Energy for generations

ESB LEADING LIGHTS SERIES

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DECARBONISING IRELAND'S INDUSTRIAL SECTOR

THE ROLE OF INDUSTRIAL HEAT PUMPS

CONTENTS

INTRODUCTION

Ireland aims to achieve a net-zero society by 2050. For this to be realised, ambitious greenhouse gas emission targets must be met over the coming decades. The purpose of this paper, researched and produced by ESB, is to describe and detail innovative electricity-based technology options to support the decarbonisation of industrial heating demand in Ireland.

The Climate Action Plan (CAP) 2019 outlines indicative sectoral targets for Ireland to 2030. For the industrial sector (which is termed 'Enterprise' in the CAP), a 10-15% reduction in CO_2, from the 2030 Pre-National Development Plan projections by the end of this decade, is targeted. The principal actions to achieve this goal are defined in the CAP as below.

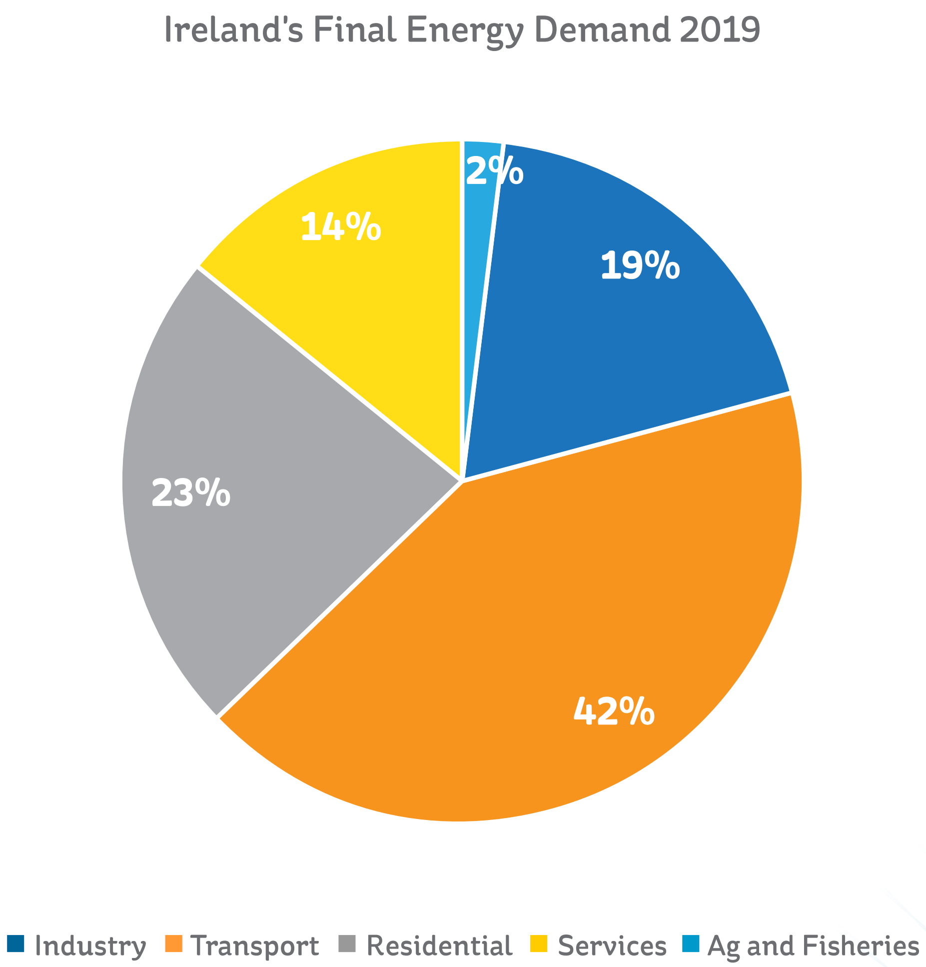
- Increasing the share of alternative fuels in cement production from circa 30% to circa 65% by 2025, and 80% by 2030.
- Meeting 70% of low-temperature heat demand in the food industry with low-carbon sources by 2025, and 80% by 2030.

The Programme for Government (PFG, 2020) has even more ambitious plans for CO_2 reduction than those in the CAP (2019). The PFG aims to achieve a 7% year-on-year reduction in CO_2, compared to 3-4% in the CAP.

I. INDUSTRY FINAL DEMAND

Globally, the industrial sector consumed 29% of energy in 2019[1] with steel, aluminium, cement and petrochemicals some of the largest energy-consuming industries. In an Irish context, industry accounted for 21.3% of energy-related CO_2 emissions in 2018[2] with cement, alumina and food/ beverage processing among Ireland's largest energy-consuming industries. In Ireland and globally, the majority of industrial CO_2 emissions are due to heating processes.

Industrial consumption makes up 19% of Ireland's final energy demand. This is shown in the figure below.

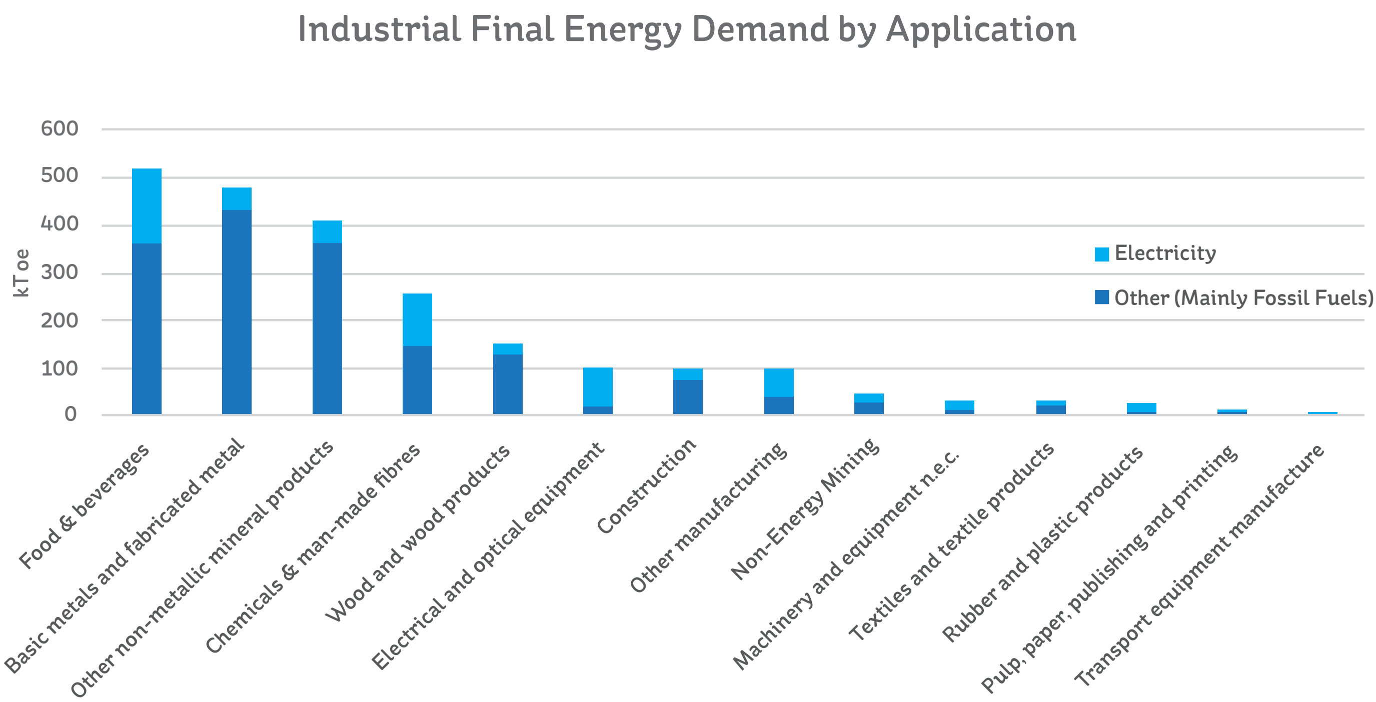


Source: SEAI

[1] BNEF. Bloomberg New Energy Outlook 2020.
[2] SEAI. https://www.seai.ie/data-and-insights/seai-statistics/key-statistics/co2/.

II. BREAKDOWN OF INDUSTRY APPLICATIONS

There is some data available regarding the detailed make-up of Ireland's industrial sector. SEAI publishes an annual energy balance[3] which breaks down final energy use by sector. The figure below shows Ireland's industrial energy demand by application for 2019.



This suggests that there are a broad range of industrial energy settings in Ireland and so these require a variety of solutions to achieve decarbonisation objectives.

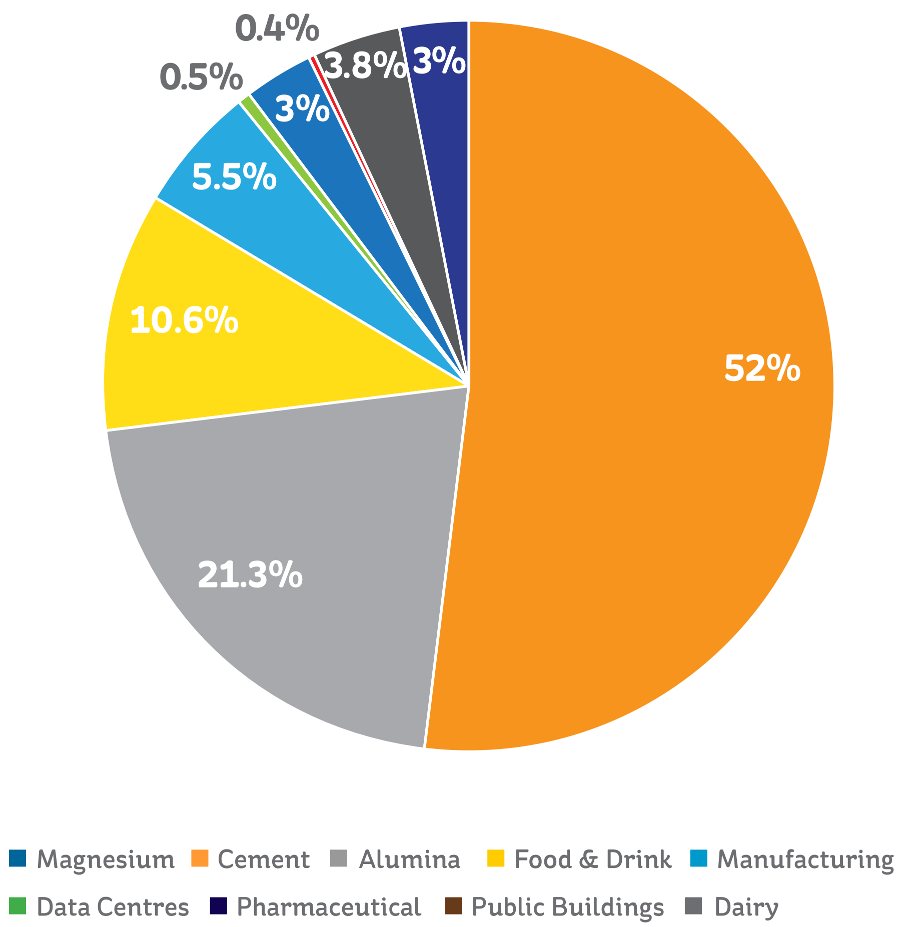
At present, there is no detailed mapping of heating applications in Ireland and therefore, it can be challenging to identify decarbonisation solutions systematically.

We have assessed company-specific data available for industrial sites in the Emissions Trading Scheme[4] – these cover CO_2 emissions rather than energy consumption. However, this does not cover all industrial sites in Ireland, but it does cover large installations. ESB has used 2018 information for the assessment below and have excluded the power sector, the oil and gas sector and aviation from consideration.

[3] Download Energy Balances (seai.ie)
[4] Greenhouse Gas Emissions – Tuesday, 19 Nov 2019 – Parliamentary Questions (32nd Dáil) – Houses of the Oireachtas https://www.oireachtas.ie/en/debates/question/2019-11-19/515.

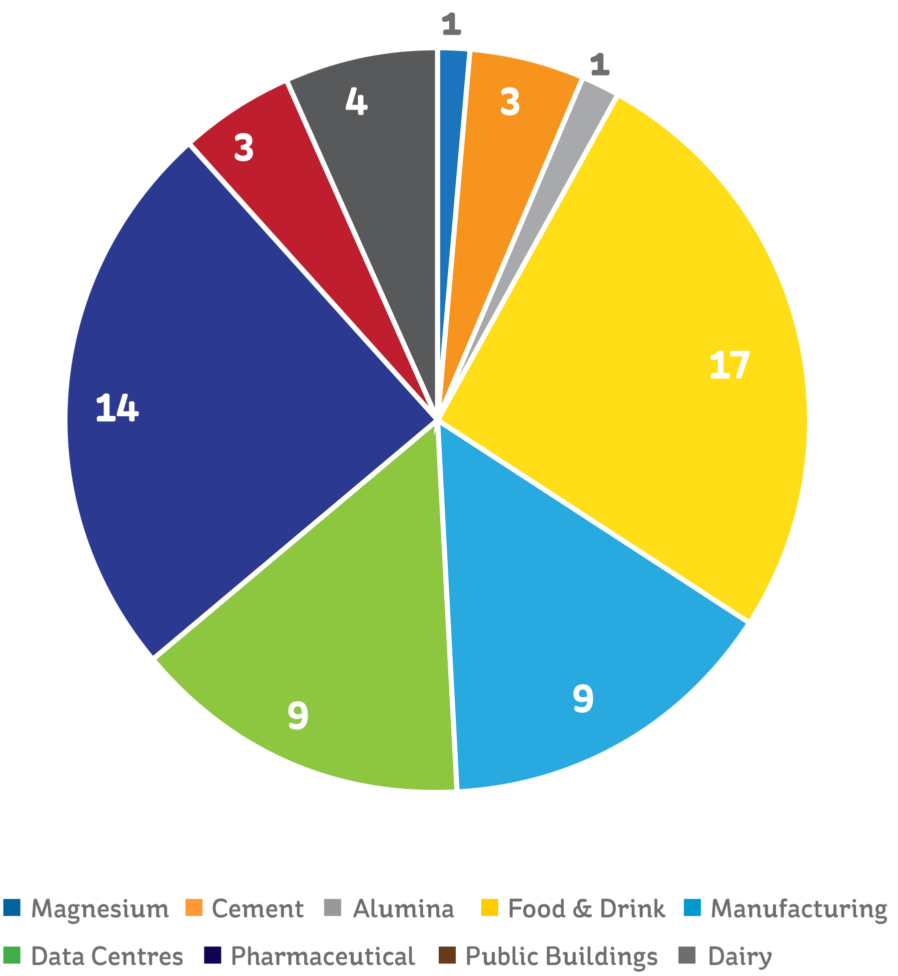
The figure below shows an analysis by ESB of the breakdown of Irelands ETS sites by share of emissions.

Ireland's ETS Industrial Emissions 2018



The above shows that a significant portion of ETS emissions are concentrated in relatively few sectors, mainly cement and alumina. By examining the data, ESB has found that there are relatively few permit holders associated with the higher emission applications. The figure below shows a breakdown of the number of ETS permits by sector based on ESB analysis.

Irelands Industrial Emissions 2018 (Permit Holders)



The above analysis, while requiring further verification, suggests that within the ETS industrial sector that was examined, almost 80% of GHG emissions arise from five permit holders with the remaining emissions spread across 56 permit holders. This suggests that outside of alumina and cement production, the industrial sites are not energy intensive and should be considered in greater detail for electrification solutions for decarbonisation.

These lower energy intensity industrial sites comprise of food and beverage companies, pharmaceutical operators and dairy processing, data centres, manufacturing sites and a small number of public buildings, mainly hospitals.

LOW CARBON INDUSTRIAL HEATING

Industrial heat is currently provided by fossil fuel energy in most cases. Low carbon or zero carbon industrial heat can be delivered in different ways, through proven fuels and technologies such as biomass, direct electric, heat pumps, geothermal and solar thermal. In the future, these will be supported by emerging sources such as biogas, hydrogen and carbon capture utilisation and storage (CCUS). The focus of this study is on the electrification of industrial heating, so the other options are not considered at this stage.

I. ELECTRIFICATION TECHNOLOGIES

There is a broad range of electrification technologies available for heating purposes. These are already used in a range of settings and include electrical resistance heating, immersion heaters, electric arc furnaces and electric boilers.

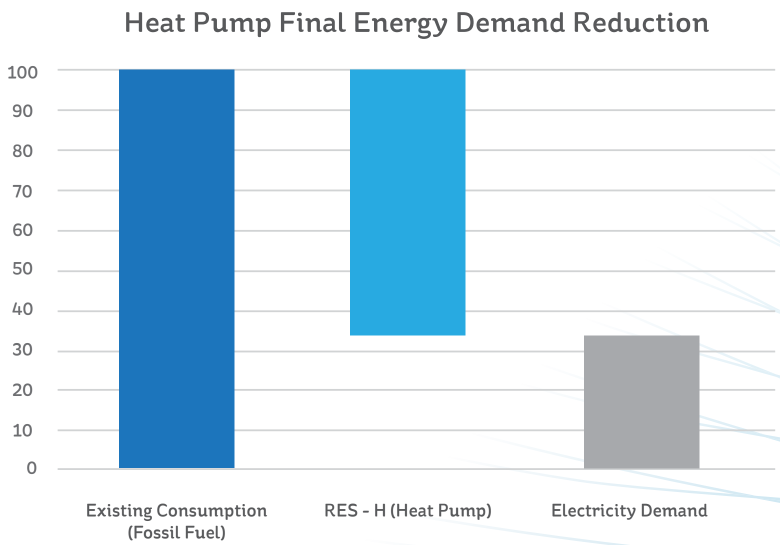
These technologies can be employed in high-temperature settings and can reach maximum efficiency of 100%. However, these technologies have difficulty displacing fossil fuels given the difference in the cost of an MWh of electricity versus fossil gas or oil. However, where these technologies can access lower-cost electricity, such as at times of high wind electricity output, they have significant potential to support decarbonisation.

The remainder of this paper looks only at heat pumps for industrial heat applications. For information, the tables in Appendix C provide a mapping of electrification technologies with candidate industries and processes. These tables are extracted from papers by EPRI[5] and Silvia Madeddu et al[6].

II. HEAT PUMPS – BUILDING APPLICATIONS

Heat pumps are attractive solutions for heat delivery because their high energy efficiency combined with electricity, the input energy source, offers a clear route to deep decarbonisation. As most of the heat energy supplied by the heat pump is sourced from waste, air, ground or water, performance is rated not by efficiency but by coefficient of performance (COP).

COP is defined as the useful heating energy delivered, divided by the electrical energy consumed. Electricity is the input to facilitate this 'moving' of heat energy and is consumed by compressors, fans and pumps. High energy efficiency also results in significantly reduced carbon emissions. It is an excellent example of sector coupling: as electricity production is decarbonised, so too is the heat delivered. The COP for typical space heating and hot water applications is in the region of three to five, meaning that for every unit of electricity consumed, three to five units of heat is delivered. The result of this is that fuel switching from fossil fuels to a heat pump has a significant final energy demand reduction impact, illustrated in the figure below.



[5] Opportunities for electrification of industry in the European Union// https://ipeec.org/en/bulletin/28-opportunities-for-electrification-of-industry-in-the-european-union.html [6] Silvia Madeddu et al 2020 Environ. Res. Lett. 15 124004 The CO_2 reduction potential for the European industry via direct electrification of heat supply (power-to-heat) (iop.org)

Further to this, heat pumps offer significant carbon emission savings compared to fossil fuels. With a projected electricity carbon intensity of 118gCO_2/kWh in 2030[7], CO_2 emissions associated with a heat pump will be around 80% lower than a fossil boiler installation. This is set out in the table below.

Heating Source	Emissions[8]
Natural Gas (gCO_2/KWh Heat)	227
Oil (gCO_2/KWh Heat)	286
Heat Pump (gCO_2/KWh Heat) (2030 Fuel Mix)	41

Heat pumps are widely used for space and water heating; this is because they operate most efficiently at lower temperatures. In Ireland, close to 70% of newly constructed homes are fitted with heat pumps. In commercial buildings, heat pumps have provided air conditioning for decades and are increasingly providing space and water heating. In the UK, the recent Climate Change Committee (CCC) Sixth Carbon Budget recommended a significant increase in heat pump deployment as being essential to meet net-zero ambitions. The UK Government now has an ambitious deployment target of 600,000 heat pumps per annum by 2030 (~25 million installations by 2050).

Given this, Ireland is now seeing a significant improvement in the heat pump value chain, including installation and maintenance as manufacturers continue to put more resources into research and development to make the technology better. Therefore, we are already seeing and will continue to see ever increasing heat pump deployment and ever decreasing fossil fuel boiler installations in the coming years, which is a key requirement if net-zero targets are to be achieved.

III. HEAT PUMPS – INDUSTRIAL APPLICATIONS

Heat pumps for use in industrial processes are not at as an advanced stage as space heating and cooling applications in buildings; this is due to the fact that fossil fuel options are cheaper, the associated technologies are lower cost and the fuels, typically oil and gas, do not adequately price in their climate impact. As a result, alternative low-carbon technologies struggle to compete for investment as they are at a cost disadvantage.

Whereas, space heating and domestic hot water applications can rely on relatively low output temperatures of <65°C, process and industrial heating generally require temperatures in excess of those traditionally associated with heat pumps. As heat pump technology improves and heat pumps are deployed in industrial process heating, they could contribute greatly to the dual objectives of increased energy efficiency and carbon reduction.

A large temperature difference between the source temperature and the required output temperature reduces COP. Therefore, the high temperatures of industrial heating historically resulted in relatively low COPs, diminishing the benefits of heat pumps. This requires heat pumps to be integrated into the overall installations process to improve efficiency; often referred to as heat recovery.

[7] Our Zero Emission Future (MaREI and EAI) - Our-Zero-e-Mission-Future-Report.pdf (eaireland.com)
[8] Natural Gas (204.7 gCO_2/kWh / 0.9). Oil (257 gCO_2/kWh / 0.9). Heat Pump (118 gCO_2/kWh /3 /0.95)

INTEGRATED SYSTEMS

The Electric Power Research Institute (EPRI) has quoted estimates which suggest that as much as 20% to 50% of the energy consumed is lost through waste heat contained in streams of exhaust gases and hot liquids, as well as through conduction, convection or radiation emanating from the surface of hot equipment[9]. It is important for high-temperature applications that, where possible, heat rejected from other processes is recovered and used in the heat pump system.

- If for high-temperature applications, the only energy source apart from electricity for the heat pump is waste heat from the specific process itself, then other supplementary dedicated sources would be needed.
- However, If the heat input into the heat pump includes waste heat from other on-site processes or waste streams, then the heat delivery for a process could be delivered entirely by the heat pump without the need for another primary heat source.

This highlights the need for competent and holistic system design and optimal use and reuse of process heat when deploying heat pumps. These integrated systems will not be classified simply as a ground or air source heat pump, for example.

INDUSTRIAL HEAT PUMP DEVELOPMENT AND DEPLOYMENT

Heat pump research and technology is constantly advancing. The European Commission says that the industrial heat pumps market in the EU is rapidly growing, with 2813 units sold over the period between 2009-2016[10]. They further state that the continent leads the way in research publications on industrial heat pumps, publishing nearly twice as many as second-place China.

Several studies have focused on the potential for heat pumps to decarbonise heat. The technology development will drive the uptake and the depth of decarbonisation, with a focus on temperature requirements for several industries and potential technological level advances to unlock these sectors.

A study of industrial heat in Denmark assumed two levels of heat pump adoption: a low scenario of up to 150°C and a high scenario of 400°C. Apart from heating processes in refineries, there was not a substantial difference in the loads that could be met through using heat pumps, as much of the process heat is required at relatively low temperatures[11].

BNEF suggested that temperatures of up to 280°C could be achieved[12], but such solutions are very much at a research stage[13]. In its research paper, BNEF suggests that several industries can be unlocked to direct electrification through heat pumps given the potential for such high-temperature outputs.

Dr Cordin Arpagaus lead-authored the publication of an important academic paper which provides a market overview and technology status for industrial heat pumps[14].
The figure on the next page, extracted from this academic paper, provides an overview (as of 2018) of processes in different industrial sectors structured by typical temperature ranges and Technology Readiness Level (TRL) of heat pumps. This is useful to get a broad understanding of temperatures used in a variety of applications.

There are a significant number of processes at lower temperatures in the food and beverage industries. Therefore, these sectors are considered some of the most promising for the adoption of heat pumps.

[9]Industrial Waste Heat Recovery Opportunities: An Update on Industrial High Temperature Heat Pump Technologies (epri.com) [10] European Commission Staff Working Document - Clean Energy Transition – Technologies and Innovations Accompanying the document (14th October 2020). [11] Bühler, Fabian, Müller Holm, Fridolin and Elmegaard, Brian. Potentials for the electrification of industrial processes in Denmark. Proceedings of ECOS 2019: 32nd International Conference on Efficiency, Cost, Optimization, Simulation and. [Online] 2019. https://orbit.dtu.dk/files/189357718/ECOS2019_B_hler_Fabian_Article_for_proceedings_PDF.pdf. [12] BNEF. Liebreich: Separating Hype from Hydrogen – Part Two: The Demand Side. [Online] https://about.bnef.com/blog/liebreich-separating-hype-from-hydrogen-part-two-the-demand-side/. [13] B.Zühlsdorf, et al. Analysis of technologies and potentials for heat pump-based process heat supply above 150 °C. [Online] https://www.sciencedirect.com/science/article/pii/S2590174519300091. [14] Arpagaus, Cordin & Bless, Frédéric & Uhlmann, Michael & Schiffmann, Jürg & Bertsch, Stefan. (2018). High temperature heat pumps: Market overview, state of the art, research status, refrigerants, and application potentials. Energy. 152. 10.1016/j.energy.2018.03.166.

Temperature

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

Technology Readiness Level (TRL) of heat pumps:

- ▨ Conventional HP < 80°C, established in industry
- 🟦 Commercial available HTHP 80 to 100°C, key technology
- 🟦 Prototype status, technology development, HTHP 100 to 140°C
- 🟦 Laboratory scale research, functional models, proof of concept, HTHP > 140°C

EXPERT OPINION ON INDUSTRIAL HEAT PUMPS

To carry out research for this paper, ESB met with experts in electrification and heat pump deployment, including:

- Electric Power Research Institute (EPRI)) who conducts research, development, and demonstration projects on a wide range of electricity projects.
- Bloomberg New Energy Finance who has a dedicated team studying advancements in industrial heat.
- DELTA-EE who carry out extensive research on heat pump development.
- We carried out desk-based research and reviewed key recommendations from the UK Climate Change Committee's recent advice on the Sixth Carbon Budget.
- We have met with industry practitioners who are working with clients to decarbonise their energy use.
- We have engaged with the European Heat Pump Association (EHPA) and reviewed developments across Europe.

ESB's initial reaction, having met with experts and reviewed international research, suggests that there is significant potential for the electrification of industrial energy demand, thereby helping to reduce emissions in this sector which might have traditionally been seen as hard to abate. Our initial views are as follows:

- The temperature range for heat pumps is increasing and will continue to increase. Based on the current global move to net-zero ambition and the continued decarbonisation of electricity, heat pumps will be able to efficiently address most medium temperature processes by the 2030s.
- There is heat use in Irish industry which could be served by heat pump technology now.
- Very high-temperature processes are likely to require other solutions such as green hydrogen or decarbonised gas but there will be a significant opportunity to part electrify processes at these sites.
- A systems integration approach is vital. Waste heat recovery should be at the heart of industrial decarbonisation both within sites but also on a cluster basis. For example, waste heat from a data centre may be utilised in a nearby district heating scheme or in another industrial site.
- There are industrial clients in Ireland who are actively looking to stop burning fossil fuels in the next decade, driven by corporate social responsibility commitments.
- Policy is key – a recurring finding from our interviews was that fossil fuels are under-priced since they do not adequately reflect the cost of their continued use to the economy. Wider electrification of the heat sector needs to be supported by a strong Government commitment to decarbonisation through instruments such as carbon and environmental pricing and appropriately designed support schemes.
- Pilot projects in this decade are key to unlocking full commercial rollout in the 2030s. We need to see evidence gathering from individual use cases to prove the technology works and to quickly address any emerging issues.
- Other European countries have developed their industrial heat pump sector to a greater extent than Ireland and may serve as useful references.

MAPPING TECHNOLOGIES TO IRELAND'S INDUSTRIES

Considering the findings in the previous section, ESB has sought to map the available electrification technologies to Ireland's industrial demand. This represents an initial screening of literature and market intelligence available to us during the time of this study. This will be continually reviewed more of the table will be populated with applications as relevant projects are identified.

Industrial category	GWh	% of total	Sample industries	Applications	Temp	IHPs	Other electric options (direct, indirect)	Case study: See Section 5
Basic metals and fabricated metal products	**5846**	19%	Alumina refining	Alumina Calcination	>1000		Electric boiler, Hydrogen (emerging technology)	
				Metals melting, welding			Resistance furnace, induction furnace, plasma technology (emerging technologies)	
Chemicals and man-made fibres	3115	10%	Pharmaceutical	Chemical production				
				Distillation of chemicals	80 - 170			1
				Cold storage - ex. Antibiotic cultures				
				Dehumidification/ climate control				
Electrical and optical equipment	3400	11%	Computer manufacturing					
Food and beverages	**5740**	19%	Dairy	Sterilisation of milk	<130		Microwave Heating project piloted	
				Refrigeration - ex. milk	4			
				Pasteurisation	<80			2
				Milk powder production	180 - 200			3
				Disinfection	<100			4
				Greenhouses climate control	<60			5
				Hot water for milking parlours	~80		Electric boilers	6
				Meat Processing	~80			7
				Alcohol Distillery	60 - 90			8

Industrial category	GWh	% of total	Sample industries	Applications	Temp	IHPs	Other electric options (direct, indirect)	Case study: See Section 5
Machinery and equipment n.e.c.	413	1%		Coating, Enamelling, Hardening,				
Non-Energy Mining	1323	4%						
Other manufacturing	1606	5%		Coating, Enamelling, Hardening,				
Other non-metallic mineral products	5299	18%	Cement	Lime calcination	1500		Hydrogen, plasma arc technology (emerging technology)	
			Brick production	Brick drying	160			9
Pulp paper publishing and printing	332	1%		Bleaching	175			
				Drying of paper and pulp	80 - 130			
Rubber and plastic products	653	2%		Polymer production			Infrared heaters	
				Coatings				
Textiles and textile products	183	1%		Dye Process drying	90 - 100			
				Cloth drying	60 - 80			
				Textiles humidity control	10 - 25			
Transport equipment manufacture	312	1%						
Wood and wood products	2030	7%	Sawmills	Drying wood in lumbar	40 - 60			10
				Chipboard manufacture	~80			11
Miscellaneous / Cross sector			Commercial Buildings	Space heating and hot water – on site	~60			12
				Air conditioning	20 -25			
			Data centres	Heat recovery for district heating	<85%			13
			Large Public Buildings	Water heating at airport	<85%			14

Heat pump solution available now, either as standalone or incorporated in existing processes to reduce fossil fuel use.

Heat pump unlikely to be available now but should be possible for 2030 timeframe. Potential now for partial electrification of processes through heat pumps.

Heat pump solution unlikely to be available. Potential for heat pumps for heat recovery and efficiency improvements.

Further research into specific technology applications in Ireland required.

CONCLUSIONS

In this paper, ESB has carried out a high-level investigation into the potential for heat pumps in decarbonising industrial heat demand in Ireland. We will continue to keep this area under review, but our initial conclusions are as follows:

- There are industrial heat applications in Ireland where heat pumps could be deployed at present.
- Heat pump technology is developing all the time and will play a significant role in the decarbonisation of industrial heat demand in Ireland.
- For temperature requirements above that of space heating, a systems integration or heat recovery approach is important and makes the operation of the heat pump more effective.
- Global and national policy will be an important driver of the heat pump industry and manufacturers will bring forward more products where they know there will be a demand.
- The rollout of pilot projects in representative industries would be the most efficient way for Ireland to get industrial heat pumps established as a decarbonisation technology.

APPENDIX A: CASE STUDIES

In the sector below we have matched case studies to key industries in Ireland, as per the table in Section 4.

Case Study 1: Ethanol Distillation
Company: Hokkaido Bioethanol Co., Ltd **Location:** Tokachi Shimizu Factory, Japan
Description: Hokkaido Bioethanol Co., Ltd. has installed a heat pump system that can recover exhaust heat and effectively supply steam at a temperature of 120°C. By recovering condensation heat from ethanol released during the distillation process, running costs and CO_2 emissions from the distillation tower were greatly reduced.
Reference: HOKKAIDO.pdf https://www.hptcj.or.jp/Portals/0/english/Learning/HOKKAIDO.pdf

Case Study 2: Milk Pasteurisation
Company: Aurivo Consumer Foods **Location:** Donegal Dairy plant, Ireland
Description: Installed heat pump that generates water at 80°C. Waste heat is captured from an electric chiller and is used as the energy source for a new heat pump system, which has been designed to deliver the required heat for milk pasteurisation.
Reference: https://www.seai.ie/case-studies/dairy-plant-cuts-costs/

Case Study 3: Drying milk powder
Company: Arla Arinco **Location:** Videbaek, Denmark
Description: A heat pump of 1.25 MW was installed utilizing energy from 40°C cooling water. The installed heat pump preheats drying air for milk powder to around 80°C. In this example, the application (drying milk powder) requires ambient air to be heated to 150°C and therefore, the solution is a hybrid heat pump and gas boiler.
Reference: https://iea-industry.org/app/uploads/annex-xiii-part-a.pdf (Page 20 of 46)

Case Study 4: Disinfection of beverage containers
Company: GVS Landi **Location:** Schaffhausen, Switzerland
Description: Heat pump takes waste heat from refrigeration and heats water to 80-95°C Process water is used for the disinfection of beverage filling plants and wind tanks and also, used for heating of storage rooms and wine tanks.
Reference: https://www.kvpdagen.se/wp-content/uploads/2019/11/Sal%201/20191017%20Industrial%20heat%20pumps%20-Oliver%20Jung.pdf (page 34/59)

Case Study 5: Heating Greenhouses
Company: ESB Energy (installers), Greencoat Capital **Locations:** Norfolk and Suffolk, UK
Description: ESB Energy is installing a combined heat pumps and CHP solution for two greenhouses, in Norfolk and Suffolk with a total area of 29 hectares. This project will have the largest installed capacity of heat pumps in the UK and will generate 70MW of thermal power. Waste heat from nearby wastewater treatment plants is used as input heat.
Reference: https://www.esbenergy.co.uk/articles/business-solutions/low-carbon-heat-solution-for-a-world-first-greenhouse-project

Case Study 6: Hot water for milking parlour
Company: Dairy Farm, Mr Joe O'Brien **Location:** Limerick, Ireland
Description: Hot water heat pump. Further description given in link below from Glen Fuels.
Reference: https://www.glenfuels.ie/articles/51/dairy_farm

Case Study 7: Meat Processing
Company: Colruyt meat processing plant **Location:** Buizingen near Brussels
Description: Colruyt Group installed a large heat pump unit which was designed to take full advantage of the heat load from the existing industrial refrigeration machine room capacity of several MWs. The 1MW Mayekawa ammonia heat pump unit consists of 3 Mycom piston compressors combined with highly efficient heat exchangers producing hot water with temperatures up to 78°C achieving high COPs.
Reference: https://www.ehpa.org/fileadmin/red/03._Media/Publications/Large_heat_pumps_in_Europe_Vol_2_FINAL.pdf (Page 12)

Case Study 8: Gin & Whiskey Distillery
Company: Shene Estate Distillery **Location:** Tasmania, Australia
Description: Shene Estate is a distillery that produces gin and whisky using traditional distillation practices. The distillation process involves heating malted barley mash. Each day 6,000 litres of hot water are required, initially at 90°C, with the temperature then reduced to approximately 64°C to 65°C, the optimum temperature to dissolve sugars contained within the starch of malted barley. Finally, the temperature is brought up again to 70°C at the end of the mashing in the process to dissolve enzymes. A 30kW Mitsubishi Heavy Industries Qton Co_2 air-to-water heat pump was installed in mid-2017.
Reference: http://www.2xep.org.au/files/A2EP_HT_Heat_pump_report.pdf (Page 42)

Case Study 9: Brick drying
Company: Wienerberger **Location:** Uttendorf, Upper Austria
Description: A heat pump demonstrator for brick drying has been installed at a Wienerberger's brick production site in Uttendorf, Upper Austria. This novel heat pump system produces heat supply temperatures of up to 160°C.
Reference: http://dry-f.eu/Demonstrations/Wienerberger-Brick-Industry

Case Study 10: Lumbar drying, and multiple additional case studies
Company: Multiple **Location:** Multiple
Description: Lumbar drying and several other heat pump applications have been compiled and summarised in a BZE report as per reference below. Detailed descriptions of the case studies are not provided. Rather this summary gives a list of the varied applications where heat pumps have replaced fossil fuel solutions.
Reference: https://bze.org.au/wp-content/uploads/2020/12/electrifying-industry-bze-report-2018.pdf.

Case Study 11: Chipboard Manufacture
Company: Krono chipboard factory **Location:** Switzerland
Description: Krono installed two GEA Grasso heat pumps to provide hot water with an energy equivalent of 10MW and at a hot water temperature of 80°C. It is a hybrid solution that works in cooperation with a biomass CHP on-site.
Reference: https://www.ehpa.org/fileadmin/red/03._Media/Publications/Large_heat_pumps_in_Europe_Vol_2_FINAL.pdf (Page 21)

Case Study 12: Heat recover for space heating
Company: Hanspeter Graßl KG **Location:** Missen, Germany
Description: A heat pump was installed at a brewery to recover heat from the batch process and used in space heating at a local hotel and restaurant.
Reference: https://iea-industry.org/app/uploads/annex-xiii-part-g.pdf (Section 7.10.16 Food A (Hanspeter Graßl KG))

Case Study 13: Waste Heat from Data Centre
Company: Calefa **Location:** Mantasala, Finland
Description: Waste heat from a data centre is transformed by heat pumps to supply heat in the local district heating network.
Reference: https://www.kvpdagen.se/wp-content/uploads/2019/11/Sal%201/20191017%20Industrial%20heat%20pumps%20-Oliver%20Jung.pdf https://celsiuscity.eu/datacentre-supplies-local-heating-in-mantsala-finland/

Case Study 14: Water heating
Company: Public/State **Location:** Copenhagen airport, Denmark
Description: A hybrid gas boiler and heat pump solution has been installed in Copenhagen Airport. The heat pump utilises the heat in flue gas and provides hot water to local district heating.
Reference: https://www.ehpa.org/fileadmin/red/03._Media/Publications/Large_heat_pumps_in_Europe_Vol_2_FINAL.pdf (Page 25)

APPENDIX B: ELECTRIFICATION APPLICATIONS

From: Opportunities for electrification of industry in the European Union//
https://ipeec.org/en/bulletin/28-opportunities-for-electrification-of-industry-in-the-european-union.html

Industry sector	Infrared Heating	Resistance Heating	Ultraviolet Curing	Microwave Heating	Radio Frequency Heating	Induction Heating/ Hardening	Induction Melting	Electric Arc Furnace
Food products								
Beverages								
Tobacco								
Textiles								
Wearing apparel								
Leather products								
Wood products								
Paper & paper products								
Printing								
Cake & refined petroleum								
Chemicals								
Pharmaceuticals								
Rubber & plastics								
Non-metallic minerals								
Basic metals								
Fabricated metal products								
Computers & electronics								
Electrical equipment								
Machinery & equipment								
Motor vehicles								
Other transport equipment								
Furniture								
Other manufacturing								
Repair and installation								

From: Silvia Madeddu et al. 2020

The CO2 reduction potential for the European industry via direct electrification of heat supply (power-to-heat) (iop.org)
https://iopscience.iop.org/article/10.1088/1748-9326/abbd02/pdf

Table 1. Electrically powered technologies for industry electrification. Efficiency is the ratio between UE output and FE input of an appliance. The COP measures the heat output (for heat pumps) or the heat absorbed (for chillers) per unit of work input (18-52).

<table>
<tr><th><100°C</th><th>100 - 400°C</th><th>400 - 1000°C</th><th><1000°C</th><th>Technological Maturity</th><th>Applications</th><th>Efficiency/ COP</th><th>Electrification Stages</th><th>Reference</th></tr>
<tr><td colspan="2">Compression heat pumps and chillers</td><td></td><td></td><td>Established in industry (only <100°C)</td><td>Space heating
Hot water
Low pressure steam
Drying Cooling and refrigeration</td><td>COP 2 - 5</td><td>1</td><td>28 - 30</td></tr>
<tr><td colspan="2">Mechanical vapour recompression (MVR)</td><td></td><td></td><td>Established in industry</td><td>Energy recovery (e.g. in distillation, evaporation) to provide steam and process heat</td><td>COP 3 - 10</td><td>1</td><td>19, 21, 31, 34</td></tr>
<tr><td colspan="3">Elecric Boilers</td><td></td><td>Established in industry</td><td>Space heating
Hot water
Thermal oil
Stream</td><td>0.95 - 0.99</td><td>1</td><td>18, 19, 21, 35, 36</td></tr>
<tr><td colspan="4">Infrared heaters</td><td>Established in industry</td><td>Drying
Paint curing
Plastic treatments
Food processing</td><td>0.60 - 0.90</td><td>1</td><td>29, 31, 33, 37-40</td></tr>
<tr><td colspan="4">Microwave & radio frequency heaters</td><td>Established in industry except ce-ment and ce-ramic firing/ sintering</td><td>Drying Ceramics firing and sintering
Cement treatment
Food processing</td><td>0.50 - 0.85</td><td>1</td><td>29,, 31, 37, 40-47</td></tr>
<tr><td colspan="4">Induction Furnace</td><td>Established in industry</td><td>Metals melting re-heating, annealing, welding</td><td>0.50 - 0.90</td><td>2, 3</td><td>26, 27, 48, 49</td></tr>
<tr><td colspan="4">Resistance Furnace</td><td>Established in industry</td><td>Metals melting, smelting
Heaters for the chemical industry
Ceramic firing
Glass melting
Calcination</td><td>0.50 - 0.95</td><td>2, 3</td><td>26, 27, 48, 49</td></tr>
<tr><td colspan="4">Electric Arc Furnaces</td><td>Established in industry</td><td>Metals melting and partial refining</td><td>0.60 - 0.90</td><td>2, 3</td><td>26, 48, 50</td></tr>
<tr><td colspan="4">Plasma Technology</td><td>Established in industry only for metals and waste treatment</td><td>Waste treatment
Metals treatments (e.g. welding
Sintering
Cement production)</td><td>0.50 - 0.90</td><td>2, 3</td><td>21, 26, 48, 49, 51, 52</td></tr>
</table>

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