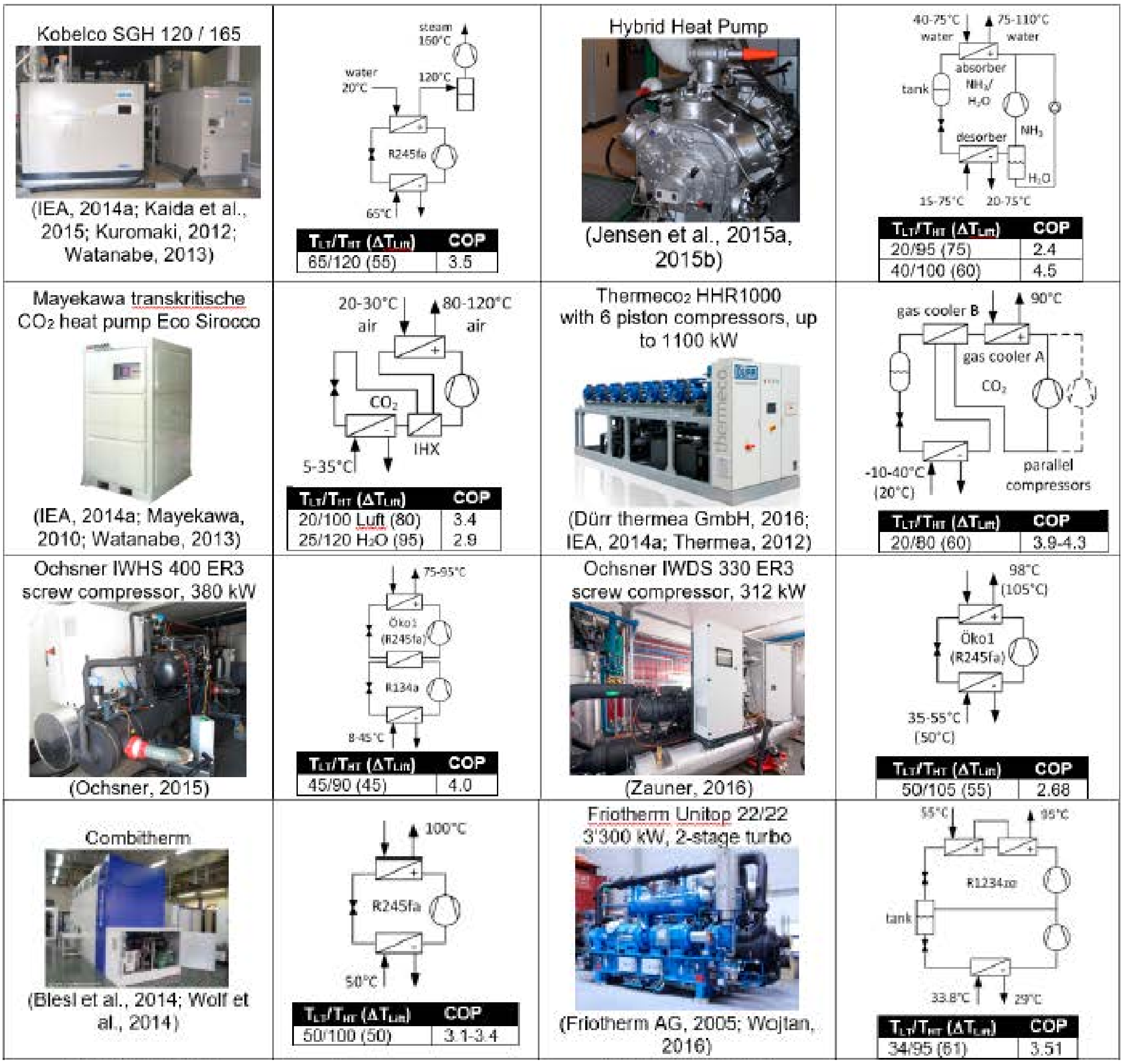
2.5.3 Performance (COP) of commercially available HTHP cycles

The Coefficient of Performance (COP) is a measure of the efficiency of the heat pump and is simply the ratio of useful heat provided to the amount of electricity used to upgrade the heat.

COP is a function of temperature lift (i.e. how much the temperature is upgraded) and decreases as the temperature lift increases.

Diagram 17 (below) provides some indicative COP for several commercial HTHP depending on cycle and working temperatures.

For this study, the useful information is that the achievable COP can be good enough (3 to 5), even at delivered temperatures above 80°C and for reasonable uplift of temperature (40°C to 60°C).



Kobelco SGH 120 / 165

(IEA, 2014a; Kaida et al., 2015; Kuromaki, 2012; Watanabe, 2013)

T_{LT}/T_{HT} (ΔT_{Lift})	COP
65/120 (55)	3.5

Hybrid Heat Pump

(Jensen et al., 2015a, 2015b)

T_{LT}/T_{HT} (ΔT_{Lift})	COP
20/95 (75)	2.4
40/100 (60)	4.5

Mayekawa transkritische CO_2 heat pump Eco Sirocco

(IEA, 2014a; Mayekawa, 2010; Watanabe, 2013)

T_{LT}/T_{HT} (ΔT_{Lift})	COP
20/100 Luft (80)	3.4
25/120 H_2O (95)	2.9

Thermeco2 HHR1000 with 6 piston compressors, up to 1100 kW

(Dürr thermea GmbH, 2016; IEA, 2014a; Thermea, 2012)

T_{LT}/T_{HT} (ΔT_{Lift})	COP
20/80 (60)	3.9-4.3

Ochsner IWHS 400 ER3 screw compressor, 380 kW

(Ochsner, 2015)

T_{LT}/T_{HT} (ΔT_{Lift})	COP
45/90 (45)	4.0

Ochsner IWDS 330 ER3 screw compressor, 312 kW

(Zauner, 2016)

T_{LT}/T_{HT} (ΔT_{Lift})	COP
50/105 (55)	2.68

Combitherm

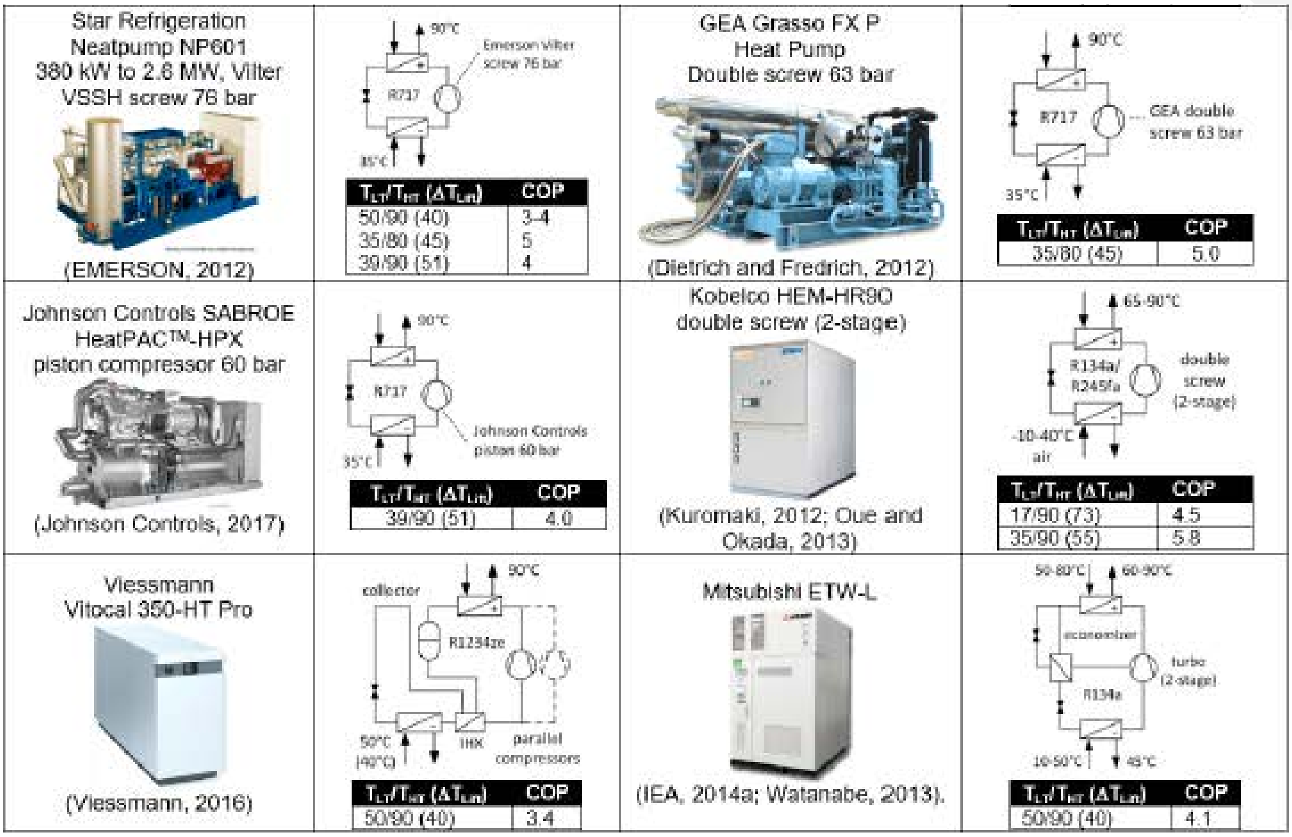
(Blesl et al., 2014; Wolf et al., 2014)

T_{LT}/T_{HT} (ΔT_{Lift})	COP
50/100 (50)	3.1-3.4

Friotherm Unitop 22/22 3'300 kW, 2-stage turbo

(Friotherm AG, 2005; Wojtan, 2016)

T_{LT}/T_{HT} (ΔT_{Lift})	COP
34/95 (61)	3.51



Star Refrigeration Neatpump NP601 380 kW to 2.8 MW, Vilter VSSH screw 76 bar (EMERSON, 2012)	90°C Emerson Vilter screw 76 bar R717 35°C T_{LT}/T_{HT} (ΔT_{Lift}) — COP 50/90 (40) — 3-4 35/80 (45) — 5 39/90 (51) — 4	GEA Grasso FX P Heat Pump Double screw 63 bar (Dietrich and Fredrich, 2012)	90°C R717 GEA double screw 63 bar 35°C T_{LT}/T_{HT} (ΔT_{Lift}) — COP 35/80 (45) — 5.0
Johnson Controls SABROE HeatPAC™-HPX piston compressor 60 bar (Johnson Controls, 2017)	90°C R717 Johnson Controls piston 60 bar 35°C T_{LT}/T_{HT} (ΔT_{Lift}) — COP 39/90 (51) — 4.0	Kobelco HEM-HR90 double screw (2-stage) (Kuromaki, 2012; Oue and Okada, 2013)	65-90°C R134a/ R245fa double screw (2-stage) -10-40°C air T_{LT}/T_{HT} (ΔT_{Lift}) — COP 17/90 (73) — 4.5 35/90 (55) — 5.8
Viessmann Vitocal 350-HT Pro (Viessmann, 2016)	90°C collector R1234ze 50°C (40°C) IHX parallel compressors T_{LT}/T_{HT} (ΔT_{Lift}) — COP 50/90 (40) — 3.4	Mitsubishi ETW-L (IEA, 2014a; Watanabe, 2013).	50-80°C 60-90°C economizer turbo (2-stage) R134a 10-50°C 45°C T_{LT}/T_{HT} (ΔT_{Lift}) — COP 50/90 (40) — 4.1

Diagram 17: Indicative COP for a sample of commercially available HTHP

Source: European Heat Pump Summit 2017

Credits: Cordin ARPAGAUS[1], FrédericBLESS[1],
Jürg SCHIFFMANN[2], Stefan S. BERTSCH[1]
[1] NTB University of Applied Sciences of Technology Buchs, Switzerland
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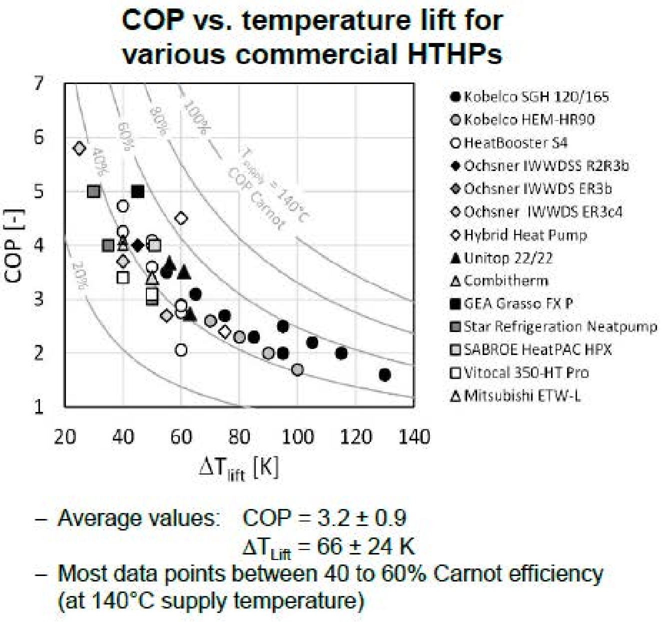
It is also important to acknowledge that no one perfect technological solution exists for every application; rather several possible technologies (e.g. cycles, working fluids, etc) may be more or less optimal depending on the application.

Chart 6 (below) shows the relative variation of COP for a few HTHP when temperature lift varies.



- Average values: COP = 3.2 ± 0.9
  ΔT_{Lift} = 66 ± 24 K
- Most data points between 40 to 60% Carnot efficiency (at 140°C supply temperature)

Chart 6: COP vs temperature lift for various commercial HTHPs

Source: European Heat Pump Summit 2017

Credits: Cordin ARPAGAUS[1], FrédericBLESS[1], Jürg SCHIFFMANN[2],
Stefan S. BERTSCH[1]
[1] NTB University of Applied Sciences of Technology Buchs, Switzerland
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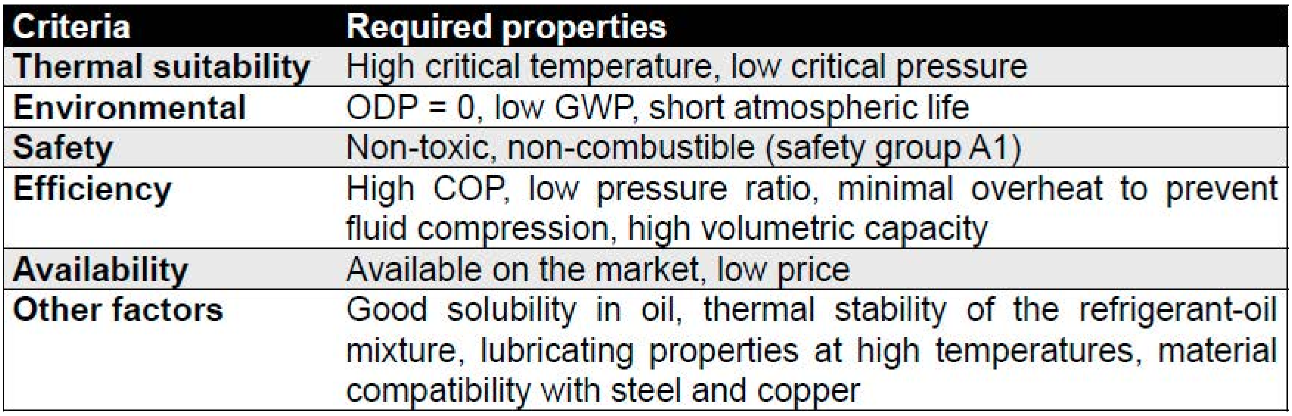
2.5.4 Working fluid

Research is continually testing new working fluids that perform well on the selection criteria shown in table 11.

Diagram 18 (below) shows some of the next generation refrigerants performances compared to the current standards.

At the moment, the more promising family of refrigerants for HTHP is the Hydro-Fluoro-Olefines (HFOs), as shown in table 12.



Criteria	Required properties
Thermal suitability	High critical temperature, low critical pressure
Environmental	ODP = 0, low GWP, short atmospheric life
Safety	Non-toxic, non-combustible (safety group A1)
Efficiency	High COP, low pressure ratio, minimal overheat to prevent fluid compression, high volumetric capacity
Availability	Available on the market, low price
Other factors	Good solubility in oil, thermal stability of the refrigerant-oil mixture, lubricating properties at high temperatures, material compatibility with steel and copper

Table 11: Selection criteria for refrigerants for HTHPs

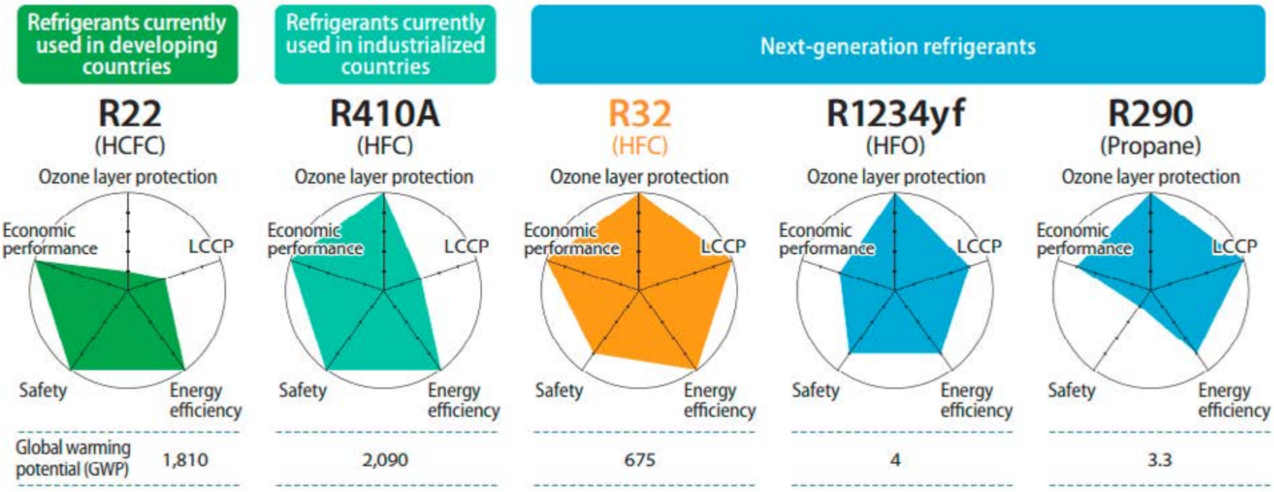


Diagram 18: Next generation refrigerant performance relative to current refrigerants

Notes: LCCP stand for Life Cycle Climate Performance.
R32 is difluoromethane CH2F2

Credits: Cordin ARPAGAUS[1], FrédericBLESS[1], Jürg SCHIFFMANN[2], Stefan S. BERTSCH[1]
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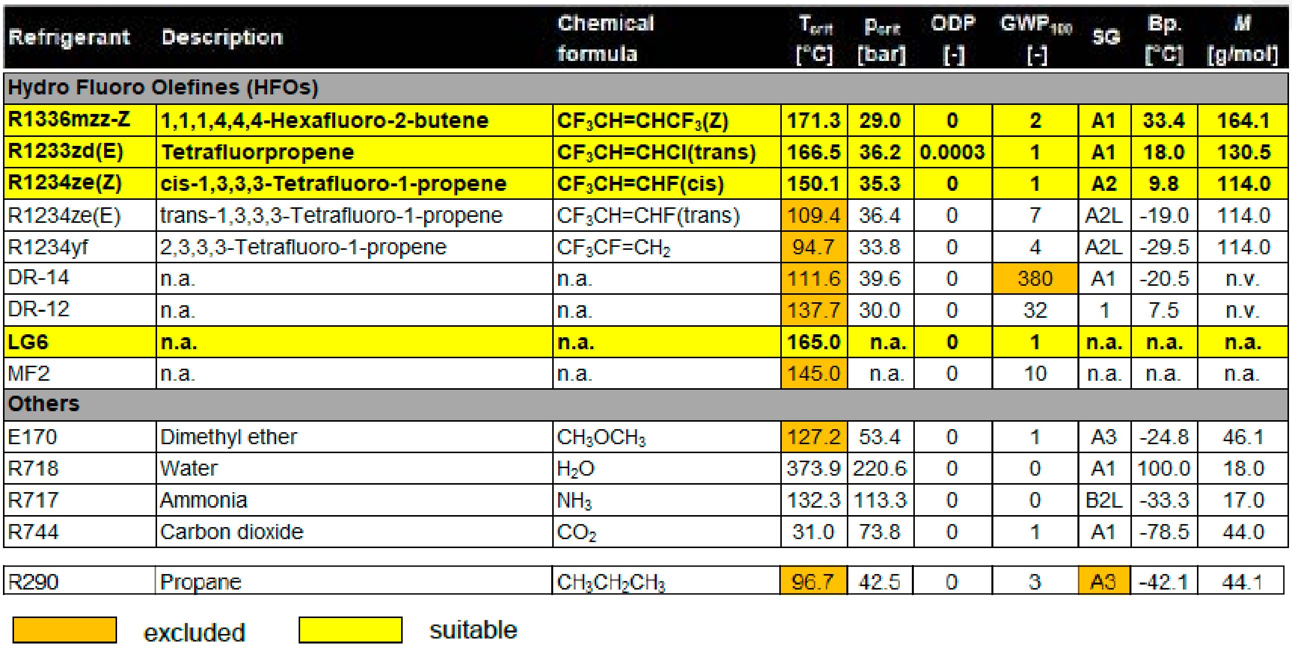


Refrigerant	Description	Chemical formula	T_{crit} [°C]	p_{crit} [bar]	ODP [-]	GWP_{100} [-]	SG	Bp. [°C]	M [g/mol]
Hydro Fluoro Olefines (HFOs)									
R1336mzz-Z	**1,1,1,4,4,4-Hexafluoro-2-butene**	**$CF_3CH=CHCF_3(Z)$**	**171.3**	**29.0**	**0**	**2**	**A1**	**33.4**	**164.1**
R1233zd(E)	**Tetrafluorpropene**	**$CF_3CH=CHCl(trans)$**	**166.5**	**36.2**	**0.0003**	**1**	**A1**	**18.0**	**130.5**
R1234ze(Z)	**cis-1,3,3,3-Tetrafluoro-1-propene**	**$CF_3CH=CHF(cis)$**	**150.1**	**35.3**	**0**	**1**	**A2**	**9.8**	**114.0**
R1234ze(E)	trans-1,3,3,3-Tetrafluoro-1-propene	$CF_3CH=CHF(trans)$	109.4	36.4	0	7	A2L	-19.0	114.0
R1234yf	2,3,3,3-Tetrafluoro-1-propene	$CF_3CF=CH_2$	94.7	33.8	0	4	A2L	-29.5	114.0
DR-14	n.a.	n.a.	111.6	39.6	0	380	A1	-20.5	n.v.
DR-12	n.a.	n.a.	137.7	30.0	0	32	1	7.5	n.v.
LG6	**n.a.**	**n.a.**	**165.0**	**n.a.**	**0**	**1**	**n.a.**	**n.a.**	**n.a.**
MF2	n.a.	n.a.	145.0	n.a.	0	10	n.a.	n.a.	n.a.
Others									
E170	Dimethyl ether	CH_3OCH_3	127.2	53.4	0	1	A3	-24.8	46.1
R718	Water	H_2O	373.9	220.6	0	0	A1	100.0	18.0
R717	Ammonia	NH_3	132.3	113.3	0	0	B2L	-33.3	17.0
R744	Carbon dioxide	CO_2	31.0	73.8	0	1	A1	-78.5	44.0
R290	Propane	$CH_3CH_2CH_3$	96.7	42.5	0	3	A3	-42.1	44.1

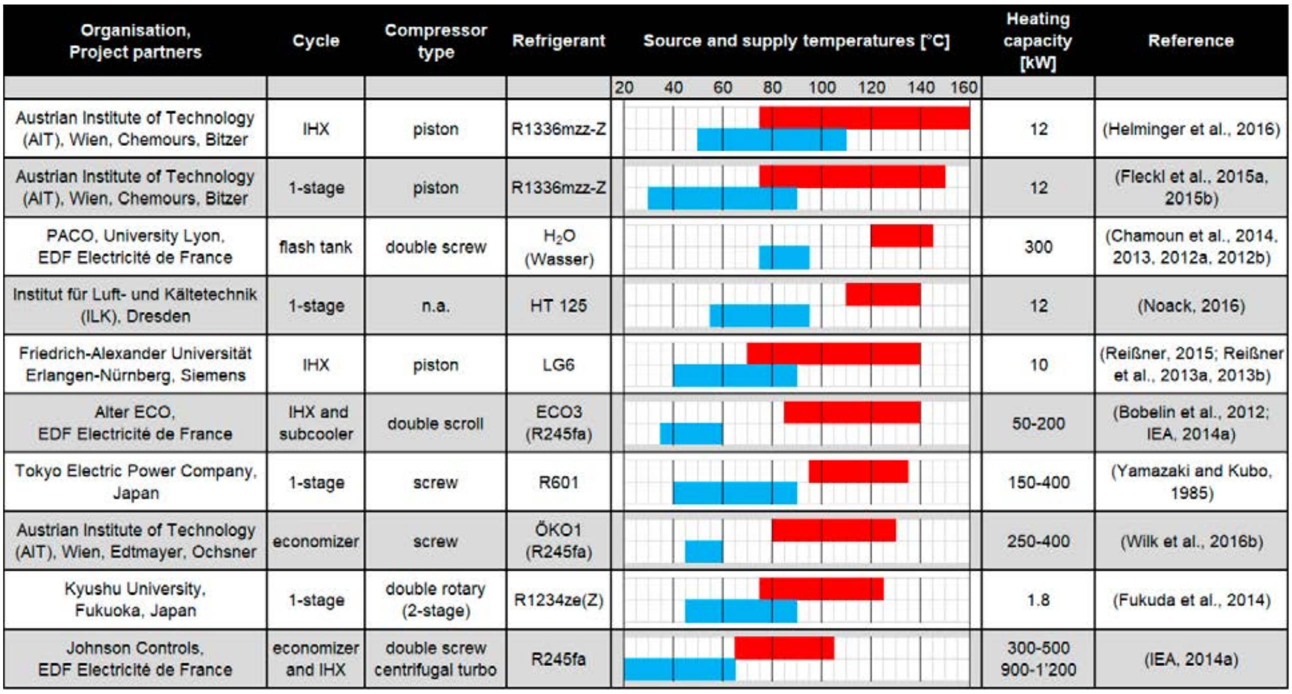
🟧 excluded 🟨 suitable

Table 12: Hydro-Fluoro-Olefines (HFOs)

2.5.5 Research projects

Table 13 (below) summarises a number of research projects in the field of HTHPs with information on the organisation, project partners, heat pump cycle, compressor type, refrigerant, heating capacity and sorted by the sink temperature.

'State of the art' for research projects is currently considered to be 120°C supply temperature and a COP of up to 6 for an uptake from 60°C to 90°C.



Organisation, Project partners	Cycle	Compressor type	Refrigerant	Source and supply temperatures [°C]	Heating capacity [kW]	Reference
				20 40 60 80 100 120 140 160		
Austrian Institute of Technology (AIT), Wien, Chemours, Bitzer	IHX	piston	R1336mzz-Z		12	(Helminger et al., 2016)
Austrian Institute of Technology (AIT), Wien, Chemours, Bitzer	1-stage	piston	R1336mzz-Z		12	(Fleckl et al., 2015a, 2015b)
PACO, University Lyon, EDF Electricité de France	flash tank	double screw	H_2O (Wasser)		300	(Chamoun et al., 2014, 2013, 2012a, 2012b)
Institut für Luft- und Kältetechnik (ILK), Dresden	1-stage	n.a.	HT 125		12	(Noack, 2016)
Friedrich-Alexander Universität Erlangen-Nürnberg, Siemens	IHX	piston	LG6		10	(Reißner, 2015; Reißner et al., 2013a, 2013b)
Alter ECO, EDF Electricité de France	IHX and subcooler	double scroll	ECO3 (R245fa)		50-200	(Bobelin et al., 2012; IEA, 2014a)
Tokyo Electric Power Company, Japan	1-stage	screw	R601		150-400	(Yamazaki and Kubo, 1985)
Austrian Institute of Technology (AIT), Wien, Edtmayer, Ochsner	economizer	screw	ÖKO1 (R245fa)		250-400	(Wilk et al., 2016b)
Kyushu University, Fukuoka, Japan	1-stage	double rotary (2-stage)	R1234ze(Z)		1.8	(Fukuda et al., 2014)
Johnson Controls, EDF Electricité de France	economizer and IHX	double screw centrifugal turbo	R245fa		300-500 900-1'200	(IEA, 2014a)

Table 13: Research projects in the field of HTHPs

Credits: Cordin ARPAGAUS[1], FrédericBLESS[1], Jürg SCHIFFMANN[2], Stefan S. BERTSCH[1]

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2.5.6 Other developments

Some technological developments are harder to classify but the following are worthy of interest.

2.5.6.1 Rotative heat pump

The rotative heat pump K7 from ECOP is quite different from other heat pump cycles.

The working fluid is Argon and doesn't change its state during the cycle (i.e. it stays in gaseous form).

Since during rotation the centrifugal force increases with increasing distance from the axis of rotation, the working gas is also strongly compressed by the centrifugal force.

Due to the pressure increase in the off-axis areas, the temperature of the working gas increases, which releases heat into a sink via a heat exchanger. When the gas that is cooled expands again, its temperature changes to a lower level due to the flow against the centrifugal force and can thereby take up heat again at the source via the heat exchanger close to the axis.

In contrast to conventional heat pumps, the rotation heat pump can cover temperature ranges in a bandwidth from minus 20°C to plus 150°C.

The fact the cycle is simpler allows for a better thermodynamic efficiency and therefore increased performance (COP): the company reports an efficiency 70% better than classic heat pumps.

This simplicity is also supposed to result in lower investment costs, even though no specific cost has been disclosed.

Probably most interesting is that this technology should allow increased flexibility.

Depending on the speed of rotation, there is a different pressure ratio between the outer and inner zone. That way, the compression and expansion pressure ratio can be changed. This results in a freely definable temperature difference between the low-pressure side (source) and high-pressure side (sink), which can be regulated via the rotational speed. Through the rotational speed of the fan, the flow rate and hence the transferrable heating capacity are regulated independently of the temperature increase.

This machine achieves a temperature rise of up to 40°C between the outlet sink and inlet source or alternatively up to 70°C between the outlet sink and outlet source. However, it is also possible to combine two machines and that way increase this value to 80°C or 110°C respectively.

Only one reference site (a biomass cogeneration plant feeding a district heating scheme) is mentioned on the company's website but this is a commercially available product.

Credits: ECOP https://www.ecop.at/en/home-4/

2.5.6.2 Hybrid heat pump

A hybrid heat pump, like the one from Hybrid energy, is based on an absorption process and a compression process, utilising a mixture of water and ammonia.

Like a Kalina cycle, the amount of ammonia in the solution can be adjusted to fit to the working conditions, allowing a better overall efficiency when conditions vary (in winter and summer for example, or when connected to several processes as heat sinks or sources).

A hybrid heat pump is built with standard ammonia compressors, with a design pressure of 25 bar. A traditional heat pump using pure ammonia, can heat water to 50°C at this pressure - a hybrid heat pump can heat water to 120°C using the exact same equipment.

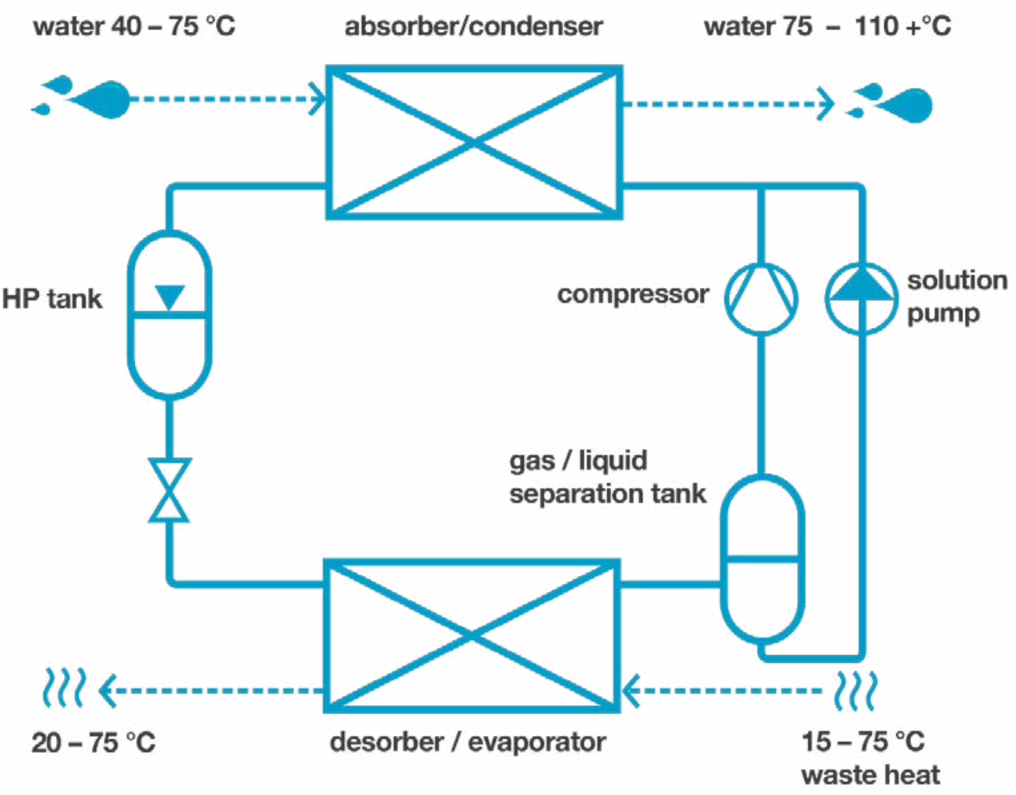


Diagram 19: Principle on a hybrid ammonia heat pump

Source: Hybridenergy

Case Study	One
Country:	Norway
Sector:	Bio-refinery
Technology:	Hybrid heat pump
Application:	Pre-heating of steam boiler feed water
Improvement:	Hybrid heat pump used to pre-heat steam boiler feed water Size: 2MW Source temperatures: 73°C to 46°C Supply temperatures: 70°C to 95°C COP: 6.1 Borregaard’s plant in Sarpsborg is one of the world’s most advanced bio refineries.
Energy savings:	60 GWh/y
Cost savings:	NC
Investment:	NC

Case Study	Two
Country:	Denmark
Sector:	Dairy
Product:	Milk
Application:	Drying
Technology:	Hybrid heat pump
Improvement:	Instead of cooling the evaporator with water from cooling towers, the excess heat from the cooling process is used to pre-heat air to the driers. Size: 1,200 kW Source temperatures: 45°C to 22°C Supply temperatures: 55°C to 85°C COP: 4.5
Energy savings:	4.6 GWh/y 1,400 tons of CO2
Cost savings:	NC
Investment:	Repayment period of 20 months

Case Study	Three
Country:	Norway
Sector:	Food processing and slaughterhouses
Product:	Feed for the aquaculture industry
Technology:	Hybrid heat pump
Application:	Drying
Improvement:	In 2013 a two-stage hybrid heat pump was installed in a factory at Stokmarknes, Norway. The hybrid heat pump recovers heat from exhaust air and uses it to pre-heat drying air and other processes. Size: 1,400 kW Source temperatures: 42°C to 28°C Supply temperatures: 35°C to 85°C COP: 5.5
Energy savings:	Reduces their overall energy consumption by 20%
Cost savings:	NC
Investment:	NC

Case Study	Four
Country:	Denmark
Sector:	District heating
Technology:	Hybrid heat-pump
Improvement:	The hybrid heat pump recovers heat from their CSP solar facility and supplies it to the district heating net. At the same time, the hybrid heat pump delivers cooled water that is used for cooling in other heat producing processes, including the solar facility. Size: 1,300 kW Source temperatures: 35°C to 17°C Supply temperatures: 35°C to 100°C COP: 4.3
Energy savings:	800 000 m3 of gas 528 tons of CO2
Cost savings:	NC
Investment:	NC

Case Study	Five
Country:	Norway
Sector:	Wastewater treatment
Technology:	Hybrid heat pump
Application:	The heat is delivered to the plants central heating system, where it is used for preheating of sludge being fed to the biogas rot tanks, heating buildings and other processes.
Improvement:	The heat pump system recovers heat from the biogas upgrading plant and treated wastewater. Size: 800 kW Source temperatures: 20°C to 14°C Supply temperatures: 75°C to 95°C COP: 2.4
Energy savings:	NC
Cost savings:	NC
Investment:	NC

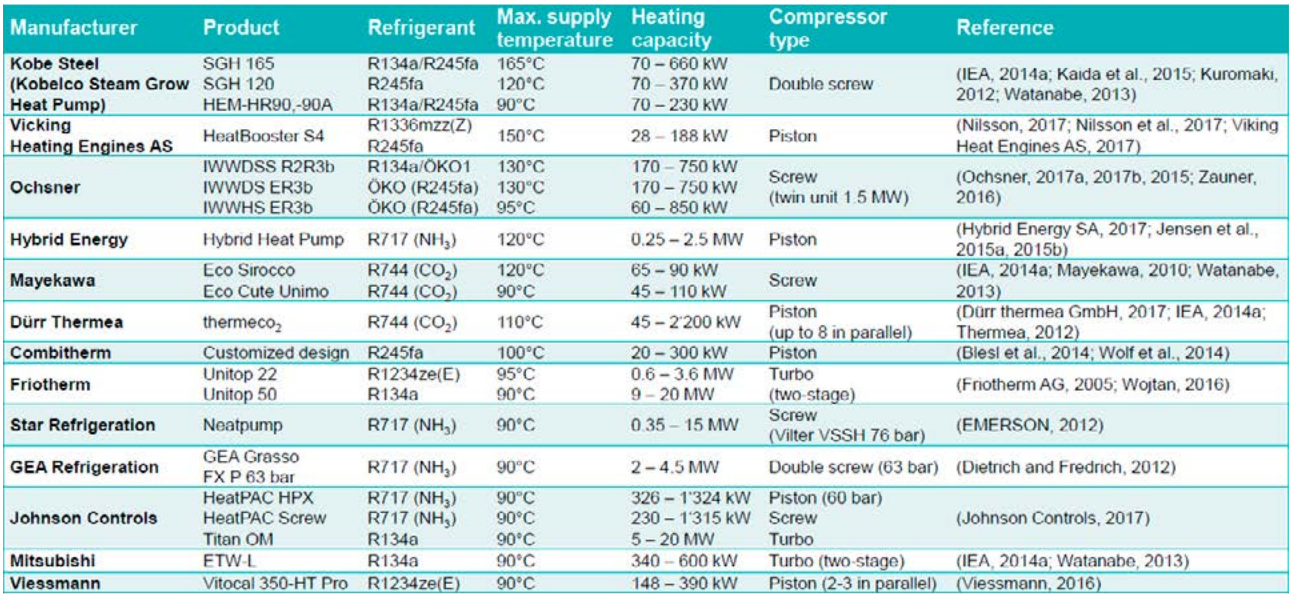
2.5.7 Case studies

Many heat pump cases studies on industrial applications of heat pumps can be found here or here and demonstrate the feasibility and benefits of heat pump integration in industrial processes.

However, most are at temperatures below 80°C.This section focuses on high temperature heat pumps (>80°C) listed as commercially available in table 13 (below).

The state of high temperature heat pumps commercially supplied, based on suppliers mentioned earlier, are:

- **Kobe steel:** products not found on their websites. No case studies found.
- **Vicking:** product at 150°C on sale. No case studies found.
- **Ochsner:** product at 82°C, 95°C and 130°C on sale. Cases studies available.
- **Hybrid energy:** see chapter above. Product on sale. Cases studies available.
- **Mayekawa:** products at 90°C (air to water), 90°C (heat recovery water to water), 90°C (water or air to water) and 120°C (air to air) on sale. Directly available in Australia / NZ. No case studies found.
- **Durr Thermea:** company ceased operations in December 2017.
- **Combitherm:** series of model up to 95°C and 120°C on sale. No case studies found.
- **Friotherm:** product at 90°C on sale. Many case studies available.
- **Star refrigeration:** product at 90°C on sale. Case studies available.
- **GEA Refrigeration:** ammonia products on sale but advertised only up to 82°C.
- **Johnson Controls:** products at 90°C on sale. Case studies available.
- **Mitsubishi:** product at 90°C (water-to-water and air-to-water) on sale. Case studies available.
- **Viessmann:** product at 90°C on sale (page 21). Case studies available.
- **Fuji electric:** product producing steam at up to 120°C (from water at 60°C-80°C) on sale. Only Japan.



Manufacturer	Product	Refrigerant	Max. supply temperature	Heating capacity	Compressor type	Reference
Kobe Steel (Kobelco Steam Grow Heat Pump)	SGH 165 SGH 120 HEM-HR90,-90A	R134a/R245fa R245fa R134a/R245fa	165°C 120°C 90°C	70 – 660 kW 70 – 370 kW 70 – 230 kW	Double screw	(IEA, 2014a; Kaida et al., 2015; Kuromaki, 2012; Watanabe, 2013)
Vicking Heating Engines AS	HeatBooster S4	R1336mzz(Z) R245fa	150°C	28 – 188 kW	Piston	(Nilsson, 2017; Nilsson et al., 2017; Viking Heat Engines AS, 2017)
Ochsner	IWWDSS R2R3b IWWDS ER3b IWWHS ER3b	R134a/ÖKO1 ÖKO (R245fa) ÖKO (R245fa)	130°C 130°C 95°C	170 – 750 kW 170 – 750 kW 60 – 850 kW	Screw (twin unit 1.5 MW)	(Ochsner, 2017a, 2017b, 2015; Zauner, 2016)
Hybrid Energy	Hybrid Heat Pump	R717 (NH_3)	120°C	0.25 – 2.5 MW	Piston	(Hybrid Energy SA, 2017; Jensen et al., 2015a, 2015b)
Mayekawa	Eco Sirocco Eco Cute Unimo	R744 (CO_2) R744 (CO_2)	120°C 90°C	65 – 90 kW 45 – 110 kW	Screw	(IEA, 2014a; Mayekawa, 2010; Watanabe, 2013)
Dürr Thermea	thermeco$_2$	R744 (CO_2)	110°C	45 – 2'200 kW	Piston (up to 8 in parallel)	(Dürr thermea GmbH, 2017; IEA, 2014a; Thermea, 2012)
Combitherm	Customized design	R245fa	100°C	20 – 300 kW	Piston	(Blesl et al., 2014; Wolf et al., 2014)
Friotherm	Unitop 22 Unitop 50	R1234ze(E) R134a	95°C 90°C	0.6 – 3.6 MW 9 – 20 MW	Turbo (two-stage)	(Friotherm AG, 2005; Wojtan, 2016)
Star Refrigeration	Neatpump	R717 (NH_3)	90°C	0.35 – 15 MW	Screw (Vilter VSSH 76 bar)	(EMERSON, 2012)
GEA Refrigeration	GEA Grasso FX P 63 bar	R717 (NH_3)	90°C	2 – 4.5 MW	Double screw (63 bar)	(Dietrich and Fredrich, 2012)
Johnson Controls	HeatPAC HPX HeatPAC Screw Titan OM	R717 (NH_3) R717 (NH_3) R134a	90°C 90°C 90°C	326 – 1'324 kW 230 – 1'315 kW 5 – 20 MW	Piston (60 bar) Screw Turbo	(Johnson Controls, 2017)
Mitsubishi	ETW-L	R134a	90°C	340 – 600 kW	Turbo (two-stage)	(IEA, 2014a; Watanabe, 2013)
Viessmann	Vitocal 350-HT Pro	R1234ze(E)	90°C	148 – 390 kW	Piston (2-3 in parallel)	(Viessmann, 2016)

Table 13: Commercially available high temperature heat pumps

Case Study	One
Country / commissioning year:	Austria / 2013
Application:	Process heat recovery for plant district heating network
Product:	OCHSNER IWHS 400 ER3  Credits : OCHSNER
Heating power:	380 kW
Source temperature:	45°C
Supply temperature:	90°C
COP:	4

Case Study	Two
Country / commissioning year:	France / 2016
Application:	Sewage water heat recovery
Product:	OCHSNER 2 x IWWHS 290 R2 R3 
Heating power:	2 x 280 kW
Source temperature:	8°C to 12°C
Supplytemperature:	70°C to 85°C
COP:	NC

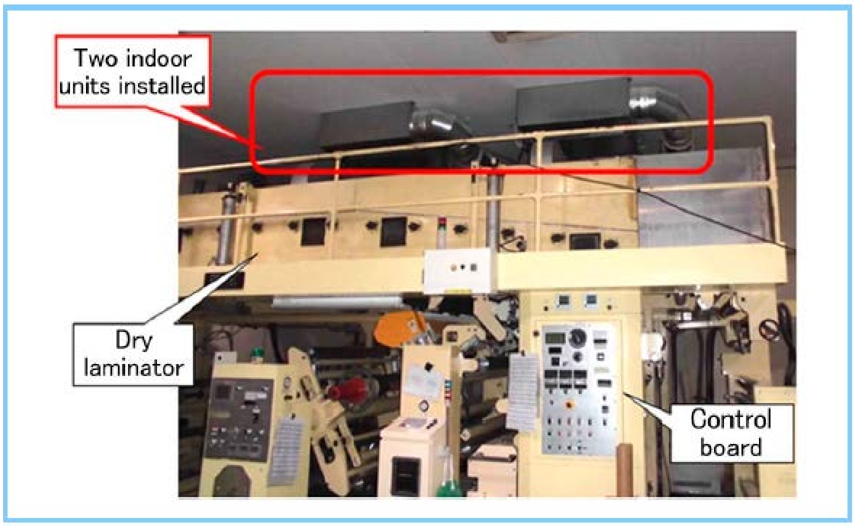
Case Study	**Three**
Country / commissioning year:	Sweden / 2003
Application:	Sea water heat pump facility for district heating  Credit: FRIOTHERM
Product:	Friotherm Unitop 50FY
Heating power:	6 x 30 MW (6 x 8MW absorbed)
Source temperature:	2.5°C to 0.5°C (sea water)
Supply temperature:	+80°C
COP:	NC

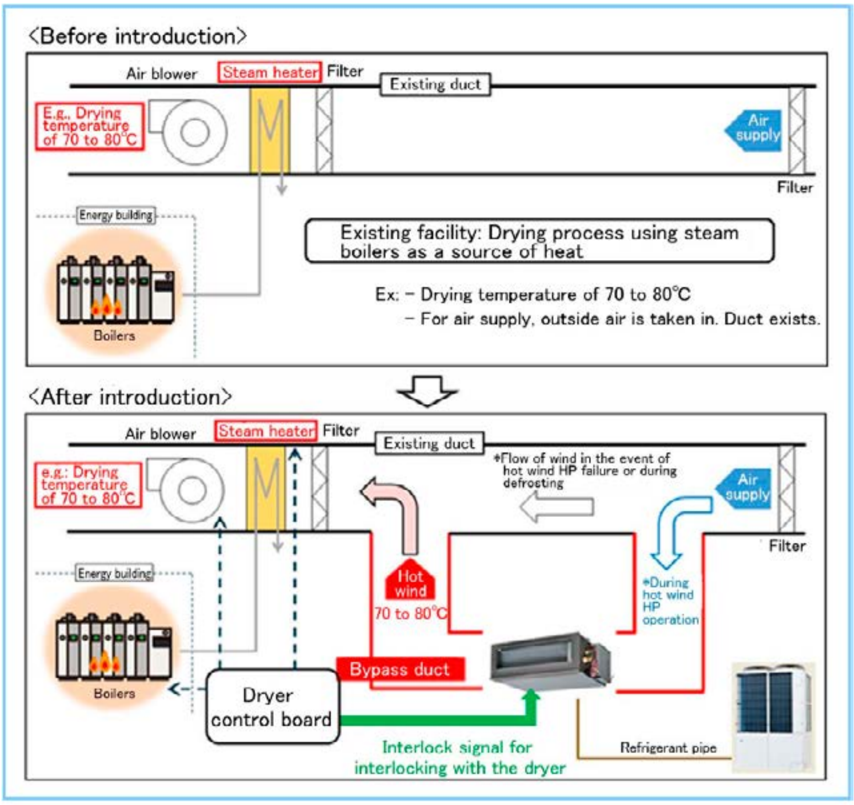
Case Study	**Four**
Country / commissioning year:	Finland / 2009
Application:	District heating and cooling from wastewater
Product:	Friotherm Unitop 50FY  Credit: FRIOTHERM
Heating power:	2 x 9 MW
Source temperature:	12°C
Supply temperature:	82°C
COP:	3.8

Case Study	Five
Country / commissioning year:	Italy / 2008
Application:	District heating from ground water
Product:	Friotherm Unitop 50FY
Heating power:	15.5 MW
Source temperature:	15°C
Supply temperature:	90°C
COP:	2.7

Case Study	Six
Country / commissioning year:	Norway / 2011
Application:	District heating with river water
Product:	Star refrigeration Neatpump
Heating power:	NC
Source temperature:	8°C
Supply temperature:	90°C
COP:	NC. Annual savings of around €2m a year and 1.5m tons CO2

Case Study	Seven
Country / commissioning year:	Japan
Application:	Drying (dry laminator)





Product:	Mitsubishi “Neppu-ton” (air-to-air)
Heating power:	2*30 kW
Source temperature:	Ambient air
Supply temperature:	70°C to 90°C
COP:	NC

Case Study	**Eight**
Country / commissioning year:	Australia / 2017 (page 49)
Application:	Distillery
Product:	Mitsubishi Q-ton
Heating power:	30 kW
Source temperature:	Ambient air
Supply temperature:	90°C
COP:	4.2 Cost: AUD$35,000 (AUD$30,000 for capital cost + AUD$5,000 for installation).

Case Study	**Nine**
Country:	Finland
Sector:	Chemicals
Product:	Adhesives
Application:	Polymerisation process
Improvement:	During the process, the reactor must be cooled mechanically. For cooling, industrial heat pumps are used to recover waste heat for heating the plant and its water. More cooling power is drawn from the ground. The hybrid system, which replaces natural gas, utilises geothermal heating and cooling in addition to the heat pump system in its heating and cooling processes. The bedrock acts as a heat storage excess waste heat for later reuse. Size: Process HP 650kW, Geothermal HP 130kW Source temperatures: NC Supply temperatures: 55°C to 75°C COP: 3.2 to 4.5 Improved cooling has significantly increased the production capacity of the polymerisation process. An larger benefit is that production plans no longer need to be changed according to the cooling capacity. Cooling water now remains at a constant temperature throughout the process, which increases the uniformity of production.
Energy savings:	1,800 MWh (350 ton CO2eq/year)
Cost savings:	€88 000
Investment:	

Case Study	Ten
Country:	Belgium
Sector:	Meat
Technology:	Ammonia
Application:	Heat recovery and upgrade from refrigeration
Improvement:	A large heat pump unit was designed to take full advantage of the heat load from the existing industrial refrigeration machine room capacity of several mega-watts, in order to produce the hot water required by the meat plant. Size: 1 MW Source temperatures: NC Supply temperatures: 78°C COP: 4.5
Energy savings:	NC
Cost savings:	NC
Investment:	NC

Case Study	Eleven
Country:	Swiss
Sector:	Wood
Product:	Chipboard
Technology:	Ammonia
Application:	Pre-drying of wood chips
Improvement:	 Size: 2 x 4.5 MW Source temperatures:39°C Supply temperatures: 83°C COP: 4.7
Energy savings:	32 GWh (6,700 ton CO2eq/year)
Cost savings:	NC
Investment:	NC

Case Study	Twelve
Country:	Denmark
Sector:	Food & beverage
Product:	Alcohol distillation
Technology:	Ammonia
Application:	Supply a district heating network
Improvement:	 Size: 7 MW Source temperatures: 75°C (distillation condensates) Supply temperatures: 55°C to 85°C COP: 10 (up to 40)
Energy savings:	NC
Cost savings:	NC
Investment:	NC

Case Study	Thirteen
Country:	Finland
Sector:	Energy
Application:	District heating network
Improvement:	Size: 158 kW Source temperatures: 45°C to 55°C (district heating return water) Supply temperatures: 70°C to 120°C COP: 2
Energy savings:	NC
Cost savings:	NC
Investment:	NC

Case Study	Fourteen
Country:	Finland
Sector:	Food & beverage
Product:	Vinegar
Application:	Fermentation and pasteurisation
Improvement:	 Size: 194 kW Source temperatures: NC Supply temperatures: 70°C COP: 3.4
Energy savings:	65,000L of diesel (310 ton CO2eq/year)
Cost savings:	NC
Investment:	NC

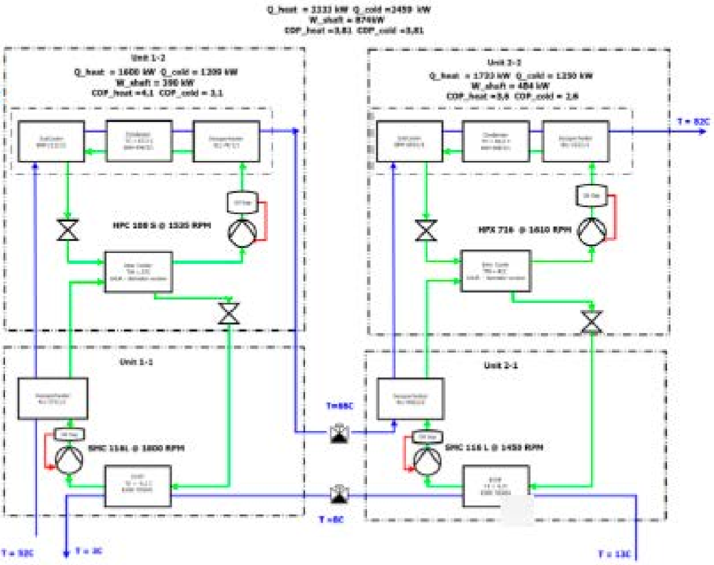
Kalundborg fjernvarme

Production of heating from cold sewage water:

6 pcs Dual PAC SMC108/HPX716 two-stage heat pumps

Design specifications

Cold side	= +13° C / +3° C
Hot side	= +52° C / +82° C
Cooling capacity	= 7.380 kW
Heating capacity	= 10.000 kW
Power consumption	= 2622 kW
COP_{heat}	= 3,24



– ENERTHERM Heat Pump Case

District heating / cooling application in Paris La Defense

OM TURBO MASTER – Heat Pump

Industrial HP (combined chilling and heating)

Heating capacity 11.3 MW 800 m3/h from 77.5° C to 90° C
Cooling capacity 7.3 MW 780 m3/h from 12° C to 4° C
Absorbed Power 4.2 MW
COP: 4.4 (11.3 + 7.3) / 4.2

- York Multi stage compressor : M 438 (4 stages compression)
- Motor : 4.5 MW - 6KV - 1450 rpm – Soft starter
- Gear Box: 1 450 to 5 400 rpm

- 3 Interstages cooling for thermodynamic cycle efficiency
- Integrated sub cooler
- Shell & Tube condenser (CS plain tubes)
- Shell & Tubes evaporator (enhanced copper tubes)

- Weight : Empty 90 T Operating 113 T
- MWP water side 23 barg Refrigerant side 41.3 barg

2.6 Biogas

Biogas

- Biogas is an under-developed energy source for those sectors that both process plants or animals and produce organic waste. The technology is mature and internationally there are many full-scale installations.
- Biogas is relevant for applications requiring a high temperature energy source (e.g. steam, cooking drying, etc), or for easier fuel switching from natural gas.
- Most biogas projects are largely driven by the waste treatment benefit, energy production being a co-benefit.

This report contains several case studies of biogas projects in the wood, paper, meat, and food & beverage sectors.

More information is available on the BANZ website.

Case Study	One
Country:	Norway
Sector:	Wood and paper
Product:	Newspaper
Technology:	Wastewater treatment
Feedstock:	WAS + fish waste
Improvement:	The wastewater treatment system of 20,000 m3 treated per day, in a system with two External Circulation Sludge Bed (ECSB) reactors followed by the aerobic step where the age of the bio-sludge will be reduced from 15-18 days to 5-8 days. This will save energy trough lowered aeration demands and, at the same time, produce a bio-sludge suitable for anaerobic digestion. Biogas up to 125 GWh per year (25 million Nm3) is generated from the ECSBs and two semi-Continuous Stirred Tank Reactors (CSTR) co-digest the bio-sludge and fish waste. Nutrient recovery is accomplished by recirculating reject water from the CSTRs into the WWT as a main source of nutrient, thus replacing urea and phosphoric acid. The digestate from the CSTRs can replace chemical fertilisers. 

Biogas is then purified and liquefied in order to produce LNG that will be used in buses.

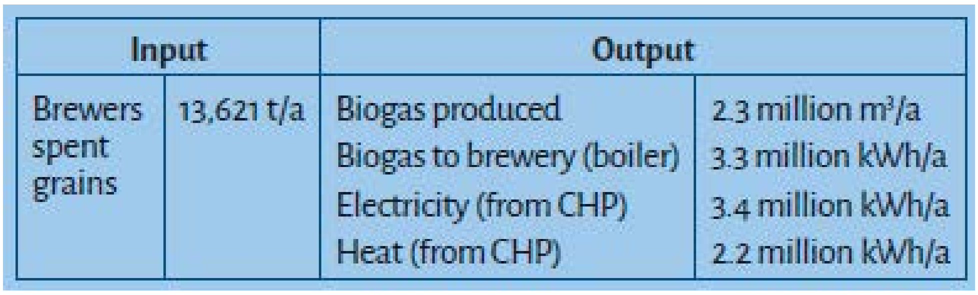
The plant is able to treat up to 3,000 Nm3/h of biogas.

Energy savings:	**Carbon savings:** 3,650 ton/y (including 1,850 for biogas fuel substitution to diesel) • reducing energy input thanks to reduced sludge age • reducing external dosing of chemicals thanks to nutrients recirculation • replacing sludge incineration with biogas production • providing sustainable fertiliser.
Cost savings:	NC Energy saving Increased capacity of wastewater treatment plant New revenue stream from biogas fuel
Investment:	NC However, investment of NOK 150m (NZD$28m) disclosed for a similar unit in Saugbrugs (Norway too).

Case Study	**Two**
Country:	France
Sector:	Wood and paper
Product:	Newspaper
Technology:	Wastewater treatment
Improvement:	Wastewater treatment plant converted to increase biogas production: 17,000 MWh/year of biogas
Energy savings:	Carbon savings of 3,100 tons/year
Cost savings:	NC
Investment:	€7.1m

Case Study	Three
Country:	Canada
Sector:	Wood and paper
Product:	Lumber & pulp
Technology:	Anaerobic hybrid digester (AHD): an anaerobic hybrid digester is an anaerobic digester that combines a free moving zone with a fixed media zone.
Improvement:	Millar Western Forest Products installed the first Canadian forest sector application of anaerobic hybrid digester (AHD) technology to improve effluent treatment from pulp mills.
Energy savings:	50% reduction in annual fuel consumption for hauling and disposal of solid biomass waste
Co-Benefits:	70% decrease in polymer, nitrogen and phosphorus usage 10% reduction in fresh water consumption Direct and indirect GHG emissions cut by 75% (direct 17%, indirect 58%) of current mill emissions
Investment:	NC

Case Study	Four
Country:	Austria
Sector:	Meat (slaughterhouse)
Product:	Pork and beef
Technology:	Two-staged anaerobic digester operated at mesophilic temperatures (35°C)
Feedstock:	The biogas plant is operated with selected fractions of the pig slaughtering process such as pig blood, minced hind gut including content and fat from dissolved air flotation. Rumen content from the neighbouring cattle slaughterhouse.
Improvement:	Anaerobic digestion of animal by-products allows to supply heat to the slaughtering facility and to reduce the disposal-costs of the pig slaughtering facility. The digestate is given off to surrounding farmers as a valuable fertiliser. A hot-water storage tank, of a capacity of 200 m3, allows decoupling of heat production from heat consumption to manage peak demand related to shifts.
Energy savings:	After the implementation of a hot water storage tank 80% of the heat demand is covered.
Cost savings:	NC
Investment:	€1.8m

Case Study	**Five**
Country:	Austria
Sector:	Food & beverage
Product:	Beer (brewery)
Feedstock:	Brewers' spent grains
Technology:	Two-staged anaerobic digester operated at mesophilic temperatures (35°C). Desulphurisation, drying and compression of biogas. Additional to the anaerobic digestion of solid wastes from the brewing process, wastewater is treated anaerobically in a UASB reactor.
Energy savings:	
Cost savings:	NC
Investment:	NC

Input		Output	
Brewers spent grains	13,621 t/a	Biogas produced	2.3 million m^3/a
		Biogas to brewery (boiler)	3.3 million kWh/a
		Electricity (from CHP)	3.4 million kWh/a
		Heat (from CHP)	2.2 million kWh/a

Case Study	**Six**
Country:	Northern Ireland
Sector:	Meat
Product:	Beef
Technology:	Digestate evaporator (Vapogant)
Improvement:	Hewitt Meats wanted to reduce the volume of substrate needed to be transported away from the AD plant and have decided to install a Vapogant digestate evaporator. The Vapogant system will remove water from the digestate through vacuum evaporation using waste heat from the CHP. This process also bounds volatile nitrogen, minimising loss during distribution and making nitrogen available as ammonium sulphate solution (ASS). A highly concentrated liquid digestate is produced, reducing the costs of transport and storage. Project of upgrade with additional gas to be liquefied and transported of site to fuel another 500 KWe CHP, at their abattoir facility in Lurgan and to run the company's fleet of biomethane trucks.
Energy savings:	NC
Cost savings:	NC
Investment:	NC

In the past, solid slaughterhouse wastes were most commonly treated by rendering, the process providing slaughterhouses with an additional source of income. However, because of the risk of TSEs, the economic value of such products has been reduced significantly, and in fact, such products must in many cases be treated as waste themselves (Palatsi et al., 2011). The cost for the safe disposal of slaughterhouse waste in recent years has thus considerably increased. This is primarily due to health risks from the presence of pathogens in such wastes.

Anaerobic Digestion (AD) is today one of the most promising methods for the disposal of slaughterhouse waste (Gwyther et al., 2011). This process not only produces a digestate which can be used as a valuable fertiliser, it also produces heat and biogas that can be converted to energy. Slaughterhouse wastes are also rich in proteins and nitrogen, and are therefore ideal substrates for the AD process. Numerous studies have reported various levels of effectiveness in the removal of different pathogens using AD.

An AD process with either a pre- or post- pasteurization step would most likely deactivate the majority of microorganisms. Prions would however survive a pasteurization and an AD process, as would spore-forming bacteria. The survival of prions should however not be a cause for concern, as any biogas plant operator should be able to prevent diseased animals or suspected TSE diseased animals from entering the process.

In Sweden, slaughterhouse wastes are treated with a 70°C pasteurization step prior to AD, and digestates are used in agriculture. No problems seem to have arisen with spore-forming pathogens such as *Clostridium* and *Bacillus* as a result of such treatment. The benefits of using AD to treat slaughterhouse wastes are immense; not only are the unpleasant waste products of the ever-growing meat industry disposed of, but renewable energy is produced.

https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3622235/

3.0 International Scan: Incentive Policies, Programmes & Technologies

3.1 Overview

This international technology scan has focused on five nations that are leading the way in terms of subsidizing and incentivising the transition to a low emission economy, namely:

- United Kingdom
- Germany
- France
- Canada
- Japan

Not all incentives and subsidies employed by other countries will be a good fit for New Zealand's specific needs. However, it does provide an initial shortlist of potential solutions to investigate and evaluate.

It also provides a strong indication of those solutions considered valuable enough internationally to be promoted and subsidised to accelerate the energy transition.

The scan indicates that, even though these countries have adopted very different approaches to policy, the targets related to heat use in the industrial sector are mostly the same, with countries developing incentives to promote:

- biomass as an alternative fuel
- solar thermal
- heat storage
- heat pump
- geothermal
- biogas injection to network
- cogeneration
- waste heat to electricity conversion (Organic Rankine Cycle)
- heat networks.

On the energy efficiency side, there has been a focus on heat pumps and boiler optimisation, which are specific targets for EECA, while other common cross-cutting technologies covered under this technological policy push include:

overall heating system optimisation (e.g. insulation, building management regulation system, use of more efficient devices like thermostatic valves or low temperature systems, etc)

- heat storage
- heat networks
- cold production
- air conditioning (e.g. efficient heating of large areas, air-to-air energy recovery, dehumidifier, etc).

Other interesting aspects identified by this international review include:

- actions specifically targeting the agricultural sector (milk, livestock and greenhouses)
- targeting specific but widely used industrial equipment to accelerate the transition to available and more efficient production technologies. One example, from France, was designed for the automotive sector in France and focused on injection moulding presses (i.e. switching from steam to electricity); a similar approach could be undertaken for primary industry in New Zealand.

The following pages provide more detailed summaries of the policies and incentives adopted by each of the five nations reviewed.

3.2 United Kingdom

In the UK, environmental programmes related to energy are administered by OFGEM. Two of these programmes are related to process heat.

3.2.1 Enhanced Capital Allowance (ECA) scheme

The ECA scheme supports businesses to invest in government-approved energy-saving plant or machinery that might otherwise be too expensive to implement.

First year allowances (also known as accelerated depreciation) enable businesses to offset 100% of the cost of the asset(s) against taxable profits in a single tax year, meaning a company can write-off the cost of the new plant or machinery against the business's taxable profits in the financial year the purchase was made.

An Energy Technology List (ETL) directly managed by the government contains all the equipment approved under this scheme (suppliers apply to have their product(s) added to this list). Each type of technological product has a corresponding factsheet.

The ETL contains the following technology categories relevant to process heat:

- steam boiler system
  - heat generators (steam boilers and localised rapid steam generators for cold start-up)
  - combustion control (burners with controls and retrofit burner control systems)
  - flue gas heat recovery (economiser and condensing economiser)
  - boiler system control (e.g. as part of a building management system)
  - waste heat recovery
- industrial refrigeration equipment
  - absorption coolers
  - air-cooled condensing units
  - automatic leak detection
  - automatic air purgers
  - refrigeration system controls
  - evaporative condensers
  - packaged chillers
  - refrigeration compressors
- pipework insulation equipment
- heat pump (although not industrial heat pumps)
- solar thermal technology (low temperature only, i.e. not process oriented)
- air-to-air energy recovery
  - cross-flow plate heat exchanger
  - rotating heat exchangers (thermal wheels and desiccant wheels)
  - run-around coil
- waste heat to electricity conversion equipment
  - Organic Rankine Cycle
  - saturated steam to electricity.

A significant downside of the ECA scheme is its limitation to standard, off-the-shelf products, which excludes many of the customised solutions required at industrial facilities.

For this reason, the UK has developed another incentive specific to process heat: the Non-Domestic RHI.

3.2.2 Non-Domestic Renewable Heat Incentive (RHI)

The Non-Domestic Renewable Heat Incentive (RHI) provides financial incentives to increase the uptake of renewable heat by businesses, the public sector and non-profit organisations.

Eligible installations receive quarterly payments over 20 years based on the amount of heat generated.

Eligible technologies in the Non-Domestic RHI are:

- solid biomass (including co-fuelling)
- solid biomass contained in waste
- ground-source heat pumps
- water-source heat pumps
- air-source heat pumps
- geothermal
- solar thermal (only below 200 kWth solar thermal parabolic, through collectors are ineligible)
- biogas combustion
- CHP
- bio-methane injection.

Detailed criteria are explained here.

3.3 Germany

Measures are designed to increase energy efficiency in the trade, retail, services, agricultural and industrial sectors. There is a particular focus on small and medium-sized enterprises (SMEs) with a bonus of 10% on the repayment subsidy.

A key aspect of the German scheme is the broad definition of what could be included ("systems"), to leave room for innovation while being technology neutral.

German incentives typically adopt a case-by-case assessment of individual projects as opposed to a more specific technology-targeted approach.

Consequently, the main tools for incentives are grants or credits through the KfW financing institution.

Ultimately, branded programmes like the **Market Incentive Programme (MAP)** for renewable energies in the heat market, the **energy efficiency incentive programme (APEE**), or the "**Offensive waste heat recovery**" of the **National Action Plan Energy improved efficiency (NAPE)**, lead to these incentive tools / financial vehicles.

The energy performance of technologies must be 15% better than the sectoral average for new investments, and 30% greater than average energy consumption for the previous three years for replacement investments.

Various technologies and innovative processes are supported, including:

- solar thermal heating systems
- heat pumps
- heat networks supplied from renewable sources.

Importantly, the programme also covers several types of heat storage.

In addition to basic funding, participants may receive a "combination bonus" for a combination of various measures such as solar thermal heating and heat pumps, an "efficiency bonus" for projects that achieve cost savings due to lower primary energy needs from the use of renewable energy, or an "innovation bonus" for especially innovative applications.

3.3.1 KfW Credit 292, 293: KfW Energy Efficiency Program - Production Systems/Processes

Objective: save energy costs during operation.

Credit covers:

- process refrigeration and process heat
- heat recovery and waste heat utilisation for production processes
- cogeneration plants.

3.3.2 KfW Credit 294: KfW Energy Efficiency Program - Waste Heat; and KfW Grant 494: KfW Energy Efficiency Program - Waste Heat Investment Subsidy

Objective: avoid and use waste heat.

Credit covers:

- process optimization
- conversion of production processes to energy-efficient technologies for the prevention or use of waste heat
- insulation of equipment, piping and fittings
- return of waste heat in the production process
- preheating of other media
- electricity efficiency measures directly related to the waste heat measure
- extraction of the waste heat
- connecting lines for the transfer of heat (for example, feed into existing heat networks)
- generating electricity from waste heat (for example, Organic Rankine Cycle (ORC) technology).

3.3.3 KfW Credit 270: Renewable Energy - Standard

Objective: using renewable energies sustainably.

Credit covers:

- construction, expansion and acquisition of plants only for heat generation based on renewable energies
- heating/cooling networks and heat/cold storage systems powered by renewable energy sources
- installations for generating electricity and heat in combined heat and power plants (CHP plants) based on solid biomass, biogas or geothermal energy.

3.3.4 KfW Credit 271, 281: Renewable Energies - Premium

Objective: invest in heat with loan and repayment subsidy.

Credit covers:

- large solar collector systems
- large plants for burning solid biomass
- heating networks powered by renewable energy
- biogas pipes for raw biogas direct-use
- large heat storage
- big efficient heat pumps
- combined heat and power plants (CHP).

3.4 France

3.4.1 White certificates

France's energy efficiency policy relies primarily on a white certificate system.

The system of energy saving certificates (white certificates) was introduced by the POPE Law in 2005 with the objective to achieve energy savings in buildings, non-ETS industry, agriculture and transport.

White certificates oblige energy retailers and fuel suppliers ('obligated parties') to offer their customers incentives to invest in energy-efficient equipment. Each obligated party receives a target, set in line with the type and volume of energy sold, for a three-year period and certificates are valid for three periods (a total of nine years).

One white certificate equals one kWh of cumulated savings of final energy ('cumac') during the whole duration of an energy-saving action, discounted at a rate of 4% per year.

Parties who not meet their obligation have to pay a penalty of EUR€0.02 per kWh-cumac, at the end of each three-year period. White certificates can be exchanged between obligated and eligible parties.

Since the introduction of the scheme the energy saving certificates issued amounted to 462 TWh-cumac of savings, with 90% of actions carried out in buildings.

There are currently 193 standardised operations sheets for obtaining white certificates, named by sector:

- agriculture
- residential building
- tertiary building
- industry
- network
- transport.

Each sheet describes the standardised operation, eligibility criteria, how to calculate the number of corresponding white certificates, and the short formula to claim them.

(Use this link for translation of sheets)

The following operations sheets are directly related to process heat (and cold):

IND-BA-112	Heat recovery system on a cooling tower
IND-UT-103	Heat recovery system on an air compressor
IND-UT-104	Economiser on the gaseous effluents of a boiler for steam production
IND-UT-105	Micro-modulating burner on industrial boiler
IND-UT-113	High efficiency refrigeration condensing system
IND-UT-115	Control system on a cold production unit to have a low floating pressure
IND-UT-116	Control system on a cold production unit allowing to have a high floating pressure
IND-UT-117	Heat recovery system on a cold production unit
IND-UT-118	Burner with heat recovery device on an industrial oven (installation of heat recovery on the oven flue gas to preheat the combustion air, auto-regenerative burner or pair of regenerative burners)
IND-UT-121	Mattress for insulation of singular points
IND-UT-122	Adsorption compressed air dryer using a heat input for regeneration
IND-UT-125	High-performance water treatment on a steam boiler (reverse osmosis or demineralisation on ion exchange resins)
IND-UT-129	Electric or hybrid injection press
IND-UT-130	Condenser on gaseous effluents from a steam boiler
IND-UT-131	Thermal insulation of flat or cylindrical walls on industrial installations
RES-CH-101	Valorisation of heat recovery network
RES-CH-105	Passage of a heating network in low temperature
RES-CH-106	Installation of thermal insulation of the pipes of a heat network
RES-CH-107	Isolation of singular points on a heat network.

Other operations sheets can be related to an extended definition of process heat (for example, heating in non-residential buildings, or agricultural applications), including:

IND-BA-110	Destratifier or air blower
IND-BA-117	Efficient decentralised heating
AGRI-EQ-102	Double heat shield
AGRI-EQ-104	Lateral thermal shields
AGRI-TH-101	Hot water storage device ("Open Buffer" type)
AGRI-TH-102	Hot water storage device
AGRI-TH-103	Milk pre-cooler
AGRI-TH-104	Heat recovery system on cold production unit excluding milk tanks
AGRI-TH-105	Heat recovery unit on a milk tank
AGRI-TH-108	Air/water or water/water type heat pump
AGRI-TH-109	Condensing heat recovery unit for horticultural greenhouses
AGRI-TH-110	Condensing boiler for horticultural greenhouses
AGRI-TH-113	Air/air heat recovery exchanger in a poultry house
AGRI-TH-116	Recovery of fatal heat from an industrial process for heating a greenhouse or livestock building
AGRI-TH-117	Thermodynamic dehumidifier for greenhouses
AGRI-TH-118	Low temperature or double heating tube for greenhouses
AGRI-UT-103	Control system on a cold production unit to have a low floating pressure
AGRI-UT-104	Control system on a cold production unit allowing to have a high floating pressure
BAT-EQ-117	Refrigeration system using subcritical or transcritical CO_2
BAT-EQ-130	High efficiency refrigeration condensing system
BAT-SE-103	Adjusting the balancing valves of a hot water heating system
BAT-TH-102	Collective boiler with high energy performance
BAT-TH-104	Thermostatic valve
BAT-TH-105	Low temperature radiator for central heating
BAT-TH-108	Regulation system with programming of intermittency
BAT-TH-109	Start-up optimizer in collective heating
BAT-TH-110	Condensation heat recovery unit
BAT-TH-111	Collective solar water heater
BAT-TH-113	Air / water or water / water type heat pump
BAT-TH-116	Building technical management system for heating and hot water
BAT-TH-125	Single flow mechanical ventilation with constant or modulated air flow
BAT-TH-126	Dual flow mechanical ventilation with constant or modulated air flow exchanger
BAT-TH-127	Connection of a tertiary building to a heat network
BAT-TH-139	Heat recovery on cold production group
BAT-TH-140	Absorption heat pump type air / water or water / water
BAT-TH-141	Air / water heat pump with gas engine.

The white certificate system is designed for cross-cutting technologies, in order to target a broad reservoir of savings.

3.4.2 Heat fund

For more tailored industrial technical solutions using renewable energies or waste heat, the main tool is the heat fund, which targets direct use of heat on-site (process or space heating) or externally (heat or cold network).

This fund pays for a proportion of the investment (with a 10% bonus for SMEs) for:

- new heat production capacity based on renewable energies, specifically:
  - biomass
  - heat pumps
  - geothermal
  - solar thermal
  - biogas (for direct use in a boiler or for injection in a gas network; cogeneration and biogas to fuel are covered by the waste fund)
- waste heat valorisation, including:
  - heat recovery on a process (e.g. distillation column, dryer, furnace, boiler, etc) for use on another part of the process
  - heat storage
  - recovery of residual heat
  - enhancement of the thermal level (heat pump or MVR)
  - distribution and heat recovery (e.g. pipes, heat exchangers, etc), for internal use (e.g. space heating) or external use (e.g. another facility, district heating network, etc).

3.5 Canada

The Canadian Industry Program for Energy Conservation (CIPEC) is based on a voluntary approach and is limited to the provision of financial help to perform an energy audit or an ISO50001 certification.

There are few incentives for an energy transition in industry: instead, Canada relies on an innovation leverage.

For example, the Investments in Forest Industry Transformation (IFIT) programme supports the deployment of innovative "first-in-kind" forestry technologies. Most of the projects funded are related to new ways of adding value to wood and paper industry co-products.

This is interesting from an economic transition perspective to reduce GHG intensity, but probably out of EECA's scope; although, considering the significance of the forest industry in New Zealand, it is worth noting this programme has funded projects related to our subject, including:

- Anaerobic Hybrid Digester (AHD) technology to improve effluent treatment from pulp mills
- Organic Rankine Cycle (ORC) in a mill.

3.6 Japan

Japan encourages energy efficiency improvement in industry through a mix of regulatory measures, voluntary actions by industry and a combination of subsidies, tax exemptions and loans for investment.

A large focus of their programme is on improving Japan's energy self-sufficiency and increasing its competitiveness, which is why some of their developments target efficient gas turbine or coal-based power plants.

Due to a lack of biomass resource, there is also an emphasis on electrification and efficiency for industry.

A mandatory aspect of the eligibility criteria (for subsidies) is the advanced nature of the technology and the likelihood it will become widely used in the future.

Therefore Japan is less focused on subsidising cross-cutting and immediately available technologies and is more willing to invest in longer term innovations (higher risk but potentially higher return) by financing:

- process innovation in the most energy intensive industrial sectors
- holistic approach of the overall production chain to reduce energy spent and material consumption
- high tech solutions (IoT, Factory Energy Management System (FEMS), etc)
- hydrogen.

Technologies sheets specific to each sector are available here (Japanese only)

Japanese industry is among the world's most energy-efficient. The result of a range of measures (including the Keidanren Voluntary Action Plans and the requirements for energy management) has been the adoption of medium and long-term plans for energy efficiency and progress reporting under the Act on the Rational Use of Energy combined with a range of subsidies and fiscal incentives for investment.

A benchmarking element to the target-setting process for several energy-intensive sectors has also been introduced.

The main part of Japan's industrial energy efficiency policy is the Keidanren Voluntary Action Plan to reduce CO2 emissions. This is a sector-by-sector approach, therefore not targeting specific cross-cutting technologies.

However, the 2014 Strategic Energy Plan (SEP) put an emphasis on crosscutting technologies:

- Combined Heat and Power generation (CHP)
- district heating and cooling
- Factory Energy Management System (FEMS)
- heat pumps.

Appendix 1: Internationally available technologies

The scan carried out on five leading countries (UK, Germany, France, Japan, Canada) identified a long list of **immediately available** technologies capable of playing a role in New Zealand's transition to a low-carbon economy.

These technologies have been classified into the following categories (below).

The level of detail is highly variable, from general categories (e.g. alternative energy sources) through to specific tuning of a system.

- **Boiler optimisation systems**
  - heat generators (steam boilers and localised rapid steam generators for cold start-up)
  - combustion control (burners with controls and retrofit burner control systems, micro-modulating burner)
  - economiser on the gaseous effluents of a boiler for steam production
  - condenser on gaseous effluents from a steam boiler
  - boiler system control (in the sense of building management system for example)
  - high-performance water treatment on a steam boiler (reverse osmosis or demineralisation on ion exchange resins)
- **Heat recovery**
  - heat recovery on a process (distillation column, dryer, furnace, boiler, etc) for use on another unit process
  - enhancement of the thermal level (heat pump or MVR)
  - heat recovery system on a cooling tower
  - heat recovery system on a cold production unit
  - heat recovery system on an air compressor
  - adsorption compressed air dryer using a heat input for regeneration
- **Air energy recovery (process)**
  - cross-flow plate heat exchanger
  - rotating heat exchangers (thermal wheels and desiccant wheels)
  - run-around coil
- **Heat pumps**
  - ground-source heat pumps
  - water-source heat pumps
  - air-source heat pumps
- **Alternative energy sources**
  - solid biomass (including co-fuelling)
  - solid biomass contained in waste
  - geothermal
  - solar thermal
  - biogas combustion and CHP
  - bio-methane injection
- **Refrigeration systems**
  - high efficiency refrigeration condensing system
  - control system on a cold production unit to have a low floating pressure
  - control system on a cold production unit allowing to have a high floating pressure
  - heat recovery on cold production group
  - absorption coolers
  - refrigeration system using subcritical or transcritical CO2
  - air-cooled condensing units
  - automatic leak detection
  - automatic air purgers
  - refrigeration system controls
  - evaporative condensers
- **Waste heat to electricity**
  - Organic Rankine Cycle
  - saturated steam to electricity
- **CHP (cogeneration)**
- **Heat (and cold) networks**
  - revamping of a heating network to low temperature
  - distribution and heat recovery (pipes, heat exchangers, etc), for internal use (space heating) or external use (other company, district heating network, etc)
  - connection of a tertiary building to a heat network
- **Heat (and cold) storage**
  - heat / cold storage systems powered by renewable energy sources
  - buffer storage for solar collectors and installations for biomass combustion
  - large innovative heat storage facilities
  - hot water storage device (agriculture)

- **Space heating system optimisation**
  - destratifier or air blower
  - single flow mechanical ventilation with constant or modulated air flow
  - dual flow mechanical ventilation with constant or modulated air flow exchanger
  - adjusting the balancing valves of a hot water heating system
  - thermostatic valve
  - low temperature radiator for central heating
  - regulation system (building technical management system for heating and hot water, programming of intermittency, etc)
- **Specific industrial machinery**
  - burner with heat recovery device on an industrial oven (installation of a heat recovery on the oven flue gas to preheat the combustion air, auto-regenerative burner or pair of regenerative burners)
  - electric or hybrid injection press
- **Specific systems for agriculture**
  - double heat shield (greenhouses)
  - lateral thermal shields (greenhouses)
  - milk pre-cooler
  - heat recovery system on cold production unit excluding milk tanks
  - heat recovery unit on a milk tank
  - condensing heat recovery unit for horticultural greenhouses
  - condensing boiler for horticultural greenhouses
  - air / air heat recovery exchanger in a poultry house
  - recovery of fatal heat from an industrial process for heating a greenhouse or livestock building
  - thermodynamic dehumidifier for greenhouses
  - low temperature or double heating tube for greenhouses
- **Factory Energy Management System (FEMS) / Smart Factory**

Appendix 2: Glossary of terms

Blanching: Blanching operations are designed to expose the entire product to high temperatures for a short period of time. The primary function of this operation is to inactivate or retard bacterial and enzyme action, which could otherwise cause rapid degeneration of quality. Two other desirable effects of blanching include the expelling of air and gases in the product, and a reduction in the product volume.

Coefficient of Performance (COP): The Coefficient of Performance (COP) is a measure of the efficiency of the heat pump and is simply the ratio of useful heat provided to the amount of electricity used to upgrade the heat.

Cross-cutting technology: A technology that has a wide array of applications. In this report, it means both cross-sectoral and cross-application.

Pasteurisation: Pasteurisation is not the same as sterilisation. Its purpose is to reduce the bacterial population of a liquid such as milk and to destroy organisms that may cause spoilage and human disease. Spores are not affected by pasteurisation. The intent of pasteurisation of milk is to eliminate pathogenic microbes. It also lowers microbial numbers, which prolongs milk's good quality under conditions of refrigeration, with chemical additives or modified atmosphere packaging, which minimise microbial growth.

PHiNZ: Acronym standing for “Process Heat in New Zealand”, an initiative from the Ministry of Business, Innovation and Employment (‘MBIE’) working with EECA. The PHiNZ initiative aims to identify the opportunities for, and address barriers to, improving the energy efficiency of process heat and increasing the input of renewable energy.

Pinch analysis: is a methodology for minimising energy consumption of chemical processes by calculating thermodynamically feasible energy targets (or minimum energy consumption) and achieving them by optimising heat recovery systems, energy supply methods and process operating conditions. The process data is represented as a set of energy streams, as a function of heat load (kW) against temperature (°C). These data are combined for all the streams in the plant to give composite curves, one for all hot streams (releasing heat) and one for all cold streams (requiring heat). The point of closest approach between the hot and cold composite curves is the pinch point.

Process step: In this report, this term replaces the more technical term “unit operation” commonly used in process engineering. Unit operations involve a physical change or chemical transformation such as separation, crystallisation, evaporation, filtration, polymerisation, isomerisation, and other reactions. For example, in milk processing, homogenisation, pasteurisation, and packaging are each unit operations which are connected to create the overall process. A process may require many unit operations to obtain the desired product from the starting materials, or feedstocks.

Sterilisation: Sterilisation implies the destruction of all viable microorganisms. It is inaccurate to tell if any food is sterile; in this report the term refers to the sterilisation of surfaces (tools, packaging, etc) that are used in the food industry.